An Evidence-Based Framework for Whole-life Cost Analysis of Residential Buildings in New Zealand

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Abstract

The construction industry plays a crucial role in the global economy, with residential building projects accounting for a significant share of activities, particularly in the Asia-Pacific region and New Zealand. Whole-life Costing (WLC) is increasingly recognised as a vital approach to fostering economic sustainability, facilitating informed decision-making, and enhancing resilience in construction projects. However, despite its acknowledged advantages, there is no tailored WLC framework available for residential buildings, particularly in New Zealand. This absence of a specific, context-aware framework has led to the underutilization of WLC principles and inadequate lifecycle cost management within the sector. This thesis fills the research gap by creating a WLC framework specifically designed for residential buildings in New Zealand, considering the unique environmental, social, regulatory, and seismic challenges the country faces. Thus, this research aims to develop a WLC framework that considers all elements to enhance the estimation accuracy of residential buildings for long-term economic sustainability, benefiting industry professionals, policymakers, homeowners, and researchers involved in New Zealand's residential.

This research adopts an interpretivist philosophy, applying an inductive approach and qualitative methodology. The study was structured in three stages: a systematic literature review and framework document analysis; 22 semi-structured interviews with industry stakeholders, including quantity surveyors, architects, engineers, project managers, facilities managers, homeowners, and government representatives; and a validation phase involving five expert participants. Initially, 80 factors influencing global Whole-life Cost (WLC) estimation were identified and refined to 37 key factors relevant to New Zealand's residential construction context. System dynamics modelling, through causal loop diagrams, was then used to uncover complex feedback loops and interactions among these factors. The Analytic Hierarchy Process (AHP) subsequently prioritised them, ensuring accurate weighting and contextual relevance. In the validation stage, expert reviewers assessed the selected factors for clarity, relevance, and applicability to the New Zealand context. Their feedback was thematically coded to identify consensus and capture suggestions for refinement. This rigorous process enhanced the robustness of the framework, confirmed the prioritisation outcomes, and strengthened its practical applicability for industry stakeholders.

Significant obstacles to WLC implementation include methodological complexity, a lack of local whole-life cost data, fragmented industry practices, and insufficient integration with standard procurement and project delivery systems. The validated framework addresses these challenges by including components for acquisition, construction, operation, maintenance, end-of-life, and external social and environmental costs. Key validation insights highlighted the importance of seismic resilience, variations in regional climate, material evaluation, differences in labour productivity, supply chain resilience, and the need for integration of local climate data. Recommendations also emphasised usability improvements, such as pre-populated datasets, scenario modelling, example case studies, and dashboard interfaces with dropdown menus.

The development of the New Zealand-specific Whole-of-Life Cost (WLC) framework represents an innovative and dynamic approach that effectively bridges theoretical concepts with practical applications. It enables stakeholders to reconcile initial construction costs with long-term operational efficiencies, resilience to hazards, and commitments to environmental sustainability. This research contributes significantly to the literature and practice of lifecycle cost modelling, providing guidance for sustainable housing development that aligns with the nation's economic and sustainability objectives. The framework serves as a vital resource for policymakers, practitioners, and researchers dedicated to improving the accuracy of lifecycle cost assessments, advancing sustainability initiatives, and incorporating holistic, long-term perspectives into the residential construction sector in New Zealand.

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Attention to authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Statement from Co-Authors

The undersigned co-authors confirm that the PhD candidate was the primary contributor to the works published and submitted in this thesis. The candidate's contributions are substantial and central to the publications, consistent with the requirements for doctoral research.

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Chapter 1: Introduction

1.1 Introduction to the chapter

This chapter is organised into several key sections to lay a solid foundation for this research. The overview begins with a global perspective on the construction industry, highlighting residential construction trends worldwide and in the Asia-Pacific region, including New Zealand. Next, it introduces the principles of Whole-life Costing (WLC), highlighting its benefits and the challenges to its adoption in the construction sector. The chapter then places WLC within the New Zealand residential market, examining the unique environmental, economic, and cultural factors that influence lifecycle costing practices. This discussion highlights the research gaps in the application of WLC in New Zealand's housing sector, motivating this study. Finally, the chapter wraps up with clear research questions framed using the Population, Intervention, Comparator and Outcome (PICO)[1] methodology, which guide the objectives and scope of this thesis.

1.2 Background

The construction industry remains a cornerstone of global economic growth, with recent forecasts indicating that the global construction market will grow from about USD 15.19 trillion in 2023 to USD 15.97 trillion in 2024 and reach roughly USD 19.86 trillion by 2028 . Much of the anticipated expansion in global construction is concentrated in a small group of large markets. Recent forecasts indicate that China, the United States, and India will remain the three largest construction markets and together are expected to account for a substantial share of global growth in construction output to 2030 (OxfordEconomics, 2025). While China's construction sector is experiencing a marked slowdown driven by residential market weakness, India's construction industry is projected to record some of the strongest growth among major economies over the next decade, establishing it as a key engine of global construction expansion (OxfordEconomics, 2025; ResearchandMarkets, 2024). North America also remains a significant contributor, with the United States continuing to generate a large share of global construction spending, underpinned by infrastructure and energy-transition investment (AECOM, 2025; OxfordEconomics, 2025). Indonesia and other large emerging markets in Asia are likewise forecast to see robust construction growth, supported by urbanisation, high-tech and data-centre investment, and sustained infrastructure programmes (Turner&Townsend, 2025). Overall, the construction industry remains crucial to global economic performance, with these major and emerging markets driving a significant portion of projected growth despite regional headwinds and cyclical slowdowns in some countries (OxfordEconomics, 2025; Turner&Townsend, 2025)

Within this context, the residential construction sector has played a particularly prominent role. Recent market profiles estimate that the global residential building construction market generated revenues of about USD 5.27 trillion in 2024 and is expected to continue growing through the remainder of the decade (ResearchandMarkets, 2025). Asia–Pacific, which includes New Zealand, accounts for the largest regional share of this market, around 41% in 2024 and is projected to remain the fastest-growing segment toward 2030 (ResearchandMarkets, 2025). In New Zealand, the residential construction market has an estimated size in the range of NZD 18–19 billion and has generally grown faster than the wider economy in recent years, supported by ongoing demand for new housing and refurbishment (IBISWorld, 2023). Residential buildings in New Zealand include stand-alone houses, townhouses, flats and units, apartments, and retirement village units, reflecting the main dwelling types recognised in national statistics (Statista, 2024, 2025). Demand has been influenced by the COVID-19 period and its aftermath, with house prices recording sharp increases around 2020–2022 driven by low interest rates, strong demand, and supply constraints (OECD, 2022). These pressures have contributed to heightened domestic refurbishment and the upsizing or reconfiguration of living spaces (GCP, 2018; MBIE, 2025). To ensure prudent management of household investments under these conditions, balancing the costs of repurposing, maintenance, renewal, and operation has become critical, and such a balance is most effectively achieved through whole life costing (WLC), also known as life cycle costing (LCC) (Ashworth & Perera, 2015; Huang et al., 2018).

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[1] PICO is conventionally defined as Population, Intervention, Comparison, and Outcome in evidence-based research; in this thesis, the same four-part structure is adapted as Product, Improvement, Comparison, and Outcome to reflect the focus on developing and enhancing a whole-life cost framework rather than studying a specific population or clinical intervention.

Kishk et al. (2003) found that practical interest in WLC in construction dates to 1950, with the formation of the Building Research Establishment (BRE), now known as the BRE Group. WLC offers numerous benefits, including balancing the associated cost of construction and maintenance, recognition of the investment purposes, integration with the building design, sustainable procurement and selection of preferred alternatives (Ashworth & Perera, 2015; Ballesty, 2021). The advantages of WLC include the reduction of operational costs in the medium and long term, while also supporting informed and standardised decision-making (Huang et al., 2018; RTO, 2003; Trusson, 2019). It allows for continued compliance with procurement regulations (Estevan et al., 2015; Hossaini et al., 2015; Hunter et al., 2005) and enables the evaluation of the environmental impact of a building's systems and materials (Vasishta et al., 2023). WLC also plays a vital role in monitoring and maximising building performance during its use phase (Opoku, 2013) and contributes to the efficient use of government funds (Dong et al., 2023).

While the benefits of WLC are becoming increasingly understood, several barriers still hinder its widespread adoption. A significant limitation lies in the lack of understanding among stakeholders, compounded by the absence of credible data, proven evidence, acceptable industry standards, and universal acceptance (Cole & Sterner, 2000; Goh, 2016; Oduyemi et al., 2014). These gaps create uncertainty and restrict the willingness of practitioners to integrate WLC principles into decision-making processes. Furthermore, the inherent complexity of WLC adds to the challenge, as its methodologies often require advanced knowledge, interdisciplinary collaboration, and specialised tools that are not readily accessible across the construction industry (Estevan et al., 2018). Another barrier is the persistent conflict between capital and revenue budgets, which often results in procurement decisions favouring the lowest upfront cost rather than long-term value. This short-term focus undervalues the operational and maintenance savings that WLC aims to capture, thereby limiting the approach's adoption in practice (Perera et al., 2009). Collectively, these barriers highlight the tension between the theoretical potential of WLC and the practical realities of its implementation, underscoring the need for improved standards, better data quality, and a shift in procurement culture towards whole-of-life thinking.

Interestingly, while WLC is widely recognised for its benefits, progress towards broad industry application remains modest. For example, in the European Union, only 2% of national governments consistently use lifecycle costing in decision-making, and more than half rarely or never use it or are unaware of its existence (UNEP, 2013). In practice, WLC applications are often limited to instances where clients are willing to incur additional fees for alternative analysis (Cole & Sterner, 2000), and seldom become an integral part of standard contracts or procurement processes (Bull, 1993a; Cole & Sterner, 2000; Oduyemi et al., 2014; Perera et al., 2009). This has led to continued separation of initial capital costs from long-term operation and maintenance costs, with most clients, especially those not occupying the buildings, favouring the cheapest upfront options (Kishk et al., 2003).

In New Zealand, the Building Act warrants the consideration of 'the costs of a building (including maintenance) over the whole of its life' and 'the need to facilitate the efficient use of energy (Page, 2007). Government guidelines recommend WLC analysis for comparing investment strategies, building refurbishment, alternative designs, and specification options (Gov.nz, 2019). Despite clear regulatory and policy support, the practical application of Whole-life Costing (WLC) in New Zealand's residential construction sector remains limited. Current methods are often either too generic or not specifically adapted, lacking the empirical backing and tools needed for reliable application in residential projects (Ashworth & Perera, 2015; Cole & Sterner, 2000).

This issue is made worse by New Zealand's unique physical and socio-economic conditions. The country sits on the Pacific and Australian tectonic plates, making it susceptible to frequent earthquakes that dictate specific resilience and design needs, which in turn affect both initial and ongoing costs (Nicol et al., 2022). The climate adds another layer of challenges, including high UV exposure, heavy rainfall, flooding, and varying regional weather patterns, which increase maintenance needs and accelerate material wear, complicating cost estimates (NIWA, 2022). Geographic isolation also plays a role in limiting material availability and supply chains, further affecting cost reliability (Abeysinghe, 2010). Socially, the housing sector must respect the cultural backgrounds of Māori and Pasifika communities, whose values of collective ownership and resilience may not fit well with standard lifecycle costing approaches (StatsNZ, 2020).

These factors together highlight the enormous gap between existing WLC methods and the actual needs of New Zealand's residential sector. Data access, customised processes, and suitable tools are still underdeveloped, resulting in decision-making that focuses too much on initial capital costs rather than long-term value and sustainability (Kishk et al., 2003). This research aims to bridge the gap by developing a WLC framework that enhances estimation accuracy and promotes its practical application. This framework will specifically consider seismic risks, severe weather, and cultural factors to enhance the economic sustainability and operational performance of homes in New Zealand.

1.3 Research Problem

While WLC is acknowledged as an effective decision-making tool in the construction industry, its application within the residential sector, particularly in New Zealand, remains poorly understood and underutilised. Much of the existing guidance originates from studies addressing commercial or large-scale infrastructure projects (Cole & Sterner, 2000; Oduyemi et al., 2014), without sufficient adaptation for residential buildings. This disconnect has resulted in a lack of specific, empirical evidence and actionable recommendations applicable to New Zealand's housing market (Collins & Bealing, 2015). Whole-life costing methods have been developed and used in the commercial and infrastructure sectors around the world (ICMS, 2019). However, these models often do not capture the unique aspects of New Zealand's residential building market. Commercial and infrastructure frameworks typically focus on larger projects with varying purchasing methods, risk profiles, and cost structures. This does not fit with the mostly small-scale, owner-occupied, and regionally varied nature of New Zealand's standalone homes (MacGregor et al., 2018; MBIE, 2013). Additionally, current WLC methods rarely consider New Zealand's specific seismic risks (MacGregor et al., 2018), the effects of geographic isolation on material supply and costs (BRANZ, 2016), and changing regulations aimed at improving building resilience and sustainability (MBIE, 2020). This lack of relevant adaptation weakens the usefulness and relevance of existing frameworks in helping to make lifecycle cost decisions for residential construction across New Zealand. As a result, there is no context-specific, empirically supported WLC framework for New Zealand residential buildings (BRANZ, 2019; MacGregor et al., 2018).

A primary obstacle to broader adoption is the lack of relevant and accessible data on the actual costs associated with residential building maintenance, renewal, operation, and disposal throughout a building's lifetime. These data limitations hinder effective life cycle estimating and decision-making for homeowners, developers, and policymakers alike (MBIE, 2020; treasury.govt.nz, 2015). Additionally, WLC methodologies that do exist tend to be complex and resource-intensive, which discourages uptake within the residential sector, where project sizes and budgets are often smaller and stakeholder expertise in life-cycle techniques is limited (Gov.nz, 2019). Compounding this issue, industry professionals find that WLC is rarely embedded into standard project delivery or procurement processes for residential construction, partly due to a lack of sector-specific research and training. Policy initiatives in New Zealand, while supportive of whole-of-life thinking, do not translate effectively into on-the-ground practices within the housing sector (MBIE, 2020). Without robust, context-specific guidance or empirical benchmarks, the ability to assess long-term value and sustainability outcomes for residential projects is significantly constrained. Consequently, the full potential of WLC to drive economically and environmentally sustainable investment in New Zealand's residential construction sector remains unrealised, highlighting the need for dedicated research focused on bridging these critical gaps. Therefore, the challenge addressed in this study is the need for a comprehensive WLC framework that takes into account all relevant elements to enhance the accuracy of estimating residential buildings, thereby ensuring long-term economic sustainability (MacGregor et al., 2018; treasury.govt.nz, 2015).

1.4 Aim and Objectives.

This study aims to develop a WLC framework that considers all elements to enhance the estimation accuracy of residential buildings for long-term economic sustainability, benefiting industry professionals, policymakers, homeowners, and researchers involved in New Zealand's residential

The objectives of the thesis are as follows.

1. To determine the specific factors and their interrelationship that impact the whole-life cost estimation of residential buildings globally.
2. To establish the system dynamics of the elements that affect the accuracy of the whole-life cost estimation of residential buildings in New Zealand.
3. To develop a WLC framework to make it suitable for residential buildings in New Zealand

1.5 Research Questions

To establish the characteristics and structure of whole-life costing frameworks, it is essential to employ a systematic approach to define the research question based on the objectives that guide this study. To achieve this, the PICO framework provides a structured methodology for identifying and articulating the core components of the research inquiry, ensuring both focus and clarity for subsequent analysis.

The Population, Intervention, Comparator and Outcome (PICO) framework is an established approach for structuring focused and answerable research questions, particularly in literature reviews where clarity of scope and direction is essential (Schardt et al., 2007). Although initially developed for clinical inquiries, its application has been increasingly adopted across fields that require structured, evidence-based analysis. In this study, the PICO framework supports the alignment of literature review boundaries, empirical investigation, and theoretical development of the proposed WLC framework. Table 1.1 shows the formulation of research questions using the PICO framework. Purssell and McCrae (2020) stated that the PICO formulation sets the scope of literature for a review, ensuring that the qualifying boundaries align with the stated aim. This thesis has followed internationally recognised Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and all research questions have been formulated using the PICO approach.

Table 1.1: PICO formulation of research questions

PICO Framework	**What factors influence the global whole-life cost estimation and the interrelationships of residential buildings?**	**What are the system dynamics of the elements that affect the accuracy of whole-life cost estimation for residential buildings, aiming to achieve long-term economic sustainability?**	**What framework components are required to develop an effective WLC model for New Zealand residential buildings?**
Product (P)	Whole-life cost estimation	Factors and their interconnections that affect whole-life cost estimation	Suitable whole-life cost framework
Improvement (I)	Residential buildings in New Zealand	Long-term economic sustainability of residential buildings in New Zealand	Residential buildings in N.Z.
Comparison (C)	Not applicable	Not applicable - Cannot compare externally as the system dynamics concern internal interconnections	Existing whole-life costing approaches
Outcome (O)	Factors influencing the Whole-life cost estimation and their interrelationship	System Dynamics	Achieving long-term economic sustainability

These structured research questions offer a clear framework for analysis. They guide the literature review, expert interviews, and empirical analyses in this thesis. By identifying the key components Product, Intervention, Comparison, and Outcome, the PICO framework focuses on the factors that affect whole-life costing worldwide. It also examines the relationships between these factors and the specific improvements needed to create a WLC framework suitable for New Zealand's residential construction sector. This approach enhances both the study's method and its practical relevance.

In accordance with the objectives and using the PICO framework, the study seeks to answer the following research questions:

1. What factors influence the global whole-life cost estimation and the interrelationships of residential buildings?
2. What are the system dynamics of the elements that affect the accuracy of whole-life cost estimation for residential buildings, aiming to achieve long-term economic sustainability?
3. What framework components are required to develop an effective WLC model for New Zealand residential buildings?

Collectively, these questions guide the research in providing an evidence-based foundation for improving whole-life costing practice and fostering more sustainable long-term decision-making in residential construction.

1.6 Research Design Overview

This thesis adopts a multi-stage research design to address the contextual gap in whole-life cost (WLC) estimation for New Zealand residential buildings. The design combines four main components: (1) systematic literature reviews and framework document analysis, (2) semi-structured interviews with New Zealand construction stakeholders, (3) Analytic Hierarchy Process (AHP) to prioritise WLC factors, and (4) system dynamics (SD) modelling to represent interrelationships and feedback loops among these factors over time.

The systematic literature reviews are used to identify global WLC and LCC frameworks, factors and factor interrelationships in a transparent and replicable way, ensuring that the proposed New Zealand framework is grounded in international evidence rather than solely in local practice. Semi-structured interviews with 22 industry participants, including quantity surveyors, architects, engineers, project managers, facilities managers, homeowners and government representatives, employ purposive sampling to capture context-specific insights from those directly involved in residential cost planning and asset management. AHP is then applied to derive consistent weights for the most influential factors, while SD and causal loop diagrams are used to model how these factors interact under New Zealand's seismic and climatic conditions, providing a dynamic representation of WLC behaviour.

A final validation phase involves five expert reviewers who assess the clarity, relevance and practical applicability of the proposed framework for the New Zealand residential sector. Further details of the philosophical stance, methodological choices, sampling procedures and analytical techniques are provided in Chapter 4, while Chapters 3, 5, 6 and 7 present the application of these methods in each stage of the research.

1.7 Scope of the Study

This research is specifically focused on the improvement and practical application of WLC methods for stand-alone residential buildings in New Zealand. The study scope is restricted to a single residential building typology: a stand-alone, two-story house designed for a family of four. The typical dwelling configuration under investigation comprises four bedrooms, two bathrooms, two garages, a living room, and a kitchen. This study focuses on a stand-alone, two-storey, four-bedroom house as the reference residential typology. A stand-alone dwelling is selected to avoid complications associated with common walls, shared maintenance responsibilities, and body corporate fee structures that arise in attached housing and apartments, ensuring that whole life cost responsibilities rest with a single owner (Clarke & Lockyer, 2021) A two-storey configuration allows explicit consideration of staircases, vertical service runs, and the additional seismic bracing required for multi-storey light-frame construction, which are key components of seismic design and important long-term cost drivers (Stanway et al., 2024). A four-bedroom layout reflects contemporary New Zealand design trends in which three bedrooms are typically reserved for family use and the remaining room commonly functions as a study, home office, or guest room, aligning the framework with modern patterns of occupancy and space use (Perkins et al., 2008). Together, these choices define a realistic and policy-relevant 'typical' New Zealand family home while keeping the analysis tractable for detailed WLC framework development.

All direct and indirect costs incurred throughout the building's life cycle are included; these comprise initial capital investments (such as land, building materials, and labour), operational and ongoing costs (including energy, water, and scheduled or reactive maintenance), component renewal and replacement, and end-of-life costs (such as demolition and disposal). In line with contemporary New Zealand procurement and sustainability guidance, environmental and sustainability considerations are factored into the assessment, reflecting the increasing significance of resource efficiency and carbon reduction in life cycle evaluations.

The study does not consider other residential typologies (such as duplexes, apartments, or townhouses), nor does it address commercial, industrial, or infrastructure assets. Although the focus is on New Zealand and a specific, representative housing configuration, global best practices and relevant international literature in WLC are referenced as comparative benchmarks. This strict focus allows the research to deliver in-depth, actionable findings for New Zealand's most common family housing model, enhancing the relevance and practical applicability of the resulting WLC recommendations.

1.8 Research Significance

WLC forecasting is integral for informed decision-making and optimising investments over a building's life cycle, especially as the housing market shifts towards refurbishment, upsizing, and increased performance requirements (Greaterchristchurch, 2018; OECD, 2020). Integrating WLC into residential project planning enables transparent financial decision-making, realistic long-term budgeting, and alignment of capital and revenue expenditures, ultimately driving better value for stakeholders over a building's service life (Ashworth & Perera, 2015; Dong et al., 2023).

By developing improved WLC approaches for residential buildings in New Zealand, this research addresses a critical gap in the current construction industry practice. The recommendations support government agencies, developers, quantity surveyors, and estimators in making more reliable, evidence-based decisions. This enhances the long-term economic sustainability of residential construction, fosters better resource efficiency, and provides a platform for more effective legislative and procurement frameworks. Empirical studies have demonstrated that implementing comprehensive WLC principles can result in cost reductions, improved sustainability outcomes, and a competitive advantage in residential markets (Dong et al., 2023; Vasishta et al., 2023).

Neglecting WLC risks cost overruns, missed sustainability objectives, and unexpected maintenance expenses, which collectively undermine the value and longevity of residential investments (Kishk et al., 2003; Perera et al., 2009). In New Zealand, these risks are significant: recent figures show average residential construction costs nearly doubling over the past decade, with costs per square metre reaching record highs of $3,245–$3,279 and average build costs for a new standard home approaching $450,000–$581,000, excluding land (Ninness, 2025; NZ, 2025). The absence of robust WLC practices leaves stakeholders vulnerable to price escalation from unforeseen factors, such as supply chain disruptions, scope changes, optimism bias, and procurement inefficiencies, which are cited as major drivers behind project failures and cost overruns in the sector (Kumar et al., 2021). Residential construction volumes have also experienced a sharp downturn, with the annual value of building work consented declining by $5.6 billion and annual new dwelling numbers dropping by more than 15,000 over the past two years, trends amplified by rising costs and economic uncertainty (CCC, 2025). Therefore, a robust approach to WLC is essential for achieving durable, financially sustainable, and environmentally responsible housing outcomes in New Zealand.

1.9 Thesis Outline

This thesis is organised into ten chapters that collectively develop, refine, and validate a whole life costing (WLC) framework tailored to New Zealand residential buildings.

Chapter 1 introduces the research background by outlining global and New Zealand construction trends with an emphasis on residential construction. It explains the importance of whole life costing, the barriers to its adoption internationally and in New Zealand, and the specific challenges posed by seismic risks and climatic conditions. The chapter then presents the research problem, aim, objectives, and PICO-structured research questions, and defines the scope around a stand-alone, two-storey, four-bedroom house, establishing the relevance and significance of the study.

Chapter 2 provides a critical literature review that underpins the thesis. It traces the historical development and conceptual foundations of Whole Life Costing (WLC) and Life Cycle Costing (LCC), clarifying their definitions and differences. The chapter examines how WLC has been applied across project life-cycle stages, with reference to the RIBA Plan of Work, and explores socio-economic, environmental, seismic, and climatic influences on residential construction costs. Existing WLC frameworks are critically analysed to identify conceptual, methodological, and contextual gaps, supporting the need for a New Zealand-specific WLC framework.

Chapter 3 reports the first manuscript, presenting a comparative analysis of WLC and LCC frameworks in nineteen countries. It uses a systematic literature review to examine how geographical and environmental characteristics are incorporated into existing frameworks and demonstrates where current models fail to address New Zealand's seismic and climatic conditions. The chapter highlights strengths and weaknesses of international practice and argues for integrating localised risk and environmental data into a future New Zealand framework.

Chapter 4 outlines the overarching research methodology and publication protocol supporting the doctoral study. It explains the interpretivist philosophical stance and the qualitative, inductive approach adopted. The chapter describes the main methods, systematic literature reviews, semi-structured interviews, and validation interviews and the analytical techniques of thematic analysis, Analytic Hierarchy Process (AHP), and system dynamics modelling. It also addresses ethical considerations and research quality, showing how the methodological design aligns with and supports the research objectives.

Chapter 5 consists of a manuscript that identifies global factors affecting WLC through a systematic review of international studies. It extracts and prioritises key factors using AHP and develops causal loop diagrams to visualise feedback relationships among them. The chapter reveals gaps in existing research, particularly the limited treatment of seismic and climatic influences, and draws out implications for both future research and practical WLC applications.

Chapter 6 presents a manuscript that builds on the international evidence by incorporating findings from twenty-two semi-structured interviews with New Zealand construction stakeholders. It expands and refines the factor set for the New Zealand context, reprioritises factors using AHP, and develops comprehensive causal loop diagrams capturing reinforcing and balancing feedback loops in WLC estimation for residential buildings. The chapter emphasises critica l issues such as seismic resilience, material durability, technology adoption, and user behaviour, and stresses the need for dynamic, context-sensitive WLC models.

Chapter 7 introduces the proposed WLC framework for New Zealand residential construction as a manuscript. The framework is structured into five hierarchical levels and aligned with international standards such as the International Construction Measurement Standards (ICMS), while incorporating New Zealand-specific seismic, climatic, economic, and regulatory factors. The chapter explains how insights from literature, interviews, AHP, and system dynamics modelling are integrated into the framework and discusses the potential role of digital tools and sustainability certifications (e.g., BIM, Green Star) in its application.

Chapter 8 focuses on validating the proposed framework through in-depth review by five experienced industry professionals. It documents their assessments of the framework's clarity, coverage, and practicality, as well as their comparative reflections against current practice. The chapter shows how expert feedback led to targeted refinements and confirms the framework's robustness and suitability for adoption in New Zealand's residential construction sector.

Chapter 9 synthesises the findings from Chapters 3 to 8 in relation to the research questions and objectives, showing how the identified factors, system dynamics, and validated framework collectively advance understanding of whole-life cost in New Zealand residential construction. It interprets the findings in terms of the theoretical, methodological, practical, and policy contributions of the study, and explains the originality of the New Zealand-specific framework in addressing seismic, climatic, and contextual cost drivers that are often overlooked in generic WLC approaches. The chapter also acknowledges the key limitations of the study and identifies areas where further investigation is needed. Overall, it demonstrates how the proposed framework strengthens long-term decision-making for residential buildings in New Zealand and supports more resilient and sustainable outcomes.

To clarify how the research aim and objectives are operationalised across the thesis, Figure 1.1 presents an integrated schematic of the overall structure. It shows how the introductory and methodological chapters (Chapters 1–3) lead into the three research objectives (O1–O3), and how each objective is addressed through specific manuscripts and chapters (Chapters 3, 5, 6, 7, and 8) in terms of literature, data collection, analysis, results, and conclusions. The figure also illustrates how the consolidated discussion and conclusion (Chapter 9) draw together the findings from all objectives, restating how each has been addressed and outlining the broader implications, limitations, and directions for future research.

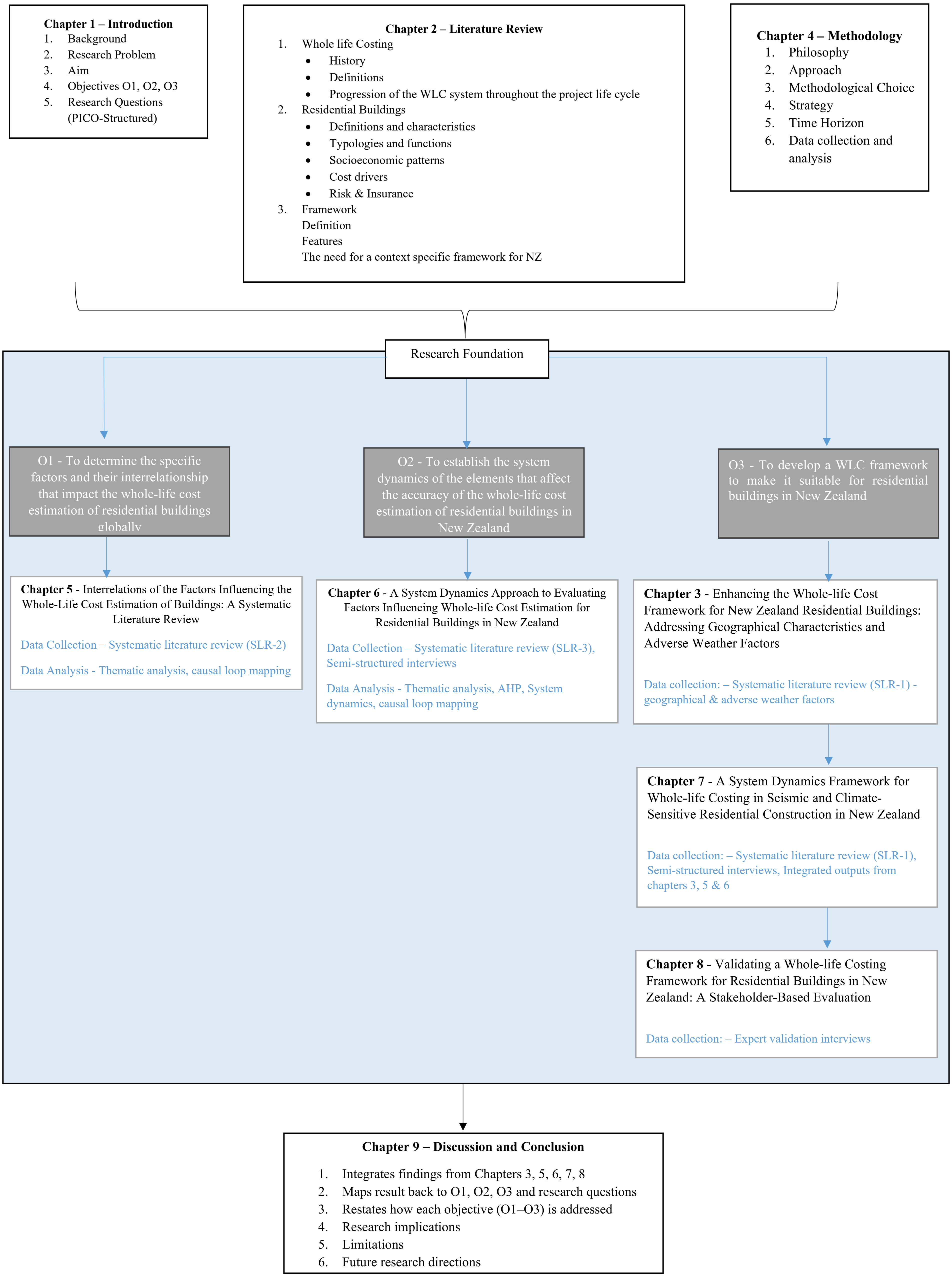


Figure 1.1: Research Framework Diagram

1.10 Summary

This chapter establishes the foundational context for this research by outlining the significance of the global and New Zealand residential construction sectors, the principles and current adoption challenges of Whole-life Costing (WLC), and the distinctive environmental, regulatory, and cultural factors that shape New Zealand's housing market. It has also identified a clear research gap regarding the limited practical application of WLC tailored to New Zealand's residential buildings. Building on this foundation, the next chapter provides a comprehensive review of the academic literature, exploring global WLC concepts, definitions, factor identification, and system dynamics approaches that inform this study.

Chapter 2: Literature Review

2.1 Introduction

Chapter 2 provides a comprehensive review of the existing academic and professional literature on WLC in the construction sector, with a particular focus on residential buildings. The chapter is organised to introduce key concepts and definitions of WLC and related costing methods. It critically examines global frameworks and their relevance and considers various factors that influence lifecycle cost estimation. The chapter pays special attention to the specific challenges faced by New Zealand's residential sector, such as seismic risk, weather variability, and cultural factors. The literature review also highlights current gaps and limitations in the practical use of WLC, paving the way for the upcoming empirical investigation and framework development.

2.2 Whole-life Costing

2.2.1 History

In recent years, Whole-life Costing (WLC) and its closely associated practice, Life Cycle Costing (LCC), have gained significant momentum in the construction sector, illustrating an industry-wide shift from focusing solely on upfront capital expenditures to evaluating the full spectrum of costs over an asset's entire lifespan (Manewa et al., 2021). This transition is primarily driven by increasing demands for cost certainty, sustainability, and optimisation of value throughout the life cycle of built assets (Arcadis, 2025). Recent literature highlights that LCC has become central to sustainability strategies in the construction industry, both in policy and practice. In the UK context, for example, LCC is aligned with national and industry standards (ISO, 2017) and is embedded in key decision frameworks such as the Building Research Establishment Environmental Assessment Method (BREEAM) and government guidance for public sector investment (Manewa et al., 2021)(Whole-life Carbon, 2025). The LCC process incorporates initial capital, operational, maintenance, renewal, and end-of-life costs, enabling project stakeholders to select design, material, and technology solutions that reflect not just short-term, but also long-term financial and environmental outcomes (Arcadis, 2025; Gov.nz, 2019).

Although the theory and benefits of LCC and WLC are well-recognised, implementation and standardisation remain variable across market contexts. Global analyses confirm that, although LCC has been referenced in construction since the late 20th century (Asiedu & Gu, 1998; Epstein, 1996), its widespread adoption has seen a significant increase over the last decade, driven by sustainability imperatives and economic pressures (Ashworth & Perera, 2015). Contemporary best practice emphasises the importance of integrating WLC analysis in the earliest project phases, as this generates the most significant opportunity for cost-effective and sustainable outcomes (Smith & Jaggar, 2016). Persistent barriers include data limitations, inconsistent methodological adoption, and mixed levels of stakeholder awareness issues that are particularly acute in rapidly evolving and cost-sensitive markets (Cole & Sterner, 2000; Dixon, 2019). Despite these challenges, there is a growing consensus that systematic WLC and LCC are now essential for informed decision-making and long-term asset management and cost accountability in contemporary construction (Yousfi et al., 2025). To fully appreciate these challenges and opportunities, it is also important to explore how WLC and LCC are defined and distinguished in recent literature and industry practice.

Goh (2016), note that LCC is an older term for what is now often described as WLC; however, the two terms are not strictly synonymous, and their distinction has become clearer in recent standards and practice. Although some frameworks, such as those used by the Government of South Australia, continue to use LCC to refer to the broader WLC concept, the standard industry distinction is that LCC is a core subset within the broader framework of WLC (Gov.au, 2021). Specifically, LCC focuses exclusively on the direct financial costs associated with constructing, operating, maintaining, and disposing of an asset throughout its functional life (Dixon, 2019). In contrast, WLC expands this scope to include not only these life cycle costs, but also indirect and client-related costs such as project financing, land acquisition, revenue generation, tax, externalities, and user costs that are not borne by the parties to the construction contract (RICS, 2016).

Figure 2.1 illustrates this hierarchy by showing how LCC constitutes the core direct costs within the more comprehensive WLC envelope, which also accounts for broader economic, social, and environmental factors. Thus, while the terms are sometimes used interchangeably in policy or older literature, it is important to recognise that, accurately, LCC should not be referred to as WLC, since WLC provides a fundamentally more holistic approach to asset cost assessment and decision-making (RICS, 2016).

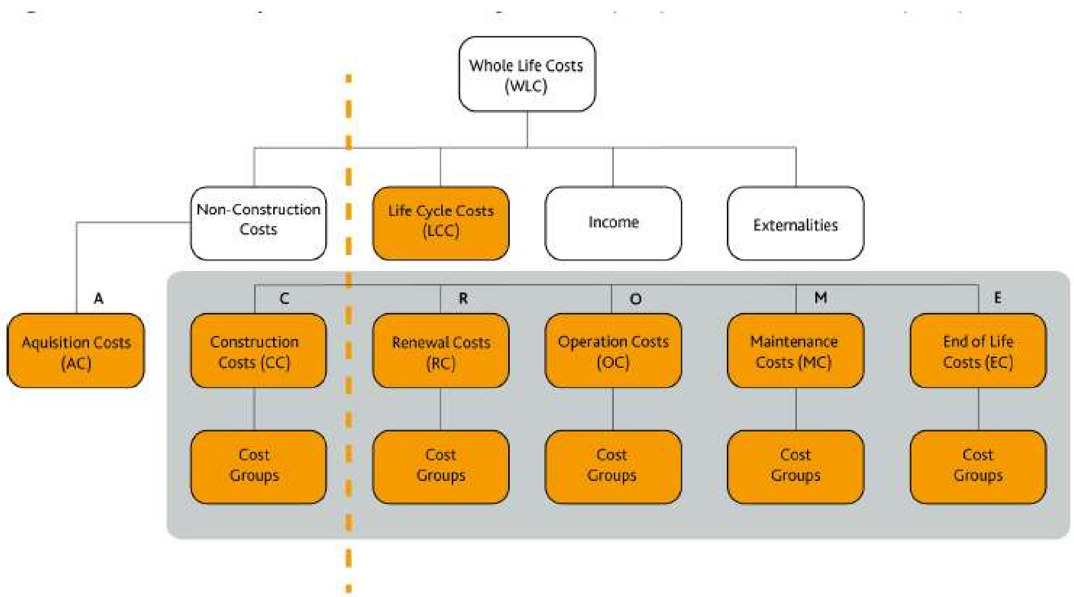


Figure 2.1 Relationship between LCC and WLC (ICMS, 2021)

Having established the growing significance and industry adoption of Whole-life Costing and Life Cycle Costing in the construction sector, it is now essential to clarify the key definitions that underpin these concepts and guide their practical application.

2.2.2 Definitions of WLC

There are various definitions of WLC. Table 2.1 summarises some of those definitions as follows.

Table 2.1 Definitions of WLC

Author	Definitions
(El-Haram et al., 2002)	WLC can be defined as a technique for examining and determining all the costs in money terms, direct and indirect, of designing, building and facility management, operating, maintenance, support and replacement of a building throughout its entire service life, including the disposal cost
OGC (2007)	The whole-life costs of a facility (often referred to as through-life costs) encompass the costs of acquiring, operating, and maintaining it throughout its entire life, from acquisition to disposal - that is, the total ownership costs.
SCI-Network, 2011	WLC is the methodology for systematic economic consideration of all whole-life costs and benefits throughout the analysis, as defined in the agreed scope
CIPS (2017)	a technique used to establish the total cost of acquisition and ownership. It is a structured approach that addresses all the elements of cost and can be used to produce a spend profile of the product over its anticipated lifespan.
BSI, 2008	Economic assessment considering all agreed-upon projected significant and relevant cost flows throughout the analysis, expressed in monetary value. The projected costs are those needed to achieve defined performance levels, including reliability, safety and availability.
BSI (2017)	WLC includes a broader economic matrix, encompassing not only construction costs and LCC but also 'non-construction costs' such as site purchase, letting or selling agent fees, procurement costs and the cost of finance

Trusson (2019)	Economic assessment considering all agreed projected significant and relevant cost flows throughout the analysis, expressed in monetary value. The projected costs are those needed to achieve a defined level of performance, including reliability, safety, and availability.
(Gov.au, 2021)	WLC (also known as life cycle costing or total cost of ownership) is a methodology used to estimate the total costs of goods or services (the supply) over the entire life cycle. It estimates the accumulated costs of acquisition, operation, maintenance, support, and disposal or decommissioning of the supply (less any income or revenue it receives)

While there are many definitions of WLC in the literature, they vary greatly in scope and practical focus. For example, El-Haram et al. (2002) provide a broad definition that includes all direct and indirect costs related to design, operation, maintenance, and disposal over a building's entire service life. This wide approach captures all cost implications but remains largely theoretical, offering little guidance on how to apply it in real project workflows. OGC (2007) definition covers total ownership costs but does not explain the methodology or intended outcomes of WLC, which may limit its usefulness for practitioners needing practical steps.

On the other hand, standards like BSI (2008, 2017) and definitions from CIPS (2017) and SCI-Network (2011) aim to formalise WLC as both an economic assessment and a structured approach. (BSI, 2017) is notable for including non-construction costs and revenues, such as land purchase or finance charges. However, this inclusivity can add complexity that may discourage practical use, especially for small residential projects. Meanwhile, Trusson (2019) prefers a simpler, performance-based definition that excludes categories such as projected significance or stakeholder alignment. CIPS (2017) describes WLC as a structured process for spending profiling, but lacks detail on broader cost drivers or external impacts.

Despite these differences, most international definitions emphasise total cost evaluation. However, they vary in detail, assumed data availability, and their adaptability to different asset types. This is especially relevant in the New Zealand residential sector. Definitions that require extensive, detailed data or refer to non-residential risk profiles, such as those in UK or EU standards, may not fit well into New Zealand's smaller, regionally varied market. Here, seismic risks and climate factors are significant, and reliable local data is often limited. Additionally, many global frameworks, as shown by BSI and OGC, assume procurement and ownership structures, such as public-private partnerships and large commercial clients, that are rare in the NZ housing market. Therefore, the best definition for this thesis should strike a balance between theoretical thoroughness and practical application, specifically addressing New Zealand's challenges, such as seismicity, adverse weather, and cultural housing values, while being feasible for practitioners with limited resources or data access.

Having clarified the key definitions and components of Whole-life Costing, the next step is to examine how WLC principles are systematically applied and progress throughout the various stages of a construction project's life cycle.

2.2.3 Progression of the WLC system throughout the project life cycle

Understanding the fundamental phases of a project's life cycle is crucial to charting the Whole-life Cost (WLC) progress. Research has shown that the earlier WLC is examined, the greater the potential benefits (Ashworth & Perera, 2015). European Commission research revealed that the most significant opportunities for cost savings occur during a project's initial planning and design phases, specifically from briefing to occupation and usage (Estevan et al., 2018). According to Figure 2.2, it is clear that the potential for significant cost reduction decreases considerably once a project advances into the construction stage (Smith et al., 2016).

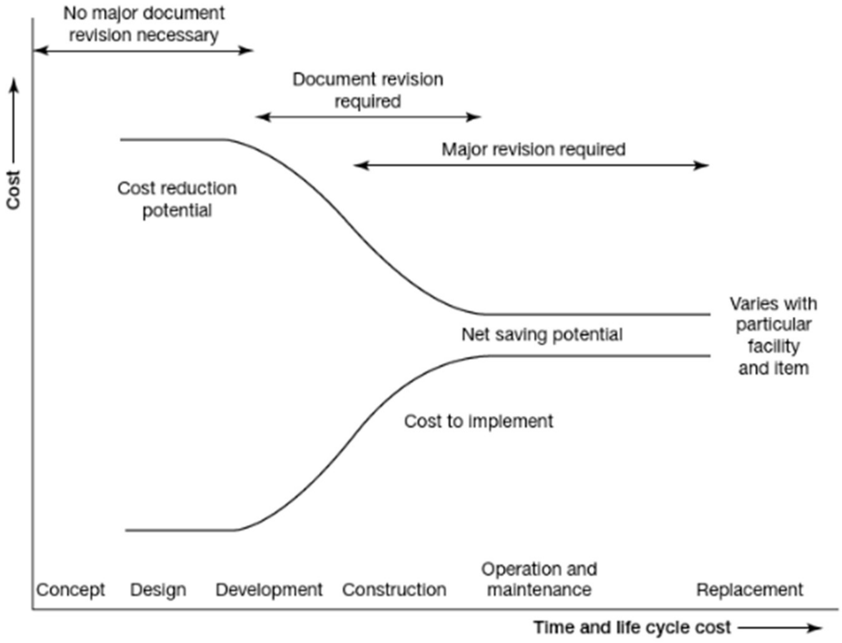


Figure 2.2: Relationship between life cycle cost savings and timing of implementation (Smith et al., 2016)

Ashworth and Perera (2015) outline the seven stages of progression and renewal that comprise the WLC process, which is shown in Table 2.2. NRM 3: Order of Cost Estimating and Cost Planning for Building Maintenance Works provides a comprehensive cost planning procedure for WLC, encompassing repair, replacement, and maintenance works, as well as an annual work program (Ashworth & Perera, 2015). NRM 3 is a valuable resource that provides essential guidance on measuring and evaluating maintenance tasks. It is instrumental in creating preliminary cost estimates for construction projects, developing elemental cost plans during the design phase, and preparing detailed cost plans for specific assets throughout the lifespan of a building project. Additionally, the guidelines aid in the procurement and cost management of maintenance works. NRM 3 aligns with the framework and principles of NRM 1 and offers direction on how to quantify and measure various aspects related to maintenance works, such as management and administration charges for maintenance contractors, overheads and profit, other associated maintenance costs, consultants' and specialists' fees, and risks associated with maintenance works and an annualised work program for repair, replacement and maintenance (RICS, 2021). NRM 3 is aligned with several standards, including the International Property Measurement Standards (IPMS) and ICMS: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions (RICS, 2021). ICMS is a principles-based international standard that provides consistency in classifying, analysing, and presenting global construction cost data at a project, regional, state, national, or international level (ICMS, 2021). NRM 3 also mapped the RIBA Plan of Work, which categorises the process of briefing, designing, constructing, and operating building projects into eight stages, explaining the outcomes, core tasks, and information exchanges required at each phase (RIBA, 2020). The RIBA Plan of Work serves as a valuable framework for architects to employ when collaborating with clients on projects. Its purpose is to provide greater transparency into the various stages of a project, and it has adapted over time to keep pace with evolving project methodologies. Its extensive implementation has made the RIBA Plan of Work an indispensable industry-standard resource (RIBA, 2020). The RIBA POW can map the whole WLC process in eight stages.

Table 2.2: Seven stages of progression and renewal that comprise the WLC process(Ashworth & Perera, 2015)

Whole-life phase	Description	Associated costs
1. Specificatio 2. Design	The formulation of the client's requirements and translating these into an acceptable design	*Initial costs* connected with land purchase, professional fees and construction
3. Installation 4. Commissioning	The construction process up to completion and the handing-over of the project to the client	*Recurring costs* necessary for occupational charges such as rates, insurance, repairs, improvements, fuel, cleaning and estate control
5. Maintenance	The use of the project for its intended purpose	
6. Modificatio	Alterations necessary to keep the project in a good standard of repair or to improve to current-day standards	*Recurring costs* required for major changes to building in respect of refurbishment and redevelopment
7. Replacement	The evaluation of the project for major refurbishment, or the site for redevelopment	

Furthermore, NRM 3 has integrated the guidelines for cost prediction reporting outlined in the most recent edition of the Cost Prediction RICS Professional Statement (RICS, 2021). Additionally, the OGC Gateway Process has been considered by NRM 3, which is still utilised by certain public sector entities (RICS, 2021). The OGC Gateway Process is an impartial and confidential peer review mechanism that evaluates projects and programs at crucial junctures in their lifecycles to gauge their advancement and predict their likelihood of successful delivery of desired outcomes (Govt.NZ, 2018).

Table 2.3: Key Stages of a Project Life Cycle (RICS, 2016)

RIBA project Stages			**RICS formal cost estimating and cost planning stages**	**RICS information stages (RICS Cost prediction PS)**	**OGC Gateways**	
Plan of Work 2020		**Digital Plan of Work (DPoW)**				
0	Strategic Definition	Strategy	**Rough order of cost estimate**	**Level 1 Estimate**	1	Business Justification
1	Preparation and Briefing	Brief	**Order of cost estimate(s)** (option costs) **Elemental cost estimate**	**Level 2 Estimate**	2	Delivery strategy
					3A	Design Brief and Concept Approval[1]
2	Concept Design	Definition	**Formal cost plan 1**	**Level 3 Estimate**		
3	Spatial Coordination		**Formal cost plan 2**[2]	**Level 4 Estimate**	3B	Detailed Design Approval[1]
4	Technical Design	Design	**Formal cost plan 3**[2]	**Level 5 Estimate**	3C	Investment Decision (see note)
	Contractor Engagement	Contractor Engagement	**Pre-tender estimate**[3] **Pricing documents**[3] (for obtaining tender prices) **Post-tender estimate**[4]	**Level 5 Estimate(s)**		
5	Manufacturing and Construction	Build and Commission				
6	Handover	Handover and Closeout	**Formal cost plan 4**[5] (renew/maintain) (measured in accordance with NRM 3)	**Level 6 Estimate**	4	Readiness for Service
7	Use	Operation			5	Operations Review and Benefits Realisation
		End of Life				

Table 2.3 outlines the key stages of a project, encompassing the RIBA Plan of Work, RICS Formal Cost Estimating, RICS Information Stages, and OGC Gateways. Out of the five project stage types presented in Table 2.4, RIBA Plan

of Work 2020 is the optimal choice for assessing WLC progression due to its clear delineation of each stage. However, it is essential to note that only the LCC cost components of construction cost (C), repair cost (R), operation cost (O), maintenance cost (M), and end-of-life cost (E) - collectively referred to as CROME (RICS, 2021) are evaluated. Non-construction costs, income, and externalities are evaluated separately. Table 2.4 displays the LCC progression steps mapped onto RIBA POW 2020.

As outlined in Table 2.4, implementing WLC consideration as a client requirement and defining WLC requirements in Stage 1 presents the best opportunity for cost reduction. In Stage 2, the Architectural Concept reviews end-user, operation, and maintenance building performance requirements and whole-life costs to produce a formal cost plan 1 for WLC. In Stage 3, they consider the impacts of any design or specification variations on building performance and whole-life cost to produce a formal cost plan 2. This plan is further developed into a formal cost plan 3 in Stage 4. WLC development work still needs to be done in Stages 5 and 6. Stage 7 is arguably the most critical in a building's life. During this stage, its performance impacts whole-life costs and, notably, the environment. The performance of future buildings can only be improved if feedback is gathered from buildings in use. Regardless, the project team designing and constructing the project increasingly needs to deliver information for asset or facilities management purposes.

In Table 2.4, the RIBA Plan of Work 2020 stages are used as the organising structure for WLC and LCC tasks. Stage 5 corresponds to ‘Manufacturing and Construction’, when on-site work is carried out and cost control focuses on managing variations against the agreed cost plan; Stage 6 is ‘Handover and Close Out’, when final cost data and asset information are compiled and transferred to the client; and Stage 7 is ‘Use’, which covers the in-use life of the building, including operation, maintenance, renewal and post-occupancy evaluation

Table 2.4: WLC/LCC application mapped on RIBA POW

	0	1	2	3	4	5	6	7
	Strategic Definition	**Preparation and briefing**	**Concept Design**	**Spatial Coordination**	**Technical Design**	**Manufacturing and Construction**	**Handover and Close Out**	**Use**
Outcome	Achieving the client's requirements	Approval of WLC in the project brief	Approval of architectural concept	Spatial coordination of architectural and engineering information	Complete all the design information required	Physical construction at the site	Handing over the built asset to the client	Use, operate and maintain the built asset
WLC Application	Integrate operation, maintenance, and whole-life cost considerations into the Client Requirements and the Business Case.	Set out the Post Occupancy Evaluation requirements, handover and Aftercare, maintenance, and Facilities Management within the Project Brief, considering whole-life costs.	Review the Architectural Concept against end-user, operational, and maintenance building performance requirements, as well as whole-life costs.			Consider the impacts of any variations to the design or Specification on building performance and whole-life cost.		Monitor operational costs for inclusion in whole-life cost assessments and provide Feedback on in-use costs as part of Post-Occupancy Evaluations undertaken.
Tasks	Prepare a rough order of cost estimate for one or more options	Prepare a cost estimate order to test the feasibility of achieving the emerging project brief. Break down the cost of elements to highlight any areas that might cause high cost related. project risks Agree on the cost limit.	Prepare a life cycle cost plan considering the renewal, repair, and maintenance of building systems throughout the built asset's lifetime. Review the maintenance and repair cost implications of iterations of the architectural concept. Identify risk allowances and uncertain areas where either provisional sum, prime cost sums or prime cost prices are required. Agree the cost limit with the client before proceeding to the next stage	Further development of the cost plan	Further development of the cost plan	Monitor and recement the cost of any variations to the building contract against the relevant element, sub-element and component cost targets using the cost plan control document	Produce benchmarking data to estimate and plan costs for future projects. Collect final cost data, building systems specification information and maintenance data from the completion of the construction phase.	Embed the final cost data from the completion of the construction phase into an asset management operating model for use in building maintenance, repair, or renewal, as required. Prepare a formal LCCP (formal cost plan 4) or update the previous LCCP. Include operational costs for inclusion in the WLC assessment, if required. Monitor actual renewal, repair, and maintenance costs against the LCCP. Monitor actual operational costs for WLC assessment.
Required cost data	Taking into account feedback from previous similar construction projects		Group cost elements	Cost elements	Sub cost elements			
Presentation of WLC	Stated in terms of estimated cost per square meter of gross internal floor area	Initial LCC plan + non-construction cost + income + externalities	Formal cost plan 1	Formal cost plan 2	Formal cost plan 3			Formal cost plan 4

With an understanding of how WLC is integrated across the project life cycle, it is now essential to consider the unique characteristics and challenges associated with applying these principles to residential buildings.

2.3 Residential Buildings in New Zealand

The residential sector represents one of the most significant segments of the global construction industry, contributing substantially to both economic activity and the evolution of the built environment. Recent studies underscore the sector's influence; for example, Robinson et al. (2021) highlight the residential sector's major role in driving construction growth through new builds, renovations, and maintenance activities. This demonstrates why advancements in the management of residential assets, including the adoption of WLC, are crucial for sustainable industry development.

2.3.1 Definition and Characteristics of Residential Buildings

Residential buildings are defined as structures primarily intended for human habitation, as distinct from industrial or commercial use. According to the Oxford English Dictionary (2023), "residential" refers to a place that is suitable for living in and comprises houses rather than factories or offices (Dictionary, 2023). As stated by Felseghi et al. (2019). A residential building is a structure comprising one or more rooms designed for housing, equipped with the necessary facilities and utilities that meet the living needs of a person or family. While construction has made significant strides since the first dwellings were erected, buildings are still heavily influenced by environmental factors, including climate, building materials, cultural traditions, legal regulations, and cost. These long-standing factors often result in buildings with similar appearances and environmental characteristics within a particular area over time (Papamanolis, 2005).

2.3.2 Typologies and Functional Considerations in Residential Building Classification

Residential buildings can be classified based on various criteria, including architectural design, building materials, and intended use. These classifications include single-family homes, which are detached houses that stand alone on their lot or land; duplexes and townhouses, which are two or more attached dwellings that share a common wall (Zinn, 2021); apartments, which are usually multi-story buildings with rented units; condominiums, which are communities of individually owned units within a larger complex; mobile homes and manufactured housing, which are prefabricated homes that are transported to a site and anchored to a foundation; and tiny homes, which are small, compact houses that are designed to maximize living space with minimal material usage. The right type of building for each person depends on factors such as household size, personal style, location, and budget (Gritton, 2023).

2.3.3 Socioeconomic Patterns and Tenure

Ownership and the way people live in a building, whether they own it, rent privately, share housing cooperatively, or reside in social housing, significantly affect the costs they face over time. For example, utility bills and maintenance expenses tend to vary widely between owners and renters, with renters often spending a larger proportion of their income on these ongoing costs (StatsNZ, 2020). Between 1988 and 2019, the proportion of renting households spending more than 30% of their income on utilities in New Zealand more than doubled (StatsNZ, 2020).

Across Europe, housing tenure structures differ substantially. Ownership rates exceed 90% in countries such as Romania and Hungary, while they fall below 60% in France, Denmark, and Sweden, where social and cooperative housing also play a prominent role (Pittini et al.; Samuel, 2022; Van Bortel et al., 2019). visually represents this variation by showing the proportion of dwellings within each tenure category as a share of the total occupied housing stock in EU member states. The Figure 2.3 helps illustrate how tenure distribution varies, reflecting demographic, economic, and policy differences across countries. These tenure patterns influence housing market dynamics such as investment value and property ownership transfers. In New Zealand, the private rental market is predominantly occupied by small investors, meaning that transactions involving owner-occupiers largely drive market trends and data comparability(Sayce & Wilkinson, 2019).

Understanding these socioeconomic patterns is crucial not only for allocating costs across different housing types but also for informing regulatory frameworks and assessing capital value changes. All these factors are integral to developing comprehensive, whole-life cost analyses that appropriately reflect tenure effects on residential housing expenditures.

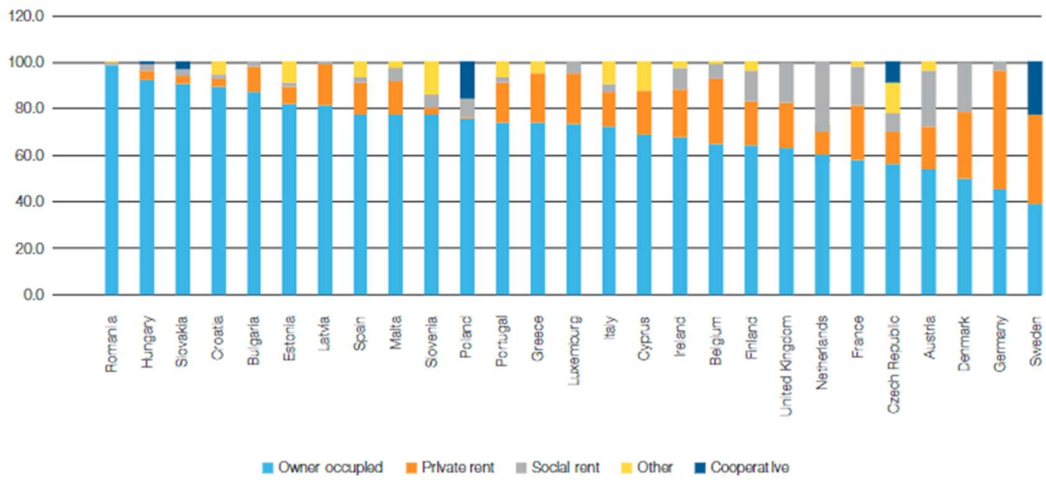


Figure 2.3: Tenure split in EU member states (StatsNZ,2020)

2.3.4 Cost Drivers: Location, Market, and Construction Factors

The location of a residential property greatly influences its market value and life cycle cost, as it affects access to amenities, socioeconomic status, neighbourhood quality, and proximity to employment or green spaces (Islam et al., 2015). Generally, rural properties tend to be more affordable because of lower land and labour costs, but they may also face higher operating expenses, particularly as transportation costs rise with distance (Odusami & Onukwube, 2008). The local availability and price of construction materials also cause significant regional and temporal variations in both initial and replacement costs (Abeysinghe, 2010). In sustainable building, location is crucial. The EPA (2023) emphasises that well-situated buildings can reduce transportation emissions, make better use of existing infrastructure, and lower long-term environmental and operational costs.

2.3.5 Risks and Insurance of Residential Buildings

Residential buildings are subject to a range of risks, including market volatility, maintenance liabilities, and natural disasters (Aucklandcouncil.govt.nz, 2019), security threats, legal issues, and financial uncertainties. Insurance is a vital tool for transferring or mitigating some of these risks (Majka, 2024); however, underinsurance remains a concern, particularly during periods of rapid economic change (Kusuma et al., 2019). Both insured parties and advisors must ensure the insured values are up-to-date and reflective of replacement or rebuilding costs, which are fundamental components of WLC (Gritton, 2023). Regular review of insurance arrangements, combined with proactive risk management, strengthens the long-term financial resilience of residential assets.

Having identified the unique characteristics, cost drivers, and risks associated with residential buildings, it is now essential to examine the underlying framework that enables systematic assessment and management of these costs throughout the building's entire life cycle.

2.3.6 Seismic hazards and implications for residential WLC

New Zealand's residential building stock is highly exposed to seismic hazards because of its location on the boundary between the Pacific and Australian plates, leading to frequent earthquakes and strong ground motions (Morris & Walker, 2011; Nicol et al., 2023). Empirical studies of recent events show that, although light timber-frame houses often avoid collapse, foundations, chimneys, claddings and internal linings can still sustain significant damage, generating high repair and reinstatement costs for homeowners (Ingham & Griffith, 2010). Life-cycle cost studies demonstrate that for buildings in seismic regions, expected earthquake losses, including repair, downtime and indirect user costs can be comparable to, or even exceed, initial construction costs over the building life (Mitropoulou et al., 2011).

As a result, decisions about residential structural systems, detailing and retrofit levels need to be evaluated on a whole-life basis rather than on first cost alone (Porter, 2015). Research on performance-based and low-damage seismic design shows that investing more in ductile detailing, rocking systems or base isolation can substantially reduce expected life-cycle losses, even if upfront capital costs are higher (Jebelli & Behnam, 2024). For New Zealand houses, seismic hazards therefore influence WLC through design and construction costs to meet or exceed current standards, periodic inspection and maintenance of structural components, post-event repair and retrofit expenditure, and potential increases in insurance premiums and deductibles in high-risk zones (Nicol et al., 2023).

2.3.7 Climatic and weather-related hazards and implications for residential WLC

Climatic and weather-related hazards also have major implications for the whole-life performance and cost of New Zealand housing. Climate projections indicate that New Zealand is likely to experience rising temperatures, more frequent heavy-rain and flood events, and changes in wind patterns and drought frequency over coming decades (Mullan et al., 2016). These changes intensify stresses on building envelopes, site drainage and services, increasing the risk of moisture ingress, mould, material deterioration and overheating in typical residential buildings (Howden-Chapman et al., 2012). Studies of building material durability show that high ultraviolet (UV) exposure and driving rain can significantly shorten the service lives of coatings, claddings, sealants and roofing, requiring more frequent maintenance and replacement cycles in exposed locations (BRANZ, 2025b).

From a WLC perspective, climatic hazards affect several cost components, including routine maintenance (e.g. repainting, resealing, reroofing), repairs after extreme weather events, adaptation upgrades such as improved insulation, shading or flood-resilient detailing, and changing energy costs for heating and cooling (BRANZ, 2025a). Recent life-cycle assessment and life-cycle cost studies of low-carbon or climate-resilient housing in New Zealand and comparable climates show that envelope improvements and passive-house strategies can reduce operational energy and carbon over the life cycle, but may increase upfront cost and alter long-term maintenance profiles (Wang et al., 2020). These trade-offs must therefore be considered explicitly when assessing residential investment decisions on a whole-of-life basis.

2.4 Framework

2.4.1 Understanding the Term 'Framework'

According to the Oxford Learner’s Dictionary (2023), a set of beliefs, ideas or rules that is used as the basis for making judgements, decisions, etc. In academic and professional discussions, a framework acts as a general structure for understanding a phenomenon, organising knowledge, and combining different processes. De Wit (2009) state that frameworks are not just collections of tools; they are dynamic systems made up of interrelated elements that operate under a defined control flow. These elements interact with one another and must be used together, making frameworks more complex than standalone tools or models (BSRIA, 2011). The power of a framework lies in its ability to create coherence and consistency across various applications while staying adaptable to specific challenges (Sutton, 2011).

2.4.2 Key Features of an Effective Framework

For a framework to work effectively, especially in construction, it must possess several key attributes. First, it should provide a systematic and logical approach to handling complexity, enabling stakeholders to identify, evaluate, and manage various cost components and influencing factors. Second, it must be flexible to fit different development scales and diverse conditions, such as geographical location, climate variations, or regulatory requirements. Third, the framework should be clear about its assumptions, methods, and data inputs to ensure credibility, repeatability, and user trust. Fourth, it should be based on real-world evidence to ensure that its assumptions and recommendations reflect practical realities. Finally, it should act as a practical decision-support tool, enabling users to simulate scenarios, compare options, and evaluate long-term effects (Brinkmann & Kvale, 2015; Jabareen, 2009). These features are significant in the creation of cost-related frameworks, where precision, relevance, and usability impact the quality of decision-making.

An effective WLC framework provides a clear, systematic structure that links cost information to the key stages of a building's life cycle and supports consistent, transparent decision-making by different stakeholders. It should define what costs are considered, when they are assessed, and how they are measured, so that capital, operational, maintenance and end-of-life costs can be evaluated on a comparable basis.

In international practice, whole-life and life-cycle cost management is strongly shaped by standardised work stages and measurement rules, which clarify when and how costs are considered across a project's life (RICS, 2014, 2021). The RIBA Plan of Work 2020, for example, structures the building process from early strategic definition through design, construction, handover, and in-use stages, and explicitly links cost planning and life-cycle assessment tasks to each stage (RIBA, 2020; RICS, 2016). Within this staged process, RICS NRM1 provides rules for order of cost estimating and cost planning of capital building works, while NRM3 extends the logic to maintenance and renewal, enabling capital and maintenance costs to be managed on a consistent basis over the building's life (RICS, 2014, 2021). Together, NRM1 and NRM3, supported by overarching classifications such as ICMS, offer a coherent structure for developing life-cycle or whole-life cost plans in many jurisdictions (ICMS, 2019; RICS, 2021). However, these standards were primarily developed for broad application and commercial or infrastructure assets, and they do not explicitly incorporate New Zealand-specific residential characteristics, seismic and climatic risks, or local data limitations, which limits their direct transferability to this context (Samarasekara, Purushothaman, Rotimi, et al., 2024; treasury.govt.nz, 2015).

2.4.3 The Need for a Customised WLC Framework for Residential Buildings in New Zealand

Despite increased recognition of the benefits of WLC approaches, their use in New Zealand's residential construction sector remains limited. While public sector procurement guidelines encourage WLC methodologies (treasury.govt.nz, 2015), there is currently no standardised framework specifically for residential buildings. This gap is especially concerning due to the unique challenges posed by New Zealand's geography, including high seismic activity and exposure to increasingly frequent extreme weather conditions, both of which can significantly impact the long-term costs and durability of residential structures. Additionally, most existing WLC frameworks assume detailed cost data is available throughout a building's life cycle, which is rarely the case for residential properties in New Zealand. The lack of sector-specific empirical data, particularly for maintenance, operational, and end-of-life costs, makes accurate forecasting and decision-making difficult. Zhang et al. (2020) note that without accessible data and localised benchmarks, decision-makers often focus on initial capital costs, overlooking the full economic impacts of their choices. This approach undermines the long-term value of investments, resulting in suboptimal outcomes in maintenance, refurbishment, and sustainability.

Another challenge is the limited awareness and understanding of WLC among industry professionals. Although tools and frameworks are available internationally, they are not widely shared or applied in the New Zealand context. Goh (2016) stresses that for a framework to be effectively adopted and used, it must align with the needs and capacities of local stakeholders. Therefore, without a simplified, context-sensitive WLC framework that reflects local construction practices, regulatory conditions, and economic factors, broad adoption within the residential sector is unlikely.

Overall, the research gap identified here is contextual rather than conceptual. Existing WLC methods and standards are well developed internationally, but they have been designed for different asset types, procurement environments, and risk profiles, and therefore do not align with the specific characteristics of New Zealand's residential sector. In particular, they do not adequately accommodate New Zealand's seismic and climate-related hazards, fragmented residential delivery structures, or the limited availability of local whole-life cost data. This misalignment creates a contextual gap: the absence of a whole-life cost framework that is tailored to New Zealand residential buildings and can be realistically applied by local stakeholders within their regulatory, economic and information constraints

2.5 Research Gap

There is a significant contextual gap in the current literature: while many WLC frameworks exist internationally, none provide a comprehensive whole-life cost framework specifically tailored to the characteristics and risk profile of New Zealand residential buildings. The existing literature does not provide a comprehensive Whole-life Cost (WLC) framework that captures the full set of factors and their interrelationships affecting the estimation accuracy of residential buildings, particularly in a New Zealand context. Most international WLC frameworks focus on non-residential assets, treat influencing variables in a largely static way, and give limited attention to seismic and climatic hazards, system-dynamics effects, and data constraints typical of residential projects. As a result, there is not empirically grounded, NZ-specific WLC framework that integrates global WLC factors (Objective 1), models how these elements interact under New Zealand's seismic and climatic conditions (Objective 2) and offers a practical decision-support tool for residential stakeholders (Objective 3). This thesis addresses this gap by systematically identifying and prioritising WLC factors, developing a system-dynamics-based representation for New Zealand residential buildings, and translating these insights into a validated, context-sensitive WLC framework.

2.6 Summary

This literature review chapter highlights the importance of WLC methods for making informed decisions and supporting sustainable asset management, especially for residential buildings. It shows how WLC differs from LCC by emphasising WLC's broader scope, which includes indirect costs, revenues, stakeholder issues, and external effects. This approach provides a better understanding of a project's actual value. The literature review also examines how factors such as building type, ownership, location, and market conditions influence cost structures. These variables add complexity to the use of standard WLC frameworks in the residential sector. While current frameworks offer solid methods, their complexity and data requirements often render them unsuitable for small-scale or residential projects, particularly in areas with limited resources or differing construction practices. Consequently, the chapter identifies a clear need for a customised, context-specific WLC framework for New Zealand residential buildings and uses the PICO framework to define focused research questions that guide this thesis. Building on insights from international WLC and LCC practices, the next chapter systematically reviews global frameworks to benchmark their strengths and weaknesses and to inform the development of a New Zealand-specific WLC framework aligned with the three research objectives.

Chapter 3. Enhancing the Whole-life Cost Framework for New Zealand Residential Buildings: Addressing Geographical Characteristics and Adverse Weather Factors

3.1 Prelude

Following the identification of the need for a tailored WLC framework in Chapter 2, this chapter builds on that discussion by examining global practices. The aim is to assess how different countries have integrated Whole-life Costing (WLC) /Life Cycle Costing (LCC) into their construction sectors and to extract lessons that can be applied to unique geographical, climatic, and regulatory conditions in New Zealand's Construction Sector. This chapter incorporates a peer-reviewed conference paper titled *"Enhancing the Whole-life Cost Framework for New Zealand Residential Buildings: Addressing Geographical Characteristics and Adverse Weather Factors,"* which was presented at the Smart and Sustainable Built Environment (SASBE) 2024 Conference. The paper represents an important milestone in the doctoral study, focusing on the contextual challenges that limit the applicability of existing WLC and LCC frameworks in New Zealand.

The research presented in the paper evaluates international WLC and LCC practices across nineteen countries and identifies critical shortcomings in the New Zealand context, particularly the limited consideration of geographical conditions, seismic risks, and adverse weather impacts in residential construction cost models. These findings underscore the importance of tailoring WLC frameworks to local realities, thereby enhancing the accuracy of cost estimation, resilience planning, and long-term decision-making.

By presenting this work at SASBE 2024, the research contributed to international dialogue on sustainable construction economics while reinforcing the originality and relevance of a framework specifically adapted to New Zealand's residential sector. Its inclusion in this thesis ensures that the comparative insights and contextual refinements established through this conference paper are consolidated as part of the broader research journey.

3.2 Introduction

The construction industry operates in a dynamic environment with diverse geographical landscapes and challenging weather conditions (Sharpe, 2021). These factors significantly influence the cost and performance of residential buildings, posing substantial challenges for developers, architects, and policymakers. Flanagan and Jewell (2008) emphasised the importance of adopting a comprehensive approach to cost assessment in construction projects, mainly through utilising Whole-life Cost (WLC) and Life Cycle Costing (LCC) frameworks. These frameworks provide data on the total cost of a building project over its entire life, considering factors such as initial construction costs, maintenance expenses, and operational expenditures (ISO, 2017).

The literature on WLC and LCC frameworks provides valuable insights into assessing construction project costs and the total cost of ownership of a building or infrastructure over its entire lifespan. These practices encompass all phases, from initial construction to operation, maintenance, and eventual decommissioning (Flanagan & Jewell, 2008). Higham et al. (2015) conducted a comprehensive review of life cycle cost analysis for sustainable construction, emphasising its importance in UK practice. Goh and Sun (2016) developed lifecycle costing methodologies tailored for buildings. Gluch and Baumann (2004) discussed the conceptual framework of the LCC approach, emphasising its relevance for environmental decision-making. Smith et al. (202) explored the assessment of the WLC of sustainable buildings, focusing on integrating environmental and social factors into cost analysis. Factors such as GC, climate, and regulatory requirements can significantly impact the costs associated with construction projects (Flanagan & Jewell, 2008). However, the literature fails to critically assess the GC in WLC.

In the context of WLC and LCC, a framework is a well-thought-out plan that considers the similarities and differences within the construction field, providing a standardised approach while allowing for variations in certain abstract aspects (ISO, 2017). These frameworks are more intricate and abstract than typical programs, interactive in nature, with a control flow that links their components and calls application-specific parts. (ISO, 2017). Comprehensive data and standardised methodologies are critical to enhancing the reliability and comparability of LCC assessments (Burton et al., 2016). Flanagan and Jewell (2008) note that framework elements must be employed as a whole, making them complex and challenging to understand and reuse. The adoption and implementation of WLC and LCC vary globally and are influenced by regional standards, regulatory frameworks, and industry practices (Goh & Sun, 2016). However, existing WLC and LCC frameworks in countries like New Zealand (NZ) may not fully account for the unique challenges of geographical characteristics (GC) and adverse weather conditions (NIWA, 2018).

3.3 Methodology

The Systematic Literature Review (SLR) employed various search strings across databases, including Scopus, ScienceDirect, Emerald Insight, SpringerLink, and Google Scholar. The study utilised primary data from books, journals, conference papers, and secondary research data, including government reports and guidance notes from standard bodies such as RICS, AIQS, ICMS, NZIOB, BSI, EU, and NATO, obtained from their respective websites. Only studies in English published between 2000 and 2024 within the engineering subject area were selected, with review articles being excluded to prevent redundancy. Data was collected to gather information on current WLC and LCC practices in 19 countries. The data included details on existing frameworks, their applicability in various sectors, purposes of utilisation, and identified strengths and weaknesses. Special attention was given to frameworks considering GC and adverse weather factors.

Table 3.1 provides detailed information on the search strings and inclusion and exclusion criteria for each database. The PRISMA flow diagram in Figure 3.1 guided the data-searching strategy for the strengths and weaknesses of existing WLC and LCC frameworks.

Table 3.1:Search Strings and results of database search for primary research data

Database	Search Strings	Inclusions	Exclusions
Scopus	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Subject Area – Engineering Language – English Open access From year 2000-2024	Review Articles
Science Direct	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Subject Area – Engineering Language – English Open access From year 2000-2024	Review Articles Book Review Product Review
Emerald Insight	abstract:"whole-life cost" OR (abstract:"life cycle cost") AND (abstract:"construction") AND (abstract:"framework")	Open Access Content Type – Articles From year 2000-2024	Review Articles
Springer Link	Construction AND framework AND "Whole-life cost" OR “life cycle cost”	Discipline – Engineering Subdiscipline - Building Construction and Design Language – English From year 2000-2024	Reference work entry Reference work
Google Scholar	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Only in title	Review Articles

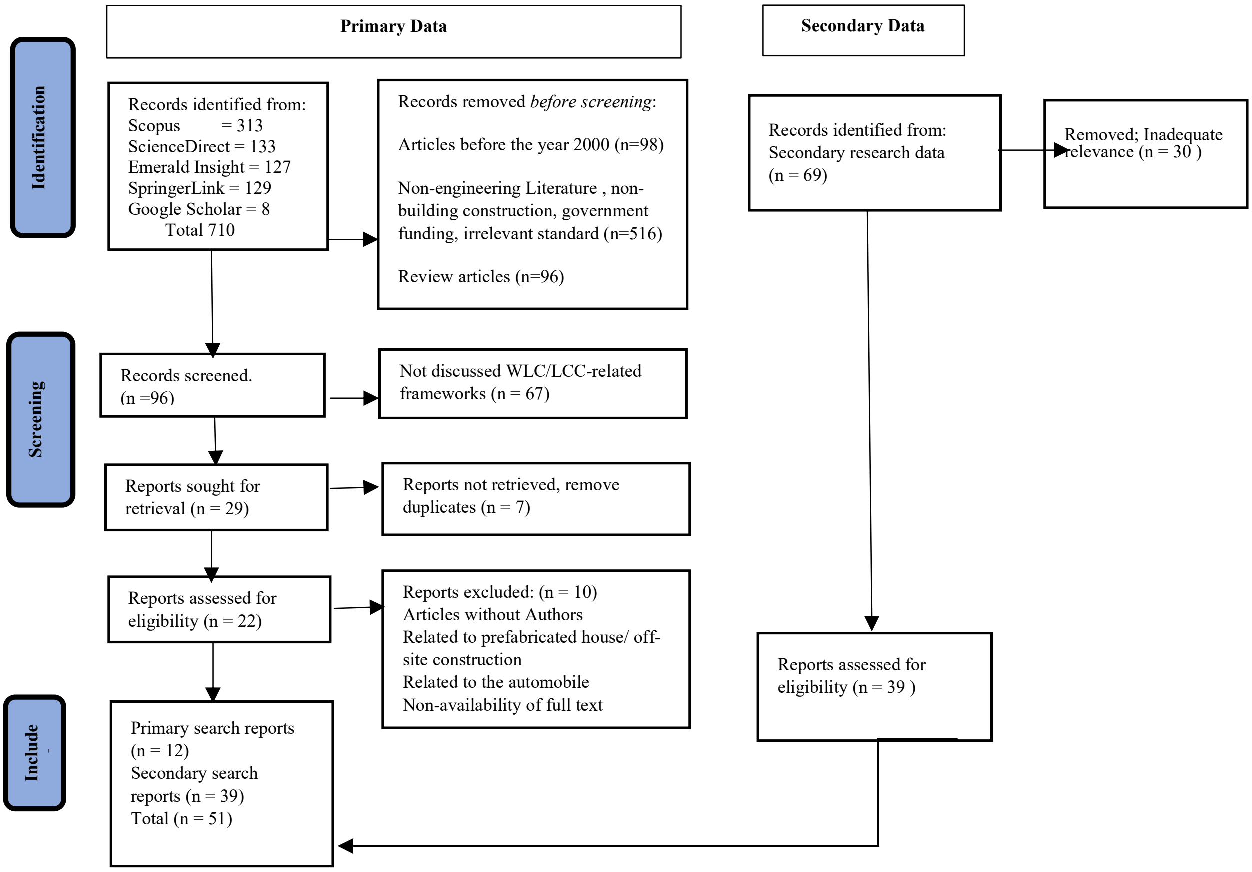


Figure 3.1 PRISMA Flow Diagram

The study reviewed 51 articles from 19 countries, as illustrated in Figure 3.2. This comprehensive analysis included contributions from nearly all regions of the world. Notably, most of these studies were conducted in the United Kingdom, Canada, and the United States, collectively accounting for 35% of the total. In contrast, Europe had the fewest studies represented in this review.

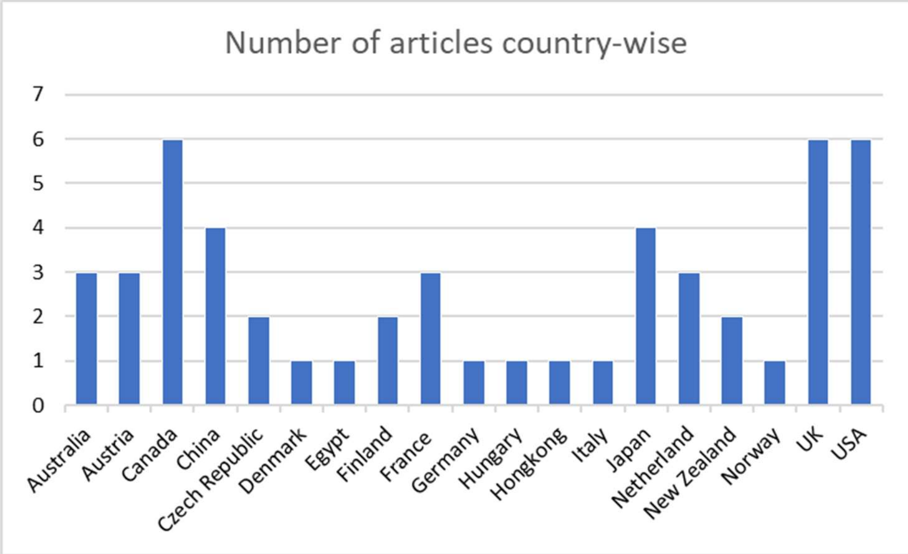


Figure 3.2: Origin of the articles included in SLR

3.4 Results and Discussion

This study aimed to identify gaps in the WLC framework used in NZ by comparing it with global WLC and LCC frameworks. Table 3.2 compares the current framework and applicable sectors of WLC and LCC practices in 19 countries (x indicates the applicability).

Table 3.2: Framework and applicable sectors

Framework and applicable sectors	Country																		
	Australia	**Austria**	**Canada**	**China**	**Czech Republic**	**Denmark**	**Egypt**	**Finland**	**France**	**Germany**	**Hungary**	**Hongkong**	**Italy**	**Japan**	**Netherland**	**NZ**	**Norway**	**UK**	**USA**
LCC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WLC			x	x										x		x		x	
Number of Frameworks associated	3	3	6	4	2	1	1	2	3	1	1	1	1	4	3	2	1	6	6
Residential																			
Commercial							x							x		x		x	
Product-specific tool		x											x	x	x				
Urban development			x				x							x				x	
Public procurement	x	x	x	x	x	x		x	x	x	x		x		x	x		x	x

Table 3.3 present the strengths, and Table 3.4 shows the weaknesses, respectively.

Table 3.3: Strengths of the LCC and WLC framework, country-wise

Strengths	**Australia**	**Austria**	**Canada**	**China**	**Czech Republic**	**Denmark**	**Egypt**	**Finland**	**France**	**Germany**	**Hungary**	**Hongkong**	**Italy**	**Japan**	**Netherland**	**NZ**	**Norway**	**UK**	**USA**
Climate change weight					x														
Economic Sustainability Analysis													x						
Procurement Environmental Impacts			x										x	x	x				
Infrastructure energy use														x	x				
Flood and storm barriers													x		x				
Energy efficiency, water conservation																			x
Simple calculations										x	x						x		
Environment-Material Impact Database															x			x	
Inflation and discount rate																x		x	
Specific database to compare LCC/WLC																		x	
Project documentation defined																		x	
Budget planning and compliance														x					
Early design decision information																		x	
Spreadsheets available										x	x				x	x			
Easy maintenance, minimal investment										x	x								
Calculation steps are visible.																		x	
Hierarchical levels and a unique coding																		x	
Pact on scope and assumptions			x																
Investigates complex issues														x					
Alternatives comparison	x																		
Adverse Weather			*x*	*x*							*x*						*x*	*x*	*x*
Seismicity														*x*					*x*

Table 3.4: Weaknesses of the LCC and WLC framework, country-wise

Weakness	**Australia**	**Austria**	**Canada**	**China**	**Czech Republic**	**Denmark**	**Egypt**	**Finland**	**France**	**Germany**	**Hungary**	**Hongkong**	**Italy**	**Japan**	**Netherland**	**NZ**	**Norway**	**UK**	**USA**
Includes acquisition cost and income	x																		
Use a series of assumptions.		x	x																
Extensive data												x							
Dependence on stakeholders' knowledge.			x																
Limited for complex projects.	x									x	x					x			
Excludes externalities.		x								x	x					x	x		
Site-specificness and local impacts are ignored.												x							
Excludes operation, disposal, and residual value																x			
Requires LCC parameter knowledge.															x	x			x
Not user-friendly													x					x	
Higher setup and maintenance costs.															x				
Significant investment for replication.					x								x						
Little public sector incentive.																			x
Insufficient published details.						x													
No national methodology or database.	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x
Lack of transparency and knowledge.																			x
Lack of Data or information													x		x	x			x

The comparative analysis shown in Table 3.2**Error! Reference source not found.** revealed varied WLC and LCC frameworks globally. In Europe, stringent sustainability regulations have integrated WLC and LCC into construction project management, with countries like the UK, Germany, and the Netherlands leading the way (EU, 2010). Organisations such as the Royal Institution of Chartered Surveyors (RICS, 2016) and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB, 2022) provide robust guidelines, emphasising the three sustainability pillars. In North America, LCC is widely used in public and private sectors, driven by federal and state-level energy regulations and supported by standards like ASTM E917 (ASTM, 2020). The U.S. Green Building Council's LEED certification promotes sustainable practices by incorporating LCC principles (USGBC, 2021).

The Asia-Pacific region has varied WLC and LCC practices. Japan and Australia have established methodologies focusing on resilience against natural disasters (MOE, 2020). China and India are gradually adopting these practices due to rapid urbanisation and growing sustainability awareness (Wang, 2016a). Middle Eastern countries, such as the UAE and Saudi Arabia, are increasingly incorporating WLC and LCC into their ambitious sustainable development projects (MoE, 2021). In Africa, adoption is primarily driven by international projects aiming at long-term sustainability (UNEP, 2020).

Canada, China, Japan, NZ, and the UK are progressively embracing WLC frameworks, recognising cost analysis benefits. Canada's proactive adoption of WLC principles promotes innovative cost management, expanding beyond traditional LCC approaches to make informed decisions considering an asset's life cycle, including durability, energy efficiency, and environmental impact. Despite the increasing recognition of WLC principles globally, several challenges persist. Factors such as terminology ambiguity, entrenched organisational practices, and reluctance to deviate from familiar methodologies hinder widespread adoption.

In countries such as Australia, there is significant confusion between LCC and WLC methodologies, particularly in procurement practices. This confusion highlights broader issues of terminology ambiguity and methodology consistency within the industry, hindering effective cost management. Common LCC frameworks often overlook the potential impact of inflation on future cash flows, introducing distortions in cost analyses. Additionally, diverse assumptions regarding present and future cash flows complicate the extraction of meaningful insights from cost analyses. Enhancing transparency in foundational assumptions and adopting a more sophisticated approach to discount rate selection is imperative to address these challenges. Addressing these challenges requires raising awareness, providing clear guidance, and demonstrating the tangible benefits of WLC in the construction industry.

NZ recognises WLC as crucial for evaluating an asset's total cost of ownership, especially in infrastructure projects. Government agencies, such as the Ministry of Business, Innovation and Employment (MBIE) and the NZ Transport Agency (NZTA), promote WLC practices to ensure long-term value in infrastructure investments. However, the current WLC framework in NZ requires further enhancement to address unique GC and adverse weather factors. The comparative analysis reveals a notable gap in applying WLC frameworks specifically tailored for residential buildings. While countries like Canada, China, Japan, New Zealand, and the UK have adopted WLC principles for various sectors, including infrastructure projects, there is no specific mention or recognition of WLC frameworks tailored for residential buildings. This gap underscores the need to develop and enhance WLC methodologies to address the unique challenges and considerations associated with residential construction in NZ. Integrating localised data on seismic risks and adverse weather conditions is essential for improving the accuracy of cost estimations and ensuring that residential buildings are resilient and cost-effective over their entire life cycle.

3.5 Conclusion

The comparative analysis with global WLC and LCC frameworks revealed varying adoption rates across countries. Despite global recognition, challenges such as terminology ambiguity and resistance to change persist, hindering the widespread adoption of WLC principles. Specifically, the need for tailored WLC frameworks for residential buildings highlights a critical gap in current practices. Addressing these gaps leads to a more resilient and cost-effective construction industry.

While NZ recognises the importance of WLC for infrastructure projects, further framework refinement is needed. It had not addressed the residential sector. Further, the unique geographical and weather-related factors that pose challenges must be effectively addressed. Integrating localised data on seismic risks and adverse weather conditions is essential to improve the WLC of residential constructions.

Overall, this study contributes to the existing body of knowledge by advocating for a tailored approach to WLC analysis in NZ, informed by the insights gleaned from the comparative global analysis and tailoring it to local conditions. The findings emphasise the importance of adapting decision-making frameworks to local conditions for optimal project outcomes, with potential applications in similar contexts globally.

Chapter 4. Methodology

4.1 Introduction

This chapter outlines the methodological foundation underpinning this doctoral research, which aims to develop a Whole-life Cost (WLC) framework tailored to New Zealand's residential building sector. The research design follows a three-stage structure. Stage 1 involved a systematic literature review and archival/documentary analysis to identify and classify the factors influencing WLC. Stage 2 focused on system dynamics modelling and the development of the WLC framework. Stage 3 comprised expert engagement and validation of the framework, for which interview data were collected in two phases (an initial round of semi-structured interviews to elicit insights and a subsequent round to review and refine the proposed framework). Guided by the research onion model proposed by Saunders et al. (2019), the chapter provides a structured explanation of the research philosophy, approach, methodological choices, strategies, time horizon, and techniques used for data collection and analysis. As this is a manuscript-based thesis, each manuscript adopts context-specific methodological strategies suited to its research objectives. However, the overarching methodological orientation remains consistent across all manuscripts. Section 4.8 summarises the methodological alignment with the broader study goals.

System dynamics modelling and the Analytic Hierarchy Process (AHP) are central methodological components of this research. System dynamics is used to conceptualise and represent the complex interrelationships between WLC factors through causal loop diagrams (CLDs) and stock–flow structures, supporting a dynamic, feedback-based understanding of cost behaviour over the building lifecycle. AHP is employed to derive relative weights for key cost-influencing factors via structured pairwise comparisons, enabling the integration of expert judgements into the prioritisation of variables within the WLC framework. Detailed descriptions of the system dynamics and AHP procedures are presented in Chapters 5 and 6, respectively; however, this chapter situates these methods within the broader research design to show how they link qualitative insights and documentary evidence to a quantified, decision-support-oriented framework.

4.2 Philosophical position

Saunders et al. (2019) define research philosophy as a framework of beliefs and assumptions regarding knowledge development. While some researchers believe that each type of research has a standard philosophy, it is recommended to design a philosophy based on relevant assumptions. A philosophical paradigm encompasses beliefs about the nature of reality (ontology), the creation of knowledge (epistemology), and values related to beliefs and practices (axiology). Saunders et al. (2019) visually represented philosophical paradigms using a research onion Figure 4.1. The research's philosophical position is described in the following subsection.

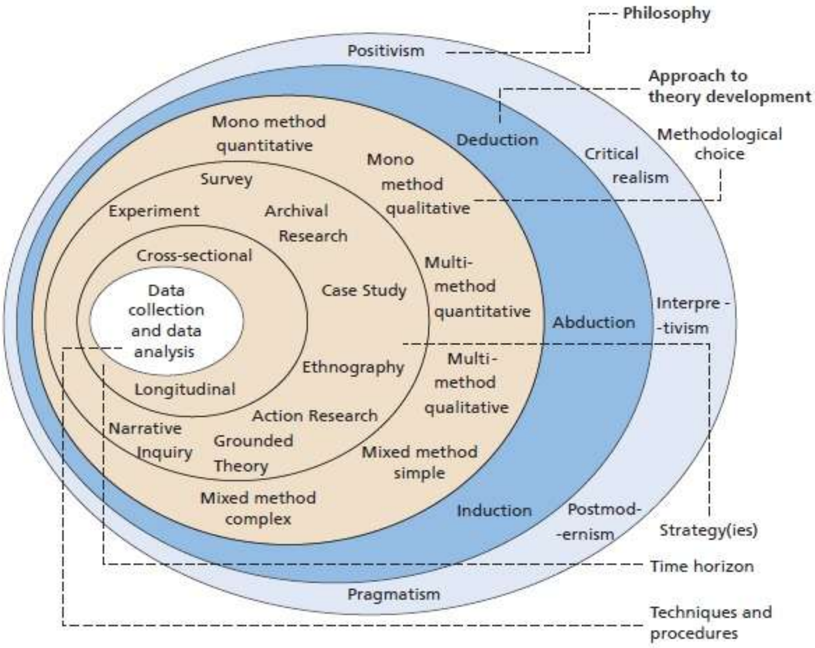


Figure 4.1: Research Onion (Saunders et al., 2019)

4.2.1 Assumptions of Philosophical Positions

This research is grounded in three foundational components: ontology (the nature of reality), epistemology (the nature of knowledge), and axiology (the role of values in research). An idealist ontology was adopted, which assumes that reality is socially constructed and shaped by individual and collective interpretations (Heron, 1996). From an epistemological standpoint, the study adopts a subjectivist perspective, valuing participants' lived experiences and acknowledging that knowledge is context-dependent and constructed through interaction (Rose et al., 2014)(Rose et al., 2014). In terms of axiology, the study accepts that research is value-laden and that the researcher's positionality influences interpretation. This philosophical triad aligns with interpretivism, which prioritises understanding over measurement and seeks to reveal multiple realities within socially complex environments (Denzin & Lincoln, 2008).

4.2.2 Philosophies

In determining the appropriate philosophical foundation for this study, five dominant paradigms were examined: positivism, critical realism, interpretivism, postmodernism, and pragmatism. Each was assessed for its alignment with the study's aim to develop a context-specific WLC framework for stand-alone residential buildings in New Zealand, as well as its capacity to support exploratory, qualitative inquiry.

Positivism asserts that reality exists independently of human perception and can be observed, measured, and generalised through objective methods (Saunders et al., 2019). This paradigm is well-suited to studies with a deductive structure and relies on quantitative data for hypothesis testing and law-like generalisations (Annells, 1996). However, positivism was considered inappropriate for this study because it failed to capture the nuanced, socially constructed understanding of WLC practices in residential construction. The rigid objectivity and detachment required by positivism limit the researcher's engagement with participants, which contradicts the interpretative and participatory nature of this study. Additionally, WLC in New Zealand's residential sector lacks extensive quantitative datasets, making a positivist approach impractical (Pham, 2018).

Critical realism offers a layered ontological perspective, distinguishing between the *empirical* (what is observed), the *actual* (what occurs), and the *real* (underlying mechanisms) (Danermark et al., 2005). It combines ontological realism with epistemological relativism, acknowledging that knowledge is fallible and socially influenced. While this duality makes critical realism valuable for exploring causal mechanisms, its realist ontological stance assumes a fixed reality that exists independently of perception, which contrasts with this research's idealist ontology, which posits that reality is constructed through stakeholder perspectives and social interaction (Soon-Chean Park & Peter, 2022). Because the objective of this study is to explore how different actors subjectively understand and apply WLC, rather than to uncover hidden causal structures, critical realism was excluded from consideration.

Postmodernism, on the other hand, critiques dominant discourses and challenges assumptions of universal truth by emphasising plurality, fragmentation, and the role of language and power in shaping reality (Best & Kellner, 1997). While this paradigm aligns with a socially constructed view of knowledge, it often resists coherence, structure, and consensus. This research, although interpretive, aims to develop a coherent and structured WLC framework that is both practical and helpful for policymakers and construction professionals. Postmodernism's deconstructive stance and tendency to avoid general frameworks or normative recommendations were therefore misaligned with the study's goal to build a usable, evidence-informed model for industry application.

Pragmatism promotes methodological flexibility and is focused on the consequences of research, emphasising problem-solving over philosophical purity (Creswell & Creswell, 2023). It supports the use of multiple methods, both qualitative and quantitative, and is particularly valuable in mixed methods designs (Morgan, 2007). While pragmatism allows researchers to draw from both interpretivist and positivist techniques, this study does not employ mixed methods; instead, its methodological coherence is built around qualitative inquiry. Moreover, pragmatism tends to prioritise utility over theory, whereas this research places equal importance on generating conceptual insight into WLC practices. Therefore, while pragmatism offers practical benefits, it was not adopted.

Ultimately, interpretivism was selected as the most appropriate philosophical paradigm for this study. Interpretivism posits that reality is socially constructed and that multiple, subjective meanings exist depending on context and culture (Denzin & Lincoln, 2008). It values context-rich, in-depth insights and often employs qualitative methods such as interviews and ethnography to explore lived experiences (Rose et al., 2014). This approach aligns well with the study's aim to understand how WLC is perceived and applied by professionals within the unique environmental, regulatory, and economic context of New Zealand. It supports the use of qualitative interviews to capture diverse stakeholder perspectives, allowing the researcher to co-construct meaning with participants, which is a crucial aspect of this study. By favouring depth over breadth and meaning over measurement, interpretivism enables the development of a nuanced and contextually grounded WLC framework.

A detailed comparison of the five philosophies mentioned above is presented in Table 4.1.

Table 4.1: Comparison of Philosophies

	Ontology (Nature of reality or being)	Epistemology (What constitutes acceptable knowledge)	Axiology (Role of values)	Typical methods
Positivism	• Real, external, and independent. • One actual reality (universalism) • Granular (things) • Ordered	• Scientific method • Observable and measurable facts • Law-like generalisations • Numbers • Casual explanation and prediction as a contribution	• Value-free research • The researcher is detached, neutral and independent of what and maintains an objective stance.	Typically deductive, highly structured, large samples, measurement, typically quantitative methods of analysis, but the range of data can be analysed.
Critical realism	• Stratified/ layered (the empirical, the actual and real) • External, independent • Intransient • Objective structures • Casual Mechanism	• Epistemological relativism • Knowledge is historically situated and transient • Facts are social constructions. • Historical causal explanation as the contribution	• Value-laden research • The researcher acknowledges bias by world views, cultural experience, and upbringing. • The researcher tries to minimise bias and errors. • The researcher is as objective as possible	Reproductive, in-depth, historically situated analysis of pre-existing structures and emerging agency. A range of methods and data types to fit the subject matter.
Interpretivism	• Complex, rich • Socially constructed through culture and language • Multiple meanings, interpretations, and realities • The flux of processes, experiences, practices	• Theories and concepts are too simplistic • Focus on narratives, stories, perceptions and interpretations. • New understandings and worldviews as the contribution	• Value-bound research • Researchers are part of what is researched; it is subjective. • Researcher interpretations key to contribution, researcher reflexive	Typically, inductive methods, small samples, in-depth investigations, and qualitative analysis are used, but the arrangement of data can still be interpreted.
Postmodernism	• Nominal complex, rich • Socially constructed through power relations • Some meanings, interpretations, and realities are dominated and silenced by others. • The flux of processes, experiences, practices	• What counts as 'truth and knowledge is decided by dominant ideologies. • Focus on absences, silences and oppressed/ repressed meanings, interpretations and voices. • Exposure of power relations and the challenge of dominant views as the contribution	• Value-constituted research • Researcher and research embedded in power relations. • Some research narratives are repressed and silenced at the expense of others. • Researcher radically reflective	Typically, deconstructive reading texts and realities against themselves, in-depth investigations of anomalies, silences, and absences A range of data types of typically qualitative methods of analysis
Pragmatism	• Complex, rich, external reality is the practical consequence of ideas. • The flux of processes, experiences, and practices	• The practical meaning of knowledge in specific contexts • True theories and knowledge are those that enable successful action. • Focus on problems, practices and relevance. • Problem-solving and informed future practice as a contribution	• Value-driven research • Research initiated and sustained by the researcher's doubts and beliefs. • Researcher reflexive	Following the research problem and research question Range of methods: mixed, multiple, qualitative, quantitative, action research Emphasis on practical solutions and outcomes

4.3 Approach to the theory development

Easterby-Smith et al. (2012) detail three reasons why choosing an appropriate research approach is essential. Firstly, it is helpful to consider which research approaches and methodological decisions will be effective and which will not. Secondly, understanding the various research traditions can help the researcher adjust their research design to account for limitations, resulting in a more informed choice about their research design beyond just the method for collecting and analysing data.

This study employs an inductive approach to develop a theory, which is a suitable fit for the exploratory goal of understanding WLC estimation for residential buildings in the often-overlooked context of New Zealand. Inductive reasoning involves creating a theory based on real-world observations by gathering qualitative data and identifying emerging patterns, themes, and connections, rather than testing an existing hypothesis or theoretical framework (Saunders et al., 2019). The main reason for using an inductive approach is the exploratory and context-specific nature of this research. WLC estimation practices in New Zealand's residential construction sector are mostly undocumented, and there is no established theoretical model to test or apply. By using induction, the study lets insights develop naturally from various qualitative sources, such as literature reviews, stakeholder interviews, and system dynamics (SD) modelling outputs. This approach helps create a theory based on real data (Gioia et al., 2013). Additionally, the inductive approach aligns well with the study's interpretivist philosophy, which posits that knowledge originates from individuals' subjective experiences and meanings (Denzin & Lincoln, 2018). Inductive logic supports this viewpoint by focusing on participants' interpretations and lived experiences, rather than seeking universal laws. This approach enables a detailed and context-sensitive WLC framework that addresses New Zealand's unique socio-technical environment (Varpio et al., 2020).

Deductive reasoning starts with an existing theory or hypothesis, which is then tested with empirical data. This method is typically associated with the positivist view and quantitative methods, which aim to test hypotheses and make statistical generalisations (Creswell & Creswell, 2023). It requires a clear theoretical framework and predetermined variables, which are not available in the context of this study's WLC estimation in New Zealand. Using a deductive approach would have limited the research to validating external models without considering the complexity, local factors, and stakeholder dynamics in the setting. Since this research aims for a deep understanding of context and the ability to transfer theory, rather than making statistical generalisations (Lincoln et al., 1985), deductive reasoning is not the best fit.

Abductive reasoning is a mixed approach that moves back and forth between empirical data and theoretical explanations, adjusting hypotheses to explain unexpected findings (Timmermans & Tavory, 2012). It works well when there is a partial or tentative theoretical framework that can be improved with new data. While abductive reasoning offers some flexibility, it assumes the existence of an initial conceptual model to guide the iterative process. At the outset, there was not sufficiently developed WLC theory available, which limits the practical application of this method. Moreover, abductive approaches are often part of mixed-methods designs (Morgan, 2007), while this research is rooted in a qualitative, single-paradigm interpretivist framework.

Taking all these points into account, the inductive approach is the most suitable choice for developing a theory in this study. It provides the openness and depth necessary to explore a new, complex, and context-driven issue, allowing theory to emerge directly from thorough engagement with literature, system modelling, and stakeholder input. This approach helps build a theory-based, yet practical WLC framework that aligns well with the study's research goals, design, and foundations.

4.4 Methodological Choice

The choice of the correct methodological approach is crucial to ensuring that the research design aligns with the underlying philosophy and objectives. As Saunders et al. (2019) Notably, methodological choices are closely linked to the research philosophy, the nature of the research questions, and the type of theory being tested or developed. This study employs a qualitative methodology with an interpretivist philosophical stance, as it explores WLC estimation in residential construction in an inductive manner. The nature of theory varies considerably in research, depending on whether it involves a quantitative, qualitative, or mixed-methods study. Therefore, a close inspection of these methods is necessary to determine the most suitable approach.

This research aims to understand the complex, context-dependent, and socially constructed factors that affect WLC estimations. The focus is not on testing predefined hypotheses or statistically measuring variables. Instead, it examines how individuals in the construction industry perceive, interpret, and respond to various cost components throughout the lifecycle of buildings. A qualitative approach suits these goals since it lets the researcher connect with participants' real experiences and meanings (Flick, 2022). Additionally, the novelty of WLC estimation in New Zealand's residential sector means that key variables may not yet be clearly defined or established. According to Morse (1994), Qualitative research is most valuable when existing theories cannot adequately explain a phenomenon or when the area is not well explored. This approach enables the development of theory from the ground up, supporting an inductive reasoning process as described by Gioia et al. (2013). Data collection and analysis occur iteratively, leading to new conceptual insights.

A quantitative approach was considered but ultimately rejected for this study because it requires predefined variables and hypotheses that are not readily available in the complex and under-theorised area of WLC estimation in residential construction. Quantitative methods are well-suited for examining relationships between measurable variables and testing hypotheses under controlled conditions (Creswell & Creswell, 2023); however, such an approach may oversimplify the complex dynamics of construction cost estimation. Moreover, the assumptions behind most quantitative studies do not align with the interpretivist stance of this research. As Walsh et al. (2015) In this context, quantitative methods often rely on objectivity and detachment, whereas this study requires a deep understanding of participants' contextual realities to construct meaningful insights.

While mixed methods research, which combines qualitative and quantitative approaches, offers the benefit of using different methods together and broader generalizability (Creswell & Creswell, 2023; Flick, 2022), this study is not set up as a fully integrated mixed-methods project. The primary focus is on qualitative research, grounded in an interpretivist perspective and informed by inductive theory-building. However, the study includes a validation phase to assess the strength and practical relevance of the framework developed from the qualitative data. This phase may employ structured methods, such as expert review, stakeholder feedback, or prioritisation tools, which may involve some limited quantitative or systematic assessment. This does not make it a traditional mixed-methods study, such as convergent, explanatory sequential, or exploratory sequential design, because the quantitative part does not occur simultaneously or equally with the qualitative data collection, and the development of theory is guided by qualitative insights, rather than statistical generalisation. Instead, the validation phase aims to refine and confirm the framework's usefulness. This approach aligns with Gioia et al. (2013), suggesting that ongoing verification in inductive research enhances trustworthiness without deviating from the central qualitative methodology. Therefore, while the study recognises and includes a minor mixed-method component during validation, it remains firmly rooted in a qualitative, inductive, and interpretivist design.

Considering these factors, this research employed a multi-method qualitative strategy within an interpretivist paradigm, guided by inductive reasoning. Data were gathered through semi-structured interviews, document analysis, and thematic coding, providing rich, context-specific insights into how different cost elements, actors, and contextual forces interact in WLC estimations. Ultimately, this approach offers the depth, flexibility, and openness necessary to develop a conceptual framework that accurately reflects the complexities and subjective interpretations of stakeholders involved in residential construction cost estimation in New Zealand and beyond.

4.5 Strategy

A strategy is a systematic approach to achieving a specific objective. When it comes to research, a research strategy is a well-thought-out plan that outlines how a researcher intends to tackle a research problem. As Denzin and Lincoln (2008) explain, strategy is the vital connection between the underlying philosophy and the subsequent selection of data collection and analysis methods. Researchers have employed different research strategies to obtain meaningful results, depending on the research question. Research strategies include surveys, archival and documentary research, case studies, ethnography, action research, grounded theory and narrative inquiry.

Survey design is a valuable research tool used to study a sample of a population and understand trends, attitudes, and opinions or test for associations among variables. However, surveys rely on a qualitative method, which may not be the best approach for this research. According to Yin (2009), a case study is a more effective method for in-depth investigation of a specific topic or phenomenon in real-life situations. This approach can be applied to various case subjects such as individuals, groups, organisations, events, and more. While a case study typically uses a deductive approach, it cannot be applied to this research due to the unavailability of the WLC framework for residential buildings. Therefore, a case study is also not an appropriate choice for this research. Ethnography is also rejected because it is used to study cultures or social groups. An action research strategy aims to promote organisational learning by producing practical outcomes through the identification of issues, planning of action, taking action, and evaluation of the action (Reason, 2006). Grounded theory develops theoretical explanations of social interactions and processes in various contexts (Saunders et al., 2019). The research objectives of this thesis are distinct and do not involve probability analysis, organisational learning promotion, or the development of theoretical explanations of social interactions. Therefore, only archival research and narrative study were discussed further in the context of this research strategy.

4.5.1 Archival Research

With the rise of digital data and the availability of online archives, as well as the growing trend of open data policies in both the public and private sectors, archival and documentary research strategies have become more accessible than ever before (Saunders et al., 2019). While these sources offer a wealth of potential research avenues, the reliability of the data they provide is often in question (Hakim, 2012). To ensure the accuracy of the information gathered, a dependable system is imperative. In this study, archival sources such as cost databases, professional guidance documents, regulatory texts, and hazard datasets were used because they provide direct evidence of how WLC is currently specified, priced, and regulated in New Zealand residential construction practice, which would be impractical to reconstruct solely through primary data collection. These materials supply the historical and contextual cost, regulatory, and hazard information needed to parameterise the framework and ensure that it reflects real-world decision environments rather than purely theoretical assumptions.

4.5.2 Narrative inquiries

Narrative refers to a personal account or story that interprets an event or series of events. In qualitative research, interviews require participants to tell their stories. Therefore, the term 'narrative' can be used to describe the nature or outcome of such interviews (Saunders et al., 2019). Narrative inquiry is a research methodology that can be used in various ways. It can be employed with a small number of participants who are representative of a larger population (Chase, 2013), or with slightly larger samples from an organisation to analyse how narratives are constructed around an event or series of events. Narrative inquiry is most suitable when the research question and objectives suggest an interpretive and qualitative strategy. It enables the analysis of the linkages, relationships, and constructed explanations that occur naturally within narrative accounts, facilitating a better understanding of complex processes (Musson, 2004).

As a component of this research, semi-structured interviews were conducted with 22 participants as part of a broader population-level narrative inquiry. In addition, follow-up validation interviews were conducted with a smaller sample of 5 participants to further explore emerging themes through in-depth narrative engagement. These methods supported the study's aim of contextualising Whole-life Cost estimation practices within real-world stakeholder experiences. Further details on both the semi-structured interviews and focus group procedures are provided in Section 4.7.1.

4.6 Time Horizon

There are two distinct time frames for conducting research. Cross-sectional (or short-term) studies are observational and descriptive. Researchers use this method to gather data from a population without manipulating any variables (Saunders et al., 2019). This type of research captures a snapshot of data at a specific time. On the other hand, longitudinal studies are a type of correlational study that collects data over an extended period, sometimes spanning years or even decades. Compared to cross-sectional studies, longitudinal studies provide a more comprehensive data evaluation (Rashid, 2021). In this research, a cross-sectional (short-term) time frame was adopted because the aim is to capture a detailed snapshot of how WLC is currently conceptualised and operationalised in New Zealand residential construction, under existing costs, regulations, and hazard understanding, rather than to track changes over time. A longitudinal design would require a consistent, multi-year time-series of lifecycle cost and performance data that are not presently available and would exceed the practical scope and purpose of this study. Following data collection, a rigorous analysis process was undertaken to extract patterns, relationships, and causal dynamics from the gathered data

4.7 Techniques and Procedure

4.7.1 Data Collection

In this thesis, data are drawn from a systematic literature review, semi-structured interviews, and a validation stage.

4.7.1.1 Systematic literature review

The SLR is a scientific approach which begins with a specific review question, identifies all relevant studies, appraises their quality and summarises their results using a scientific methodology" (Rother, 2007). In this study, an SLR was essential because the aim is to develop a New Zealand-specific WLC framework that is nevertheless grounded in global evidence, rather than relying solely on local practice or a narrative review of selected sources. A structured SLR allows the thesis to systematically identify WLC frameworks, factors and interrelationships reported internationally, compare their relevance to the New Zealand residential context, and minimise selection bias in building the conceptual basis for the new framework. Articles undertaking systematic literature reviews are regarded as unique work since they adhere to strict methodological standards (Rother, 2007). There are many advantages of SLR. It employs extracting search strategies to ensure that the maximum extent of relevant research has been considered, original articles are methodologically evaluated and synthesised using strict methods to locate, evaluate, and synthesise all research on a topic, and it provides a straightforward methodology that lowers the risk of bias by adhering to a strict and repeatable protocol of procedures (O'Brien & Mc Guckin, 2016). However, while bias reduction is one of the main advantages of SLR, DistillerSR (2023) argued that bias can occur at any stage, as poor study design and execution, as well as selective outcome reporting, significantly threaten the validity of a systematic review.

Two types of data were collected for the SLR. Primary data are sourced from databases such as Google Scholar, Scopus, Emerald Insight, SpringerLink, and ScienceDirect. The confidentiality of WLC cost data is of utmost importance. As a result, this thesis has relied on secondary research data from reputable sources, including paid databases, company annual reports (such as those of Turner and Townsend, Arcadis, and Branz), as well as government publications, news articles, press releases, and webcasts specific to companies operating in the market. The sources for secondary research data are extensive and include Factiva, OneSource, Hoovers, and Statista. It is worth noting that each cost data point is treated as a case study to ensure the accuracy and reliability of the findings.

For this research, the SLR was run thrice to capture the articles that provided specific information. First for framework (see chapters 3 and 7), second for factors (see chapter 5), and interrelationships of the factors and system dynamics (see chapter 6). In Chapters 3 and 7 for the frameworks, the search string included framework, WLC and LCC, the period was post 2000, which helped to capture specifics of the frameworks and their developments. LCC was included, as most countries' standards are stated in terms of LCC, while a few countries mention it as WLC. In Chapter 5, the search string included only WLC, construction, and factors, which helped focus on specific factors affecting the WLC in construction. In chapter 6, for interrelationships of the factors and system dynamics, the same search strings as chapter 5 were considered, but the period considered was from 2012 to 2024. This helped in the recency of factors and their interrelationships in the digital era.

4.7.1.2 Semi-structured interviews

The semi-structured interviews were conducted to comprehensively identify the factors influencing WLC and their interrelationships, beyond those highlighted in the systematic literature review (SLR). This qualitative approach aimed to deepen the understanding of the system dynamics associated with these factors and facilitate a thorough evaluation of existing frameworks for assessing WLC in New Zealand's residential buildings. To achieve this, the qualitative data was gathered through semi-structured interviews, which were specifically chosen for their exceptional ability to elicit rich, nuanced insights from experienced professionals within the construction industry. This method strikes a balance between structure and flexibility, allowing the interviewer to follow a pre-prepared guide while also probing deeper into emerging themes and insights during the conversation. This adaptability ensures both consistency and depth in the data collected, enriching the overall findings and analysis (Gill et al., 2008; Kallio et al., 2016).

Semi-structured interviews were therefore more suitable than a structured questionnaire or fully unstructured conversations for the purposes of this study. They enabled participants to discuss not only individual WLC factors but also the relationships, trade-offs, and contextual conditions that shape their influence, which is essential when exploring complex system dynamics. In addition, this format aligns with the interpretivist, inductive orientation of the research, which seeks to understand how practitioners conceptualise and operationalise WLC in real project settings rather than to generate purely quantitative, standardised responses (Gill et al., 2008).

The selection of participants was strategically executed through purposive sampling, focusing on professionals with a minimum of five years' experience in roles directly related to construction economics, project planning, cost estimation, asset management, and sustainability. This rigorous selection aimed to gather diverse expert perspectives, engaging quantity surveyors, architects, engineers, government authority employees, project managers, and facilities managers. Invitations for participation were sent via email and LinkedIn, along with a Participant Information Sheet and Consent Form (see Appendix 2 and 5) to ensure transparency and ethical compliance. All interviews were conducted online through Microsoft Teams, accommodating participant preferences, and were recorded with consent for accurate transcription and analysis (Opdenakker, 2006).

The interview protocol was meticulously developed based on insights from the literature review. The interview questions (see Appendix 3) consisted of open-ended questions. The interview primarily focused on creating a robust WLC framework for residential buildings in New Zealand. It began by establishing trust and explaining the research's objectives, followed by collecting background information about participants' experience in WLC estimation. The discussion then explored identifying key cost-influencing factors and their interactions within various economic and geographical contexts. System dynamics were studied to understand the interrelationships between these factors, guiding improvements to the estimation process. The existing WLC frameworks in New Zealand were reviewed, highlighting current methodologies, tools, stakeholder collaboration, and challenges. Subsequently, participants evaluated a proposed WLC framework under development, offering insights on its relevance, implementation feasibility, and areas for refinement. The interview concluded with a strong emphasis on the importance of ethical data handling and secure storage protocols to protect participant confidentiality and data integrity. Each interview session was typically 30 minutes, during which participants were encouraged to provide real-world examples from their projects to illustrate the practical implications of various WLC drivers. A total of 22 participants (7 quantity surveyors, 3 project managers, 2 facility managers, 2 site supervisors, 2 electrical engineers, 2 homeowners, 2 architects, and 1 government authority employee) participated in the semi-structured interviews. The interviews were conducted until saturation was reached.

In line with qualitative research guidance, data collection continued until data saturation was reached, that is, the point at which additional interviews no longer generated new themes or insights relevant to the research questions (Guest et al., 2006). Continuing beyond this point would have added redundancy rather than substantive new information, while still incurring additional time and resource demands, so it was considered both methodologically and practically appropriate to stop data collection once saturation had been achieved (Saunders et al., 2019).

4.7.1.3 Validation Interview

Following the development of the proposed WLC framework for residential buildings in New Zealand, a second round of semi-structured interviews was conducted to validate its structure, practicality, and relevance. These validation interviews assessed whether the framework accurately reflected industry realities and addressed the key factors identified through earlier data collection and system dynamics modelling. The process also aimed to refine the framework based on expert feedback and ensure its applicability in real-world contexts (Creswell & Poth, 2016).

Five participants participated in the validation interviews. All 22 practitioners who took part in the earlier semi-structured interviews were invited to participate in the validation phase. Four of these agreed to be involved in the follow-up interviews, and one additional expert with relevant experience consented to join, resulting in a validation panel of five participants. This number was considered sufficient for the purpose of framework validation, as the goal was not statistical generalisation but in-depth, practice-based critique from a group of experienced professionals. The inclusion of four participants who were already familiar with the study ensured continuity and an informed assessment of how the framework reflected earlier findings, while the participation of one new expert provided an external perspective and independent scrutiny**.** They were selected based on their professional backgrounds in quantity surveying, construction project management, commercial management, government advisory, and facilities management.

Together, the five participants represented the main professional roles involved in planning, procuring, delivering, and operating residential buildings, ensuring that the framework was reviewed from multiple, practice-relevant perspectives rather than a single disciplinary viewpoint. The Quantity Surveyor (QS) contributed expertise in cost planning, measurement, and lifecycle cost structure; the Project manager (PM) provided insights into project delivery, sequencing, and risk management; the Commercial Manager (CM) represented client-side commercial and financial decision-making; the Government Authority Representative (GA) brought a policy and regulatory perspective relevant to WLC adoption and standards; and the Facilities Manager (FM) contributed an operational and long-term maintenance viewpoint. Together, these roles cover design, procurement, construction, policy, and operation stages of residential projects, ensuring that the framework was not validated from a single disciplinary angle but was instead reviewed by experts who collectively span the full Whole-life Costing perspective.

Most participants had previously taken part in the exploratory interviews, ensuring continuity and familiarity with the research context. Before the validation interviews, participants received a detailed report of the proposed framework to support informed feedback. Each interview was conducted via Microsoft Teams and lasted approximately 30 minutes.

The validation interviews were structured around six key themes to ensure a comprehensive evaluation of the proposed WLC framework. Participants were first asked to reflect on their general understanding of WLC and its relevance within the New Zealand residential construction sector. This was followed by discussions on the framework's comprehensiveness, including whether it effectively captured critical cost components such as operational, maintenance, and end-of-life costs. A significant focus was placed on assessing how well the framework addressed New Zealand-specific factors such as seismic activity, adverse weather conditions, and local construction practices. Participants also provided insights into the framework’s usability and practical application across various project types, particularly regarding data availability and ease of integration into existing workflows. Furthermore, the interviews examined the framework’s alignment with international standards, such as ICMS, and sought suggestions to enhance its compatibility. Finally, feedback was gathered on potential implementation pathways and enhancements to promote its adoption within the industry, including policy support, digital tools, and training initiatives. Participants were encouraged to critique the framework's logic, clarity, and usability. This process provided valuable insights into how the framework could be adapted to align more closely with industry workflows and local conditions (Brinkmann & Kvale, 2018).

Data from the interviews were analysed using thematic analysis. Feedback highlighted the framework’s strengths, including its focus on regional resilience and long-term decision-making. It also identified areas for refinement, such as more apparent cost-benefit linkages and simplification of technical language for broader use. These insights informed minor modifications to the framework, enhancing its practical relevance and strengthening its reliability and value for stakeholders in New Zealand’s residential construction sector.

4.7.2 Data analysis

The data analysis plan is structured around thematic analysis, employing a methodologically sound approach supported by theoretical justifications to extract meaningful themes and insights from the data. Thematic analysis was adopted as the primary analytic approach because it provides a flexible yet rigorous method for identifying, organising, and interpreting patterns of meaning across qualitative interview data, without being tied to a single theoretical framework (Braun & Clarke, 2006). It is well-suited to studies that seek to move from participants’ detailed accounts toward higher-level themes that explain how cost factors, interrelationships, and contextual influences are understood in practice, rather than to test predefined hypotheses. Thematic analysis also accommodates both inductive coding (allowing unexpected issues to emerge from the data) and deductive coding (informed by the WLC literature and system dynamics concepts), making it appropriate for this research, which integrates existing theoretical insights with practitioner perspectives. Thematic analysis is a qualitative method used to identify, analyse, and interpret patterns (themes) within data. It involves systematically coding and categorising data to uncover underlying themes and understand the meaning and significance of those themes in relation to the research questions or objectives. Thematic analysis is widely used across various disciplines to analyse qualitative data from interviews, focus groups, and open-ended survey responses (Braun & Clarke, 2006).

The computer-assisted Qualitative Data Analysis (CAQDAS) technique was used as a tool for thematic data analysis, utilising NVivo software to analyse the data in this research. NVivo is a code-based system that provides advanced and adaptable tools, particularly its ability to support structured qualitative data and integrate materials from various other applications, such as bibliographic sources (Lewins & Silver, 2014). Using NVivo for data analysis in semi-structured interviews offers several advantages over traditional methods, aligning well with the objectives of qualitative research. NVivo enables the systematic organisation, coding, and analysis of qualitative data, facilitating in-depth exploration and interpretation of complex datasets. (Jackson et al., 2019). The software enables researchers to manage large volumes of data efficiently, facilitating the identification of patterns, themes, and relationships within the data. (Attride-Stirling, 2001). Furthermore, NVivo provides tools for collaboration, allowing multiple researchers to work on the same dataset simultaneously, thereby enhancing reliability and rigour in the analysis process. (Thomas & Harden, 2008).

One of NVivo's key advantages is its flexibility in handling diverse data sources, including text, audio, video, and images. This capability is particularly beneficial for analysing semi-structured interviews, which often involve a variety of data formats. (Braun & Clarke, 2006). NVivo's ability to code and categorise data allows researchers to systematically analyse responses and identify recurring themes or patterns across different interview sessions (Gibbs, 2014).

4.7.2.1 Stage 1 Data Analysis

Analysing data gathered from Stage 1 interviews involved a systematic approach to distilling meaningful insights from participants' responses. Transcriptions of the interviews formed the basis for analysis within NVivo, ensuring that all details and nuances are accurately captured. Thematic coding in NVivo was used to identify recurring themes and patterns within the data, allowing for a structured examination of factors influencing whole-life cost estimation. The analysis aimed to uncover key trends and insights relevant to the research objectives by categorising coded data into broader themes and sub-themes. Comparing and contrasting responses across participants provided valuable perspectives on commonalities and variations in cost estimation practices. Ultimately, interpreting synthesised data using NVivo led to conclusions about the factors driving cost estimation accuracy, addressing challenges encountered, and implications for practice.

Stage 2 Data Analysis

The data analysis from Stage 2 validation interviews evaluated the effectiveness and applicability of the developed framework in enhancing accuracy in estimating whole-life costs. The researcher meticulously examined participant feedback and responses to validation questions within NVivo to assess the framework’s clarity, comprehensiveness, and practical utility. Through a comprehensive analysis of the feedback in NVivo, the study identified the strengths, weaknesses, and areas for improvement in the framework. The refinement process involved integrating suggested modifications, additions, or adjustments based on participant feedback to ensure alignment with the research objectives. The validity and reliability of the refined framework were established through a rigorous evaluation process using NVivo. The refinement process was diligently documented, and a comprehensive report was crafted to communicate the findings, insights, and recommendations derived from Stage 2 data analysis. This contributed to a profound understanding of effective cost estimation practices in residential building construction. The following Figure 4.2 summarises the data analysis process.

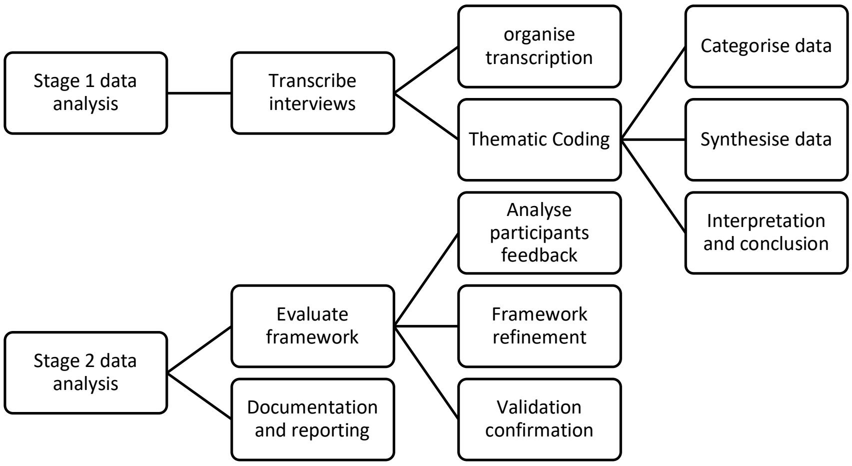


Figure 4.2 Data Analysis Process

4.8 Summary

Chapter 4 describes the research framework for this doctoral study, which is divided into three separate manuscripts. Each manuscript plays a crucial role in achieving the research goals while maintaining consistent beliefs, methods, and approaches. While different strategies address each goal, the manuscripts share the same interpretivist philosophy, inductive approach, and qualitative methods. This ensures a unified and cumulative investigation. Below is an overview of how the manuscripts address each goal:

<u>Objective 1: Identify Specific Factors and Their Interrelationships Impacting WLC Estimation Globally</u>
The primary objective is to identify the key factors that influence WLC estimations worldwide and to examine their interrelationships. This is achieved through a SLR, a well-established method for identifying and organising existing knowledge. By reviewing peer-reviewed articles, industry reports, and case studies, the SLR allows for a thorough examination of factors that influence WLC in a global context. The relationships between the identified factors are analysed by comparing and synthesising findings from different studies, ultimately resulting in a conceptual model that illustrates these connections. This method provided a structured and evidence-based approach to understanding factors and their interrelationships in WLC estimation in NZ.

<u>Objective 2: Establish System Dynamics of Factors Affecting WLC Accuracy in New Zealand's Residential Buildings</u>
The second objective focuses on the system dynamics of WLC factors in New Zealand's specific residential context. To explore this, semi-structured interviews were conducted with 22 industry professionals, including quantity surveyors, architects, and developers. This qualitative method was chosen to gain deeper insights into local practices, challenges, and perceptions that influence the accuracy of WLC in New Zealand. The collected data has then been integrated into system dynamics modelling, a method that represents complex, interacting factors over time. By modelling the relationships and feedback loops between various factors, such as seismic activity, climate conditions, and local construction practices, SD offers a dynamic and visual way to show how these factors impact WLC accuracy. This combination of interviews and system dynamics modelling effectively helps understand the details of WLC estimation in New Zealand's residential sector and provides a clear picture of the factors involved.

<u>Objective 3: Propose Improvements to the WLC Framework for Residential Buildings in New Zealand</u>
The third objective is to propose a customised WLC framework for residential buildings in New Zealand. This goal is achieved through framework development, which builds on the findings from the first two objectives. The methodology includes five validation interviews with industry professionals to assess the practicality of the proposed framework. These interviews serve as an important feedback tool, ensuring that the framework is both relevant and workable in the real world. The framework's validation is further supported by a conference paper that synthesises feedback from the validation interviews and highlights its potential for improving long-term economic sustainability

in New Zealand's housing market. This approach ensures the framework is not only sound in theory but also practical for New Zealand's residential construction sector.

Each objective is accomplished through a tailored research methodology that ensures a thorough, context-sensitive understanding of WLC estimation. The systematic literature review provided a comprehensive overview of WLC factors and their relationships. At the same time, the semi-structured interviews and system dynamics modelling offer detailed insights into New Zealand's residential context. The framework development and validation interviews guarantee that the proposed WLC framework is both solid and practical for local use. Together, these methods create a cohesive and systematic approach that meets the research objectives and offers a comprehensive solution to improving WLC practices in New Zealand's residential construction sector. The Methodology for each research question is summarised in Table 4.2.

Table 4.2 Summary of Research Methods

Research Question	**What factors influence the global whole-life cost estimation and the interrelationships of residential buildings?**	**What are the system dynamics of the elements that affect the accuracy of whole-life cost estimation for residential buildings, aiming to achieve long-term economic sustainability?**	**What improvement in the WLC framework makes it suitable for New Zealand residential buildings?**
Research Design Aspects	Presented as Manuscript 1	Manuscript 2	Manuscript 3
Type of Manuscript	Systematic Literature Review	Journal Article	Journal Article
Philosophy	Interpretivism	Interpretivism	Interpretivism
Approach	Inductive	Inductive	Inductive
Methodological Choice	Qualitative	Qualitative	Qualitative
Strategy	Archival Research	Narrative Inquiries	Narrative Inquiries
Time Horizon	Cross-sectional time frame	Cross-sectional time frame	Cross-sectional time frame
Data Collection	Systematic Literature Review	Semi-structured interviews	Systematic Literature Review, Semi-structured interviews and validation interviews
Data Analysis	Interrelationships + CLD + frequency analysis	Thematic Analysis	Thematic Analysis
Presentation	Vos Viewer visualisation map Causal loop diagram	Causal Loop Diagram	Table

Chapter 5. Interrelations of the Factors Influencing the Whole-Life Cost Estimation of Buildings: A Systematic Literature Review

5.1 Prelude

This chapter aims to explore the specific factors and their interrelationships that influence the whole-life cost (WLC) estimation of residential buildings. The following question guides the research:

Research Question 1: What factors influence the global whole-life cost estimation and the interrelationships of residential buildings?

This question was addressed through a systematic literature review (SLR) combined with a systems dynamics perspective. A total of 84 peer-reviewed studies were analysed, leading to the identification of 51 distinct factors impacting WLC estimation. These factors were organised within the International Construction Measurement Standards (ICMS) framework and examined through pairwise comparisons. The resulting relationships were visualised using causal loop diagrams (CLDs), revealing six reinforcing loops and one balancing loop among the variables. These visualisations highlighted that many lower-level factors interact horizontally within their level before influencing higher-level cost components, reflecting the complex and interconnected nature of WLC systems.

This chapter is based on the published article titled *"Interrelations of the Factors Influencing the Whole-Life Cost Estimation of Buildings: A Systematic Literature Review"* (Buildings, 2024, 14, 740). The publication has successfully achieved the first objective of this thesis: *To determine the specific factors and their interrelationship that impact the whole-life cost estimation of residential buildings globally.*

The findings provide a foundational understanding of WLC complexity, offering valuable insights to cost professionals, academics, and policymakers. The work also establishes a platform for subsequent analysis tailored to the New Zealand residential construction context in later chapters.

5.2 Introduction

The construction sector has significantly contributed to the overall construction industry, accounting for 44% of the total construction activities in 2020, which amounted to $6800 billion (Robinson et al., 2021). However, this sector declined steadily from 2021 to 2023 (BDO, 2023; stats.govt.nz, 2023). The decline can be attributed to several factors, including the impact of the COVID-19 pandemic on the construction market. This has led to increased house prices and a shift towards residential renovation and larger living spaces. Moreover, there has been a trend of repurposing redundant space from traditional housing construction sectors (Robinson et al., 2021). As a result, construction experts are now paying more attention to the Whole-life Costing (WLC) principle to address the current challenges posed by the shift in the residential market.

Construction cost estimation and control have traditionally focused on minimising capital costs as much as possible, without considering the long-term implications. This leads to inappropriate design and specification, resulting in poor-quality buildings that perform poorly in the long term. Nevertheless, since the 1990s, the emphasis has shifted to obtaining Value for Money (VFM), and it is now widely acknowledged that design should consider long-term operation and maintenance expenses. According to Kishk et al. (2003), practical interest in WLC in construction dates back to 1950 with the formation of the Building Research Establishment (BRE) Group.

There are various definitions of WLC. WLC can be defined as a technique for examining and determining all the costs in monetary terms, direct and indirect, of designing, building and facility management, operating, maintenance, support and replacement of a building throughout its entire service life, including the disposal cost" (El-Haram et al., 2002). As OGC (2007) defines, "The whole-life costs of a facility (often referred to as through-life costs) are the costs of acquiring, operating, maintaining over its whole-life through to its disposal - that is, the total ownership costs". According to SCI-Network (2011b), "WLC is the methodology for systematic economic consideration of all whole-life costs and benefits throughout analysis, as defined in the agreed scope". defined WLC as "a technique used to establish the total cost of acquisition and ownership. It is a structured approach which addresses all the elements of cost and can be used to produce a spend profile of the product over its anticipated lifespan". WLC is defined in the draft International Standard, ISO 15686 Part 5 as: "economic assessment considering all agreed projected significant and relevant cost flows throughout analysis expressed in monetary value. The projected costs are those needed to achieve defined performance levels, including reliability, safety and availability"(BSI, 2008). After analysis of the above definitions, the WLC definition can be simplified as "Whole-life cost refers to the total evaluation of all direct and indirect expenses connected with obtaining, possessing, operating, maintaining, and disposing of an asset throughout its entire lifespan. It is a systematic approach to understanding the complete cost of ownership, considering all the relevant expenses and benefits expressed in monetary terms".

WLC offers numerous benefits, including enhancing occupants' productivity, identifying design inflection points, striking a balance between construction and maintenance costs, and sustainable procurement (Ashworth & Perera, 2015; Trusson, 2019), recognising the investment purposes (Cole & Sterner, 2000), evaluating the environmental impact of a building's systems and material (Hossaini et al., 2015), Improve efficient use of government funds (Wang, 2016a). Informed and standardised decision-making (Flanagan & Jewell, 2008; Khatri & Moore, 2017; Opoku, 2013; Ristimäki et al., 2013; RTO, 2007). Despite the benefits of WLC, numerous barriers exist to its application. Whenever a client demands that an L.C.C. be used to compare alternative strategies and is willing to provide additional fees for the service, it would be undertaken by the design team and the cost consultant (Cole & Sterner, 2000). However, unless it is formalised in contractual terms, the design team will typically not volunteer it (Bull, 1993b; Cole & Sterner, 2000; Oduyemi et al., 2014; Perera et al., 2009). The capital cost of construction is almost always separated from the operation cost; it is standard practice for clients to accept the cheapest initial price if they are not occupying the building (Kishk et al., 2003). Also, there is no clear definition of the buyer, seller, and their responsibilities towards the operating and maintenance costs (Bull, 1993b). The complexity of analysis (Cole & Sterner, 2000; Kishk et al., 2003; Opoku, 2013; Ristimäki et al., 2013; Trusson, 2019) is another drawback that could be improved in their assessment.

Understanding the relationship between factors that influence WLC estimation is crucial. Knowing these relationships is critical for several reasons. Firstly, it helps to evaluate comprehensively the factors that affect WLC, allowing stakeholders to make more informed decisions about resource allocation, budgeting, and project management. By clarifying these relationships, it becomes possible to identify potential dependencies, synergies, and trade-offs among different factors, thus enabling a more nuanced and accurate estimation of WLC. Moreover, understanding the relationships between influencing factors enhances the predictive capabilities of WLC models and frameworks. By understanding how changes in one factor may impact others, stakeholders can better anticipate and mitigate potential risks and uncertainties associated with cost estimation. This proactive approach can lead to more robust and resilient project planning and execution, ultimately improving project outcomes and minimising cost overruns and delays. Furthermore, clarifying the relationship between influencing factors promotes greater transparency and accountability in the decision-making process. By providing stakeholders with a clear understanding of how various factors interact and influence WLC, it becomes easier to justify investment decisions and garner support from relevant stakeholders. This transparency can help build trust and confidence in the project's financial management, ultimately contributing to its success.

Various factors influence the WLC; geographical location plays a significant role due to regional variations. Therefore, it is imperative to consider geographical characteristics while analysing WLC. For instance, New Zealand is situated on the convergent boundary of the westward-moving Pacific Plate and the northward-moving Australian Plate (Sherburn et al., 2015). Additionally, twelve countries are situated in an area of high seismic activity, known as the Ring of Fire, a series of volcanic regions and seismic activity sites encircling the Pacific Ocean. The Ring of Fire encompasses about 90% of all earthquakes and 75% of all active volcanoes on Earth (Nationalgeographic, 2023). However, it is worth noting that not all twelve countries are situated in one seismic zone, and some regions are more prone to severe earthquakes than others (McSaveney, 2017).

In addition to global seismic activity, unpredictable weather conditions such as snow, heat waves, cyclones, rising sea levels, flooding, and wildfires put extra pressure on the construction market. For example, in N.Z., the sun's Ultraviolet (UV) rays are incredibly harsh, snow may fall anytime, especially on the South Island, and rain can cause landslides and floods. Additionally, wind is significantly more hazardous than rain (MSC, 2023). The New Zealand Treasury calculated that the 2007–2008 and 2012–2013 droughts collectively decreased N.Z.'s GDP by around $4.8 billion. Adverse weather is thought to be responsible for about $800 million of these expenses (nzherald.co.nz, 2020). The 12 most expensive extreme weather events that produced flooding in NZ between 2007 and 2018 led to over $140 million in insurance claims (NIWA, 2023). The weather extremes have had a substantial negative impact on society and the economy in the UK. For instance, the cost of the 2007 summer floods to the economy was projected to be over £3.2 billion (Chatterton et al., 2010), but the 2010 harsh winter cost the insurance business over £365 million (Clemo, 2008). Therefore, considering seismicity and adverse weather events is essential for whole-life costs.

Current WLC models often fail to provide a comprehensive risk assessment that considers the unique geographical challenges of a region. These models prioritise initial construction costs, overlooking long-term risks associated with seismic events and adverse weather conditions. As a result, construction projects may be vulnerable to unexpected disruptions and expenses. Additionally, these existing WLC models may not be flexible enough to adapt to the diverse regional seismicity and weather pattern variations. Their generic nature can lead to inaccurate cost projections that underestimate the unique challenges faced by specific locations, jeopardising the overall viability of construction projects. Moreover, environmental factors such as harsh UV rays, snowfall, landslides, floods, and wind are not always factored into the existing WLC estimations. This oversight can result in insufficient budget allocations for maintenance, repairs, and disaster recovery, particularly in regions prone to environmental stressors. Furthermore, the existing WLC models may not adequately address the long-term resilience of structures against seismic and weather-related challenges. Emphasising initial costs can drive compromises in construction materials and methodologies, which ignore the importance of durability and the ability to withstand environmental extremes throughout the project's lifecycle.

Acquiring knowledge of the cost throughout the entire lifespan of a building is vital to ensure optimal utilisation of the capital cost incurred in constructing the building and the expenses associated with its operation (BREgroup, 2022). Applying WLC in capital works projects within the construction industry can result in the commissioning of entirely different buildings and structures. However, a practical problem arises because, although initial construction costs are relatively straightforward and predictable at the design stage, operational costs are not. The design stage focuses on planning and conceptualising the project's physical aspects, while operational costs relate to maintaining and operating the facility. Operational costs are subject to various dynamic factors, making it challenge to predict their long-term impact accurately. External factors, such as economic, regulatory, and technological changes, can significantly impact operational costs and are often difficult to anticipate during the early design stages. Therefore, costs in use are subject to significant errors in their assessment (Ashworth & Perera, 2015). To mitigate this error, it is essential to identify the specific factors influencing the WLC. However, it's important to note that these factors do not operate in isolation; they interact with one another, influencing the WLC estimation process as a whole. Therefore, it's crucial to focus on the interrelationships between these factors rather than their individual effects. This research aims to highlight the interrelationships of various factors that influence the WLC in construction. The objective of the research is to identify the factors and their interrelationships. The research question "What are the interrelationships of WLC estimation factors in construction?" has been formulated following the patient/population, intervention, comparison and outcomes (PICO) framework.

The PICO framework is a structured approach widely used in evidence-based medicine and healthcare research to formulate clinical research questions. The acronym "PICO" represents four key elements:

P - Patient/Population/Problem: This refers to the specific population or patient group under study or the problem being addressed.

I - Intervention: This refers to the intervention, treatment, exposure, or factor being studied.

C - Comparison: This refers to the alternative or comparator intervention, treatment, or exposure being considered, if applicable.

O - Outcome: This refers to the outcome or endpoint the researcher is interested in measuring or evaluating.

The PICO framework helps researchers to define their research question precisely by identifying the key components of the study: the population being studied, the intervention or exposure being investigated, any relevant comparison, and the desired outcome (Kloda et al., 2020). Regarding construction-related research, the PICO framework can be adapted to formulate research questions about construction methods, materials, safety practices, project management strategies, and other relevant topics. Using the PICO framework in construction-related research can help researchers structure their studies, identify relevant variables, and clarify the research question, ultimately leading to more focused and effective research outcomes. The PICO key elements used in this research are as follows;

Product (P)	=	WLC estimation
Improvement (I)	=	construction
Comparison (C)	=	N/A
Outcome (O)	=	Interrelationships of WLC factors

The following research methods were used to address the research question.

5.3 Research Methods

A systematic literature review (SLR) was conducted to identify the various factors that impact the estimation of whole-life costs for building construction. Then, a pairwise comparison of the factors was conducted using the Analytical Hierarchy Process. A note of caution is that only the pairwise comparison concept from the Analytical Hierarchy Process was utilised. The step-by-step approach for the pairwise comparison adopted from the Analytic Hierarchy Process includes the following:

Step 1: Define the problem and Criteria
Step 2: Define factors
Step 3: Establish polarity amongst criteria using pairwise comparison.
Step 4: Checked consistency amongst the pairwise comparisons.
Step 5: Evaluated relative factors from pairwise comparisons
Step 6: Performed sensitivity analysis using CLD and found interacting loops

Note: To simplify the interrelationships into four hierarchical levels, the ICMS framework was used, and the results are presented in the CLDs.

SLR is the standard strategy for thoroughly understanding the research domain in construction (Rother, 2007). The SLR is a scientific method that starts with a specific question, finds all relevant studies, evaluates their quality, and summarises their results using a scientific approach (Rother, 2007). Articles undertaking systematic literature reviews are regarded as unique work since they adhere to strict methodological standards (Rother, 2007). There are many advantages to SLR. It employs extracting search strategies to ensure that the maximum extent of relevant research has been considered, original articles are methodologically evaluated and synthesised using strict methods to locate, evaluate, and synthesise all research on a topic, and it provides a straightforward methodology that lowers the risk of bias by adhering to a strict and repeatable protocol of procedures (O'Brien & Mc Guckin, 2016). However, while bias reduction is one of the main advantages of SLR, DistillerSR (2023) argued that bias can come at any stage because poor study design and execution, and selective outcome reporting, significantly threaten a systematic review.

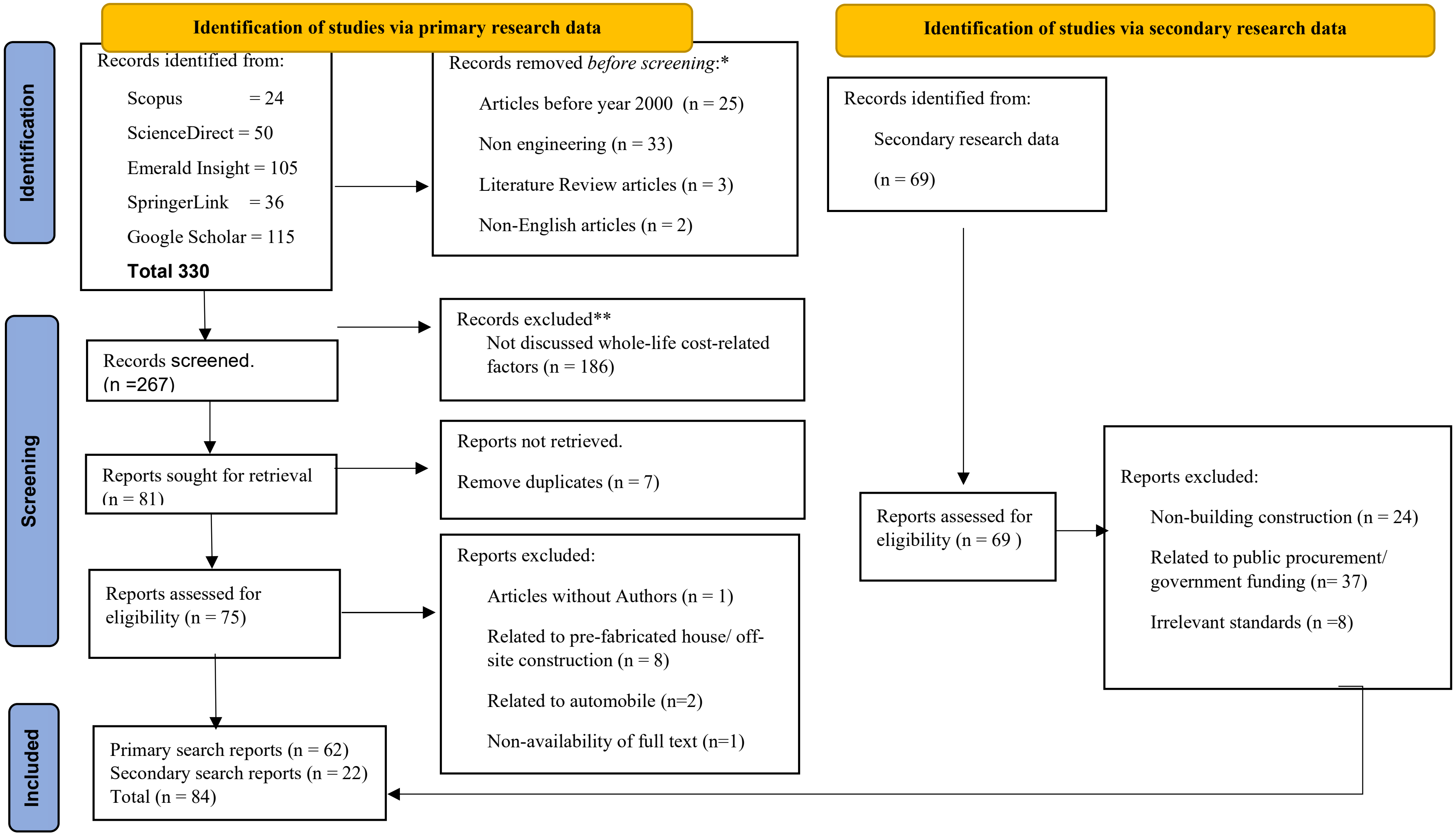
The SLR was conducted using various search strings across the Scopus, ScienceDirect, Emerald Insight, SpringerLink, and Google Scholar databases. Table 5.1 shows the search strings and results for all databases used. This study used primary data from books, journals, and conference papers.

Table 5.1 Search strings and results of database search

Database	Search Strings	Inclusions	Exclusions	Without filters	Range (2000 - 2023)
Scopus	"Whole-life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area – Engineering Language - English	Review Articles	24	24
ScienceDirect	"Whole-life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area – Engineering Language - English	Review Articles Book Review Product Review	50	50
Emerald Insight	abstract: "whole-life cost" OR (abstract: "wlc") AND (abstract: "construction") AND (abstract: "factors")	Access – Only content that I have access to Content Type - Articles	Review Articles	105	105
Springer Link	Construction AND factors AND "Whole-life cost"	Discipline – Engineering Subdiscipline - Building Construction and Design	Reference work entry Reference work	42	36
Google Scholar	Construction AND factors "Whole-life Cost."	Only in the title	Review Articles	115	115
Other databases		Nil	All other databases are excluded due to limitations in article retrieval.		
Total				336	330

Apart from preliminary research data, government reports, and guidance notes issued by standard bodies such as RICS, AIQS, ICMS, NZIOB, BSI, NATO, as well as market research reports conducted by AECOM, BRANZ, Turner and Townsend, BDO, and the Oxford Economist, have also been used as secondary research data. The secondary data was collected from relevant websites. Only studies in English were selected, with the duration limited from 2000 to 2023. Although most principles of WLC are well developed in theory, they did not receive a wide practical application until the end of the 19th century(Larsson & Clark, 2000). However, implementing a new project delivery system of private finance initiative (PFI) in 1992 seems to have overcome the practical application obstacle (Bull, 1993b). Therefore, the year 2000 has been selected as the cutoff point for the literature search. The subject chosen was engineering, excluding review articles to avoid repetition. Once the data searching strategy was established, the PRISMA flow diagram Figure 5.1 was followed.

Initially, 330 articles were identified as primary search data, and 62 documents were removed using the database search engine's automation tool, in accordance with the established search strategy. Two hundred sixty-seven were used for document screening. Each abstract was analysed to exclude irrelevant studies. The exclusion criteria were used to remove documents that were not indicated in the "WLC-related factors" section of the abstract. The abstract screening process resulted in the retention of 81 papers. Seventy-five papers could be retrieved and were fully assessed for eligibility after duplicates were removed. Articles without authors related to prefabricated/off-site building construction were removed. They were constructed under controlled conditions, procuring a bulk of materials, using different technologies and special skills required (Rotimi et al., 2022). Therefore, the acquisition cost differed from the inflation's effect on the acquisition cost, which differs from the on-site construction. Sixty-four documents were included from the primary search data, and sixty-nine were selected from secondary search data and carried forward for the eligibility assessment. Forty-seven were excluded as irrelevant, and 22 chosen documents were included. The total number of papers included was 84. All the articles selected are listed in Appendix 7.



**Records excluded by automation **Records excluded by human*

Figure 5.1: PRISMA Flow Chart

The articles were from 30 countries, as shown in Figure 5.2 below. The study encompassed nearly all the world's regions, with the majority of studies conducted in the United Kingdom, accounting for 29.5% of the overall studies. A recent interest in the topic is evident in Nigeria, as well as in Canada and Australia.

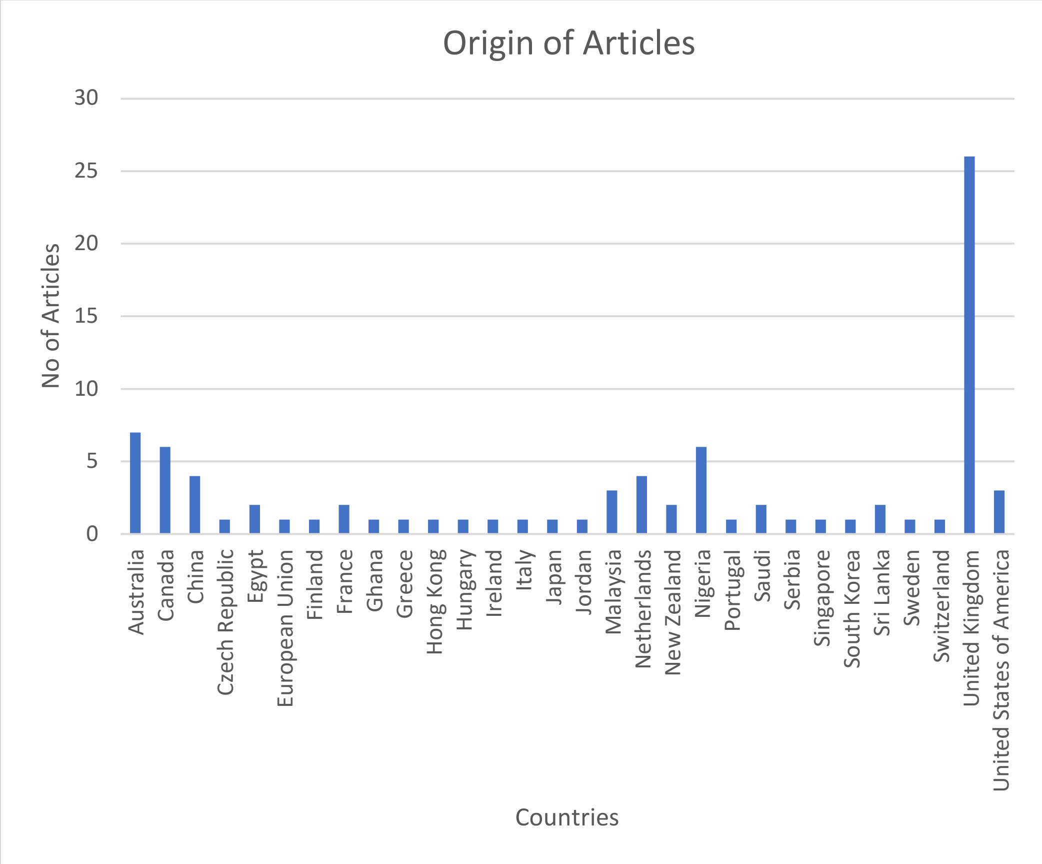


Figure 5.2: Origin of the Articles

The factors identified from the articles included in SLR were then put in a table alongside the authors, country of origin, and year of publication and shown on a visualisation map using the VOS Viewer programme. The data was sorted to identify factors influencing the whole-life cycle cost and their interrelationships, and the two variables are the factors influencing the WLC and their interrelationships. The outcome of the factors and their interlinks is measured by the number of authors who have addressed that in the literature. However, we were unable to assess the risk of biases in the studied literature; hence, this remains a limitation.

The SLR results were then analysed in pairs to examine their interaction and gain a more comprehensive understanding of how the two elements relate. To simplify the identified factors and evaluate their polarities, the ICMS framework was integrated into an Analytical Hierarchy Process (AHP) tool. AHP is a structured technique that involves pairwise comparisons, making it a useful tool for decision-making in complex, multi-criteria situations. AHP has been widely applied in various fields, including planning, resource allocation, conflict resolution, and optimization (Vaidya & Kumar, 2006). Many studies have demonstrated its versatility. Although the AHP process involves six stages, including criteria identification, hierarchical structure, pairwise comparison, scoring, consistency check, and aggregation (Saaty, 2008), this research only focuses on the pairwise comparison stage.

ICMS is a principles-based international standard that outlines how to classify, define, measure, record, analyse, present, and compare construction project life cycle costs and carbon emissions in a structured and logical format. Although life cycle costs include only construction, renewal, operation, maintenance and end-of-life costs, ICMS also makes provision for including acquisition costs, which may significantly impact a project's budget (ICMS, 2021). Figure 5.3 illustrates the ICMS framework, which outlines four levels within a framework. At the first level, the primary WLC system is highlighted, further divided into four main factors at level 2: non-construction cost, Life Cycle Cost (LCC), income, and externalities. The LCC factor is divided into construction, maintenance, operation, renewal, and disposal costs (or end-of-life costs) at level 3.

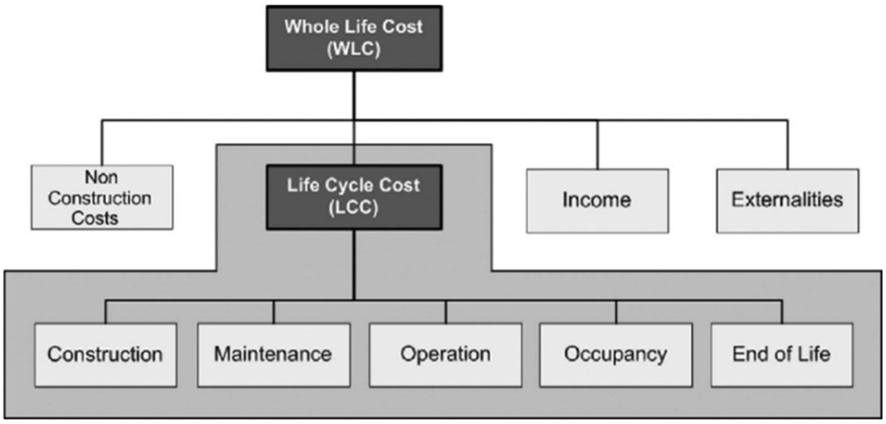


Figure 5.3: ICMS Framework (ICMS, 2021)

To start the pairwise comparison, a hierarchy has been established, referring to the levels of the ICMS framework as shown in Figure 5.4. The level 4 factors were then plotted on the horizontal and vertical axes of a table for pairwise comparison. The horizontal axis was the fundamental factor that interacted with the secondary factor in the vertical axis. All the positive polarities were displayed in blue, while all the negative polarities were shown in red. Then, the pairwise comparison results were translated into Causal relationships in the Causal Loop Diagram. A causal loop diagram (CLD) is a graphical representation used to visualise the causal relationships between variables in a system. It is a part of system dynamics, a method for understanding the behaviour of complex systems over time. CLDs are particularly useful for modelling dynamic systems where variables interact with each other in feedback loops (reference). The positive and negative polarities identified in the pairwise comparison have been used to determine the causal relationships. Positive relationships indicate that an increase in one variable leads to an increase in another, while negative relationships indicate that an increase in one variable leads to a decrease in another. Add arrows representing causal links between variables, indicating the direction of influence based on the results of pairwise comparisons. Arrows were then labelled with appropriate sign conventions (+ or -) to denote the directionality of the relationships. Three individual CLDs were created for income, LCC, and non-construction costs, and a comprehensive CLD was then produced by combining the three individual CLDs. Finally, balancing and reinforcing loops were identified within the SLR articles utilised for the research.

Employing a causal loop diagram (CLD) to represent pairwise comparison results offers a powerful means of visualising and understanding the complex interdependencies between variables within a system. Causal Loop Diagrams (CLDs) offer a visual representation of the relationships between different variables. This visual format makes it easier for stakeholders, who may not be familiar with quantitative analysis techniques, to understand and communicate the results of pairwise comparisons. CLDs are part of the system dynamics methodology, which focuses on understanding how variables interact and influence each other over time. The results of pairwise comparisons may reveal important causal relationships between variables, and CLDs help to illustrate these relationships within the broader context of the system. Pairwise comparisons may reveal feedback loops where changes in one variable affect another, which in turn influences the first variable. CLDs are well-suited for representing these feedback loops, whether they are reinforcing (positive feedback) or balancing (negative feedback) in nature. CLDs capture the dynamic behaviour of systems, showing how variables change.

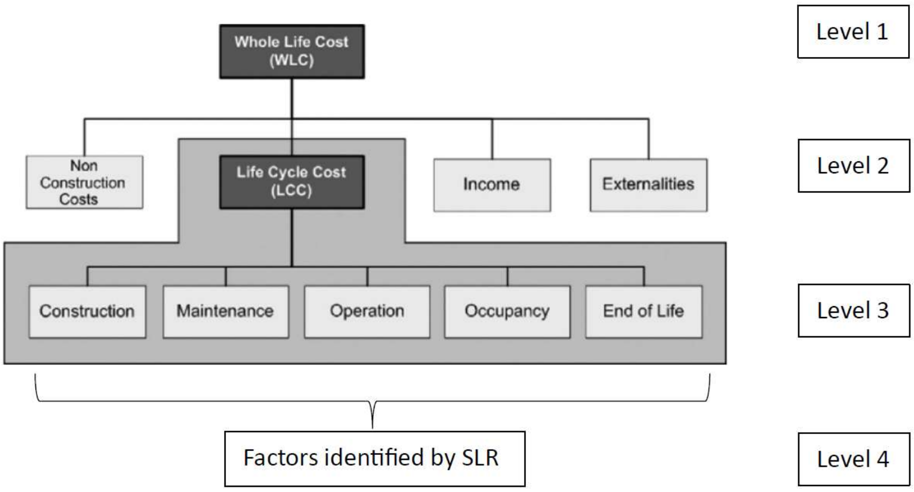


Figure 5.4: Hierarchical Levels

The overall research methodology process has been summarised in Figure 5.5.

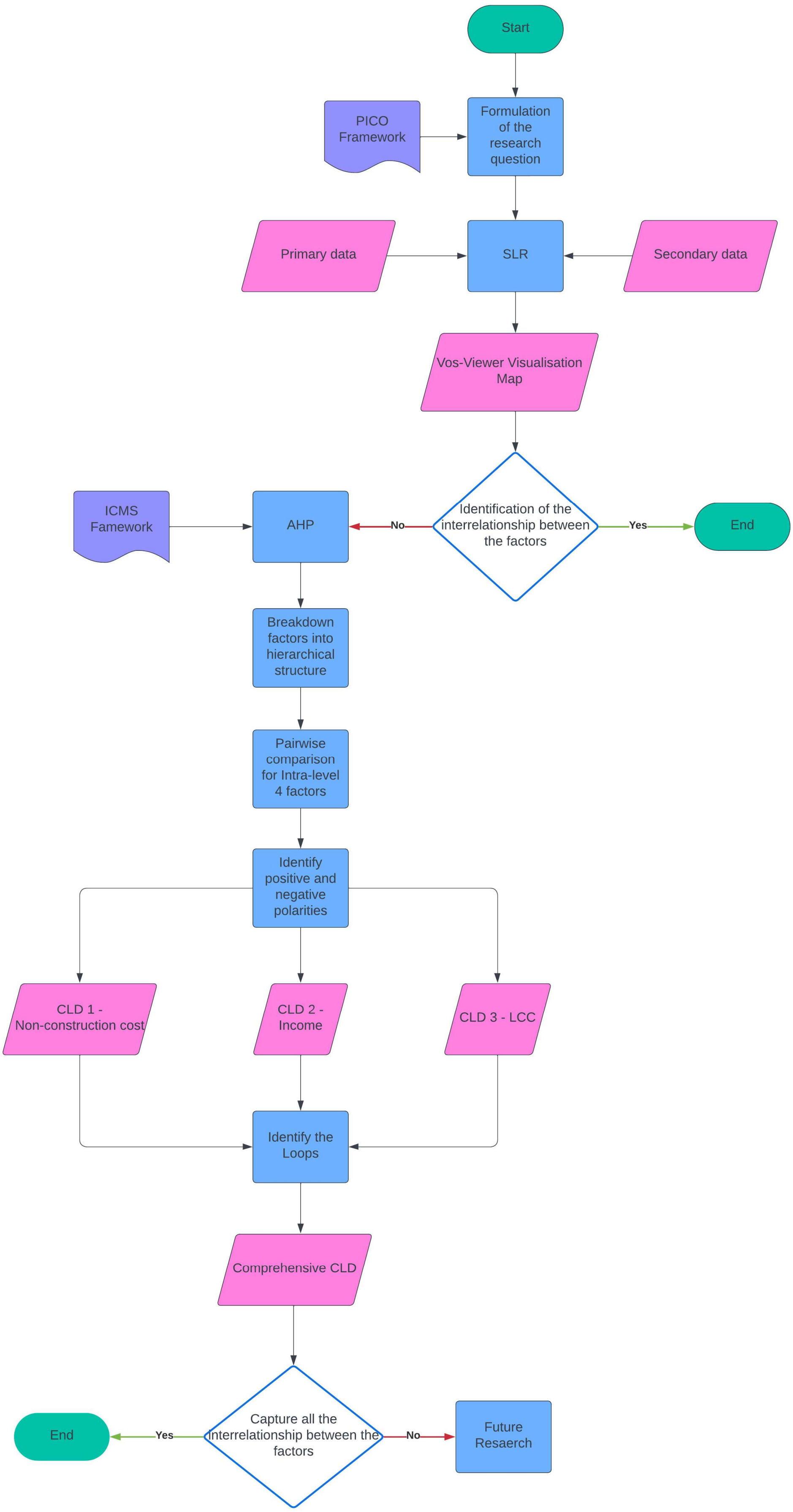


Figure 5.5: Research Process

5.4 Results

Appendix 6 lists the SLR findings from 84 studies and identifies 51 distinct factors. Appendix 7 shows that 70-plus studies have considered maintenance, operating, renewal, disposal, and construction costs as the most often mentioned components. Government fees, upfront acquisition costs, residual value, material availability & service life, time value of money, discount rate, income generated from assets, taxation, inflation, building stamina, and analysis period were considered in 25-plus studies. In comparison, the least was the estimated annual occupancy hours, environmental factors, real cost, nominal cost, foreign exchange, Legislative, statutory charges, technology, level of uncertainty, insurance, building type, functionality, size, number of floors, GFA, location, environmental impact, risk allowances, and waste management that appeared in 7 to 21 studies. The least discussed factors include methods of financing, demand and supply of materials, foreign exchange, seismic resistance, and fire resistance, which appeared in one to four studies.

The identified factors affecting the WLC of buildings have been visualised on a VOS Viewer map, refer to Figure 5.6. Overall, the VOSviewer visualisation map provides valuable insights into the factors that influence the WLC, relationships, and trends within a dataset, helping to identify important topics, contributors, and patterns within the map. It also identified the different clusters of WLC. The nodes with larger sizes or greater centrality in the visualisation map represent items (such as authors, journals, or keywords) that are more influential or central within the dataset. The connections between nodes indicate relationships or associations between items. Though the factors are grouped into different clusters and visualised on the map, the clusters are confusing. Also, the visualisation map did not capture the expected interrelationships among the factors and their polarities. Lack of contextual understanding, complexity that can be overwhelming, and the potential for misleading representation of the factors due to inappropriate visualisation techniques or misinterpretation of data are some of the reasons that confuse the clusters. Additionally, static VOS viewer maps may not be interactive, which limits users' ability to explore data dynamically and conduct detailed analyses. Poor design choices and inadequate data quality can further exacerbate these challenges, potentially hindering the map's ability to convey insights effectively. Therefore, it is essential to have thoughtful design and rigorous data validation to ensure the usefulness of VOS viewer visualisation maps for decision-making and insight generation despite their scalability limitations and the potential for ineffective communication (Van Eck & Waltman, 2010). To overcome the limitations, the ICMS framework was incorporated into an Analytical Hierarchy Process (AHP) tool, which breaks down the identified factors into hierarchical levels and conducts pairwise comparisons to assess the polarities of the factors.

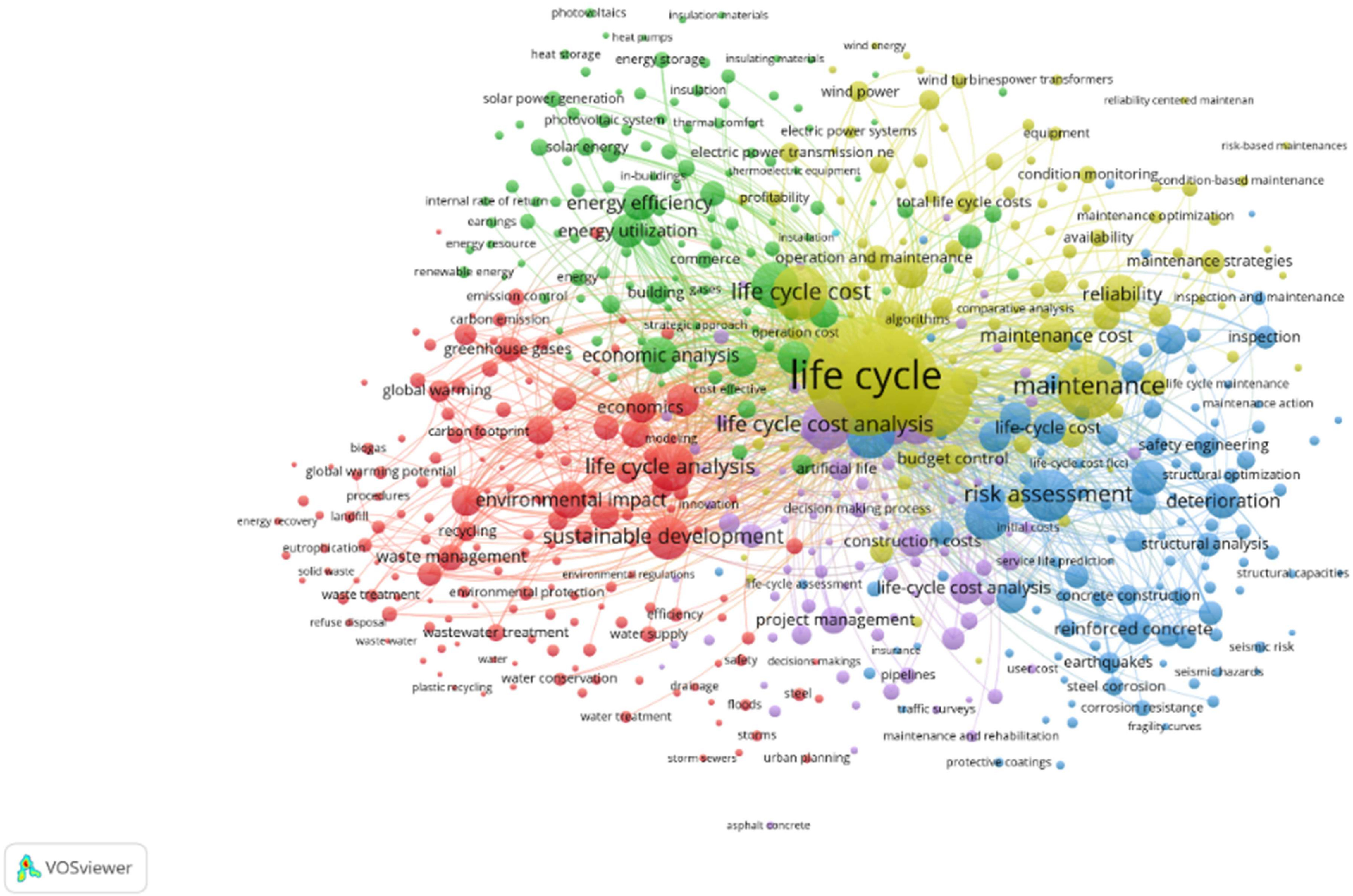


Figure 5.6: VOS Viewer visualisation map of the factors influencing the WLC/LCC

Figure 5.7 visually represents the ICMS Framework, depicting the structured levels and their interconnections. The identified 51 factors are mapped in hierarchical levels 3 and 4, as influenced by the ICMS framework, as illustrated in Figure 5.7. This visualisation further aids in grasping the intricate relationships and guides a pairwise comparison of the factors to identify their polarities.

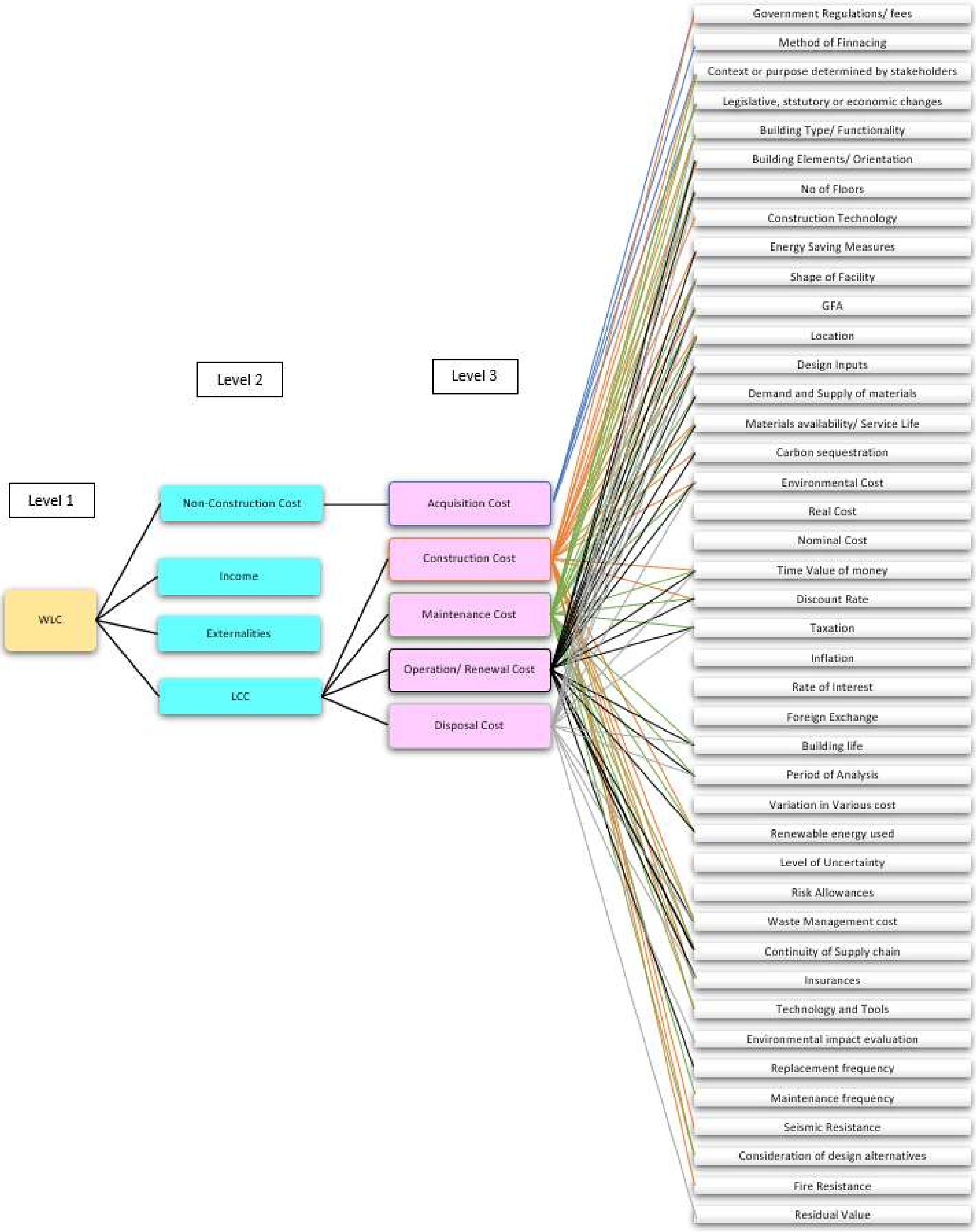


Figure 5.7:Modified levels of factors using the ICMS Framework

The analysis of 84 papers revealed 51 factors that affect WLC. Out of these, 54 papers discussed how different factors are interconnected. The results obtained from Table 2 were subjected to pairwise comparisons. Each Level 4 factor is linked to other Level 4 factors through the influence of Level 3 factors. The pairwise comparison did not reveal any connectivity between level 3 factors. Consequently, pairwise comparisons only revealed level 4 interactions. The pairwise comparison of 51 pre-identified factors is shown in Appendix 8. This comparison aimed to provide insights into the interactions between different factors. In this analysis, the vertical axis of the table was designated as the primary factor, while the horizontal axis represented the secondary factor. Instances, where a factor was compared to itself (central diagonal), were highlighted in grey.

The selection of the secondary factor was driven by the objective of understanding its impact on the primary factor. If the secondary factor positively influenced the primary factor, the presentation denoted this with a blue colour, accompanied by the author's name (who identified the interrelationship between the factors) and the publication year. Positive polarity was further indicated with a +ve sign. Conversely, negative impacts were represented in red along with the -ve sign, providing a visual cue for better comprehension. For example, using renewable energy sources has varying effects on the financial aspects of building construction and upkeep. Although it reduces operational expenses, it concurrently increases the costs of procuring and maintaining renewable energy sources. Blue conveys the positive correlation between renewable energy and construction and maintenance costs. In contrast, red indicates the inverse relationship between renewable energy and operational expenses and is indicated with a -ve sign.

Appendix 8 shows the interrelations among the fifty-four authors mentioned. Only seven of the interrelations had negative polarity, whereas others had positive polarity. The residual value featured five negative interrelationships (time value of money, building life, the analysis period, legislative, statutory, or economic changes, and location), which was the highest. The other two negative interrelations are the costs of maintenance versus energy-saving measures and the costs of renewable energy versus operational and renewal costs. The most interesting aspect of the table is that Ballesty (2021) stated the capital cost to taxation as positive polarity, whilst ICMS (2021) noted the same as negative polarity. Therefore, the relationship between capital cost and taxation was considered neutral.

5.5 Discussion

WLC is a technique for evaluating the long-term financial impact of design choices. In addition to the capital costs, it considers all expenses associated with usage, including operation, renewal, maintenance and disposal costs. It is crucial to understand the factors that impact WLC for the WLC process to be as successful as possible. Prior studies have noted factors influencing WLC, but none have considered the interrelation of these factors. To determine the interrelationship and specific factors impacting WLC, this research classified 51 factors into four hierarchical levels, utilising the ICMS hierarchical level diagram to provide the flow of factors. However, it does not capture every interrelationship, nor their polarities, identified through pairwise comparison. To better understand these complex interrelationships, we employed the causal loop diagram. These systems thinking tools allowed us to pinpoint the key variables within the system and illustrate the causal relationships between them.

To comprehensively capture the interrelations of factors that impact WLCs and their respective polarities, three individual causal loop diagrams (CLDs) were developed for the level 2 factors of the ICMS framework, including non-construction costs, income, and LCCs. The fourth level 2 factor (refer to Figure 5.8), “externalities,” had no level 3 or level 4 factors and was kept as a stand-alone factor. Figure 5.8 shows the CLD of non-construction costs.

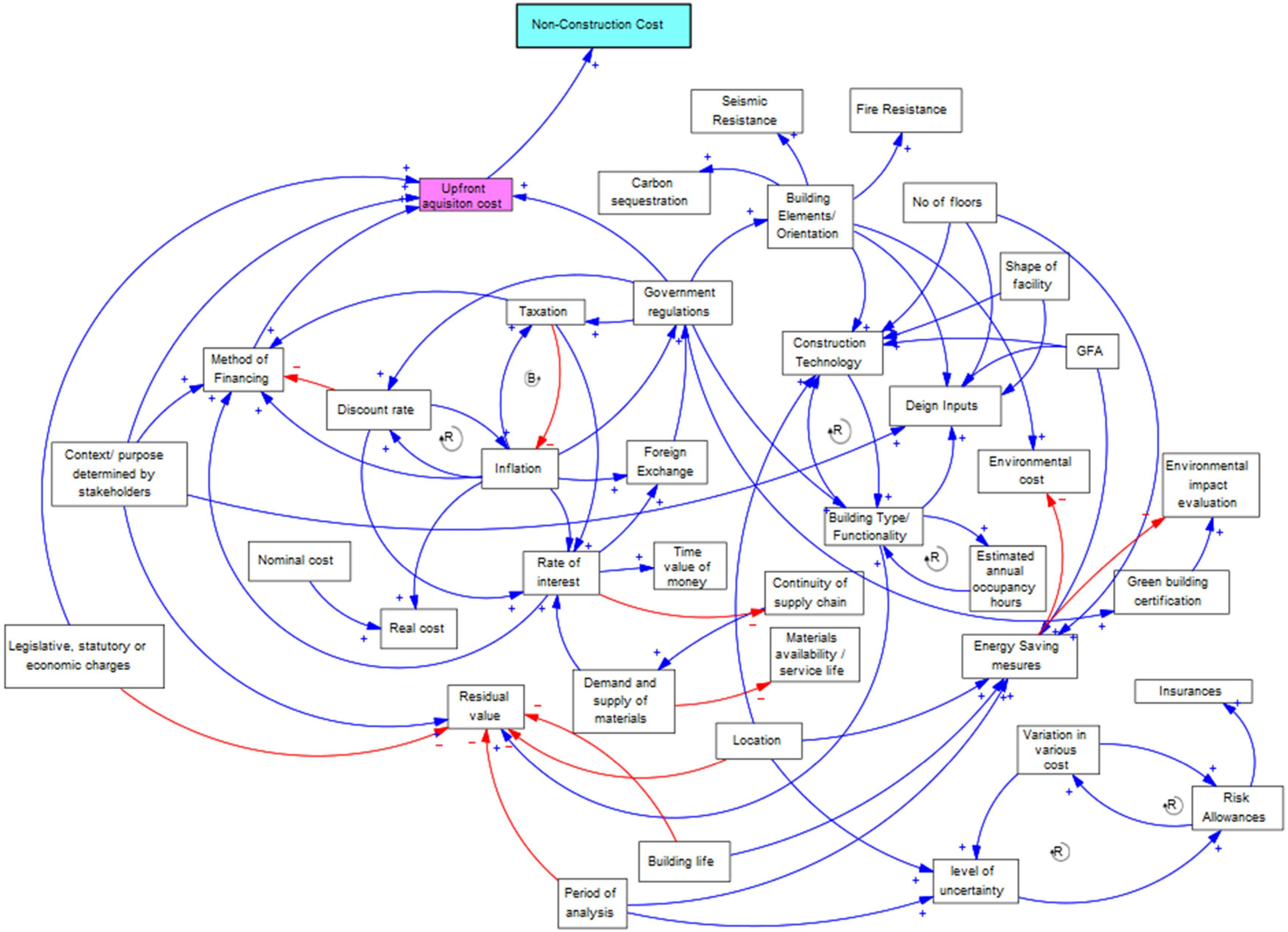


Figure 5.8: Causal Loop Diagram for the Non-construction costs, created by VENSIM Software

The Causal loop diagram shows that the upfront acquisition cost, a level 3 factor in the ICMS framework, is the only factor affecting non-construction costs. This cost is directly influenced by government regulations, methods of financing, context/purpose determined by stakeholders, and legislative, statutory, or economic charges. Government regulations play a pivotal role in influencing various aspects of the economy, including taxation and interest rates. Conversely, inflation significantly impacts the formulation of government regulations (Ashworth & Perera, 2015; RICS, 2016). Therefore, understanding the interplay between government regulations and inflation is crucial in crafting effective fiscal policies and driving sustainable economic growth, particularly in terms of the upfront acquisition cost. The government holds the authority to shape taxation and other obligations, aiming to manage inflation rates through various measures, including establishing interest rates. These actions can significantly impact the business sector, affecting the expenses of acquiring labour and materials and the cost of financing purchases (RICS, 2016). On the other hand, higher interest is a policy response to rising inflation. However, none of the previous studies identified this connection. There is a reinforcing loop between inflation and the discount rate. Government authorities determine the discount rate, encouraging banks to lend more money when it is lowered, allowing them to increase their reserves at a lower cost (Cook & Hahn, 1988). This results in additional loans for businesses and consumers, thereby increasing the money supply and spurring economic activity, which ultimately leads to inflation.

Conversely, as inflation rises, the value of future cash flows decreases, leading to a higher discount rate. Additionally, a balancing loop can be observed between inflation and taxation, wherein the government increases taxes to discourage spending when inflation is high (Beer et al., 2023). Raising taxes results in lower inflation. Currency exchange rates can significantly impact the cost of imported construction materials and equipment, as well as economic growth, capital flows, inflation, and interest rates. However, these interconnections were not captured in previous studies. The availability of materials, demand and supply chain continuity, interest rates, taxation, inflation, discount rates, and government regulations are all interconnected. The demand for supply materials, discount rate, and taxation affect the interest rate. If the discount rate is high, it can indicate a higher interest rate, inflation, or a higher risk associated with receiving future cash flow (Bekas et al., 2015; RICS, 2016). When the interest rate increases, the continuity of the supply chain is reduced, discouraging purchasing power. As a result, demand increases, material availability decreases, and construction and maintenance costs Increase. There is a reinforcing loop between inflation and the discount rate. Government authorities determine the discount rate, encouraging banks to lend more money when it is lowered, allowing them to increase their reserves at a lower cost (Cook & Hahn, 1988). This results in more loans for businesses and consumers, thereby increasing the money supply and spurring economic activity, which ultimately leads to inflation.

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There are five other reinforcing loops between the following factors:

- Estimated annual occupancy hours and building type/ functionality
- Construction technology and building type/ functionality
- Variations in various costs and risk allowances
- Variation in various costs, level of uncertainty and risk allowances.
- Government regulations, taxation, rate of interest, and foreign exchange

According to Figure 5.8, insurance is only influenced by risk allowances. However, the construction insurance has also been influenced by the building type/ functionality, building elements/ orientation, number of floors, GFA, facility shape, location, building life, context/ purpose determined by stakeholders and location. Unfortunately, the previous studies failed to capture these interconnections. Within the ICMS framework, income is the second crucial element that can be influenced by multiple factors, including residual value, building lifespan, and the intended use, as determined by stakeholders. These income interconnections are illustrated in Figure 5.9.

Residual value plays a significant role in determining income. It is defined as the monetary value assigned to an asset at the end of the analysis period. Residual value is the only factor that has more negative polarities than positives from other factors, as shown in Figure 6. Building life, period of analysis, location, legislative, statutory, or economic changes interact negatively with residual value, implying that an increase in any of these elements reduces residual value (Ashworth & Perera, 2015; BCIS, 2012; El Hadidi et al., 2022; Moges et al., 2017; RICS, 2016). On the contrary, context/ purpose determined by stakeholders, design inputs, and energy-saving measures interact favourably

(Ebrahimi et al., 2014; Rahim et al., 2016; Ristimäki et al., 2013), meaning these features increase residual value. Notably, residual value only influences the income, as shown in Figure 5.9.

An asset's generated income, including rent and residual value, is dependent on how effectively it serves its intended purpose, which stakeholders establish (RICS, 2016). Additionally, stakeholders indirectly impact income through the building's predetermined lifespan. However, the income generated from the assets is also influenced by inflation and discount rates. Inflation is a rise in the general price level reflecting a decline in the purchasing power of money. As a result, the cost of use rises, and the target income is reduced. However, previous studies do not highlight the negative impact of inflation and the discount rate on income.

The life of a building can significantly affect its rental income potential. A prolonged lifespan typically translates to a higher rental yield; however, it may also diminish the property's salvage value upon the conclusion of its life cycle. Hence, the lifetime of a building can have a dual impact on income, both advantageous and disadvantageous. However, only the positive polarity was captured in the previous study.

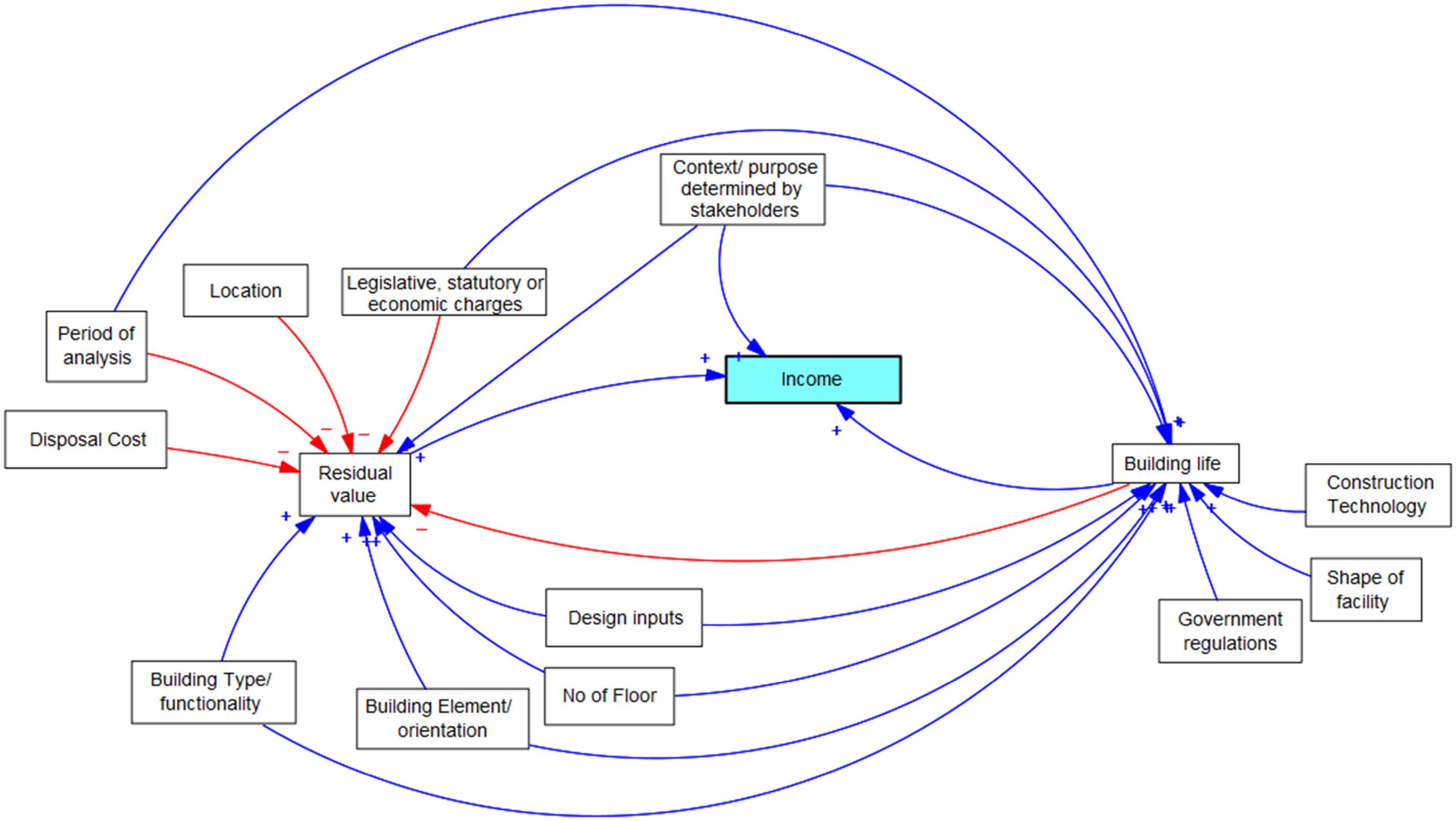


Figure 5.9: Causal Loop Diagram for the Income, created by VENSIM Software

LCC is the 3rd level 2 factor of the ICMS framework, and it is mainly positively interconnected with the construction, maintenance, operation/renewal, and disposal costs, as shown in Figure 5.9. Construction cost is inclusive of site costs or opportunity costs, finance charges, professional fees, construction and infrastructure costs, tax allowances, statutory charges, development grants, planning gain, and third-party costs (such as rights of light, oversailing charges, wayleaves and easements) (RICS, 2016).

Maintenance Cost: The total cost of labour, material, and other related costs to retain a Constructed Asset or its parts so that it can perform its required functions (Vasishta et al., 2023). Maintenance costs exclude renewal costs. However, it consists of all related management, cleaning services, repainting, repairing, or replacing parts necessary for the constructed asset to be used for its intended purpose (Cole & Sterner, 2000). Building consumers are typically motivated by the cost of ownership concerns. They can be ready to pay a higher capital cost, provided they have some assurance that cheaper maintenance costs would be more than compensated. They may choose for themselves what each option is worth. Maintenance cost is positively influenced by building parameters such as building type/ functionality, building elements/ orientation, no of floors, shape of facility, GFA, location, context/purpose determined by stakeholders, environmental factors, maintenance frequency, demand and supply of materials, material availability, continuity of supply chain, discount rate, taxation, insurance, building life, period of analysis, environmental impact evaluation, technology and tools, design and technology, government regulations, legislative, statutory, or economic changes, maintenance frequency, and waste management. For example, if building parameters increase, the amount required for maintenance also increases. The analysis period influences the maintenance cost directly and indirectly through the maintenance frequency.

Operation Costs: Costs incurred in running and managing a Constructed Asset during the occupation, including administrative support services, rent, insurance, energy and other environmental/regulatory (ICMS, 2021). Renewal Costs: The costs of replacing a constructed asset and its significant components once they reach the end of their life, where the client elects to treat these costs as capital rather than revenue budget (ICMS, 2021). All the factors that affect maintenance costs favourably impact operation/renewal costs as well, although the usage of renewable energy and energy-saving techniques has the opposite polarity. In addition, replacement frequency and estimated annual occupancy hours have positive polarities. However, none of the authors discussed the impact of income generated from the asset on the operation/ renewal cost. The rental income has a negative polarity to the operation and renewal costs. The analysis period influences the operation/ renewal costs directly and indirectly through the replacement frequency.

Disposal/end-of-life costs are another factor that directly relates to the LCC. While RICS (RICS, 2016) and ICMS (ICMS, 2021) classified disposal costs as a component of end-of-life costs, BS ISO 15686-5 (ISO-15686, 2017) recognised disposal and end-of-life costs as two distinct things. ICMS has given a broad definition for end-of-life cost as "the net costs or fees for disposing of an asset at the end of its service life after deducting the salvage value and other income due to disposal, including costs resulting from disposal inspection, decommissioning and decontamination, demolition and reclamation, reinstatement, asset transfer obligations, recycling, recovery, disposal of components and materials, and transport and regulatory costs" (ICMS, 2021). Accordingly, disposal/end-of-life costs also interact with maintenance and operation/renewal costs, except for maintenance frequency, replacement frequency, consideration of design alternatives, supply chain continuity and insurance.

The interconnections related to LCC are shown in Figure 5.10. According to Figure 5.10, legislative, statutory, or economic charges, location, and the context/ purpose determined by stakeholders are everyday influencers of all these factors. Constructing a building is a multifaceted process that requires collaboration from all parties involved to ensure success. Throughout the building's life cycle, various stakeholders influence its requirements based on their needs and preferences. To accurately calculate the WLC, the process must reflect the inputs from these stakeholders over time. The client/developer must clearly understand the costs of land, professional fees, design-related expenses, and expected future income. Financial institutions must contribute through loan/credit facilities and establish interest rates that can be used in WLC calculations. Contractors, subcontractors, and suppliers must provide precise cost estimations for initial capital and subsequent adaptation costs. In contrast, maintenance and operation costs of the building after completion can be gathered from facilities managers and project quantity surveyors. Finally, all these measurable costs and benefits must be expressed in present-day values. It is evident that project stakeholders hold critical knowledge and play key roles in improving WLC for adaptable buildings and contributing towards the information supply, which controls the accuracy of the WLC outcome (Manewa et al., 2009).

Buildings start to deteriorate and become obsolete as soon as they are constructed. Physical deterioration can be controlled by choosing suitable materials and components during the design phase. Still, obsolescence is much harder to manage because it involves predicting uncertain events like changes in appearance, technological advancement, and innovation (Ashworth & Perera, 2015). Although obsolescence is influenced by the context/ purpose determined by the stakeholders, their influence on it has not been thoroughly explored in prior studies. Rather, obsolescence has been linked to the lifespan of a building in resources such as the RICS guidance note on Life Cycle Cost (RICS, 2016) and Cost studies of buildings (Ashworth & Perera, 2015). Technological life, functional life, economic life, social life, legal life, and aesthetic life are several types of obsolescence. It is recommended that the analysis period be less than any of the periods described along with these types of obsolescence (RICS, 2016). In this way, the construction of a building can also be influenced by the context and purpose determined by stakeholders.

The location of a construction project plays a crucial role in determining the overall cost of the project (Moges et al., 2017). The cost of building in a remote area can be significantly higher than in an urban area due to several factors. Firstly, remote areas often lack the necessary infrastructure required for construction, such as roads, electricity, and water supply. This means the construction company may need to invest in building these facilities, which can increase the project's overall cost. Secondly, remote areas may have limited access to materials required for construction. This means that the construction company may have to transport the materials from a distant location, which can be expensive. Additionally, transporting materials to remote areas may be challenging due to poor road conditions, which can further increase the project's cost.

On the other hand, building in an urban area may be less expensive due to the availability of infrastructure and materials. Urban areas often have well-developed transportation networks, making it easier to transport materials to the construction site. Additionally, urban areas have a higher concentration of construction companies, resulting in increased competition and lower prices. Therefore, the location has both negative and positive impacts on the construction, maintenance, operation/renewal, and disposal costs.

Figure 5.10 illustrates that construction, maintenance and disposal costs have only positive polarities, while operation/renewal costs have a mix of positive and negative polarities. Using renewable energy sources has varying effects on the financial aspects of building construction and upkeep (BRANZ, 2016). Although it reduces operational expenses, it concurrently increases the costs of procuring and maintaining renewable energy sources.

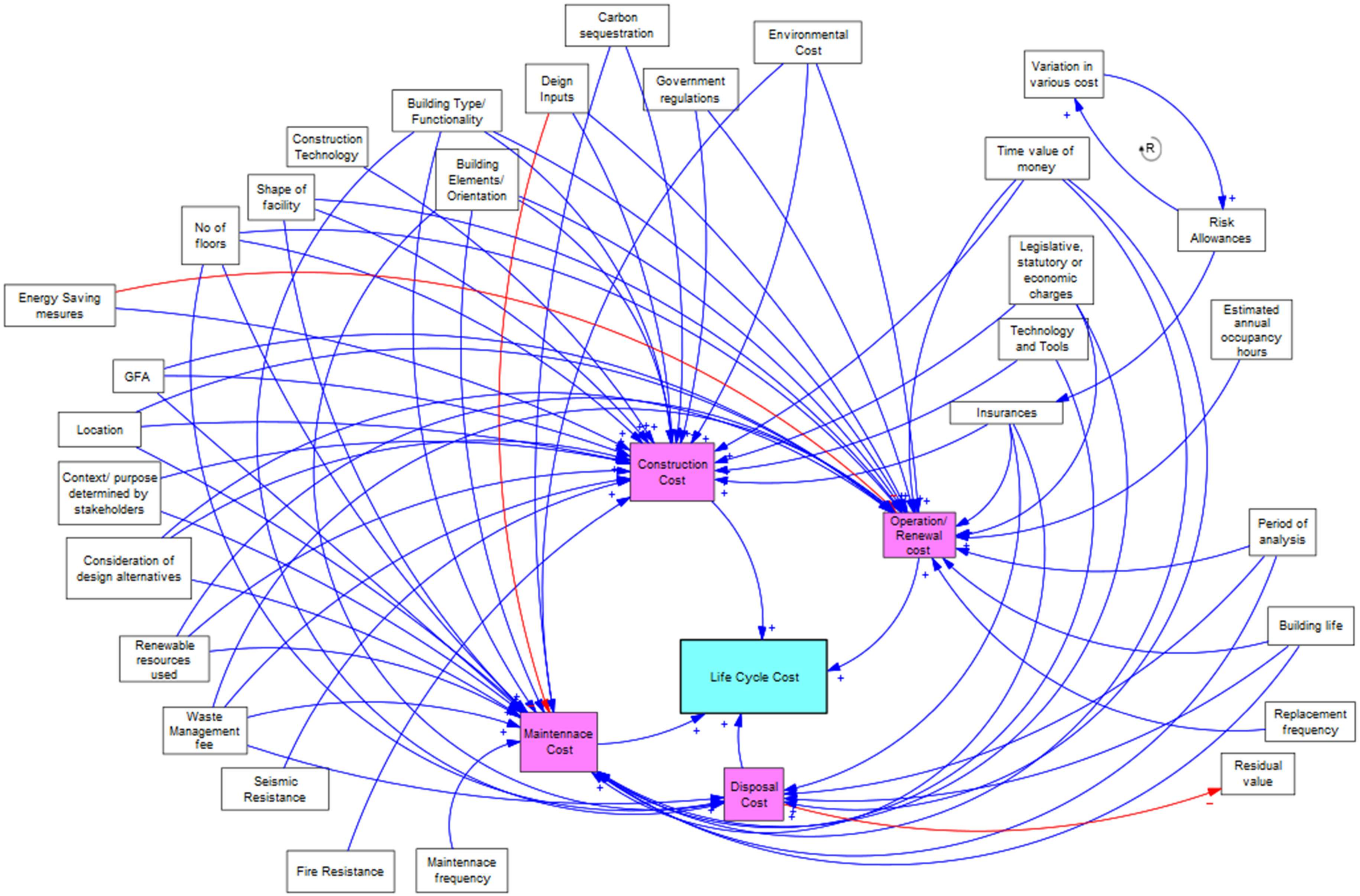


Figure 5.10:Causal Loop Diagram for the LCC, created by VENSIM Software

The three causal loop diagrams of non-construction cost, income, and LCC were combined to produce a comprehensive causal loop diagram for WLC, shown in Figure 5.11. The CLDs in Figure 5.8, Figure 5.9 and Figure 5.10 revealed a few loops that were mentioned in the literature, revealing that much research needs to be done to enhance the knowledge regarding the connections and loops.

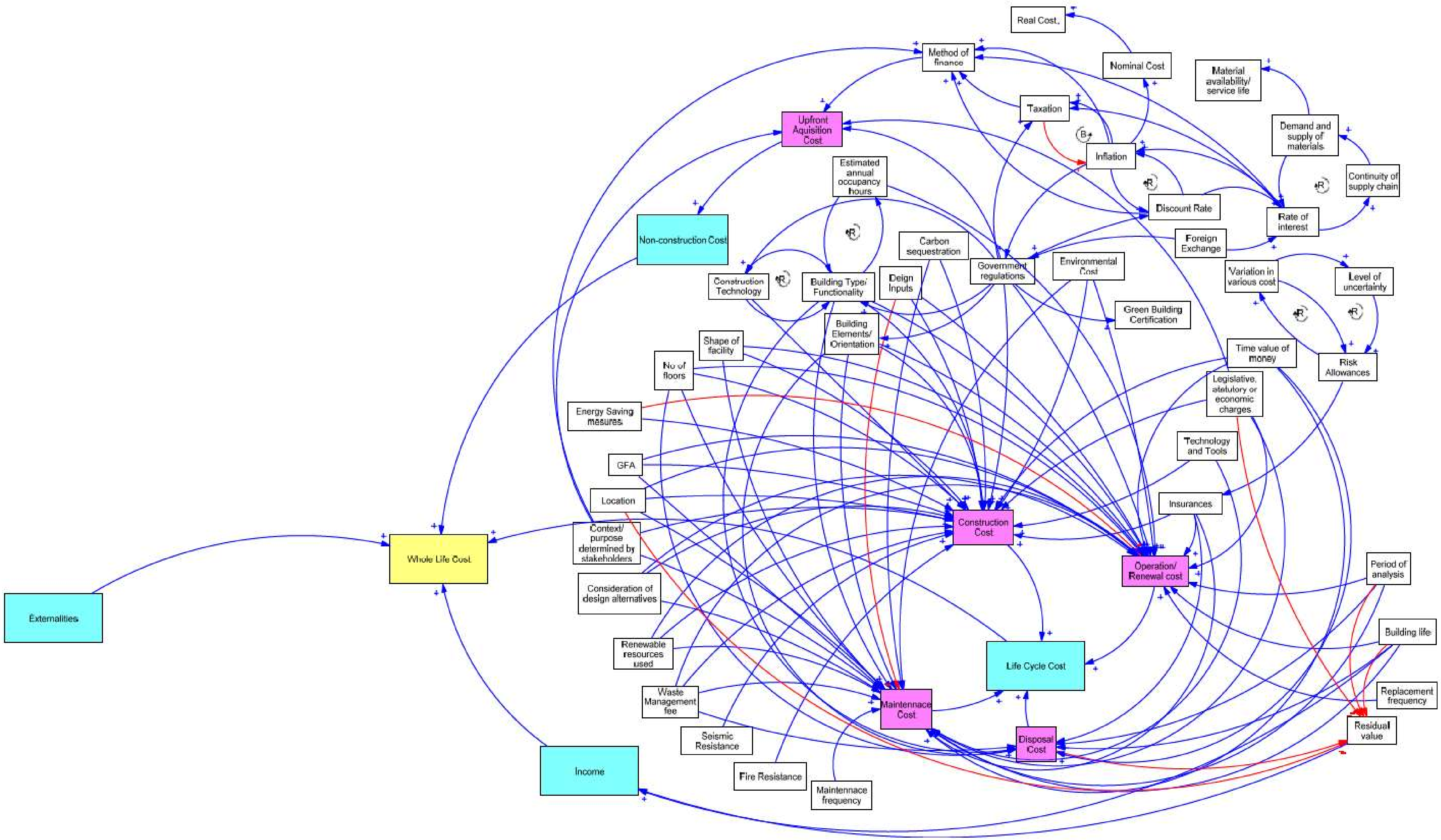


Figure 5.11: Comprehensive Causal Loop Diagram for the WLC, created by VENSIM Software

Figure 5.11 reveals one balancing loop and the six reinforcement loops, which are the same as in Figure 5.8, Figure 5.9, and Figure 5.10. This indicates no additional loops were identified in Figure 5.11.

Figure 5.11 also shows that level 4 factors, such as discount rate, taxation, inflation, foreign exchange, green building certification, variation in various costs, risk allowance, real cost, nominal cost, material availability/ service life, rate of interest, demand and supply of materials, and level of uncertainty, are not directly linked to level 3 factors. Instead, they are interconnected with other level 4 factors. For instance, the level of uncertainty is not directly related to any of the level 3 factors. It is connected to risk allowances, which are linked to insurance. Insurance, in turn, is only connected to construction, maintenance, operation/renewal, and disposal costs. Additionally, Figure 5.11 Shows that context/purpose determined by stakeholders, residual value, and building life are directly interconnected with the level 2 income factor and interlinked with LCC and Non-construction cost factors through level 3 factors.

Moreover, Figure 5.11 shows that minor attention has been given to the time value of money and real and nominal costs, as they have few interconnections. Real Cost: The cost expressed as a value at the Common Date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation. Nominal Cost: The expected price payable paid when a cost is due to be paid, including estimated changes in price due to, for example, forecast changes in efficiency, inflation or deflation and technology (ISO-15686, 2017). The time value of money refers to investment and price movements over time (RICS, 2016). Net Present Value (NPV) and Annual Equivalent Value (AEV) are the two methods of evaluating the time cost factor (Ballesty, 2021) . The present value represents the amount of investment today required for the capital cost plus all future operating (revenue) costs. NPV is the difference between the amount invested and the present value of all future costs, with the latter being lower than the nominal total because some costs occur in the future (Fregonara et al., 2017). The loss incurred by investing money in a building instead of a bank is known as AEV (Ballesty, 2021). Collectively, the figure illustrates 51 factors that are interconnected through six reinforcing loops and one balancing loop. However, geographical and weather factors, such as seismicity and flood resistance, haven't been identified by the SLR authors and have not been reflected in the ICMS framework or the Causal loop diagram.

5.6 Conclusions

While WLC is recognised for its advantages by construction professionals, it is not widely employed in the industry due to apprehensions about its estimation accuracy. Enhancing the precision of WLC necessitates discerning the factors that affect it. Nevertheless, these factors are not independent but are interrelated and function together. Therefore, comprehending the interconnections between these factors that impact the WLC is essential.

A systematic literature review was conducted to identify the factors influencing the estimation of the WLC in building construction. The study found 51 variables from 84 research publications visualised on a map using the VOS Viewer (Figure 5.6). Their search results categorised the factors into the hierarchy in the ICMS framework (Figure 5.4). However, the map and framework did not capture the expected interrelationships among the factors, as each factor belonged to only one cluster. A pairwise comparison method was employed to analyse the relationships between the different factors and their polarities. This method obtained an understanding of how the factors are interrelated.

The study has revealed a sole balancing loop that links the discount rate and inflation. Furthermore, six reinforced loops exist that interconnect inflation and discount rate, building type and functionality, estimated annual occupancy hours, building type and functionality, construction technology, variations in various costs and risk allowances, and variations in various costs, risk allowances, and level of uncertainty. Additionally, government regulations, taxation, interest rates, and foreign exchange rates are shared among the specific CLDs depicted in Figure 5.8, Figure 5.9, and Figure 5.10. However, the researchers in SLR did not explore the relationship between government regulations, energy-saving measures, and waste management.

The paper emphasised the importance of considering geographical and weather factors such as seismicity and flood resistance for WLC estimation, but none of the SLR articles addressed it. According to the ICMS framework, the identified interrelationships and polarities were divided into four hierarchical levels. It was found that not all level 4 factors are directly connected to level 3 factors. Instead, they interact with factors at the same level before connecting with level 3 factors.

It is essential to acknowledge that this study has several potential limitations. The systematic literature review's sample bias is a significant constraint. While the SLR methodology is simple to implement, the selective outcome relied on a relatively small number of databases to identify potentially eligible studies. The authors were unable to determine the biases prevalent in the literature searched. Hence, the risk of biases in the studied literature could not be assessed and remains a limitation.

Additionally, the websites used to display the data employed artificial intelligence and were not under the authors' control, which remains a limitation for systematic literature reviews worldwide. Although WLC is not a commonly used term, it was included to capture the relevant ones for the study; however, irrelevant papers were manually eliminated. Moreover, although the construction search string yielded many irrelevant non-building construction articles, the term "construction" was used independently to broaden the search area. Furthermore, the location-specific results of Google Scholar have remained a limitation, as the authors have been searching from New Zealand.

Limiting the study to a thorough systematic literature review and establishing pairwise relations based on the SLR-produced CLDs fails to manifest all the relevant causal relationships. Therefore, future research should prioritise identifying the system dynamics of the interrelationships between the factors that influence the WLC. Future research should also consider the geographical characteristics of WLC, as there is a lack of research exploring the correlation between geographical characteristics and WLC. The theoretical and practical applications include enhanced knowledge for cost estimators, quantity surveyors, and academics who can thoroughly understand the entire WLC system, including the interrelationships of the factors identified in this research. The building construction industry would gain insights into the interrelationships and could potentially include relevant cost factors to provide a more accurate WLC.

5.7 Summary

Chapter 5 presents the findings of Objective 1, which aims to identify specific factors and their relationships that affect WLC estimation worldwide. This is done through a SLR, which combines insights from various peer-reviewed articles, industry reports, and case studies. These sources help identify key factors that influence WLC estimations across different building types and regions. The chapter categorises these factors into construction-related costs, operational and maintenance costs, end-of-life costs, and external influences such as climate and location. It also examines how these factors relate to one another, resulting in a conceptual model that visually illustrates their interactions. The insights from this chapter provide a crucial foundation for the following research objectives, particularly in understanding how these global factors apply to New Zealand's residential sector. This sets the stage for creating a customised WLC framework in the following chapters.

Chapter 6. A System Dynamics Approach to Evaluating Factors Influencing Whole-life Cost Estimation for Residential Buildings in New Zealand

6.1 Prelude

This chapter introduces the second peer-reviewed manuscript included in this thesis. It builds on the earlier chapter's findings by analysing how multiple, interconnected factors impact the accuracy of whole-life cost (WLC) estimation in residential construction. It supports the overarching goal of this doctoral research to enhance WLC estimation practices and methodologies for New Zealand's residential sector by applying systems thinking to uncover dynamic interactions between cost-related variables.

The research objective addressed in this chapter is to establish the system dynamics of the elements that affect the accuracy of the whole-life cost estimation of residential buildings in New Zealand. The research question guiding this investigation is:

Research Question 2: What are the system dynamics of the elements that affect the accuracy of whole-life cost estimation for residential buildings, aiming to achieve long-term economic sustainability?

This chapter is based on the published article titled 'A system dynamics approach to evaluating factors influencing whole life cost estimation for residential buildings in New Zealand' (Urbanization, Sustainability and Society, 202, Vol. 3, pp.77-96). The publication has successfully achieved the second objective of this thesis: to integrate expert-based prioritisation and system dynamics modelling to represent how key WLC factors and their feedback loops influence the whole-life cost estimation of residential buildings.

Building on a systematic literature review and semi-structured interviews with industry professionals, this study identifies 80 factors impacting WLC and employs the Analytic Hierarchy Process (AHP) to prioritise them. It then applies a System Dynamics (SD) approach to map the complex interactions between these factors, revealing causal feedback loops that influence cost behaviours over time. The research highlights a key insight: internationally recognised frameworks such as the International Construction Measurement Standards (ICMS) are not sufficiently equipped to reflect New Zealand's unique construction context. Factors like high seismic risk, climatic variability, local supply chain constraints, and behavioural influences significantly impact cost planning in this setting. However, these are not adequately captured in global frameworks designed for broad, cross-national application.

By identifying and modelling these regional dynamics, this paper establishes the need for a tailored WLC framework for residential buildings in New Zealand. Although this paper does not propose such a framework, it provides the essential analytical groundwork for its development. The insights and modelling shared here directly inform the next phase of this research, where a customised framework is conceptualised to enhance WLC estimation accuracy and relevance within the local context.

This manuscript was prepared and submitted in accordance with the guidelines of Urbanisation, Sustainability and Society.

6.2 Introduction

Whole-life cost (WLC) estimation plays a vital role in the planning, execution, and maintenance of residential buildings, serving as a cornerstone for achieving long-term sustainability and economic viability in construction projects (Wong, 2010). Practical WLC estimation facilitates effective budget management and supports informed decision-making across a building's lifecycle (Liu & Luo, 2023). Globally, the construction industry is under increasing pressure to provide affordable and sustainable housing solutions amid rapid urbanisation, climate change, and resource scarcity. As such, lifecycle cost evaluation has become essential for project-level financial planning and supporting broader policy goals related to resilience, decarbonisation, and inclusive urban development.

Aligned with the United Nations Sustainable Development Goal 11 (SDG 11) – Sustainable Cities and Communities, which aims to "make cities and human settlements inclusive, safe, resilient, and sustainable," WLC estimation contributes directly to improving housing affordability, enhancing infrastructure resilience, and promoting sustainable construction practices. Accurate and adaptive cost planning is critical in ensuring that urban development not only meets immediate needs but also remains financially and environmentally viable over the long term (UN, 2015).

Despite growing interest in lifecycle-based approaches, existing WLC frameworks such as the International Construction Measurement Standards (ICMS) are often static and insufficiently adaptable to complex, real-world conditions (Zhao et al., 2019). They rarely reflect the interdependent and time-sensitive nature of decisions made throughout a building's lifecycle. Furthermore, they assume broad applicability across geographic regions, despite varying construction contexts, risk profiles, and socio-environmental constraints. These limitations are particularly evident in the New Zealand residential construction sector, where contextual challenges such as seismic activity, climate variability, supply chain volatility, and evolving regulatory environments complicate traditional cost estimation practices (MacGregor et al., 2018), Accurate lifecycle costing in this setting requires a context-aware, systems-based approach capable of modelling how dynamic interactions and feedback loops influence long-term cost outcomes. However, a significant research gap remains, as no prior studies have examined WLC in New Zealand through a comprehensive systems thinking lens that integrates regional risks, behavioural insights, and decision interdependencies.

To address this gap, the current study applies a System Dynamics (SD) approach (Sterman, 2001) to investigate the complex interrelationships among factors influencing WLC estimation for residential buildings in New Zealand. A total of 80 influencing factors were identified through a systematic literature review and semi-structured interviews with local industry professionals. Building on the foundational review by (Samarasekara, Purushothaman, & Rotimi, 2024), the study introduces additional context-specific factors and prioritises them using the Analytic Hierarchy Process (AHP), ensuring a structured and reproducible framework (Boussabaine & Kirkham, 2008).

In doing so, this research makes three core contributions. First, it provides a structured, evidence-based model that maps the reinforcing and balancing feedback loops critical to accurate WLC forecasting in a dynamic environment. Second, it advances methodological rigour by combining qualitative and quantitative techniques (SD and AHP). Third, and importantly, about the journal's themes, this study situates WLC estimation within the broader discourse on urbanisation, sustainability, and society, by highlighting how cost planning influences housing affordability, environmental resilience, and long-term infrastructure performance. In a rapidly urbanising New Zealand, where housing delivery intersects with seismic risk and sustainability commitments, improving the accuracy and contextual relevance of WLC estimation is timely and essential.

6.3 Literature Review

6.3.1 Overview of Whole-Life Cost Estimation

Whole-life costing (WLC) is a technique used to assess and determine all direct and indirect costs associated with the design, construction, facility management, operation, maintenance, support, replacement, and disposal of a building throughout its entire service life (El-Haram et al., 2002). WLC provides a comprehensive approach to evaluating the total cost of ownership over a building's lifecycle, considering not only the initial construction costs but also operational, maintenance, and end-of-life costs (Ashworth & Perera, 2015). This method enables stakeholders to make more informed decisions that balance upfront expenditures with long-term economic sustainability, offering a broader financial perspective for better decision-making in the construction industry. WLC's significance lies in its ability to reflect the total financial commitment over a building's lifespan, helping to identify cost-saving opportunities and enhance long-term value. (Kishk et al., 2003).

Despite the growing recognition of its value in promoting sustainability and cost-efficiency, accurate WLC estimation remains challenging due to the complex interdependencies among the factors that influence costs. Traditional models often overlook the interactions between project decisions, stakeholder roles, and other dynamic elements, resulting in inaccuracies in predicting the actual cost of ownership.

New Zealand further amplifies these challenges by increasing sustainability expectations, seismic risks, volatile supply chains, and stringent environmental regulations. These factors directly impact construction practices and cost structures, particularly in urban areas where population growth and housing demand pressure affordability and infrastructure resilience. As urbanisation intensifies, accurately estimating lifecycle costs becomes essential for resource optimisation and addressing broader societal outcomes, such as equitable housing access, public health, and environmental impact. WLC, therefore, serves as a critical tool in supporting sustainable urban development and informed policy-making that aligns with long-term societal well-being.

6.3.2 SD in Construction Projects

SD is an effective tool for modelling complex systems with interconnected variables, feedback loops, and time-dependent behaviours. Its use in construction projects enhances understanding of interactions between project factors, aiding decision-making (Bala et al., 2017). SD provides a framework for understanding these complexities, particularly to whole-life costing (WLC) (Azar, 2012). Research demonstrates that SD improves estimation accuracy; for example, Yi et al. (2023) applied SD for life cycle cost assessments in environmental scenarios, while Liu and Luo (2023) used it for cost estimation in prefabricated construction. Lou and Guo (2020) further leveraged SD techniques to analyse cost-influencing factors in prefabricated buildings. Additionally, Dabirian et al. (2023) used SD to manage cash flow in construction. SD's ability to track changes and incorporate feedback mechanisms (Li & Fan, 2022) allows for effective predictions (Zhang et al., 2017). Despite its potential, the use of SD for WLC in specific contexts, such as New Zealand's seismic and climate challenges, remains limited.

6.3.3 Feedback Loops and Time Delays in WLC Estimation

Feedback loops are crucial for understanding the dynamics related to costs. Positive feedback (reinforcing loops) can enhance benefits, such as improved design quality and lower maintenance costs (Wynn & Maier, 2022). Negative feedback (balancing loops) regulates behaviours, exemplified by trade-offs between construction speed and quality (Wynn & Maier, 2022). Time delays complicate WLC predictions; for instance, design decisions might only affect costs years later, especially regarding energy consumption and material durability (Keoleian & Menerey, 1994). Recognising these delays is crucial in New Zealand, where seismic activity impacts long-term building performance.

6.3.4 Frameworks and Methodologies

Current WLC frameworks categorise costs into construction, operation, maintenance, and disposal, but often fail to address regional complexities (Samarasekara, Purushothaman, & Rotimi, 2024). The International Construction Measurement Standards (ICMS) framework, although widely recognised, has limitations when applied to specific local contexts. Its classification into non-construction costs, life-cycle costs (LCCs), income, and externalities offers a standard structure (ICMS, 2021). However, it lacks adaptability to diverse regional realities. The ICMS's treatment of LCC categories overlooks critical factors, such as seismic risks and extreme weather, which significantly impact construction costs in sensitive areas like New Zealand. Samarasekara, Purushothaman and Rotimi (2024) emphasise that these omissions restrict the framework's accuracy and utility in specific contexts. Integrating SD with ICMS may help overcome these limitations, offering a more nuanced approach to cost assessment.

6.3.5 Advancing WLC Estimation with SD

Recent literature highlights the importance of adaptive models in capturing the complexity of WLC. SD is increasingly recognised for its ability to model cost interdependencies, particularly in dynamic environments. For instance, Leon et al. (2018) found SD effective in revealing long-term impacts of design and material choices in modular buildings. Such adaptive modelling is especially relevant in New Zealand, where construction practices must address unique geographic, climatic, and regulatory conditions. Integrating SD with WLC allows for a responsive framework that reflects local risks, stakeholder input, and evolving policy. This study aims to develop a New Zealand-specific WLC estimation model by synthesising existing literature and applying SD principles. The proposed framework considers local materials, energy standards, and sustainability goals to improve estimation accuracy and support long-term planning.

6.4 Research Methods

6.4.1 Research Design

This study adopts a qualitative research design to investigate the complex and interdependent factors influencing WLC estimation in the New Zealand residential construction context. A combination of systematic literature review (SLR), semi-structured interviews (SSI), the Analytic Hierarchy Process (AHP), and System Dynamics (SD) modelling was used to identify, prioritise, and model these factors.

The methodology follows a three-stage structure:

1. **Factor Identification:** An SLR was conducted to collect globally reported factors influencing WLC estimation. SSI supplemented this with New Zealand-based construction professionals to capture context-specific insights.
2. **Factor Prioritisation Using AHP:** The combined set of 80 factors (51 from SLR and 29 from SSI) was evaluated using the AHP. AHP was selected for its ability to handle multi-criteria decision problems, enabling structured pairwise comparison of factors to determine their relative importance. This process helped streamline the number of variables for modelling and reduced bias in selecting influential factors.
3. **System Dynamics Modelling:** The prioritised factors were used to construct causal loop diagrams (CLDs), mapping out key feedback mechanisms and interrelationships among cost drivers. This SD approach facilitated understanding of how changes in one factor may influence others over time, especially within dynamic and uncertain project environments.

6.4.2 Data Collection

6.4.2.1 Systematic Literature Review (SLR)

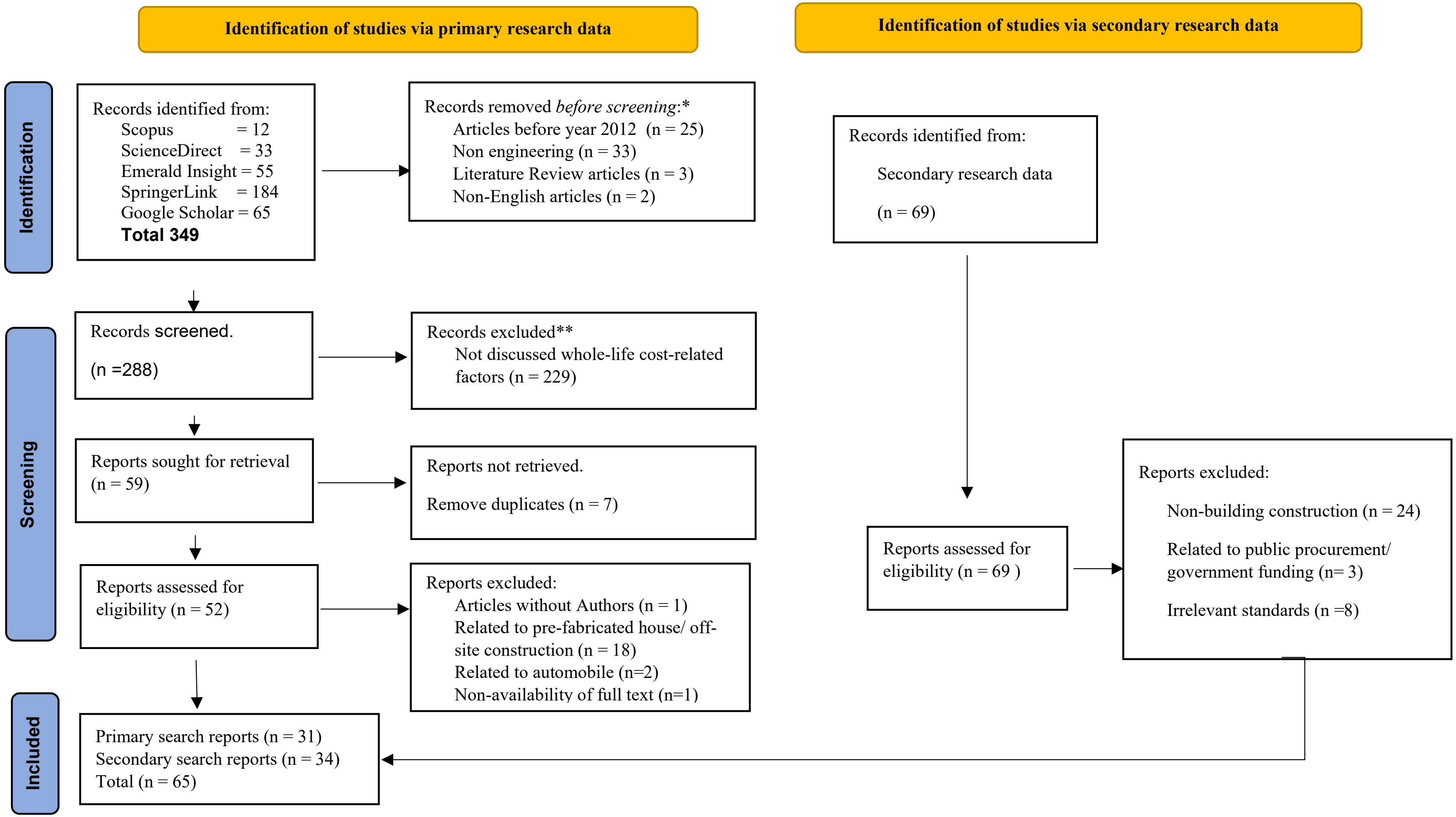
The SLR was conducted to identify factors influencing WLC estimation for New Zealand residential buildings, with a focus on both primary and secondary data sources. The primary data included scholarly, peer-reviewed research such as academic books, journals, and conference papers, accessed via databases like Scopus, ScienceDirect, Emerald Insight, SpringerLink, and Google Scholar. Secondary data included industry reports, standards, and guidelines published by organisations such as RICS, AIQS, ICMS, and NZIQS, which provided insights into industry practices and benchmarks.

Table 6.1 presents the search strategy, inclusion and exclusion criteria, and results from each database. This process adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring a systematic and transparent approach to data collection (Figure 6.1). The insights derived from the SLR established the theoretical and practical dimensions required to inform the SD model. While the SLR generally excluded review articles to prioritise primary studies, Samarasekara, Purushothaman and Rotimi (2024), a recent and comprehensive systematic literature review, was included as a key reference due to its thorough synthesis of factors influencing whole-life cost estimation. Our study is not an extension of this work but instead builds upon it by integrating new empirical data collected through semi-structured interviews (SSI) with industry experts. These interviews elicited additional factors and enriched the understanding of contextual and practical considerations specific to New Zealand's residential construction sector. Table 6.2 distinguishes between factors identified through the SLR, including those from Samarasekara, Purushothaman and Rotimi (2024) and novel factors derived from the SSI, thus providing a transparent overview of the factor origins. Furthermore, the decision to limit the literature search to studies published from 2012 onwards was informed by significant regulatory and contextual shifts in New Zealand's construction environment. Following the Canterbury earthquakes of 2010, the government introduced significant reforms to the Building Code and seismic design standards through the 2012 Building Act amendments (MBIE, 2012), which reshaped building practices and lifecycle costing frameworks. Literature prior to 2012 does not adequately reflect these changes or the subsequent adoption of technologies such as BIM and prefabrication. Therefore, setting 2012 as the lower bound ensures the inclusion of research that is both methodologically current and contextually relevant to today's construction practices in New Zealand.

Table 6.1 Search strings for database search

Database	Search Strings	Inclusions	Exclusions	Range (2012-2024)
Scopus	"Whole-life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area—Engineering Language—English	Review articles	12
Science Direct	"Whole-life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area—Engineering Language—English	Review articles Book review Product review	33
Emerald Insight	Abstract: "Whole-life cost" OR (abstract: "we") AND (abstract: "construction")AND (abstract: "factors")	Access—Only content that I have accessed Content Type—Articles	Review articles	55
Springer Link	"Construction" AND "factors" AND "Whole-life cost"	Discipline Engineering Subdiscipline—Building Construction and Design	Reference work entry Reference work	184
Google Scholar	"Construction" AND "factors" AND "Whole-life cost"	Only in title	Review articles	65
Other databases		Nil	All other databases are excluded due to article retrieval limitations.	
Total				349

Once the data searching strategy was established in Table 6.1, the PRISMA process was followed; the flow diagram is shown in Figure 6.1.



**Records excluded by automation **Records excluded by human*

Figure 6.1: PRISMA Flowchart

6.4.2.2 Semi-Structured Interviews (SSI)

Semi-structured interviews were conducted with a purposively selected group of 22 industry professionals, including quantity surveyors, project managers, architects, engineers, facility managers, and policymakers. Participants were identified through professional networks, referrals from industry contacts, and publicly available directories such as LinkedIn and industry association membership lists (e.g., NZIQS and NZIA). This recruitment strategy ensured access to experienced professionals with relevant expertise in residential construction and whole-life cost estimation.

Once potential participants were identified, they were contacted via email or LinkedIn messaging with an invitation outlining the study's purpose, ethical considerations, and interview process. All participants provided informed consent through a formal consent form prior to the commencement of the interviews. Interviews were conducted via Microsoft Teams, recorded with permission, and transcribed for analysis. SSI were conducted in four parts:

1. General experience with WLC in residential projects,
2. Identification of key influencing factors,
3. Exploration of interdependencies among factors, and
4. Prioritisation of critical factors.

These interviews informed the identification of additional context-specific factors, validated factor categorisation for the AHP and clarified the nature of relationships used in SD modelling. The interview guide, designed to ensure consistency and comprehensiveness, is provided in *Appendix 3: Interview Questions (Stage 1)*.

Table 6.2: The criteria for selecting participants.

Participants	Selection Criteria	No of Participants
Home Owners	Clients who built residential houses and were involved in financial decision-making	2
Architects	Experts in residential design and sustainable design practices.	2
Engineers (Service and Structural)	Professionals with expertise in the technical and engineering aspects of residential buildings.	4
Quantity Surveyors	Professionals with experience in cost estimation and WLC analysis.	8
Project Managers	Individuals oversee residential projects from initiation to completion.	3
Facility Managers	Experts in the management and maintenance of residential buildings post-construction.	2
Government Authorities	Representatives from regulatory bodies with expertise in building regulations and standards.	1

This selection process ensured a comprehensive range of perspectives on the factors influencing WLC estimation in New Zealand.

6.4.3 Data Analysis

6.4.3.1 Analytic Hierarchy Process (AHP)

The AHP is a structured technique for organising and analysing complex decisions, based on mathematics and psychology (Milkova et al., 2019). In this study, AHP was applied to prioritise WLC-influencing factors identified through the SLR and SSI, establishing their relative importance for the New Zealand context (Samarasekara, Purushothaman, & Rotimi, 2024). The AHP framework was structured hierarchically, with accurate WLC estimation at the top level, followed by relevant criteria and sub-criteria, and specific factors at the lowest level (de FSM Russo & Camanho, 2015). Figure 6.2 shows the modified levels of factors using the ICMS framework. This structure allowed for systematic pairwise comparison of factors, using a standard 1–9 scale to capture subjective judgments (Kou et al., 2016).

1: Equal importance
3: Moderate importance
5: Strong importance
7: Very strong importance
9: Absolute Importance

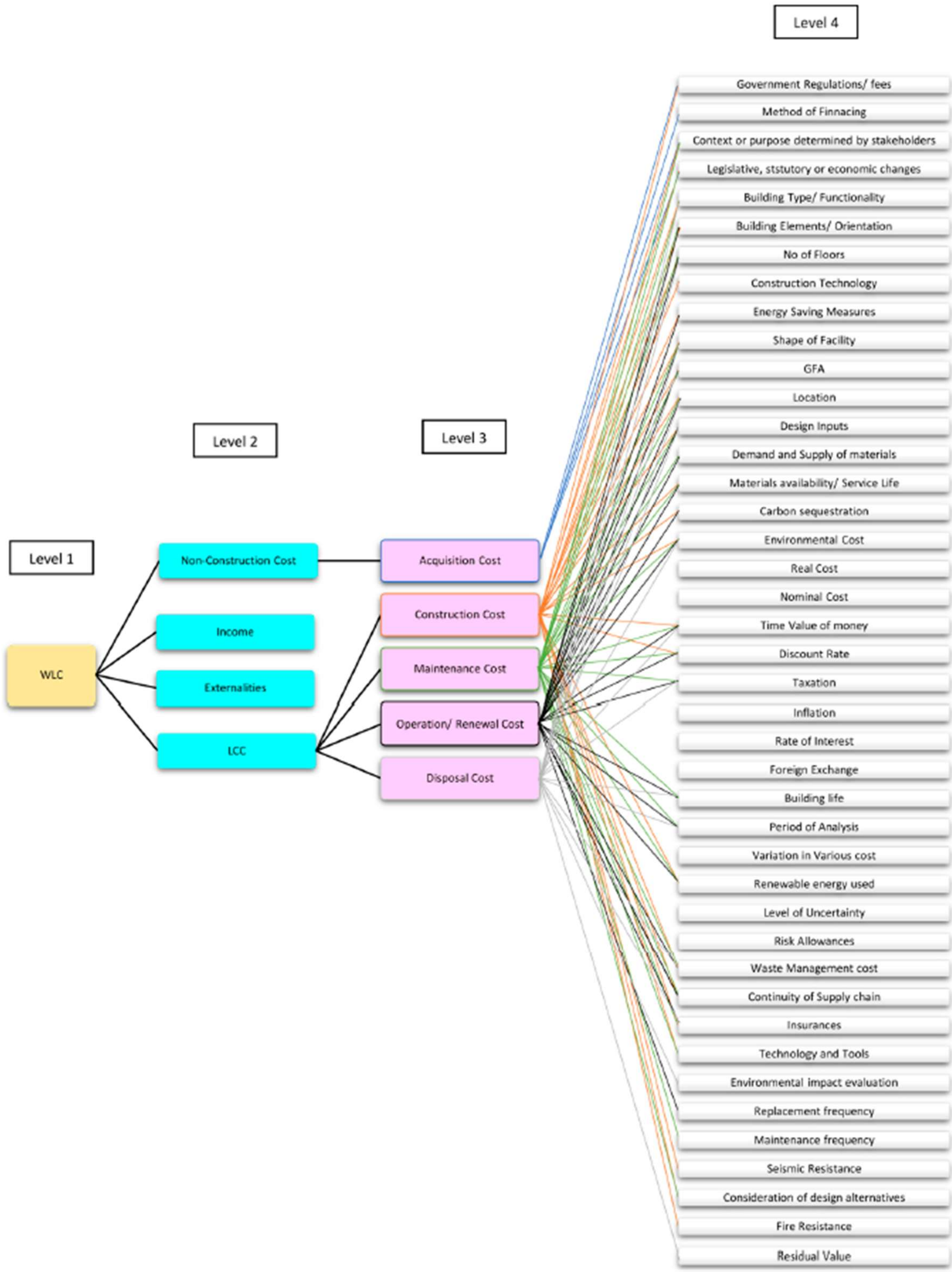


Figure 6.2: Modified levels of factors using the ICMS framework (Samarasekara, Purushothaman, & Rotimi, 2024)

To justify the scores applied in the pairwise comparison matrix (Appendix 8), a frequency-based scoring method was adopted for both the SLR and the SSI.

For the SLR (51 factors from 65 sources), importance scores were derived based on the frequency with which each factor appeared across the reviewed studies. The scoring thresholds and illustrative examples are summarised in Table 6.3.

Table 6.3: Scoring Justification Based on SLR Frequency

SLR Score	Citation Frequency in SLR Sources	Interpretation	Example Factors
9	≥ 50 sources	Universally cited as critical in the literature	Maintenance Cost (59), Construction Cost (55)
7	35–49 sources	Frequently cited in the majority of studies	Residual Value (46), Discount Rate (32)
5	20–34 sources	Moderately cited and contextually significant	Time Value of Money (29), Taxation (17)
3	10–19 sources	Occasionally cited; moderate influence	Environmental Impact Evaluation (14), Inflation (16)
1	< 10 sources	Rarely cited or marginal in academic discourse	Fire Resistance (1), Foreign Exchange (1)

For the SSI (29 factors from 22 participants), factor importance was based on the number of interviewees who identified or discussed each factor. The scoring rationale is summarised in Table 6.4.

Table 6.4:Scoring Justification Based on SSI Mentions

SLR Score	Citation Frequency in SLR Sources	Interpretation	Example Factors
9	≥ 15 participants	Strong consensus across industry professionals	Material Durability (17), Construction Quality (16)
7	10–14 participants	Frequently mentioned by a wide range of roles	Seismic Resistance (12), Building Orientation (11)
5	6–9 participants	Common but not dominant across interviews	Supply Chain Resilience (7), Smart Systems (8)
3	3–5 participants	Occasionally mentioned, some practical relevance	Green Star Rating (5), Tech Depreciation (4)
1	< 3 participants	Rare or minor focus among stakeholders	Acoustic Performance (2), Foreign Exchange (1)

Where a factor was identified in both SLR and SSI, the higher of the two scores was retained in the matrix to ensure that either academic consensus or practical relevance could independently validate the importance level. A pairwise comparison matrix was created to assess the relative influence of each factor. The matrix was then normalised by dividing each cell by the total of its respective column, enabling accurate computation of relative weights (Talukder et al., 2017). The row averages of the normalised matrix were calculated to determine the weights for each factor (Collins et al., 2023).

The normalisation process involves two key steps. First, column-wise normalisation was performed by dividing each element in column j by the sum of all elements in that column, transforming the matrix so that each column sums to 1:

$$a_{\{ij\}}^{\{norm\}} = \backslash frac\{a_{\{ij\}}\}\left\{\sum_{\{i=1\}}^{\{n\}a}{}_{\{ij\}}\right\}$$

This step results in a normalised matrix where each column totals unity. Second, to obtain the final normalised weight vector, the average of each row I was calculated across the normalised matrix:

$$w_i = \backslash frac\{1\}\{n\} \sum_{\{j=1\}}^{\{n\}a_{\{ij\}}^{\{norm\}}}$$

This gives a single scalar value per row, representing the relative priority or weight of each factor. The reason the final output is expressed as a single-column vector is that the primary goal of AHP is to rank the criteria by their relative importance. This single column is not derived from any particular column of the original matrix, but rather from the row-wise averages of the column-normalised matrix, thus effectively capturing the overall priorities.

Then, a consistency ratio (CR) was computed to ensure consistency in judgment. A CR value below 0.1 was considered acceptable; otherwise, the matrix was revised to improve logical coherence (Karapetrovic & Rosenbloom, 1999).

After confirming consistency, relationships among factors were further analysed. Positive relationships were characterised by proportional effects (i.e., an increase in one factor led to a corresponding increase in another), while negative relationships indicated inverse effects. In the final matrix, positive relationships were multiplied by +1, and negative relationships by -1, to reflect their directional influence on WLC estimation (Zhang et al., 2021). Due to the novelty of system dynamics modelling within the local construction sector, polarities between factors were assumed based on logical reasoning and cross-referenced literature, as industry participants lacked familiarity with SD concepts. Finally, these weighted and directional relationships were mapped to establish an interconnected framework, revealing how individual factors influence each other within the WLC estimation system. This approach facilitated a more nuanced and dynamic understanding of factor behaviour, moving beyond static weightings to identify reinforcing and balancing effects across the system (Rush & Roy, 2023).

6.4.3.2 Thematic Analysis and Integration with SD

The data gathered from the semi-structured interviews were analysed using thematic analysis following Mahesh Babu, P., Seadon, J. and Moore, D. (2023). This process involved familiarising with the data, coding relevant responses based on research questions, and grouping them into broader themes. These themes were then interpreted to identify the most significant factors influencing WLC estimation in New Zealand. The thematic analysis helped identify critical insights regarding the interrelationships between factors and challenges in current WLC estimation practices. Thematic analysis was conducted using NVivo software to code, organise, and analyse qualitative data from the semi-structured interviews. This allowed for the systematic identification of recurring themes, relationships, and contextual insights relevant to WLC estimation.

The insights from the interviews were used to enhance the understanding of the interrelationships between the identified WLC factors, which were mapped using SD modelling. This modelling approach was employed to visualise feedback loops and dependencies, which informed the development of a more accurate, contextually relevant WLC framework for New Zealand. The model incorporated local factors, such as seismic risks and climate conditions, that were not captured in existing frameworks.

6.4.4 Ethical Considerations

The study was conducted in accordance with the Auckland University of Technology Human Ethics Guidelines and was approved by the AUT Ethics Committee (24/206).

6.4.5 Limitations of the Methodology

This study's methodology is subject to some limitations. While using a purposive sample ensures relevant expertise, the findings may not fully represent the diversity of experiences across New Zealand's residential construction sector. Furthermore, the qualitative nature of the research means that the findings may not be generalisable to other contexts. However, the in-depth insights from the interviews, combined with the integration of the SLR, provide a robust basis for refining WLC estimation frameworks specific to New Zealand.

6.5 Results and Discussion

This section presents the findings from the SLR, SSI, AHP, and SD modelling to address the research objectives, particularly establishing the system dynamics of elements affecting the accuracy of WLC estimation for residential buildings in New Zealand. The results highlight key factors, their interactions, critical feedback loops, and prioritised factors, culminating in practical implications for stakeholders. The discussion integrates these findings to enhance WLC estimation accuracy, considering New Zealand's seismic and climatic challenges.

6.5.1 Key Factors Influencing WLC

The SLR, covering 65 sources from 2012 to 2024, identified 51 factors influencing WLC, as detailed in Samarasekara, Purushothaman and Rotimi (2024). These factors encompass the construction, operation, maintenance, and disposal phases, with a focus on sustainability, seismic resilience, energy consumption, and operational costs. Table 6.5 consolidates these factors.

Table 6.5: Consolidation of SLR factors mentioned in Samarasekara, Purushothaman and Rotimi (2024)

Factors	No of sources
Maintenance Cost	59
Disposal/end-of-life cost	57
Operation Cost/ Renewal Cost	57
Construction Cost	55
Residual Value	46
Time value of money	38
Upfront acquisition cost	35
Discount Rate	32
Period of Analysis	29
Building Life	27
Government regulations/ fees	20
Income generated from the asset	18
Materials availability/ Service Life	17
Taxation	17
Inflation	16
Building Type/ functionality	15
Environmental impact evaluation	14
Building Element/ orientation	13
Maintenance frequency	13
Gross floor Area	12
Replacement frequency	12
Risk Allowances	12
Waste management cost	11
Design Inputs	10
Environmental cost	10
Location	9
No of floors/ Height/ level above and below ground	9
Nominal Cost	9
Rate of interest	9
Carbon sequestration	8
Construction technology	8
Context or purpose determined by stakeholders	8
Energy saving measures and cost	7
Real cost	7
legislative, statutory, or economic changes	6
Estimated annual occupancy hours	5
Externalities	4
Green building certification cost	4
Shape of facility	4
Technology and Tools	3
Consideration of design alternatives	2

Continuity of supply chain	2
Level of uncertainty	2
Renewable resources used	2
Variations in Various cost	2
Demand and supply of materials	1
Fire Resistance	1
Foreign Exchange	1
Insurances	1
Method of financing	1
Seismic Resistance	1

The SSI, involving 22 participants as detailed in Table 6.2, identified 29 additional factors summarised in . Table 6.6 Key factors included building automation, renewable energy systems, and regional variations. These factors are particularly relevant to New Zealand's unique context, where seismic risks and adverse weather conditions significantly affect the accuracy of WLC estimation. For example, participants stressed the need to use corrosion-resistant materials in coastal zones and implement seismic bracing in regions near fault lines, which aligns with the post-earthquake reforms outlined by MBIE (2012).

Table 6.6: Additional factors influencing WLC identified in SSI

Item	Interview Ref	Profession	Factors																													
			Building occupancy type	Building Age	Insurance and risk mitigation	Construction quality	Water management system	Building automation and smart system	Building resilience to natural hazards	Renewable energy system	Supply chain resilience and cost	Building maintenance technologies	Building orientation and solar gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Others (already included in (Samarasekara, Purushothaman, & Rotimi, 2024))	Greenstar Rating	Material Durability	Installation practice	Comparability with other building	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication	Availability of skilled labour
1	GA	Government Authority																														
2	A1	Architect			1														1			1										
3	A 2	Architect							1			1			1				1	1												
4	HM 1	Homeowner																					1									
5	HM 2	Homeowner																				1		1								
6	EE 1	Electrical Engineer																				1										
7	EE 2	Electrical Engineer																				1										
8	SSM 1	Structural site manager														1			1												1	
9	SS 1	Site supervisor (Fit-out)																	1						1	1	1	1				
10	FM 1	Facilities manager																			1										1	
11	FM 2	Facilities manager																				1										
12	PM 1	Project Manager			1																											
13	PM 2	Project Manager														1				1												1
14	PM 3	Project Manager																				1										
15	QS 1	Quantity Surveyor	1	1	1	1		1											1	1									1			
16	QS 2	Quantity Surveyor																				1										
17	QS 3	Quantity Surveyor														1						1	1	1						1		
18	QS 4	Quantity Surveyor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1										
19	QS 5	Quantity Surveyor																				1										
20	QS 6	Quantity Surveyor																		1		1										
21	QS 7	Quantity Surveyor																			1	1										
22	QS 8	Quantity Surveyor																				1										
	Totals		**2**	**2**	**4**	**2**	**1**	**2**	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**4**	**1**	**1**	**6**	**5**	**2**	**13**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**1**

SSIs with 22 construction professionals in New Zealand revealed a range of practical, context-specific factors that influence the accuracy of whole-life cost estimation in residential buildings. As detailed in Table 6.4, these factors extend beyond those commonly discussed in the literature, highlighting unique operational and environmental conditions in the New Zealand context. Among the most frequently cited were material durability, construction quality, installation practices, technology depreciation, and regional or geographical conditions. These elements reflect professionals' experiences working across various roles and contribute to more accurate cost projections over a building's lifespan. Table 6.6 also identifies occupancy behaviours, Green Star ratings, and building orientation as significant influences on long-term performance and operational costs. These factors are often overlooked in standard cost frameworks but were highlighted by practitioners as key drivers that shape building efficiency and user experience over time. Their inclusion underscores the importance of behavioural and environmental variables in developing reliable cost estimations.

Several interviewees also emphasised localised risk factors such as seismic resilience, insurance requirements, and the influence of regional hazards on material selection and structural systems. These risks were discussed in greater detail than typically found in the literature, pointing to their relevance in initial decision-making and long-term cost planning. Furthermore, insights in Table 6.6 reveal that supply chain resilience, availability of skilled labour, and the effectiveness of on-site communication play a crucial role in determining project outcomes and associated costs. Rather than isolated technical inputs, these are dynamic and interconnected processes that influence project efficiency, rework frequency, and delivery timelines. For example, poor coordination between teams or delays due to labour shortages were cited as causes of unforeseen expenditures and budget overruns. The responses are summarised in Table 6.6 demonstrate that WLC estimation in New Zealand's residential sector is shaped by an integrated set of behavioural, environmental, technical, and managerial factors. These findings suggest that accurate WLC modelling must consider component-based costs and the broader interaction system that evolves throughout the building lifecycle.

Together, 51 SLR factors are shown in Samarasekara, Purushothaman and Rotimi (2024) and SSI findings produced a consolidated list of 80 factors, later refined through AHP and SD modelling to highlight only those with significant interdependencies.

6.5.2 Integration of Pairwise Comparisons into System Dynamics Modelling

The relationships among the 80 identified factors were mapped using SD modelling to construct the Causal Loop Diagram (Appendix 11), which revealed 11 reinforcing (R1–R11) and 12 balancing (B1–B12) feedback loops driving WLC dynamics. Key themes emerging from the updated codebook include cost factor feedback, environmental influences, geographic variations, estimation challenges, factor interactions, and systemic interdependencies, as summarised in Table 6.7.

To quantify the strength of interrelationships, AHP pairwise comparisons were conducted (Appendix 8: Pairwise Comparison Matrix). For each factor, the geometric mean of comparison values was calculated and normalised (Appendix 9: Normalised Weights), resulting in a priority vector with weights summing to one. The consistency of expert judgments was validated using the Consistency Index (CI) and Consistency Ratio (CR), based on the principal eigenvalue (λmax) derived from the weighted sum vector. The resulting CR was effectively zero, indicating excellent consistency in the comparisons.

The directional influence of each factor was determined by integrating the normalised weights with relationship polarity identified through interview data and literature (Appendix 10: Relationship Polarity Table). Positive relationships retained their normalised weights, reflecting direct influence (e.g., increased investment in renewable energy leading to reduced operational costs). In contrast, negative relationships were adjusted to reflect inverse influence (e.g., higher upfront costs leading to long-term savings). This integration of strength and polarity was then used to construct the directional linkage matrix (Appendix 12: Linkage Weight Matrix), enabling the causal structure to accurately reflect real-world feedback behaviour within WLC estimation.

The CLD's reinforcing loops, such as the link between regional seismic risks, investment in seismic design, and increased building life (R1), and energy-saving measures reducing long-term costs (R3), highlight how certain factors amplify WLC dynamics. Conversely, balancing loops such as trade-offs between construction quality, cost, and long-term maintenance stabilise the system and reveal key cost tensions (e.g., B1, Cost Factor Feedback). These interdependencies reflect New Zealand's seismic and climatic challenges (MBIE, 2012) and emphasise the need for adaptive, long-term planning.

By combining structured weighting, directional mapping, and qualitative insights, this approach offers a context-sensitive alternative to static cost frameworks. It supports the development of a responsive WLC estimation model tailored to the complexity and uncertainty of residential construction in New Zealand.

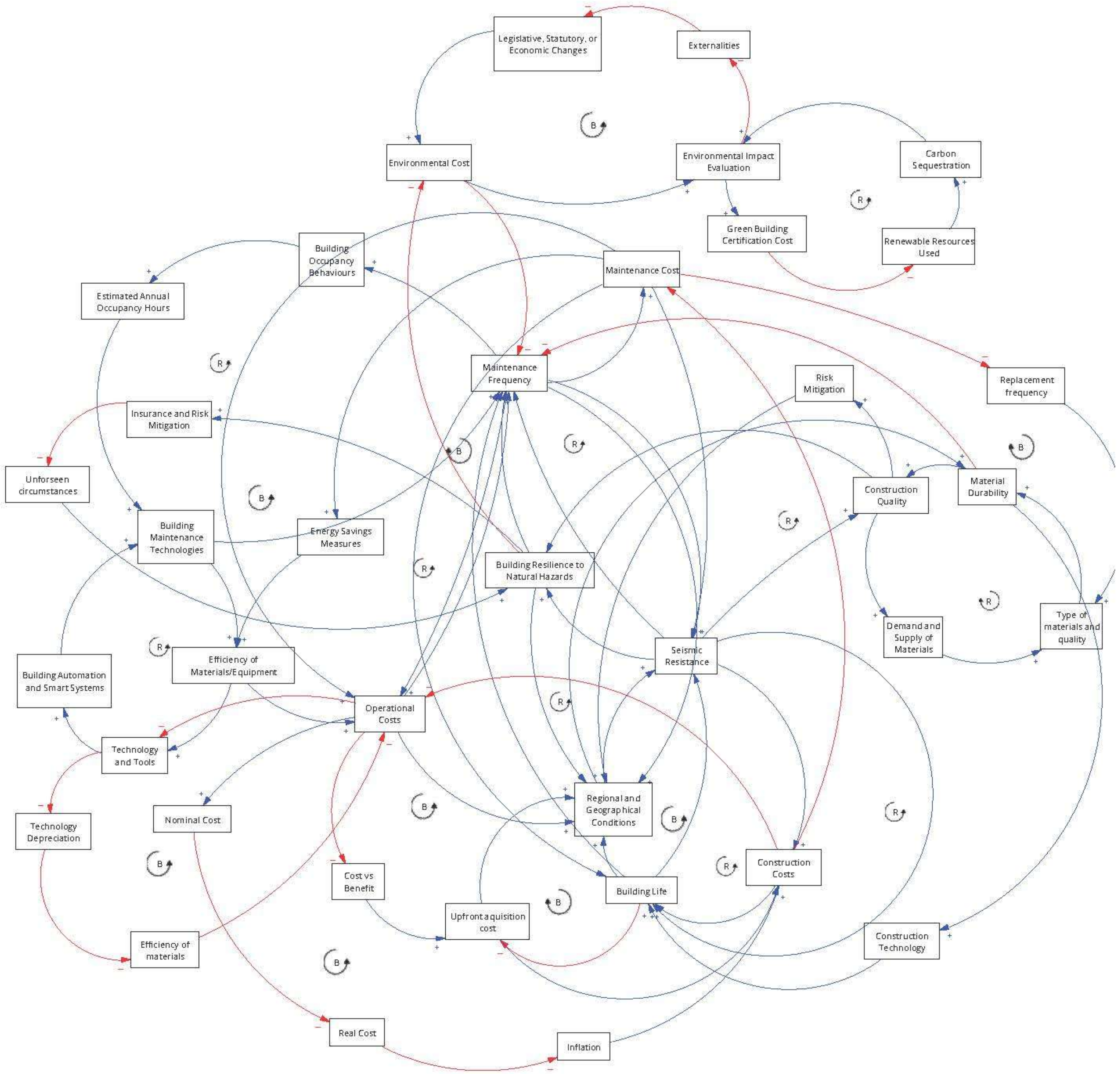


Figure 6.3: Reinforcing and Balancing loops

Recognising the reinforcing and balancing loops identified in the CLD (Figure 6.3) makes capturing the ripple effects of decisions across a building's lifecycle essential. For example, the reinforcing loop between innovation and cost efficiency can encourage further technology adoption, strengthening supply chain resilience. As shown in the causal loop diagram (Figure 6.3) and summarised in Table 6.7, mapping these relationships supports a strategic, systems-based approach to sustainable construction.

Table 6.7: Summary of Causal Feedback Loops in WLC Estimation

Loop ID	Loop Name	Loop Variables	Type	Main Driver	Main Consequence
R1	Seismic Investment & Longevity	Regional Conditions → Seismic Resistance → Construction Costs → Building Life → Regional Conditions	Reinforcing	Regional Conditions	Increased investment in durable, long-life buildings
R2	Seismic Operational Savings	Regional Conditions → Seismic Resistance → Maintenance Frequency → Operational Costs	Reinforcing	Seismic Resistance	Lower maintenance and operating costs
R3	Energy Efficiency Loop	Energy Measures → Equipment Efficiency → Operation/Renewal Cost → Maintenance Frequency → Maintenance Cost	Reinforcing	Energy Saving Measures	Reduced lifecycle costs and resource use
R4	Green Certification Feedback	Certification Cost → Renewable Resources Used → Carbon Sequestration → Environmental Evaluation	Reinforcing	Certification Efforts	Increased sustainability and justification of green costs
R5	Resilience & Maintenance Reduction	Seismic Resistance → Hazard Resilience → Maintenance Frequency → Maintenance Cost	Reinforcing	Seismic Resistance	Reduced damage and long-term maintenance costs
R6	Durable Materials Demand Cycle	Demand & Supply → Material Quality → Material Durability → Construction Quality → Demand & Supply	Reinforcing	Market Demand	Higher construction quality and lifecycle performance
R7	Smart Tech Efficiency Loop	Technology → Automation/Smart Systems → Maintenance Tech → Equipment Efficiency → Technology	Reinforcing	Technology Adoption	Higher system efficiency and predictive maintenance
R8	Occupancy Behaviour Feedback	Occupant Behaviour → Occupancy Hours → Maintenance Tech → Maintenance Frequency → Occupant Behaviour	Reinforcing	Occupant Awareness	Reduced wear, costs, and more sustainable user practices
R9	Regional Seismic Quality Loop	Region → Seismic Resistance → Construction Quality → Resilience → Region	Reinforcing	Regional Risk Profile	Safer buildings aligned with local hazard conditions
R10	Regional Material Durability	Region → Material Durability → Construction Technology → Building Life → Maintenance Frequency	Reinforcing	Climate/Geographic Conditions	Reduced frequency of maintenance
R11	Risk Mitigation Feedback	Region → Seismic Resistance → Construction Quality → Risk Mitigation	Reinforcing	Seismic Risk	Stronger construction and reduced seismic vulnerability
B1	Seismic Cost-Value Loop	Seismic Resistance → Construction Cost → Maintenance Cost → Building Life → Seismic Resistance	Balancing	Seismic Design Standards	Long-term savings balance high initial costs
B2	Upfront vs Lifespan Cost	Regional Conditions → Seismic Resistance → Building Life → Upfront Acquisition Cost	Balancing	Regional Risk	Justifies high acquisition cost via extended lifespan

B3	Resilience & Environmental Impact	Seismic Resistance → Hazard Resilience → Environmental Impact → Renewal Cycles	Balancing	Seismic Resilience	Reduces lifecycle environmental impact
B4	Cost-Benefit Trade-Off Loop	Cost vs Benefit → Upfront Cost → Construction Cost → Operational/Renewal Cost → Cost vs Benefit	Balancing	Cost-Efficiency Consideration	Aligns high upfront cost with long-term efficiency gains
B5	Inflation Impact Loop	Inflation → Construction/Maintenance Cost → Nominal Cost → Real Cost → Inflation	Balancing	Inflation	Adjusts financial decisions based on real vs nominal value
B6	Environmental Compliance Feedback	Legislative/Economic Changes → Environmental Cost → Evaluation → Externalities → Policy Changes	Balancing	Regulatory Environment	Adapts policies to manage unintended environmental impacts
B7	Durability Investment Loop	Material Durability → Maintenance Cost → Replacement Frequency → Material Quality → Material Durability	Balancing	Material Quality	Encourages durable material use for lifecycle cost stability
B8	Insurance & Resilience Loop	Hazard Resilience → Insurance/Risk Mitigation → Unforeseen Events → Hazard Resilience	Balancing	Natural Hazard Exposure	Improves risk planning through resilient design
B9	Tech Depreciation Cycle	Technology → Depreciation → Efficiency → Operational/Renewal Cost → Technology	Balancing	Tech Lifecycle	Maintains performance through reinvestment
B10	Occupancy-Cost Adjustment	Occupancy Type → Occupant Behaviour → Maintenance Cost → Operational Cost → Occupancy Type	Balancing	Occupant Behaviour	Aligns occupancy patterns with cost-efficient usage
B11	Resilience-Cost Feedback	Hazard Resilience → Insurance/Risk → Construction Cost → Hazard Resilience	Balancing	Risk Management	Reinforces resilient design by reducing financial exposure
B12	Eco-Cost Reduction Loop	Environmental Cost → Greenstar Rating → Renewable Use → Carbon Sequestration → Environmental Cost	Balancing	Green Certification Systems	Drives down environmental costs through sustainable choices

6.5.3 Identification and Impact of Factors within System Feedback Loops

From the 80 factors identified through a comprehensive systematic literature review and stakeholder interviews, the final selection of 37 factors was made based on their involvement in the dynamic causal feedback loops modelled using system dynamics. This refinement process ensures that only factors substantially influencing WLC estimation within New Zealand's residential construction context are included.

The initial evaluation involved a detailed pairwise scoring and comparison of all 80 factors (see Appendix 8: The Pairwise Score Table), followed by normalisation of scores to determine relative importance (Appendix 9: The Normalisation Table). Subsequently, pairwise relationships among factors were analysed to understand their interactions (Appendix 10: The Pairwise Relationships). This process identified factors that actively reinforce and balance feedback loops within the system. The causal loop diagram (Appendix 11: The Causal Loop Diagram) visualises these interactions, showing how 37 factors consistently interact within the system to drive lifecycle cost behaviour. These factors include critical elements such as seismic resistance, material durability, construction quality, energy efficiency, and occupant behaviour, which emerged repeatedly from stakeholder interviews and literature.

Table 6.8 presents these 37 impactful factors, selected for their embeddedness within the system's behaviour rather than isolated effects. Their influence spans multiple lifecycle stages, including design, construction, operation, maintenance, and disposal. It captures important New Zealand-specific drivers such as seismic risk, local climate conditions, technology adoption, and construction practices. Appendix 12: The Linkage Table details the further refinement and linkage of these factors, mapping the systemic pathways through which these variables affect Whole-life Cost. This approach ensures the model's clarity and practical relevance, avoiding unnecessary complexity while maintaining a robust representation of real-world cost dynamics.

By grounding the WLC estimation model in these 37 interconnected, context-specific factors, the research bridges theoretical cost frameworks with practical construction realities in New Zealand. This selection supports improved accuracy, stakeholder engagement, and policy direction to enhance lifecycle cost predictability and performance in residential buildings.

Table 6.8 Summary of the factors interacting in feedback loops

Factor	Description
Regional and Geographical Conditions	Determine construction requirements based on local challenges, such as salinity, cold weather, and seismic zones, which impact materials, design, and costs. These factors influence maintenance, efficiency, and resilience, making them critical for WLC analysis.
Seismic Resistance	Ensures structural integrity in earthquake areas, lowering repair costs and safeguarding occupant safety. While incurring upfront costs, it enhances asset longevity and reduces lifecycle costs.
Construction Costs	Immediate impact on project feasibility and long-term operational costs. Accurate estimation and resource allocation optimise lifecycle cost outcomes, emphasising the importance of efficient financial planning.
Building Life Cycle	Defines the timeframe during which a structure remains functional. Longer life cycles reduce replacements and waste while lowering operational costs, supporting sustainability and cost-effectiveness.
Maintenance Frequency	Influences operational budgets and financial sustainability. Durable materials and advanced maintenance technologies minimise intervention needs, aligning with cost-efficiency goals.
Operational Costs	Encompass energy consumption, repairs, and upkeep. Efficient systems and durable materials reduce expenses, ensuring predictable costs over the building's lifespan.
Energy Savings	Investments in energy-efficient systems yield significant cost savings and align with sustainability goals, increasing market value and reducing environmental impact.
Material and Equipment Efficiency	High-performance materials and energy-efficient equipment reduce wear and tear, as well as utility bills, thereby extending asset lifespan and lowering maintenance needs.
Green Building Certification Costs	Upfront compliance investments improve property value, attract eco-conscious tenants, and reduce long-term operational costs through sustainable practices.
Renewable Resources	Incorporating solar energy, sustainably sourced timber, and other environmentally friendly materials reduces dependency on finite resources, lowers operational costs, and aligns with environmental goals.
Carbon Sequestration	Materials that absorb carbon dioxide reduce a building's environmental impact, aligning with sustainability strategies and improving environmental impact evaluations.
Environmental Impact Evaluations	Guide better material selection and design decisions, ensuring regulatory compliance and reducing financial penalties while influencing WLC.
Building Resilience to Natural Hazards	Investments in resilient materials and designs mitigate repair costs and operational disruptions, improving lifecycle performance and occupant safety.
Construction Quality	Ensures durability, reducing defects and long-term costs while enhancing lifecycle efficiency and project success.
Demand and Supply of Materials	Stable supply chains prevent delays and cost overruns, enabling efficient management of budgets and timelines.
Material Durability	Durable materials withstand environmental stress, reducing the frequency of maintenance and replacement for improved resource utilisation.
Building Automation and Smart Systems	Optimise energy use, reduce errors, and predict maintenance needs, leading to cost savings and enhanced operational performance.
Building Maintenance Technologies	Predictive systems reduce maintenance frequency and costs by preventing large-scale repairs, enhancing asset performance.
Building Occupancy Behaviours	Responsible usage patterns reduce strain on systems, extending equipment lifespan and minimising costs, significantly impacting WLC.
Estimated Annual Occupancy Hours	Optimised usage reduces energy consumption and wear, enhancing cost efficiency over the building's lifecycle.
Technology and Tools	Improve construction precision and efficiency, reducing waste and ensuring better resource management for lower WLC.
Technology Depreciation	Managing depreciation ensures operational efficiency and minimises costs as older systems become less effective.
Insurance and Risk Mitigation Strategies	Reduce financial exposure to unforeseen events, enhancing financial stability and lifecycle performance.
Environmental Cost	The financial impact of ecological damage drives sustainable practices, reducing long-term expenses and the ecological footprint.

Maintenance Cost	Durable materials and advanced practices lower costs, making maintenance management vital for WLC.
Type of Materials and Quality	High-quality materials reduce lifecycle costs by minimising repairs and replacements, crucial for WLC planning.
Construction Technology	Improves efficiency, reduces waste, and aligns with sustainability goals, optimising WLC outcomes.
Upfront Acquisition Costs	While raising initial expenses, quality investments ensure long-term savings, justifying their inclusion in WLC strategies.
Risk Mitigation	Prevents costly disruptions, ensuring lifecycle efficiency through proactive planning.
Cost vs Benefit Analyses	Guides decisions by weighing upfront investments against long-term savings and performance improvements, ensuring financial prudence.
Inflation	Impacts material and labour costs, requiring accurate projections to ensure sustainable budgeting.
Nominal Costs	Focus on immediate feasibility but ensure it is balanced with long-term performance for optimal outcomes.
Real Costs	Adjusted for inflation, they provide a realistic view of financial impacts over time, supporting sustainable planning.
Legislative, Statutory, or Economic Changes	Shape cost structures and compliance. Staying ahead of changes ensures alignment with regulations and goals.
Externalities	Pollution and resource depletion influence sustainability strategies, aligning projects with ecological and social objectives.
Replacement Frequency	Durable designs minimise replacement needs, reducing lifecycle costs and enhancing sustainability.
Unforeseen Circumstances	Proactive risk management minimises the financial impact of unexpected events, ensuring lifecycle stability.

6.6 Practical implications for policymakers and stakeholders

The findings of this study have important implications for policymakers and stakeholders. Developing localised WLC frameworks that incorporate seismic and weather-specific considerations is essential for policymakers. Offering subsidies or tax benefits for projects that integrate energy-efficient and sustainable systems could incentivise the broader adoption of these practices. Additionally, promoting training initiatives to enhance stakeholder knowledge of WLC principles would support the implementation of more robust frameworks.

For stakeholders, fostering early-stage collaboration among architects, engineers and clients can help align expectations and optimise designs, improving cost efficiency. Integrating renewable energy systems and innovative technologies is also crucial for reducing operational costs. Prioritising investments in seismic-resistant designs can mitigate lifecycle repair costs, ensuring long-term value and safety.

Adopting improved WLC frameworks at an industry-wide level could lead to enhanced sustainability practices, better resource allocation and more resilient building systems tailored to New Zealand's unique challenges. By addressing the interplay of factors identified in this study, stakeholders can make more informed decisions, ultimately contributing to the economic and environmental sustainability of residential construction projects

6.7 Conclusion

This study employed a SD approach to investigate the complex and interconnected factors that influence the accuracy of WLC estimation for residential buildings in New Zealand. By integrating findings from a systematic literature review, semi-structured interviews with industry professionals, and a structured factor prioritisation process, the research identified a broad set of 80 factors that affect cost estimation across the building lifecycle. From this comprehensive list, 37 factors were ultimately identified as the most impactful, as shown in Table 6.8. These factors were selected based on their relevance to recurring themes raised by practitioners, their strong presence in practical construction settings, and their active roles in influencing other elements within the system. The selection focused on those factors that influenced lifecycle decisions and outcomes, particularly where interrelationships and feedback loops were evident. This refinement process ensured that the final system dynamics model concentrated on factors with meaningful influence, avoiding the dilution of insights through less consequential variables.

The study revealed that conventional Whole-life Cost frameworks often fail to capture the dynamic, context-specific conditions of residential construction in New Zealand. They do not adequately reflect local risks such as seismic activity, coastal exposure, regional material availability, and changing regulatory environments. This study demonstrated how key factors interact over time through causal loop diagrams, reinforcing or balancing cost impacts throughout a building's lifecycle. For example, investment in resilient design can reduce maintenance frequency and operational disruptions, while behavioural choices and technology use can significantly influence long-term cost trajectories.

To enhance the analytical depth of the model, AHP pairwise comparisons were used to generate a structured weighting of all 80 factors. Geometric means were calculated and normalised to produce a priority vector, and the CR was assessed to ensure the reliability of expert judgments. The resulting CR value, which was effectively zero, confirmed the internal consistency of the pairwise matrix. These weights were then integrated with directional polarity information derived from interview themes and literature to construct a quantitatively robust linkage matrix, which directly informed the causal loop diagram.

The findings have significant implications for both policymakers and stakeholders in the construction industry. For policymakers, there is a need to support the development of locally adapted Whole-life Cost frameworks that reflect New Zealand's unique environmental and regulatory context. Incentives such as subsidies or tax benefits for sustainable and resilient design choices can promote better lifecycle performance. Education and training initiatives could also help increase awareness and capability within the industry regarding lifecycle planning and cost estimation. For industry professionals, the study highlights the value of early collaboration across disciplines, integrating cost, design, and performance considerations from the outset. Innovative systems, durable materials, and efficient maintenance technologies were among the most frequently cited strategies for improving lifecycle outcomes. Additionally, addressing regional risks and user behaviours from the early design stage emerged as a critical consideration for achieving more accurate and resilient cost planning.

Although this study did not propose a ready-to-use WLC framework, it identified the essential factors and relationships such a framework must incorporate. The absence of a region-specific model and the limited familiarity with Whole-life Costing practices among practitioners highlight opportunities for further research and development in this area.

In conclusion, this study makes a significant contribution to Whole-life Cost estimation practice by uncovering the system-level dynamics that shape cost outcomes over time. By combining qualitative insights with structured expert weighting and validated modelling, the approach presented here provides a replicable pathway for developing more robust, adaptive, and evidence-based WLC estimation tools. The findings provide a strong foundation for developing more robust, adaptive, and sustainable approaches to lifecycle costing in the New Zealand residential construction sector.

Chapter 7. A System Dynamics Framework for Whole-life Costing in Seismic and Climate-Sensitive Residential Construction in New Zealand

7.1 Prelude

This chapter presents the third peer-reviewed manuscript of this doctoral study. It builds on insights from the previous two manuscripts to develop a specific Whole-life Costing (WLC) framework for residential buildings in New Zealand. While global WLC methodologies provide structured ways to evaluate lifecycle costs, there is no existing framework specifically tailored to the residential construction sector in New Zealand. Current models are mostly generic. They are developed for commercial or large-scale infrastructure projects and do not capture the unique environmental, regulatory, and economic conditions in New Zealand. These limitations are particularly significant in the residential sector, which is characterised by high seismic risk, varied climatic conditions, evolving building codes, and ongoing housing affordability issues. To address these gaps, the approach must be tailored. It needs to combine system dynamics with local data and expert insights. This chapter goes beyond identifying factors (Chapter 4) and modelling their interactions (Chapter 5). It develops a specific framework for WLC suited to residential buildings in New Zealand. The research question guiding this investigation is:

Research Question 3: What improvement in the WLC framework makes it suitable for New Zealand residential buildings?

This chapter is based on the published article titled 'A System Dynamics Framework for Whole-Life Costing in Seismic and Climate-Sensitive Residential Construction in New Zealand' (Smart and Sustainable Built Environment, 2025). The publication has successfully achieved the third objective of this thesis: to develop a New Zealand-specific WLC framework that explicitly incorporates seismic and climate-related risks into the lifecycle cost estimation of residential buildings.

To answer this question, semi-structured interviews were conducted with industry professionals. These methods helped design a hierarchical, dynamic framework that incorporates key regional issues such as seismic resilience, climate adaptation, and cost variability throughout a building's lifecycle. Experts further refined the framework to confirm its practicality for policymakers, quantity surveyors, and developers. By including regulatory, environmental, and behavioural factors in a system dynamics model, this chapter proposes a tailored WLC framework. This evidence-based approach aims to improve the accuracy and relevance of cost estimation in New Zealand's residential construction sector. This work addresses a vital need for a locally based, lifecycle-focused approach to costing. It ultimately contributes to better financial planning, long-term sustainability, and resilience in residential housing.

The following section introduces the study's background and contextual foundation, laying the groundwork for developing this tailored framework.

7.2 Introduction

Whole-life Costing (WLC) is a pivotal methodology in the construction sector, enabling stakeholders to comprehensively assess a building's total cost throughout its lifecycle, including capital investment, barrier, maintenance, and eventual decommissioning costs (Flanagan & Jewell, 2008; ISO, 2017). By aligning financial planning with long-term environmental objectives, WLC plays a crucial role in fostering sustainable development within the construction industry. Despite its successful application in larger infrastructure and commercial projects globally, most existing WLC frameworks are generic and inadequately cater to the unique needs of residential buildings (Goh & Sun, 2016; RICS, 2016). These models often lack the adaptability needed for specific regional conditions.

In the context of New Zealand, the absence of a nationally standardised or residential-specific WLC framework creates fragmented practices and hinders effective long-term cost planning (MBIE, 2013; NIWA, 2022). Specifically, New Zealand faces unique challenges, including significant seismic risks, varying climatic conditions, and evolving regulatory requirements, which substantially impact lifecycle costs. Without a robust WLC methodology tailored to these conditions, homeowners, developers, and public sector entities face escalating long-term costs. For instance, estimates from the Ministry of Business, Innovation, and Employment, MBIE (2013) Seismic retrofitting could cost upwards of NZD 100,000 per dwelling in high-risk areas, such as Wellington and Christchurch. Furthermore, climate-related weather events have incurred costs exceeding NZD 1 billion over the past decade, underscoring the urgent need for lifecycle-focused planning in residential development. (NIWA, 2022). These economic impacts and ongoing affordability pressures highlight the urgent need for lifecycle-conscious planning in residential development.

This research addresses the gap by developing a WLC framework specifically designed for New Zealand's residential construction sector. The aim of this study is to propose improvements to the WLC framework, making it suitable for residential buildings in New Zealand.

The central research question addressed by this study is:
What specific improvements are required to adapt or enhance the whole-life costing approach for residential buildings in New Zealand?

To address this research question, the following objectives were formulated:
Objective 1: To identify the key cost drivers that affect WLC estimation for residential buildings in New Zealand.
Objective 2: Develop a comprehensive WLC framework that integrates these factors, with a particular focus on seismic resilience, energy efficiency, and climate-related impacts.

By identifying and addressing the limitations of existing frameworks, this study provides a robust, region-specific tool that incorporates the unique geographical, environmental, and regulatory factors affecting residential construction in New Zealand. The framework offers significant value to stakeholders by supporting more accurate long-term cost planning, enhancing decision-making in the design, procurement, and maintenance phases, and ultimately fostering more sustainable and resilient residential buildings.

The methodology used to achieve these objectives includes a systematic literature review (SLR) and expert interviews to identify key cost drivers. Additionally, system dynamics (SD) and causal loop diagrams (CLDs) were applied to integrate the identified factors into the framework and model their relationships across the lifecycle stages.

7.3 Literature Review

7.3.1 Global Perspectives on WLC and Its Limitations

Whole-life Costing (WLC) evaluates the total cost of a building throughout its entire lifecycle, encompassing acquisition, operational, maintenance, and disposal considerations (Flanagan & Jewell, 2008; ISO, 2017). Its implementation supports sustainable decision-making, shifting the focus from initial capital expenditure to long-term value. However, high upfront capital costs remain a significant barrier to adopting sustainable practices, highlighting the need for integrated frameworks that address these challenges (Nasereddin & Price, 2021). While international standards, such as ISO 15686-5, and guidelines from organisations like the Royal Institution of Chartered Surveyors (RICS) advocate for structured approaches to lifecycle cost assessments, particularly in commercial and infrastructure projects, these models often remain inadequate for residential applications. (RICS, 2016). These frameworks tend to be generic, failing to account for region-specific risks, local construction practices, and socio-behavioural factors (Goh, 2016).

Several countries, including the UK, Germany, and Japan, have developed extensive WLC databases and tools, but these are often tailored to local construction norms and environmental conditions, which may not translate well to other contexts (ESCAP, 2019; USGBC, 2019). For example, the BREEAM, LEED, and Green Star systems primarily focus on environmental performance during the design stage and lack comprehensive long-term financial planning for the building's entire lifecycle (USGBC, 2019). Furthermore, many established frameworks rely on static estimation methods that fail to account for the evolving nature of construction risks, user behaviour, and long-term asset performance (Goh & Sun, 2016), limiting their applicability in regions like New Zealand, where risk profiles are highly dynamic and influenced by frequent seismic events, climate change, and other factors.

The global research gap lies in the lack of frameworks that integrate dynamic environmental factors, real-time data, and context-specific risks into a comprehensive, adaptable lifecycle cost model for residential buildings. Existing models often overlook the unique challenges faced by countries with highly variable climatic and seismic conditions, leading to fragmented and less reliable long-term cost planning for residential projects. There is a clear need for models that consider evolving risks over time and incorporate local factors, such as seismic resilience and material durability, that significantly affect long-term building costs.

7.3.2 Contextual Challenges and System Dynamics in New Zealand Residential Construction

In New Zealand, the WLC application in the residential sector is minimal. The country faces challenges such as frequent seismic activity, diverse climatic conditions, coastal exposure, and evolving compliance frameworks (MBIE, 2013; NIWA, 2022). Although public sector documents like MBIE's Total Cost of Ownership Guide and the Treasury's Whole of Life Costs Guidance promote life cycle thinking, they primarily focus on public infrastructure and are not consistently applied in residential projects (treasury.govt.nz, 2015). This leads to fragmented long-term cost planning. A study by Samarasekara, Purushothaman and Rotimi (2024) identified 51 interrelated factors affecting WLC estimations, showing that international models often overlook unique conditions in New Zealand's housing sector, including the costs associated with seismic retrofitting. Similarly, BRANZ (Jaques et al., 2015) indicates the economic benefits of sustainable housing, such as reduced maintenance costs, but these insights have not yet led to a cohesive residential-specific WLC framework. Emerging research emphasises the importance of circular economy strategies, promoting material reuse and recycling to enhance resource efficiency and reduce lifecycle costs (Bao, 2023).

Moreover, traditional WLC frameworks used in New Zealand tend to treat lifecycle costs as static estimates, which hinders their ability to respond to changing environmental conditions or user behaviour over time. There is a growing advocacy for the integration of systems thinking through methodologies like System Dynamics (SD), which can capture interdependencies and feedback loops between cost drivers over time (Seetharaman et al., 2017). SD provides an effective tool for modelling complex, time-delayed relationships that are particularly important in risk-prone regions like New Zealand. For example, Wellington's lifecycle costs must account for seismic resilience, while high-rainfall regions need to factor in enhanced drainage and weatherproofing costs (Hay & Mimura, 2006; Lakshmanan et al., 2008). Similarly, energy efficiency strategies, such as high-performance glazing and passive heating, can reduce long-term energy demand (Lehmann, 2013), while water-saving features lower utility costs (Memon et al., 2015).

Despite these advantages, SD remains underutilised in the WLC field, particularly for residential buildings. While recent studies have begun to explore Causal Loop Diagrams (CLDs) and degree centrality analysis to model interactions and prioritise influential factors(Crielaard et al., 2024; Samarasekara, Purushothaman, & Rotimi, 2024), these methods have not been fully integrated into existing WLC frameworks. This creates a significant gap in the literature, as the ability to model the dynamic, evolving nature of WLC in residential buildings has been largely neglected. Research gaps in the New Zealand context are clearly defined. While traditional WLC frameworks overlook the complexities of regional risk, material durability, and energy efficiency, there is a need for an integrated approach that combines System Dynamics with local environmental factors, enabling stakeholders to make more accurate long-term predictions. This study fills this gap by proposing a tailored WLC framework that addresses the unique needs of New Zealand's residential construction sector.

The current literature on WLC frameworks for residential construction is fragmented and often inadequate in addressing context-specific challenges, such as regional risk, construction practices, and environmental conditions. Existing frameworks typically fail to integrate dynamic risks over time, relying on static cost estimations that do not account for the evolving nature of construction projects. There is a clear need for models that integrate System Dynamics, circular economy principles, and region-specific variables to provide more accurate long-term cost predictions. This study fills this gap by proposing a tailored WLC framework that addresses the unique needs of New Zealand's residential construction sector.

7.4 Methods

This study adopts a qualitative approach to develop a context-specific Whole-life Costing (WLC) framework for residential buildings in New Zealand. It integrates insights from a systematic literature review (SLR) and 22 semi-structured expert interviews to identify and validate critical cost drivers, which were then modelled using system dynamics tools, including Causal Loop Diagrams (CLDs) and degree centrality analysis.

7.4.1 Systematic Literature Review

An SLR was conducted in accordance with PRISMA guidelines to identify critical factors influencing WLC estimation in residential construction. Peer-reviewed articles, industry reports, and relevant standards were sourced from databases like Scopus, ScienceDirect, and Google Scholar, covering the period from 2000 to 2024. The search strings, exclusion and inclusion criteria are shown in Table 7.1.

While academic databases like Scopus and Web of Science are important for finding widely indexed research, publisher platforms such as Emerald Insight and SpringerLink were explicitly added to the search strategy. These platforms provide access to a wider range of peer-reviewed articles and often provide full-text access to journals and resources that may not be fully indexed in traditional academic databases. This choice ensures a more complete and inclusive review, capturing both high-impact and specialised studies that are crucial for understanding the details of WLC in residential construction. The decision to utilise these publisher platforms aimed to enhance the review process and ensure a comprehensive representation of the relevant literature.

Initially, an exhaustive search was performed using a set of specific search strings across academic databases and publisher platforms. This yielded a substantial number of articles. To ensure the quality and relevance of the review, we implemented several screening stages to refine the results, including: Title and Abstract Screening: Articles were first assessed based on their titles and abstracts to determine their relevance to the study's focus on WLC in residential construction, and Full-Text Review: For articles that passed the initial screening, full texts were examined to confirm they offered substantial, original content directly related to the research objectives.

The studies included in this review were published between 2020 and 2024 to ensure the relevance and currency of the data in the context of the rapidly evolving construction industry, particularly regarding emerging methodologies and environmental challenges. This timeframe captures the most recent research, ensuring that the findings reflect the latest advancements in WLC methodologies and their application in residential construction. The exclusion of review articles, book reviews, and other forms of publications, such as product reviews and reference work entries, was implemented to maintain focus on original research that offers empirical data, theoretical development, or novel methodologies directly related to the application of WLC in the context of residential buildings. This approach minimises bias from secondary sources and provides a clearer picture of the current state of research in this field. Furthermore, by excluding these types of publications, we aim to enhance the quality of the review by prioritising studies that contribute directly to the development of the WLC framework, ensuring the transparency and replicability of the review process.

Our review pinpointed 73 distinct influencing factors, grouped into technical, environmental, economic, regulatory, and behavioural categories. This provides a solid foundation for designing interviews and developing models. We've also created a literature matrix, which outlines key findings from selected studies and how our study builds on or differs from them (see Appendix 13). The PRISMA flow diagram is presented in Figure 7.1.

Table 7.1: Search strings and results of the database search for primary research data

Database	Search Strings	Inclusions	Exclusions
Scopus	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Subject Area – Engineering Language – English Open access From 2000 to 2024	Review Articles
Science Direct	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Subject Area – Engineering Language – English Open access From 2000 to 2024	Review Articles Book Review Product Review
Emerald Insight	abstract: "whole-life cost" OR (abstract: "life cycle cost") AND (abstract: "construction") AND (abstract: "framework")	Open Access Content Type – Articles From 2000 to 2024	Review Articles
Springer Link	Construction AND framework AND "Whole-life cost" OR “life cycle cost”	Discipline – Engineering Subdiscipline - Building Construction and Design Language – English From 2000 to 2024	Reference work entry Reference work
Google Scholar	"whole-life cost" OR "life cycle cost" AND "construction" AND "framework"	Only in the title	Review Articles

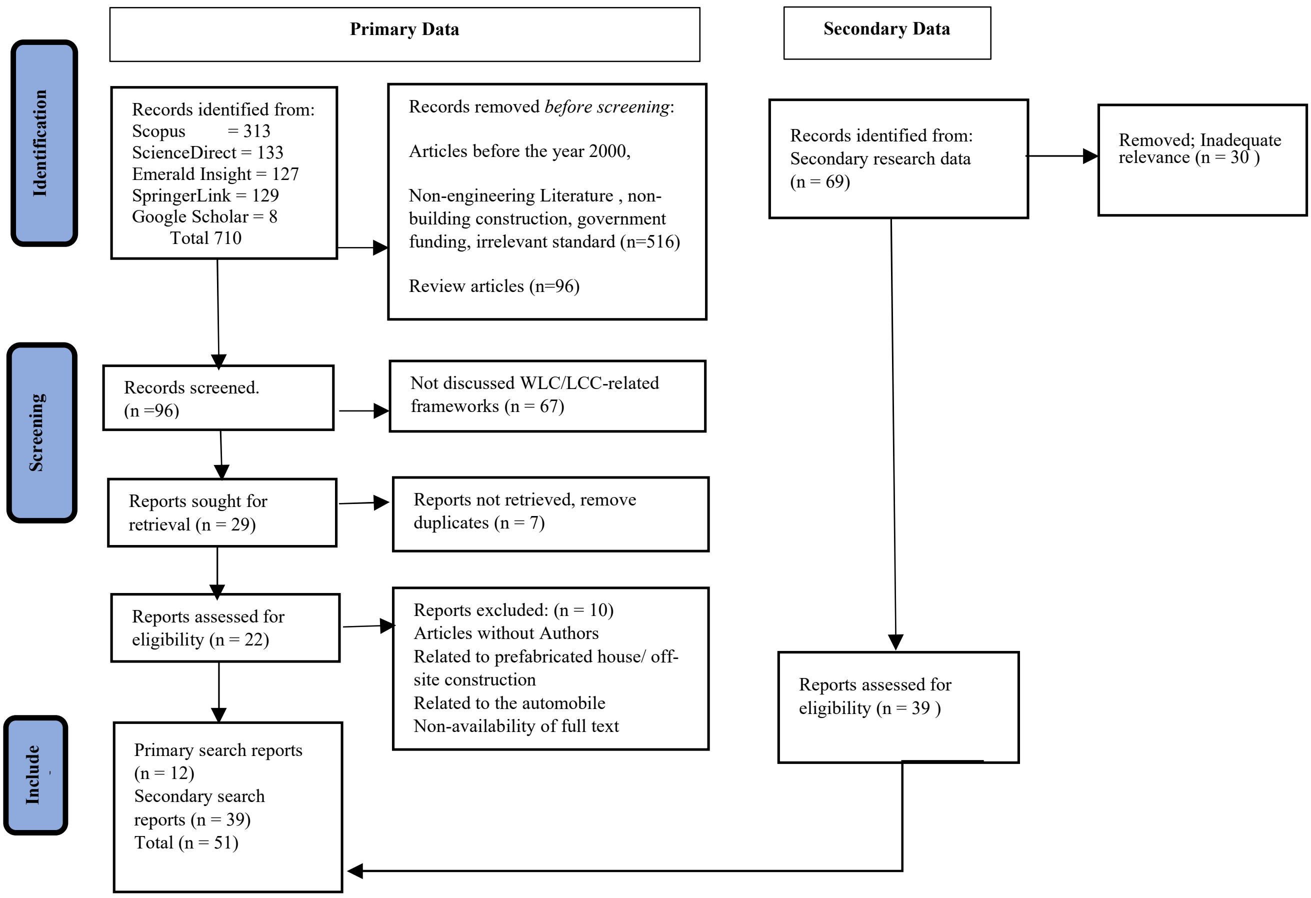


Figure 7.1: PRISMA Flow diagram adapted from PRISMA 2020 Statement (Page et al., 2021)

7.4.2 Semi-Structured Interviews

To validate the literature-based factor set and gain practical insights, 22 semi-structured interviews were conducted with industry professionals. This method was selected for its flexibility in exploring complex topics in depth, enabling clarification of responses and the capture of contextual insights often missed in structured surveys (Kallio et al., 2016). Given the complexity of Whole-life Cost (WLC) factors in New Zealand's residential construction, semi-structured interviews were deemed appropriate to ensure robust validation from multiple professional perspectives.

A purposive sampling strategy was employed to recruit participants who represented key stakeholder roles in residential construction, such as quantity surveyors, architects, developers, project managers, engineers, facilities managers, and homeowners (Palinkas et al., 2015). Eligibility requires at least five years of direct professional involvement in residential projects within New Zealand. The principle of thematic saturation guided the sample size; saturation was achieved after approximately 15 interviews, with the remaining seven confirming no substantial new themes. The final sample composition is shown in Table 7.2. Interviews were conducted online via Microsoft Teams and lasted approximately 30–40 minutes, employing open-ended questions that covered lifecycle cost components, barriers to WLC adoption, local construction challenges, and feedback on a preliminary factor framework. All interviews were audio-recorded with consent, transcribed verbatim, and de-identified to maintain participant anonymity. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (AUTEC Reference: 24/206).

Table 7.2: Demographics of Participants in Role-wise

Role	No of Participants
Government Authority	1
Project Managers	3
Architects	2
Quantity Surveyors	8
Electrical Engineers	2
Structural Engineer	1
Site manager	1
Facilities Managers	2
Homeowners	2

Recurring themes included the cost burden of seismic retrofitting, the difficulty in accessing long-term cost data, the influence of occupant behaviour on operational costs, the limited use of smart systems, and the gap between capital investment and lifecycle value. Participants emphasised the need for a national framework that integrates lifecycle thinking into residential design and procurement.

7.4.3 Data Analysis

The qualitative data analysis in this study followed Braun and Clarke (2006) six-phase framework for thematic analysis. This approach ensured a systematic and transparent method for coding and developing themes. The process began with familiarisation, where two researchers read and reread the interview transcripts to understand the content and context thoroughly. This deep dive helped identify preliminary patterns and initial analytical observations.

The next phase involved generating initial codes systematically. Using NVivo qualitative data analysis software, the researchers highlighted relevant features of each transcript and assigned open codes. Both deductive and inductive coding strategies were used. Deductive codes reflected pre-existing categories from the literature review, while inductive codes arose from unexpected issues or new insights during the interviews. In the following phase, the researchers grouped similar codes to form potential themes and explored their relationships to create broader thematic categories. During the fourth phase, the team reviewed, assessed, and refined these candidate themes. This step ensured that each theme was coherent and distinct from the others. The research team held ongoing discussions and conducted multiple reviews of the coded data to resolve any discrepancies or ambiguities in the coding.

Once clear and distinct themes were established, the researchers defined and named each theme. This allowed the team to explain the boundaries and essential qualities of each thematic pattern. The final phase involved creating a detailed report, in which the themes were integrated into the presentation of results and discussion, supported by relevant excerpts from participant interviews. Throughout this process, the team improved reliability through cross-checks among researchers and ensured transparency by carefully documenting coding decisions and theme definitions.

7.4.4 Development of the WLC Hierarchy

The final WLC framework was developed through structured synthesis of evidence from literature, expert interviews, and system dynamics modelling. A five-level hierarchy was created to categorise influencing factors across the lifecycle of residential buildings, serving as both a classification system and the foundation for dynamic modelling. The hierarchy was aligned with the International Construction Measurement Standards (ICMS), which define four levels of cost breakdown:

- **Level 1** (Orange): *Whole-Life Cost (WLC)* – representing the total lifecycle cost of the asset.
- **Level 2** (Yellow): *Primary Categories* – including non-construction costs, lifecycle costs, income, and externalities.
- **Level 3** (Blue): *Subcategories* – acquisition, operational, and end-of-life costs.
- **Level 4** (Grey): *Functional Breakdown* – detailing specific project components like site services, utilities, and decommissioning.

To contextualise the framework for New Zealand, a **fifth level** was introduced:

- **Level 5** (Green): *Contextual Influencing Factors* – derived from the systematic literature review and expert feedback. This level captures region-specific drivers such as seismicity, regulatory changes, occupant behaviour, energy efficiency, supply chain risks, material resilience, and insurance considerations.

Each level is colour-coded for visual clarity in subsequent modelling diagrams (refer to Section 7.5.6). The hierarchy provided the structural basis for causal loop diagramming (CLD), enabling the visualisation of feedback mechanisms and interdependencies among lifecycle cost drivers. These insights informed the prioritisation of variables through the degree of centrality analysis, ultimately guiding the design logic of the final WLC framework.

7.4.5 System Dynamics and Causal Loop Modelling

A system dynamics (SD) approach was applied to explore the interrelationships among WLC factors. SD effectively understands nonlinear interactions, feedback loops, and time delays in complex systems. Based on the validated factor set, Causal Loop Diagrams (CLDs) were developed to visualise system behaviours and identify feedback patterns. The CLDs illustrated how technical, environmental, and behavioural factors reinforce or balance lifecycle outcomes. For instance, the selection of durable materials positively reinforces lower maintenance costs, while delayed repairs introduce balancing loops through increased degradation and eventual cost spikes. Interviews contributed a nuanced understanding of these interactions, particularly around the long-term effects of seismic planning, energy upgrades, and occupant-led wear and tear.

The polarity of each causal relationship was determined through a combination of evidence from the systematic literature review and validation by semi-structured expert interviews. Positive (+) polarity denotes that the two variables change in the same direction (i.e., an increase in one leads to an increase in the other, or a decrease leads to a reduction). Negative (–) polarity denotes an inverse relationship (i.e., an increase in one leads to a decrease in the other, or vice versa). All polarity assignments were reviewed with domain experts to ensure contextual accuracy for the New Zealand residential construction sector.

7.4.6 Degree of Centrality Analysis

To identify the main factors within the Whole-life Costing (WLC) system, we conducted a degree centrality analysis on the directed network formed from the validated causal loop diagrams (CLDs). In this network, each node represents a WLC factor, and each directed link shows a causal influence from one factor to another.

Degree of centrality was calculated in three ways:

1. Out-Degree Centrality (CD-out) measures the number of direct causal influences a node has on other nodes. High out-degree values suggest potential driver variables that impact many other factors.
2. In-Degree Centrality (CD-in) measures the number of direct causal influences that a node receives from other nodes. High in-degree values indicate dependent variables that are sensitive to changes in the system.
3. Total Degree Centrality (CD-total) is the sum of in-degree and out-degree values, showing the overall connectivity of a given node within the network.

The centrality scores were calculated from the binary adjacency matrix of the CLD structure, using an adjacency matrix where each causal connection was coded as a directed edge, following the CLD mapping protocol. We included both reinforcing and balancing loops. The sign of the causal link did not matter in the degree calculations since we focused on structural connectivity rather than polarity.

High out-degree values highlight potential driver variables influencing many others (Borgatti et al., 2024; Freeman, 1978). High in-degree values reveal variables sensitive to external changes (Borgatti et al., 2024; Opsahl et al., 2010). A high total degree indicates systemic importance, capturing overall network embeddedness (Opsahl et al., 2010)

7.4.7 Framework Development

Building upon the established hierarchy, CLD and centrality analysis, a tailored WLC framework has been developed to facilitate lifecycle decision-making within New Zealand’s residential construction sector. This framework effectively integrates a five-level hierarchical structure with prioritised cost drivers and feedback pathways identified through rigorous modelling processes. Highly central, high-leverage variables, specifically energy design, seismic strategy, and material durability, are strategically positioned at the framework's core, whilst contextual and outcome-based variables (such as maintenance costs and building performance) extend from these foundational nodes. The framework is meticulously designed to be modular and adaptable, thereby accommodating the diverse needs of a wide range of stakeholders, from early-phase design and procurement to regulatory review and long-term asset management. It promotes lifecycle-conscious decision-making by emphasising variables that yield compounding cost benefits or risks over time. This framework serves as the foundation for the subsequent results and discussion sections, where its application is critically evaluated and refined.

The methodological framework has been summarised in Figure 7.2.

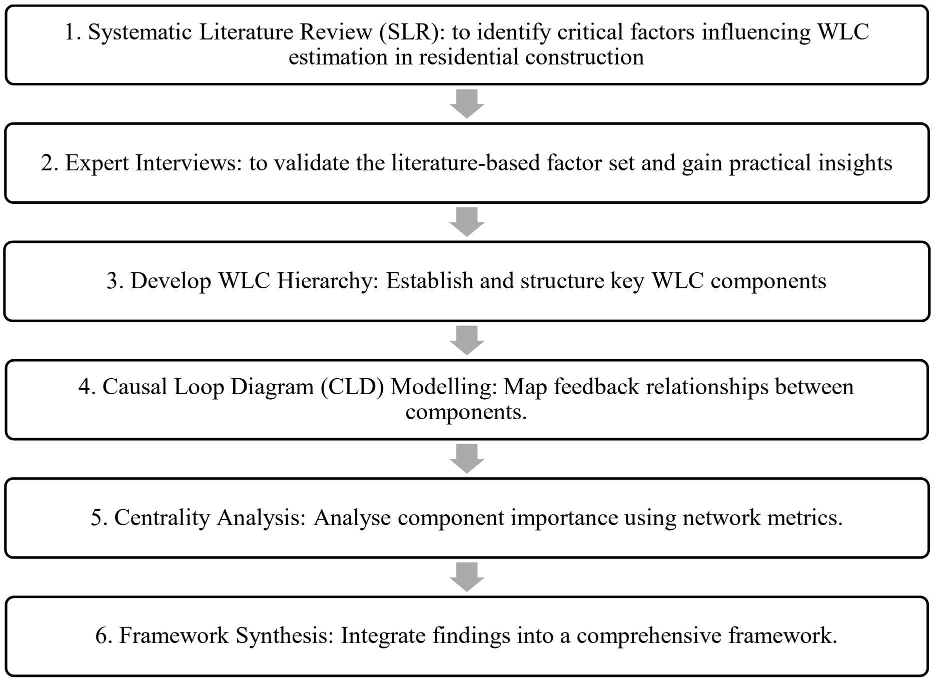


Figure 7.2: Methodology Flowchart

7.5 Results

This section presents the study's empirical findings, beginning with insights from industry interviews and summarising the CLD modelling and centrality analysis to prioritise key cost factors. The proposed WLC framework, which integrates interview themes, hierarchical structure, and feedback mapping, is also introduced, with each component described in terms of its relevance supported by figures and tables.

7.5.1 Geographical Representation of WLC and LCC Frameworks

Figure 7.3 illustrates the global distribution of WLC and LCC research, highlighting a predominance in the UK and the US, each with six studies, followed by Austria and Denmark, with four studies each. Limited contributions from countries such as China, Finland, and Italy, and only one article from New Zealand, suggest a significant research gap, particularly for context-specific frameworks in New Zealand's residential sector. This concentration in developed, English-speaking nations reflects challenges in economic capability and governmental support for sustainability.

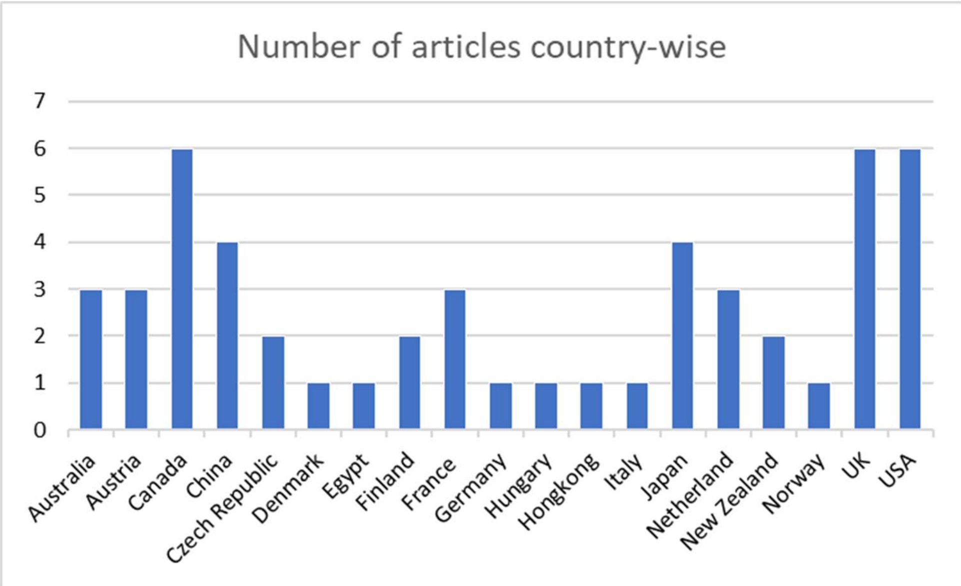


Figure 7.3: Origin of the articles included in SLR

7.5.2 Sectoral Focus of Existing Frameworks

Table 7.3 shows that LCC frameworks are widely applied across 19 countries, with WLC frameworks less common. While the UK and US utilise WLC in public procurement and urban development, most frameworks primarily focus on the commercial and infrastructure sectors, with limited residential applications. New Zealand notably lacks tailored WLC frameworks for residential buildings, presenting further development opportunities.

Table 7.3: Frameworks and applicable sectors

Framework and applicable sectors	**Country**																		
	Australia	**Austria**	**Canada**	**China**	**Czech Republic**	**Denmark**	**Egypt**	**Finland**	**France**	**Germany**	**Hungary**	**Hongkong**	**Italy**	**Japan**	**Netherland**	**NZ**	**Norway**	**UK**	**USA**
LCC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WLC			x	x										x		x		x	
Number of Frameworks associated	3	3	6	4	2	1	1	2	3	1	1	1	1	4	3	2	1	6	6
Residential																			
Commercial							x							x		x		x	
Product-specific tool		x											x	x	x				
Urban development			x				x							x				x	
Public procurement	x	x	x	x	x	x		x	x	x	x		x		x	x		x	x

7.5.3 Strengths and Weaknesses of Existing Frameworks

A detailed review of international Life Cycle Costing (LCC) and Whole-life Costing (WLC) frameworks reveals a broad spectrum of strengths and weaknesses that influence their applicability across regions and sectors. This variability is particularly pronounced when considering the unique demands of residential construction in high-risk settings, such as New Zealand. Integration of Environmental Metrics - Frameworks from the UK and Denmark successfully incorporate environmental assessments, allowing for more sustainable decision-making processes. These frameworks facilitate the evaluation of environmental impacts, although they may struggle with adaptability in sectors like residential construction.

- Incorporation of Climate and Environmental Factors: Frameworks from countries such as the UK, Denmark, and Japan effectively integrate climate-related risks and environmental impact metrics within their costing models. These frameworks embed considerations such as flood mitigation (Abdullah et al., 2025), embodied carbon impacts, and renewable energy systems, offering a more holistic assessment that aligns economic costs with sustainability objectives (UKSI, 2015). For example, Denmark's framework emphasises the environmental impacts of procurement (Rolfstam & Petersen, 2014), while Japan's models robustly address seismic risks and resilience measures (Akiyama et al., 2020). Such integration is vital for New Zealand, which faces both seismic hazards and climate variability.
- User Accessibility and Practical Tools: Robust spreadsheet-based tools and transparent calculation methodologies are characteristic of frameworks from Australia (QTC, 2019), New Zealand (MBIE, 2013), and the USA (ASCE & ENO, 2014). The use of hierarchical cost coding and detailed breakdowns, often following International Construction Measurement Standards (ICMS, 2019), facilitates ease of use among practitioners, including quantity surveyors and project managers, fostering practical uptake. The availability of user-friendly tools, such as Excel templates and modules linked to software like CostX and BIM platforms, reduces barriers to adoption (Purushothaman & Aguas, 2025), enabling smaller firms and non-experts to engage meaningfully with WLC.
- Focus on Resilience and Risk: Certain frameworks have advanced the integration of risk-based variables, including seismic strengthening, wind bracing, and flood resilience. This is particularly evident in Japan's and some US models, which set a precedent for embedding risk mitigation costs and insurance implications directly into lifecycle assessments (ASCE & ENO, 2014; Minami, 2003). Such focus is crucial for New Zealand's residential sector, where insurance premiums and retrofit expenses can be significant contributors to total costs.
- Structured and Hierarchical Modelling: The adoption of tiered frameworks with hierarchical levels extending from acquisition through operational to end-of-life costs improves transparency and enables detailed scenario analysis (RICS, 2016). Additionally, frameworks incorporating metadata for local factors, such as geographic risk profiles, promote more accurate and tailored cost estimation.

The strengths of these frameworks, summarised in Table 7.4, demonstrate considerable progress in integrating key environmental and sustainability considerations.

Table 7.4: Strengths of the LCC and WLC framework, country-wise

Strengths	**Australia**	**Austria**	**Canada**	**China**	**Czech Republic**	**Denmark**	**Egypt**	**Finland**	**France**	**Germany**	**Hungary**	**Hongkong**	**Italy**	**Japan**	**Netherland**	**NZ**	**Norway**	**UK**	**USA**
Climate change weight					x														
Economic Sustainability Analysis													x						
Procurement Environmental Impacts			x										x	x	x				
Infrastructure energy use														x	x				
Flood and storm barriers													x		x				
Energy efficiency, water conservation																			x
Simple calculations										x	x						x		
Environment-Material Impact Database															x			x	
Inflation and discount rate																x		x	
Specific database to compare LCC/WLC																		x	
Project documentation defined																		x	
Budget planning and compliance														x					
Early design decision information																		x	
Spreadsheets available										x	x				x	x			
Easy maintenance, minimal investment										x	x								
Calculation steps are visible.																		x	
Hierarchical levels and a unique coding																		x	
Pact on scope and assumptions			x																
Investigating complex issues														x					
Alternatives comparison	x																		
Adverse Weather			*x*	*x*							*x*						*x*	*x*	*x*
Seismicity														*x*					*x*

However, alongside these strengths, significant limitations exist across the frameworks, as detailed in Table 7.5. The main weaknesses are;

- Lack of National Standardisation and Consistency: A pervasive issue across many countries, including New Zealand, Australia, and several European and Asian nations, is the absence of unified, nationally recognised methodologies. This fragmentation hinders consistent application and undermines the comparability and credibility of lifecycle cost assessments, leading to disparate industry practices and missed opportunities for economies of scale in data collection and knowledge sharing (Liu et al., 2023).
- Limited Focus on Residential Sector and Local Context: While many frameworks are tailored or primarily designed for commercial infrastructure projects (DGNB, 2022; EU, 2019; ÖBB, 2005), few provide comprehensive, adaptable tools for the residential sector. This gap is pronounced in New Zealand, where unique seismic vulnerabilities, diverse climatic zones, and local market conditions demand specialised modelling approaches. Existing models rarely account adequately for factors such as localised hazard probabilities, region-specific material performance, or the socio-economic dynamics of residential construction.
- Inadequate Data Quality and Availability: Many frameworks rely heavily on assumptions or sparse, regionally disaggregated data, weakening the fidelity of lifecycle cost predictions (ASTM, 2020). This limitation is compounded by reliance on expert judgment and often excludes critical cost drivers such as long-term material degradation, maintenance variability, and evolving regulatory requirements (Goh & Sun, 2016). The lack of comprehensive databases hinders model calibration and validation, making it challenging for practitioners to deliver reliable estimates.
- Omission of Certain Lifecycle Phases and Externalities: Frequent exclusion of secondary costs such as disposal, residual value, insurance, and social externalities, including health impacts and community displacement, results in partial lifecycle analyses. This narrow scope diminishes the effectiveness of WLC as a holistic decision support tool, particularly when evaluating sustainability and social cost dimensions (Gov.au, 2021).
- Usability Challenges and Resource Intensity: Some frameworks impose high setup and maintenance burdens through complex data requirements, sophisticated software integration, or costly implementation (CACQS, 2016; Gov.ca, 2012). These factors disproportionately discourage adoption among small to medium-sized enterprises and owner-builders, who constitute a significant portion of New Zealand's residential construction market (OECD, 2022).
- Limited Integration with Emerging Technologies and Incentive Mechanisms: Although tools like BIM and Green Star are gaining traction (Lim et al., 2025), their integration with WLC remains inconsistent. Furthermore, the scarcity of financial incentives or regulatory mandates linking WLC adoption to project approvals or funding constrains market-driven uptake, highlighting the need for policy support mechanisms (USGBC, 2021).

Table 7.5: Weaknesses of the LCC and WLC framework, country-wise

Weakness	Australia	Austria	Canada	China	Czech Republic	Denmark	Egypt	Finland	France	Germany	Hungary	Hongkong	Italy	Japan	Netherland	NZ	Norway	UK	USA
Includes acquisition cost and income	x																		
Use a series of assumptions.		x	x																
Extensive data												x							
Dependence on stakeholders' knowledge.			x																
Limited to complex projects.	x									x	x					x			
Excludes externalities.		x								x	x					x	x		
Site-specificness and local impacts are ignored.												x							
Excludes operation, disposal, and residual value																x			
Requires LCC parameter knowledge.															x	x			x
Not user-friendly													x					x	
Higher setup and maintenance costs.															x				
Significant investment for replication.					x								x						
Little public sector incentive.																			x
Insufficient published details.						x													
There is no national methodology or database.	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x
Lack of transparency and knowledge.																			x
Lack of Data or information													x		x	x			x

7.5.4 How the Proposed Framework Addresses Identified Weaknesses

Building on the identified weaknesses detailed in the previous section, this section explains how the proposed system dynamics-based Whole-life Costing (WLC) framework addresses these critical gaps and enhances lifecycle cost assessment for New Zealand's residential construction sector.

A key issue highlighted was the absence of a nationally standardised methodology, which leads to fragmented practices and undermines consistency and comparability across projects. The proposed framework directly addresses this by offering a unified, structured approach specifically tailored for New Zealand, developed through rigorous empirical research that combines a broad systematic review with extensive consultation of local industry experts. By aligning with international classification systems such as the International Construction Measurement Standards (ICMS), while adding a dedicated fifth level to reflect unique regional factors, the framework facilitates consistent application and benchmarking at a national scale. Furthermore, the envisioned national database for WLC data, including material performance, cost drivers, and risk profiles, intends to foster data harmonisation and knowledge sharing, enabling repeated refinement and greater transparency. This centralised resource is projected to reduce duplication of effort and unlock economies of scale in data collection, reinforcing coherence across the industry.

The framework also overcomes the common shortcoming of inadequate focus on the residential sector and local contextualisation. Many existing models focus on commercial or infrastructure projects and lack relevance to the distinct characteristics of New Zealand's residential construction environment, which is influenced by high seismic risks, varied climate zones, and nuanced market conditions. Drawing on a comprehensive set of 73 validated cost drivers, the framework explicitly incorporates metrics such as seismic resilience, localised hazard probabilities, material durability in diverse climates, and socio-economic impacts. By embedding these factors into the hierarchical structure and dynamic modelling tools, the framework equips stakeholders to capture the complexities and specificities of residential projects, enabling more reliable and context-sensitive lifecycle cost predictions.

Data quality and availability have been pervasive challenges in existing approaches, often relying on sparse datasets, assumptions, or expert judgment without sufficient empirical grounding. This vulnerability is mitigated through the methodical integration of expert insights obtained from industry professionals across disciplines, alongside thorough literature synthesis. The use of system dynamics facilitates modelling feedback loops and delay effects that traditional static models overlook, enhancing robustness in simulating cost trajectories over time. Moreover, the framework advocates for establishing well-maintained, accessible databases that capture regional cost patterns, material degradation rates, and evolving regulatory requirements. These steps are crucial for enabling accurate calibration, validation, and continuous updating of the model parameters, thereby enhancing confidence and practical applicability.

The omission of essential lifecycle phases and externalities in many models diminishes their holistic value as decision-making tools. In contrast, the presented framework broadens the scope to include end-of-life costs such as disposal, residual values, and insurance considerations, as well as social and environmental externalities covering community displacement, public health impacts, and broader societal costs. Incorporating these dimensions enables a more comprehensive assessment of sustainability and resilience outcomes, aligning financial analysis with broader policy and community priorities. This is achieved through the multi-level hierarchical classification and feedback-rich causal loop diagrams, which capture complex interdependencies and trade-offs often excluded in simpler models.

Usability concerns and resource intensity, particularly for small and medium enterprises and owner-builders, are directly addressed by designing adaptable model complexity tiers. The framework supports scaled implementation, ranging from full-featured BIM-integrated applications suitable for large projects to streamlined, spreadsheet-based, or web-based tools tailored for less-resourced users. Coupled with training initiatives and template provision via government or industry bodies, this accessibility strategy lowers barriers to adoption and democratises advanced lifecycle costing methods. The modular design and explicit codification enable users to focus on critical factors, such as material resilience and regulatory compliance, without overwhelming data demands, thereby balancing usability with modelling fidelity.

Finally, to overcome the limitations of limited integration with emerging technologies and insufficient policy incentives, the framework explicitly promotes embedding WLC workflows within widely used digital platforms, such as BIM and cost estimation software (e.g., CostX), with configurable attributes that capture location-specific and risk-related parameters. Furthermore, it supports linkage to certification systems such as Green Star and advocates for policy mechanisms to mandate or incentivise WLC submissions, especially for developments in high-risk zones. These strides aim to catalyse market uptake through greater visibility, standardisation, and alignment with regulatory compliance, fostering a culture of informed, sustainable investment decisions.

Collectively, these measures ensure that the proposed framework remedies the principal weaknesses of prior WLC models by delivering an empirically grounded, nationally standardised, context-aware, inclusive, user-friendly, and technologically integrated solution tailored to the evolving needs of New Zealand's residential construction industry. The framework thus lays a foundation for enhancing the quality, consistency, and impact of lifecycle cost assessments in pursuit of resilient and sustainable housing outcomes.

7.5.5 Findings from Semi-structured Interviews

Semi-structured interviews with 22 industry professionals revealed significant gaps in WLC adoption and provided critical insights into the sector's current practices, challenges, and areas for improvement. Respondents included quantity surveyors, project managers, architects, engineers, and facility managers. While many recognised WLC's theoretical benefits, most admitted its application in residential projects remains limited and informal.

7.5.5.1 Adoption and Awareness of WLC in Residential Construction

Most participants reported that WLC is seldom applied in residential projects, which tend to prioritise upfront costs. While WLC is more commonly integrated with commercial and infrastructure projects, residential developments rely heavily on basic cost tools, such as spreadsheets or quotes. Tools such as Green Star and CostX are occasionally used, but their application to comprehensive lifecycle analysis remains inconsistent.

7.5.5.2 Variation in WLC Tools and Methodologies

Interviewees described a fragmented tool landscape. Some quantity surveyors utilise digital tools like CostX and Primavera in large-scale projects, whereas residential projects often rely on manual estimates or basic software. This inconsistency reflects the absence of a standardised, universally accepted WLC framework for the sector.

7.5.5.3 Challenges and Limitations of Existing WLC Frameworks

As summarised in Table 7.6, respondents cited several recurring limitations: lack of standardisation, informal spreadsheet-based methods, narrow cost scopes, and minimal integration with BIM or other digital tools. Quantity surveyors particularly emphasised the omission of key cost elements, such as insurance, operational, and financing expenses, as well as poor technological integration.

Table 7.6: Key Challenges and Limitations of Existing WLC Frameworks

Challenges/Limitations	GA	PM1	PM2	PM3	SM	A1	A2	SS	QS1	QS2	QS3	QS4	QS5	QS6	QS7
No standardised WLC approach / No unified methodology												✓	✓	✓	✓
WLC frameworks not used in residential projects	✓				✓										
Frameworks are informal or Excel-based				✓								✓			
Limited scope - focus mainly on costs, missing risk analysis.							✓						✓		✓
Lack of integration with tools like BIM										✓					
Narrow cost components - missing financing/insurance/operation										✓	✓				

7.5.4.4 Variations in WLC Practices: Key Insights by Profession

Interview data highlighted how regional factors such as seismicity, coastal exposure, and remoteness significantly affect lifecycle costs in Table 7.7. High-risk areas require resilient design, resulting in increased expenditures both upfront and in the long term. Urban projects benefit from economies of scale, whereas rural developments face higher logistics and labour costs. Sectoral differences also influence WLC adoption; the commercial and infrastructure sectors lead implementation due to higher regulatory and financial scrutiny, whereas residential projects lag behind due to low awareness and perceived affordability issues.

Table 7.7: Regional and Sectoral Variations in WLC Adoption

Variations in WLC Practices	GA	PM 1	PM 2	PM3	SM	A1	A2	EE	EI	FM1	FM2	HO1	HO2	SS	QS 1	QS 2	QS 3	QS 4	QS 5	QS 6	QS 7	QS 8
Regional Differences																						
Differences by project type	✓	✓	✓											✓			✓		✓			
High seismicity areas have stricter costs.				✓	✓							✓								✓		✓
Climate impacts long-term costs.						✓	✓	✓	✓								✓					
Insurance rates influence cost planning.	✓		✓		✓			✓					✓						✓			
Some clients consider WLC; others ignore it.				✓		✓			✓	✓				✓							✓	
Variations due to seismic risks, climate, and local standards	✓	✓			✓							✓						✓				
Local material costs affect decisions.										✓	✓			✓	✓					✓		
High-risk areas factor in resilience costs.	✓	✓											✓			✓						✓
Energy pricing & climate impact cost planning				✓		✓			✓									✓		✓		
Practices vary between urban and rural areas.							✓	✓											✓			✓
Sectorial differences																						
High-seismic regions require extra reinforcements; coastal areas need corrosion-resistant materials.											✓	✓			✓						✓	
Green certifications gaining traction			✓										✓		✓						✓	
Lifecycle tracking interest is increasing.		✓		✓						✓									✓			
Commercial projects leading WLC innovation				✓		✓																

Each profession approaches WLC differently, shaped by its responsibilities and industry focus. Project Managers prioritise risk management and compliance, considering WLC necessary in high-risk, legally mandated projects. Architects focus on sustainable design and material efficiency, supporting WLC in theory, but acknowledge the slow adoption in residential projects. Quantity Surveyors analyse cost structures and market feasibility, balancing financial viability with long-term cost benefits. Facility managers view WLC as critical for reducing long-term maintenance costs, while electrical engineers and inspectors emphasise its importance in enhancing energy efficiency and supporting infrastructure investments. Site managers and supervisors face practical implementation challenges, arguing that contractors prioritise immediate costs over long-term efficiency. Finally, Homeowners largely ignore WLC due to upfront affordability concerns unless required by regulations or financial incentives.

While all professions recognise WLC's potential benefits, key differences in priorities create barriers to adoption. Moving forward, financial incentives, standardised cost estimation tools, and regulatory support are likely to be essential for expanding WLC adoption across all sectors.

7.5.5.5 Recent Developments in WLC Frameworks

Participants reported increased emphasis on sustainability and risk integration within newer WLC models. While Green Star and BIM tools are gaining traction, as shown in Table 7.8, their adoption remains patchy. Despite regulatory shifts and growing interest in climate resilience, a unified approach to WLC is still lacking across the industry.

Table 7.8: Recent Developments in WLC Frameworks

Recent Developments	GA	PM 1	PM 2	PM3	SM	A1	A2	EE	EI	FM1	FM2	HO1	HO2	SS	QS 1	QS 2	QS 3	QS 4	QS 5	QS 6	QS 7	QS 8
Focus on sustainability & resilience.	✓	✓	✓		✓			✓				✓	✓						✓			
Compliance & regulatory changes	✓		✓		✓				✓				✓					✓				✓
Green Star as a reference, but limited use		✓										✓		✓								✓
Limited industry-wide improvements			✓			✓	✓								✓					✓		
Integration of sustainability metrics & digital modeling for cost predictions			✓			✓		✓						✓				✓				
Custom modules for regional factors	✓			✓				✓											✓			
Risk assessment & climate data integration	✓	✓	✓		✓			✓	✓							✓						✓
No major initiatives observed				✓					✓	✓				✓								
Interest in AI & data analytics for cost predictions	✓	✓	✓									✓		✓								
AI-driven maintenance prediction models & sustainability tools			✓						✓	✓	✓											
Inclusion in building regulations	✓				✓			✓					✓									✓
More NZ-specific data is needed.					✓			✓					✓	✓				✓				
Better climate adaptation models	✓		✓				✓					✓										✓
Seismicity & weather resilience integration		✓	✓					✓	✓					✓						✓		
More risk modelling is required			✓		✓								✓	✓							✓	
Focus on sustainability & resilience.	✓	✓	✓		✓			✓				✓	✓						✓			
Compliance & regulatory changes	✓		✓		✓				✓				✓					✓				✓

7.5.5.6 Improvements Needed in WLC Frameworks

Table 7.9 outlines recommended improvements, including better material evaluation, stronger integration with compliance and planning processes, improved data forecasting, and regional risk modelling. Participants advocated for more regulatory support, the adoption of digital tools, and standardised frameworks. They also noted the lack of NZ-specific cost data, limiting accurate estimations. While some called for government-led initiatives, others suggested voluntary industry reform supported by financial incentives.

Table 7.9: Recommended Improvements to WLC Frameworks

Recommended Improvements	GA	PM 1	PM 2	PM3	SM	A1	A2	EE	EI	FM1	FM2	HO1	HO2	SS	QS 1	QS 2	QS 3	QS 4	QS 5	QS 6	QS 7	QS 8
Better material evaluation methods	✓		✓			✓		✓					✓					✓				
More emphasis on compliance costs		✓						✓				✓		✓								
Stronger integration in project planning	✓	✓	✓		✓			✓	✓							✓						✓
Education and advocacy for WLC adoption				✓					✓	✓				✓								
Improvements in data integration & forecasting models	✓	✓	✓			✓		✓						✓				✓				
Regional climate-based modules	✓			✓				✓											✓			
Enhanced regulatory integration	✓	✓	✓		✓			✓	✓							✓						✓
Awareness & standardised software tools				✓					✓	✓				✓								
Better incorporation of geographical risks	✓		✓				✓					✓										✓
More real-time data integration & predictive models		✓					✓					✓				✓						
Climate change adaptation in WLC frameworks	✓		✓				✓					✓										✓
Integration of climate risk & resilience models		✓	✓					✓	✓					✓						✓		
Use of dynamic cost modelling & risk assessment			✓		✓								✓	✓							✓	

7.5.5.7 The Necessity of Integrating Seismicity and Adverse Weather in WLC Frameworks

Most participants supported integrating seismic and climatic risks into WLC frameworks (refer to Figure 7.3). These risks have a significant impact on lifecycle costs in New Zealand. Participants emphasised the need for regionally tailored cost models and more accurate quantification of the long-term value of resilient materials. However, implementation remains a challenge due to the limited availability of modelling tools and affordability concerns in smaller projects.

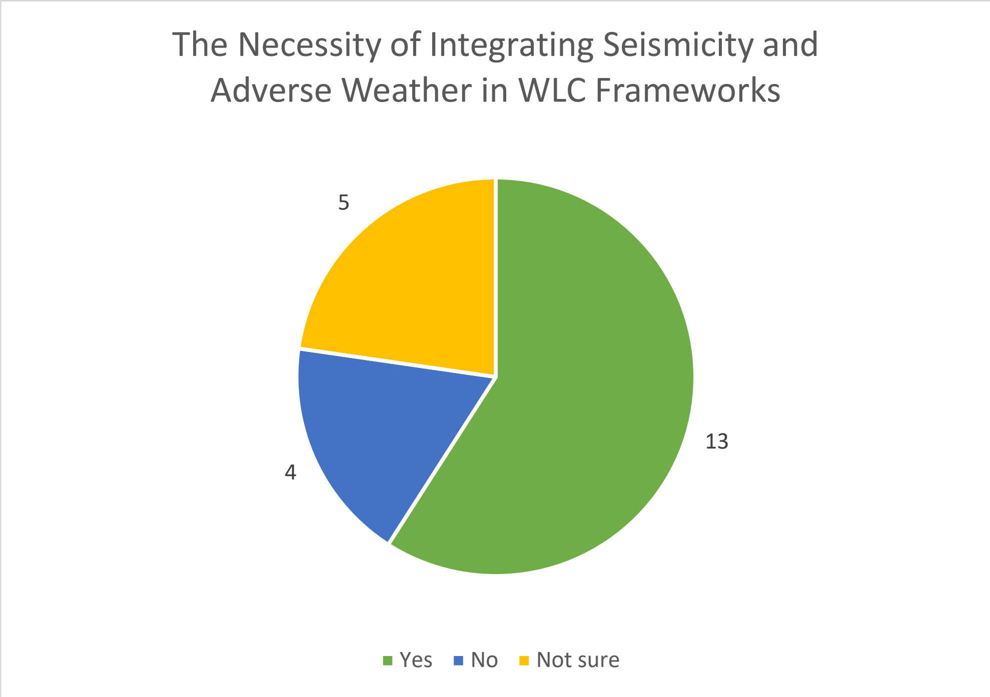


Figure 7.3: Responses to the inclusion of seismicity and adverse weather factors

7.5.5.8 Strategies for Incorporating Seismicity and Adverse Weather in WLC Frameworks

As shown in Table 7.10 , professionals proposed diverse strategies: mandating risk-based assessments, developing region-specific models, integrating predictive technologies, and incentivising resilient construction. Improved data collection and public awareness were also deemed essential. While opinions differed on the best implementation pathway, a consensus emerged on the need for collaboration among government, industry, and end-users to mainstream WLC in high-risk environments.

Table 7.10: Strategies for Incorporating Seismicity and Adverse Weather in WLC Frameworks

Strategies	GA	PM 1	PM 2	PM3	SM	A1	A2	EE	EI	FM1	FM2	HO1	HO2	SS	QS 1	QS 2	QS 3	QS 4	QS 5	QS 6	QS 7	QS 8
Develop region-specific WLC models.	✓	✓	✓	✓		✓	✓			✓	✓					✓				✓		
Mandate risk-based cost assessments in regulations.	✓		✓	✓	✓				✓				✓					✓				✓
Enhance material and design standards for resilience.	✓	✓		✓	✓	✓		✓		✓	✓			✓			✓					
Use predictive maintenance & AI-driven risk models.		✓	✓				✓	✓	✓													
Improve data collection on climate and seismic risks.	✓			✓				✓					✓	✓			✓					✓
Integrate climate resilience costs into project planning and management.		✓	✓			✓				✓				✓					✓			
Expand financial incentives for resilient construction.			✓			✓			✓	✓								✓				
Adopt lifecycle tracking for high-risk zones.	✓		✓		✓		✓	✓	✓		✓				✓				✓	✓		
Increase WLC awareness among stakeholders.	✓	✓		✓						✓		✓	✓	✓							✓	

7.5.6 Hierarchical Representation of WLC Factors

The five-level hierarchical model developed in Section 7.4.3 was applied to classify and visualise key cost components affecting residential building lifecycle outcomes (refer to Figure 7.4). This structure integrates global best practices (via ICMS Levels 1–4) with New Zealand-specific variables at Level 5 identified by this research. It serves as a foundation for identifying feedback loops and centrality-driven priorities. This visual representation illustrates how high-level cost categories are broken down into subcategories and functional tasks, while contextual variables at Level 5 shape dynamic outcomes such as maintenance, insurance, and depreciation. This hierarchy is critical in framing the system dynamics model and informing the final framework design (presented in Table 7.13).

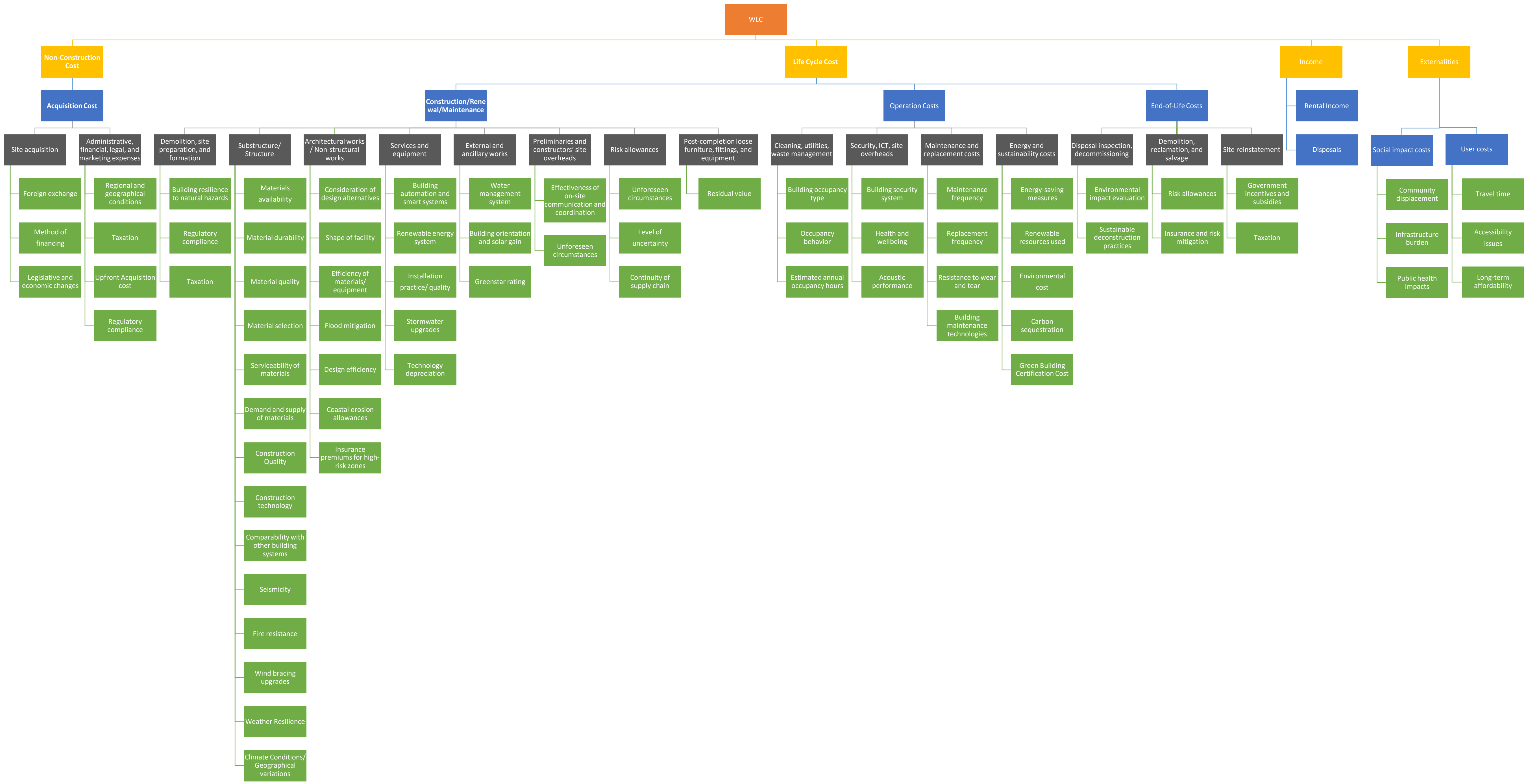


Figure 7.4: The five-level WLC hierarchy

Note = To improve readability, the detailed response distribution presented in Figure 7.4 is also provided in tabular form in Appendix 15

7.5.7 System Dynamics Modelling of WLC Influencing Factors

To capture the complex interdependencies among WLC factors in New Zealand's residential sector, this study employs a systems thinking approach, utilising Causal Loop Diagrams (CLDs). Existing frameworks, such as ICMS, offer structured cost classifications but often overlook regional challenges, including seismic risks, extreme weather, and evolving regulations. Traditional WLC models isolate cost categories, ignoring the effects of early-stage decisions on downstream outcomes. The five-level hierarchy from Section 7.5.6 serves as a foundation for the CLD, identifying key cost drivers across the acquisition, construction, operation, and end-of-life phases, while incorporating unique contextual variables specific to New Zealand. The CLD maps dynamic feedback relationships among these variables.

This method reveals reinforcing and balancing loops that explain how changes in one factor can amplify or counteract effects in others. This feedback perspective provides a more realistic understanding of lifecycle cost behaviour than linear models. Subsequent subsections present the developed CLD (Figure 7.5), describe key feedback loops, and show how these insights informed factor prioritisation through centrality analysis.

7.5.8 CLD and Loops Analyses

With the WLC hierarchy established in Figure 7.4, the next step is to understand the dynamic interactions over time. A CLD was developed to capture reinforcing and balancing feedback loops influencing long-term cost behaviour in residential projects. This systems-based lens illustrates circular causality, where a change in one variable impacts other and generates feedback that reinforces or counteracts the original change. This insight is vital for accurate WLC estimation and effective decision-making in New Zealand's complex construction environment.

Feedback Polarities and Visual Conventions

In the CLD:

- Positive relationships are shown with blue arrows and a (+) symbol, indicating that a change in one variable leads to a change in the same direction in the connected variable (e.g., increased energy-efficient investment lowers operational costs).
- Negative relationships are indicated with red arrows and a (–) symbol, reflecting inverse relationships (e.g., higher upfront costs may reduce long-term maintenance needs).

These conventions help distinguish between reinforcing loops, which amplify changes, and balancing loops, which stabilise the system.

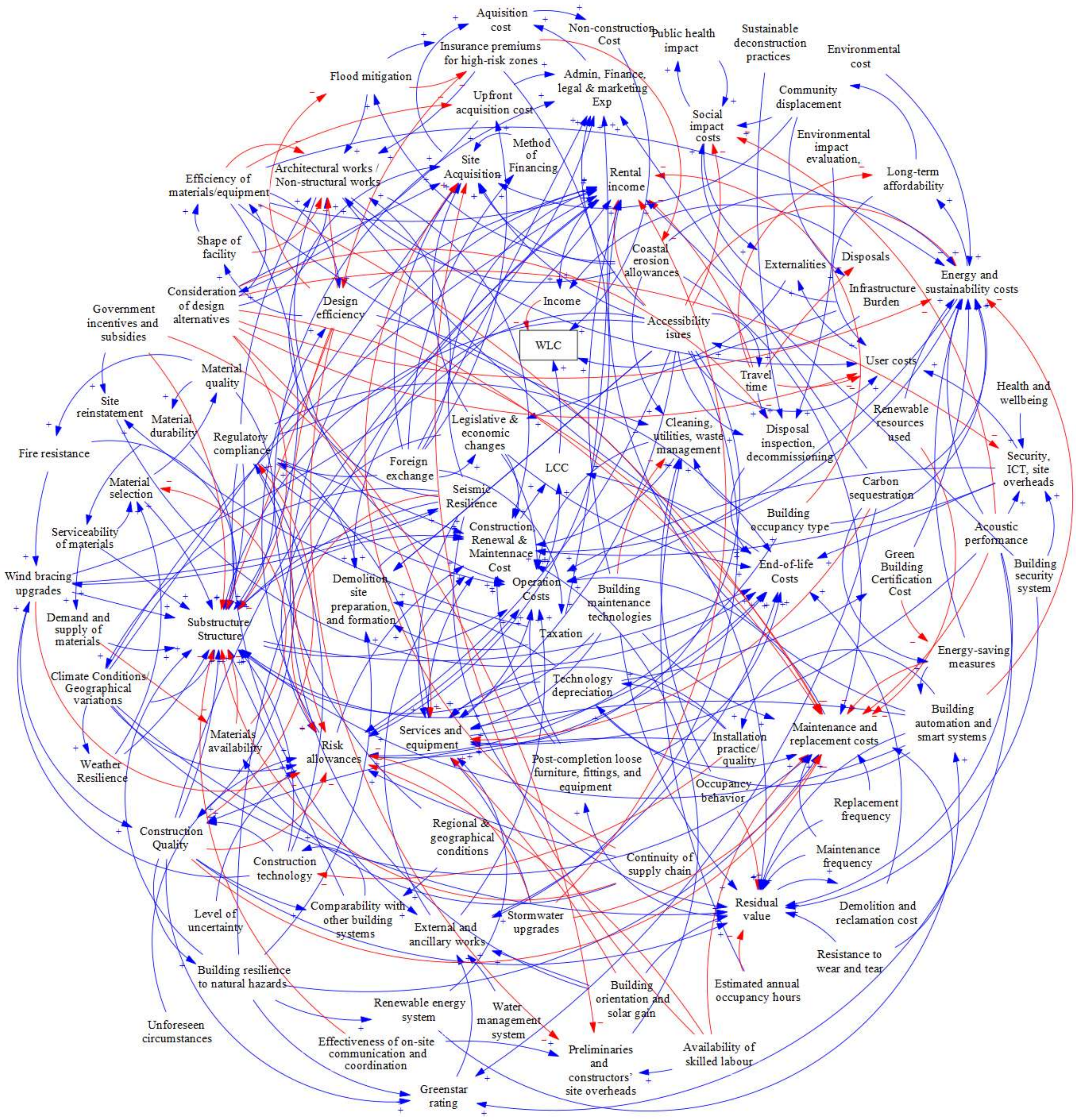


Figure 7.5: Causal Loop Diagramme

Figure 7.5 illustrates the dynamic interactions among various variables stemming from the WLC factor hierarchy, highlighting reinforcing and balancing loops. Sixteen reinforcing loops and five balancing loops were identified through qualitative mapping. These loops include material selection, design efficiency, and regulatory compliance.

Table 7.11: Summary of Feedback Loops

Loop ID	Loop Name	Loop Variables	Type	Main Driver	Main Consequence
R1	Social Health Spiral	Social Impact Cost ➔ Public Health Impact ➔ Social Impact Cost	Reinforcing	Social Impact Cost	Increased societal health burden
R2	Material Longevity Loop	Material Selection ➔ Material Quality ➔ Material Durability ➔ Serviceability of Materials ➔ Material Selection	Reinforcing	Material Selection	Enhanced material service life
R3	Market Feedback on Materials	Material Selection ➔ Material Quality ➔ Material Durability ➔ Serviceability of Materials ➔ Demand and Supply ➔ Material Availability ➔ Material Selection	Reinforcing	Material Selection	Stronger supply-demand cycle
R4	Resilience by Material Quality	Material Selection ➔ Material Quality ➔ Fire Resistance ➔ Wind Bracing ➔ Seismic Resilience ➔ Climate Conditions ➔ Weather Resilience ➔ Material Selection	Reinforcing	Material Selection	Improved disaster resilience
R5	Seismic Strengthening Loop	Wind Bracing Upgrades ➔ Seismic Resilience ➔ Wind Bracing Upgrades	Reinforcing	Wind Bracing	Advanced structural integrity
R6	Comparative Quality Cycle	Comparability with Other Systems ➔ Construction Technology ➔ Wind Bracing ➔ Construction Quality ➔ Comparability with Other Systems	Reinforcing	Comparability	Construction quality uplift
R7	Smart Resilience Technology	Construction Technology ➔ Wind Bracing ➔ Construction Quality ➔ Resilience ➔ Renewable Energy ➔ Automation ➔ Installation Quality ➔ Construction Technology	Reinforcing	Construction Technology	Integrated smart-resilient systems
R8	Installation-Performance Loop	Installation Practice ➔ Construction Technology ➔ Construction Quality ➔ Resilience ➔ Renewable Energy ➔ Automation ➔ Installation Practice	Reinforcing	Installation Quality	Reliable technology performance
R9	Regulatory Installation Feedback	Installation Practice ➔ Construction Technology ➔ Regulatory Compliance ➔ Construction Quality ➔ Resilience ➔ Renewable Energy ➔ Automation ➔ Installation	Reinforcing	Installation Quality	Compliance-driven tech adoption
R10	Bracing-Driven Smart Buildings	Installation Quality ➔ Construction Technology ➔ Wind Bracing ➔ Construction Quality ➔ Resilience ➔ Renewable Energy ➔ Automation ➔ Installation Quality	Reinforcing	Installation Quality	Robust and smart residential buildings
R11	Quality-Driven Tech Advancement	Construction Quality ➔ Comparability ➔ Construction Technology ➔ Construction Quality	Reinforcing	Construction Quality	Accelerated technology uptake
R12	Seismic Quality Benchmark Loop	Construction Quality ➔ Comparability ➔ Construction Technology ➔ Wind Bracing ➔ Construction Quality	Reinforcing	Construction Quality	Safer, high-performing homes
R13	Compliance-Driven Quality Cycle	Construction Quality ➔ Comparability ➔ Construction Technology ➔ Regulatory Compliance ➔ Construction Quality	Reinforcing	Construction Quality	Stronger compliance and durability
R14	Coastal Insurance Resilience	Coastal Erosion Allowances ➔ Flood Mitigation ➔ Insurance Premiums ➔ Coastal Erosion Allowances	Reinforcing	Coastal Erosion Planning	Lower insurance risk in coastal zones
R15	Flood-Resilient Design	Design Efficiency ➔ Flood Mitigation ➔ Insurance Premiums ➔ Design Efficiency	Reinforcing	Design Efficiency	Lower insurance and flood risks
R16	Form-Based Efficiency Loop	Design Efficiency ➔ Shape of Facility ➔ Material/Equipment Efficiency ➔ Design Efficiency	Reinforcing	Design Efficiency	Improved resource efficiency
B1	Acquisition-Operational Trade-off	Upfront Acquisition Cost ➔ Greenstar Rating ➔ Energy Saving Measures ➔ Operational Cost ➔ Long-Term Affordability ➔ Upfront Acquisition Cost	Balancing	Upfront Acquisition Cost	Controlled lifecycle cost

B2	Repair Risk Control	Maintenance Frequency ➔ Resistance to Wear and Tear ➔ Replacement Frequency ➔ Repair Risk Allowances ➔ Maintenance Frequency	Balancing	Maintenance Frequency	Stability in maintenance cost
B3	Insurance Risk Feedback	Building Security ➔ Risk Allowances ➔ Insurance Premiums ➔ Insurance and Risk Mitigation ➔ Building Security	Balancing	Building Security	Stabilised insurance costs
B4	Environmental Material Loop	Environmental Impact Evaluation ➔ Carbon Sequestration ➔ Renewable Resource Use ➔ Material Selection ➔ Environmental Impact Evaluation	Balancing	Environmental Impact Evaluation	Optimised resource selection
B5	Green Certification Cost-Value Loop	Green Building Certification Cost ➔ Greenstar Rating ➔ Government Incentives ➔ Long-Term Affordability ➔ Green Building Certification Cost	Balancing	Certification Cost	Balanced green certification investment

7.5.9 Degree of Centrality and Influential Factors

A comprehensive centrality analysis was conducted to enhance prioritisation within the proposed WLC framework, grounded in the causal relationships delineated in the CLD and corresponding feedback loops. Each factor was conceptualised as a node, with the directional influences extracted from the CLD structure employed to compute the out-degree, in-degree, and total degree centrality values. This quantitative analysis elucidates which factors exhibit the highest influence (characterised by elevated out-degree), are most susceptible to external influences (indicated by high in-degree), or are systemically essential (denoted by high total degree). Such insights serve to augment the qualitative loop analysis by pinpointing leverage points and response variables within the WLC system. Table 7.12 articulates the ranked centrality scores for all salient WLC factors.

Table 7.12: Degree of Centrality Rankings for All WLC Factors

Factor	Out-Degree	In-Degree	Total Degree
Material selection	8	3	11
Building orientation and solar gain	6	4	10
Seismic Resilience	6	4	10
Energy-saving measures	6	4	10
Foreign exchange	5	4	9
Material durability	5	4	9
Technology depreciation	6	3	9
Building occupancy type	5	4	9
Health and well-being	5	4	9
Design efficiency	6	3	9
Materials availability	6	3	9
Insurance and risk mitigation	5	4	9
Infrastructure burden	5	4	9
Material quality	4	4	8
Environmental cost	4	4	8
Taxation	4	4	8
Weather Resilience	6	2	8
Climate Conditions/ Geographical variations	5	3	8
Renewable energy system	5	3	8
Efficiency of materials/equipment	4	3	7
Estimated annual occupancy hours	5	2	7
Availability of skilled labour	4	3	7
Public health impacts	5	2	7
Acoustic performance	5	2	7
Water management system	4	3	7
Long-term affordability	4	3	7
Construction technology	5	2	7
Legislative and economic changes	5	2	7
Upfront Acquisition cost	2	5	7
Wind bracing upgrades	3	4	7
Serviceability of materials	3	4	7

Construction Quality	5	2	7
Comparability with other building systems	4	3	7
Community displacement	5	1	6
Carbon sequestration	2	4	6
Regulatory compliance	5	1	6
Building resilience to natural hazards	2	4	6
Maintenance frequency	4	2	6
Building security system	4	2	6
Flood mitigation	2	4	6
Insurance premiums for high-risk zones	2	4	6
Effectiveness of on-site communication and coordination	4	2	6
Building automation and smart systems	5	1	6
Fire resistance	3	3	6
Level of uncertainty	3	2	5
Building maintenance technologies	3	2	5
Accessibility issues	2	3	5
Regional and geographical conditions	3	2	5
Sustainable deconstruction practices	2	3	5
Environmental impact evaluation	1	4	5
Green Building Certification Cost	3	2	5
Stormwater upgrades	4	1	5
Renewable resources used	2	3	5
Resistance to wear and tear	3	2	5
Method of financing	1	4	5
Greenstar rating	4	1	5
Demand and supply of materials	3	2	5
Installation practice/ quality	3	1	4
Shape of facility	3	1	4
Unforeseen circumstances	1	3	4
Residual value	3	1	4
Continuity of supply chain	1	2	3
Consideration of design alternatives	1	2	3
Replacement frequency	1	2	3
Risk allowances	1	2	3
Government incentives and subsidies	1	2	3
Coastal erosion allowances	2	1	3
Travel time	1	2	3
Occupancy behaviour	1	1	2

These results provide a comprehensive understanding of the structural and dynamic relationships among WLC factors. The Top 10 WLC Factors by Total Centrality Score are presented in Figure 7.6 highlighting the most influential variables within the system dynamics model. The following section discusses the implications of these findings, interpreting how feedback mechanisms and centrality patterns influence long-term cost performance and inform the design of a context-specific WLC framework for New Zealand.

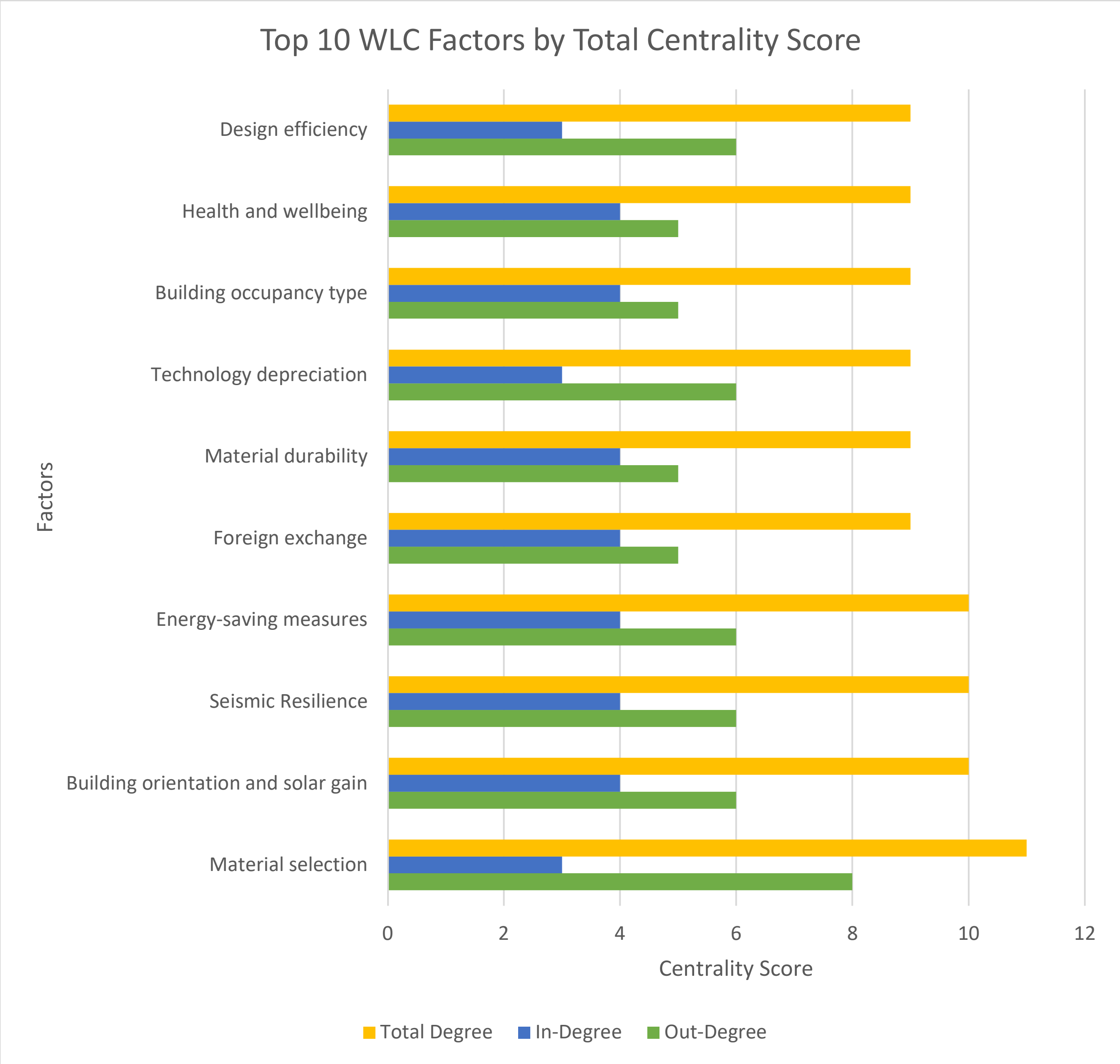


Figure 7.6: Top 10 WLC Factors by Total Centrality Score

7.6 Discussion

This section interprets the findings in relation to the study objectives and broader WLC discourse, highlighting implications, limitations, and future development directions.

7.6.1 Insights from the Literature Review

The literature indicates a lack of geographically tailored WLC frameworks for residential construction in New Zealand. While international standards, such as ISO 15686 and ICMS, are widely adopted, they often generalise conditions and neglect region-specific factors, including seismicity, climatic variability, and compliance differences. Section 7.5.1 shows that most WLC research comes from the UK and the USA, highlighting the need for frameworks that address local construction practices and risks. Many current frameworks focus on commercial and infrastructure projects, offering limited relevance for residential developments and often exclude vital factors like long-term energy performance, occupant behaviour, and environmental externalities. This omission detracts from the effectiveness of financial planning and the sustainability of housing developments. Countries like Japan and the Netherlands have incorporated seismic and weather risks, while New Zealand's frameworks remain basic. Learning from these nations emphasises the need to integrate durability, sustainability, and regulatory compliance into lifecycle models. Addressing this gap is essential for New Zealand's economic and environmental resilience.

7.6.2 Expert Insights and Framework Structuring

The semi-structured interviews confirmed literature-based gaps and added practical depth. Industry professionals stressed that current WLC tools are inconsistent, often limited to cost spreadsheets without integration of long-term planning, risk assessment, or digital technologies. Interviewees also noted a lack of alignment between construction decisions and lifecycle outcomes, particularly in residential projects. Key priorities included standardisation, regional risk modelling, better integration of smart systems and material durability. For instance, seismic resilience and compliance were repeatedly flagged as major cost drivers, often omitted in typical models. Regulatory volatility and insurance premiums were also cited as long-term concerns. These themes directly informed the structure of the proposed WLC framework, ensuring its practical relevance and alignment with professional expectations. Refer to Table 7.6 to Table 7.10 from section 7.5.4 for supportive evidence.

7.6.3 Interpreting System Feedback and Centrality Prioritisation

This section synthesises the system dynamics findings presented in Section 7.5.7, focusing on their broader implications for WLC prioritisation in New Zealand's residential construction sector. The feedback loops detailed in Table 7.11 demonstrate how key WLC variables interact over time. These loops highlight the reinforcing or balancing effects of material durability, seismic resilience, design efficiency, and smart system integration. Instead of repeating those narratives, this section highlights the overarching insight that early-stage design and technology choices have a significant impact on downstream lifecycle outcomes. For example, investing in resilient materials or flood mitigation measures not only reduces long-term maintenance and insurance costs but also creates a positive feedback loop that enhances building quality and cost predictability.

The centrality analysis conducted in this investigation constitutes a pivotal network-based methodology for identifying the most structurally embedded factors within the WLC system. By scrutinising the direction and density of connections derived from the CLD, this approach quantifies the systemic role of each factor across three dimensions:

- Out-degree centrality quantifies the number of other factors influenced by a variable, thereby revealing its potential as a driver or leverage point within the system.
- In-degree centrality assesses the number of factors that exert influence upon a given variable, thus indicating its sensitivity to upstream decisions.
- Total degree centrality amalgamates both metrics, reflecting a factor's overarching significance within the WLC structure.

This quantitative dimension complements the qualitative insights gained from the feedback loop analysis, elucidating the relative influence and dependency of key WLC factors. The ranked scores presented in Table 7.12 facilitate a more lucid understanding of which elements warrant prioritisation for intervention, evaluation, or integration within the proposed WLC framework. The results yield several critical insights. Factors such as material selection, seismic resilience, building orientation, solar gain, and energy-saving measures demonstrate the highest total centrality. These variables are deeply embedded within the system and exert substantial influence over a wide array of other cost drivers, performance metrics, and lifecycle outcomes. Their elevated ranking substantiates their placement within the upper tiers of the proposed framework hierarchy, wherein they can function as key levers for achieving systemic improvement.

In terms of out-degree centrality, material durability, design efficiency, and construction quality emerged as significant contributors. Their capacity to influence multiple downstream variables underscores their role as principal enablers of performance and cost-effectiveness over the building lifecycle. These findings accentuate the significance of upstream decision-making in shaping operational and post-occupancy outcomes. Conversely, factors such as occupant behaviour, public health implications, and insurance premiums scored highly on in-degree centrality, denoting their function as indicators of outcomes. These variables are profoundly influenced by antecedent decisions made during the processes of design, construction, and material specification. Monitoring these factors facilitates feedback-driven refinement of policy and planning practices and supports adaptive lifecycle cost estimation.

Several contextual elements, including foreign exchange rates, climatic variability, and regional conditions, also ranked prominently across centrality dimensions. Their robust systemic positions underscore the need for locally tailored WLC models that can accommodate environmental and economic fluctuations, particularly pertinent within New Zealand's diverse regional landscape. Notably, the findings related to centrality provide a logical foundation for structuring the WLC framework. Variables exhibiting high total centrality are prioritised as core components of system control, directing policy, resource allocation, and design focus. Those with elevated in-degree but diminished out-degree function as performance measures, which are valuable for evaluating the success of interventions. Conversely, factors characterised by intermediate centrality, exhibiting both in- and out-degrees, serve as systemic enablers, synthesising upstream inputs with downstream outcomes. These mid-network connectors are crucial for maintaining system coherence and enhancing feedback loops.

By aligning the framework with insights derived from centrality analysis, the model achieves both practical clarity and theoretical robustness. It ensures that design decisions, policy interventions, and regulatory efforts are concentrated on areas with the most substantial systemic impact while simultaneously embedding the capability for monitoring, adaptation, and optimisation over time. In the forthcoming section, the prioritised insights from both the feedback loop and centrality analyses are synthesised into a bespoke WLC framework. This framework is meticulously developed for New Zealand’s residential construction sector and aspires to promote durable, affordable, and climate-resilient housing outcomes through strategically aligned lifecycle planning.

7.6.4 Framework Design

To enhance the applicability and contextual relevance of WLC within the New Zealand residential construction sector, a hierarchical framework has been systematically developed in alignment with the International Construction Measurement Standards (ICMS). This approach provides a globally recognised structure for organising construction-related costs and ensures analytical coherence throughout a building's lifecycle. However, while the ICMS classification system traditionally provides a four-level structure, this study introduces a tailored fifth level to account for the unique environmental, seismic, social, and regulatory conditions specific to New Zealand. This new classification layer was necessitated by insights from a rigorous Systematic Literature Review (SLR) and further refined through Semi-Structured Interviews (SSI) with local industry experts and stakeholders.

The inclusion of Level 5 significantly enhances the granularity of the cost framework by integrating critical context-specific variables such as seismic resilience strategies, flood mitigation measures, and evolving regulatory compliance costs. These elements, often underrepresented in international models, are essential for accurately capturing the total cost implications of residential projects in New Zealand. By incorporating them, the framework provides a more accurate representation of real project costs and improves its utility as a decision-making tool for project managers, developers, and policymakers. The detailed, tailored framework is presented in Table 7.12, and its visual hierarchy is illustrated in Figure 7.3. It provides an explicit, structured reference for how cost components interact and are prioritised across multiple dimensions.

The hierarchical model comprises five distinct levels, each represented by a specific colour to visually denote its place within the structure and differentiate between the original ICMS framework and the bespoke adaptations introduced in this study. At the top of the hierarchy is Level 1 (orange), which classifies costs into four overarching categories: Construction Cost, Non-Construction Cost, Income, and Externalities. These categories encapsulate the broadest understanding of Whole-life Costs, forming the foundation upon which more detailed layers are built. Level 2 (yellow) disaggregates these broad cost categories into primary cost types, such as Acquisition Cost, Operation Cost, and End-of-Life Cost, along with discrete elements of Income (e.g., Rental Income) and Externalities (e.g., Social Impact Cost, User Cost, and Disposal Cost). This layer offers a more nuanced breakdown, supporting informed financial planning across the various stages of a building’s lifecycle.

At Level 3 (blue), the framework transitions into more tangible and operational categories such as construction fees, site acquisition, energy and water consumption, and maintenance frequency. These categories reflect the everyday financial considerations in construction projects and are central to budget development, contract scoping, and risk management. Level 4 (grey) introduces performance-based determinants that influence cost outcomes, including energy efficiency of design, health and well-being impacts, sustainability practices, and the longevity and quality of materials. This layer bridges financial considerations with performance metrics, promoting long-term value creation rather than short-term cost optimisation.

The newly introduced Level 5 (green) reflects the tailored requirements of the New Zealand residential context. It encompasses variables derived from Sustainable Life-cycle Risk (SLR) assessments and Site-Specific Influences (SSI), including wind bracing enhancements, embodied carbon thresholds, long-term affordability constraints, and regulatory variations related to environmental and seismic zoning. These elements directly affect capital and operational costs, and their explicit integration into the framework ensures that project evaluations are contextually robust and forward-looking.

The structure and prioritisation of this hierarchical framework were deeply informed by systems-based insights from the CLD developed earlier in the study. The CLD revealed a complex web of interactions comprising sixteen reinforcing and five balancing loops, illustrating the dynamic feedback structures inherent in construction cost behaviours. These feedback loops illuminated how improvements or disruptions in one part of the system, such as investments in energy-efficient design, enhanced material durability, or changes in regulatory pressure, can cascade through other parts of the system and significantly alter whole-life cost outcomes. These interdependencies are directly reflected in the positioning and weighting of factors throughout the five levels of the framework. For example, reinforcing loops that emphasised the benefits of better material selection on long-term maintenance costs and serviceability are operationalised within Levels 3 and 4, while balancing loops involving affordability constraints and policy pressures informed the inclusion of long-term socio-economic impacts at Level 5.

In tandem with the CLD, a comprehensive centrality analysis was employed to quantify the structural importance of each factor within the network. The development of the WLC framework for New Zealand's residential construction sector was guided by a methodologically rigorous sequence, beginning with the identification of influencing factors through the Systematic Literature Review (SLR) and Semi-Structured Interviews (SSI). After establishing a comprehensive list of context-relevant factors, an ICMS-based hierarchical structure was adapted and extended with a new Level 5 tier to incorporate specific New Zealand challenges and dynamics. However, the most critical step in aligning systemic interactions with framework design was using a CLD and degree of centrality analysis, which ensured the strategic placement and prioritisation of variables.

To justify the direct use of a degree of centrality in framework development, the centrality scores of each factor and its participation in feedback loops were used to indicate systemic influence and interconnectivity. Centrality analysis, particularly degree centrality, measures the extent to which each factor is well-connected within the causal network. A higher centrality rank implies that a factor has numerous direct relationships with others and potentially acts as a leverage point for systemic change. This measure helped identify essential variables and those that would create cascading impacts throughout the cost structure if managed effectively. For instance, "Energy Use" held the highest centrality rank and featured prominently across six reinforcing loops. Its presence across multiple tiers of the framework (Levels 3, 4, and 5) reflects its strategic importance in shaping operational and environmental costs. Similarly, "Material Durability" and "Affordability" were placed across Levels 4 and 5, or Levels 3 and 5, to reflect their dual influence on both design-level decisions and site-specific contextual factors.

This centrality-informed approach ensured that highly influential factors were embedded in generic cost categories and the newly introduced Level 5, which accommodates unique New Zealand-specific risk factors such as seismic resilience and flood mitigation. For example, "Seismic Resilience" ranked fourth in centrality and is exclusively placed in Level 5, demonstrating how local contextual importance and systemic connectivity converge in the framework. Thus, the final framework is not merely a categorical classification of costs but a dynamic system model where the positioning of each factor reflects its systemic role. The mapping of centrality-ranked factors to their framework placement (see Table below) illustrates the intentional translation of causal dynamics into structural hierarchy. This method ensures that the WLC model is comprehensive, locally relevant and strategically prioritised for maximum cost-effectiveness and resilience.

What distinguishes this framework from conventional cost models is its embedded responsiveness to both dynamic system feedback and context-specific challenges. Rather than treating cost categories as static or mutually exclusive, the framework accommodates the interconnected nature of real-world construction decisions. It provides a structure that aligns technical, financial, and regulatory considerations in a way that is both analytically rigorous and practically relevant to New Zealand. The combined use of CLD and centrality metrics ensures that important cost categories are included, and their placement reflects their dynamic behaviour and systemic importance. This makes the framework a diagnostic and prescriptive tool for guiding investment decisions and managing lifecycle performance in residential construction.

To facilitate practical adoption, the proposed WLC framework can be embedded into existing digital tools such as CostX and Building Information Modelling (BIM) platforms. Specifically, Level 5 context-specific variables, such as seismic risk, climate exposure, and material durability, can be configured as custom attributes within BIM models, enabling automated cost tracking throughout the project lifecycle. For instance, design teams could use BIM-linked cost codes to estimate resilience-related maintenance costs during early design stages. Quantity surveyors using CostX can tag cost items with lifecycle-related metadata, enabling the visualisation of cumulative costs from acquisition to decommissioning. A national WLC database should be developed to support consistent inputs. This database could be hosted by MBIE or BRANZ and populated with verified cost curves, material degradation profiles, and region-specific hazard data. Stakeholders, particularly SMEs, could access simplified templates or plug-ins for mainstream tools, reducing the learning curve and cost barriers associated with WLC adoption.

In summary, the proposed hierarchical framework represents a significant advancement in Whole-Life Costing methodology for the New Zealand residential construction sector. It preserves the global consistency and analytical clarity of the ICMS structure while enriching it with critical local dimensions by including a bespoke Level 5 classification. Grounded in systems thinking and supported by empirical analysis, this framework provides a robust foundation for lifecycle-informed decision-making, helping practitioners navigate complexity, anticipate risk, and realise long-term value in residential construction projects nationwide.

These findings are consistent with earlier research indicating that WLC adoption in residential construction remains limited compared to commercial sectors (Flanagan & Jewell, 2008; MBIE, 2013), but the results extend the discourse by identifying seismic resilience, coastal exposure, and evolving climate adaptation requirements as critical cost determinants in the New Zealand context. Prior LCC/WLC frameworks, such as those by Goh and Sun (2016) and (Lehmann, 2013), provide comprehensive cost–benefit or sustainability integration, yet often omit hazard-related costs and feedback effects between early design choices and downstream lifecycle performance. The present framework addresses this gap through the combined application of systems thinking, ICMS-aligned cost structuring, and network-based centrality analysis, offering a novel tool for lifecycle-conscious decision-making in hazard-prone residential environments.

7.6.5 Framework

To successfully implement the Whole-life Costing (WLC) framework in New Zealand's residential construction sector, it is essential to adopt a structured approach that incorporates both the technical aspects of the framework and specific regional needs. This section guides the reader through each step of applying the framework, from initial planning to long-term monitoring, providing practical advice for industry stakeholders.

The first step in using the WLC framework is to define the project's specific context. This involves evaluating factors such as location, climate, and seismic risks that may impact construction. For example, residential projects in high-risk seismic areas, such as Wellington and Christchurch, must consider additional costs for seismic safety. Likewise, areas facing severe weather, such as heavy rainfall or coastal conditions, require cost estimates for improved drainage, protection from the elements, and materials that resist corrosion. By considering these local factors, the framework ensures that all relevant cost factors are incorporated into lifecycle planning from the outset.

Next, the framework supports a detailed cost categorisation process. The five-level hierarchical structure from Section 7.6.4 acts as a guide for breaking down various cost components, from acquisition to end-of-life expenses. Stakeholders should begin by categorising costs into broad categories, such as acquisition, operation, and end-of-life, and then delve into subcategories that include construction costs, energy expenses, and long-term maintenance. The framework's consideration of local variables (such as seismic risk, material strength, and energy use) within these categories enables more precise and context-specific estimates. For instance, when choosing materials in a high-seismic zone, it is advisable to select those that offer both structural strength and long-lasting durability, thereby impacting both initial costs and future maintenance expenses.

After categorising the cost drivers, the next step is to use system dynamics modelling to examine relationships and feedback loops among the identified variables. By utilising the Causal Loop Diagrams (CLDs) from earlier sections, stakeholders can visualise how a choice in one area (like selecting more energy-efficient materials) might affect other costs throughout the lifecycle. The feedback loops revealed through system dynamics analysis help users understand the long-term consequences of their choices. For example, investing in durable materials may lower future maintenance costs, but it could require a higher upfront investment. These dynamic connections support more informed decision-making, enabling stakeholders to anticipate potential cost shifts and adjust their plans as needed.

To make the framework usable across different project sizes, it is important to focus on scalability in its application. The WLC framework should apply to various stakeholders, ranging from large developers to smaller owner-builder projects. For smaller endeavours, a simplified version of the framework could be adopted, highlighting the most significant factors, such as material longevity, seismic safety, and energy efficiency. This easier version could be offered through an Excel tool or web calculator, allowing stakeholders with limited resources to perform basic lifecycle cost estimates. This phase also includes collaborating with local organisations, such as BRANZ or councils, to provide training and templates that help stakeholders in underprivileged or remote areas implement the framework effectively.

Additionally, regulatory systems are likely to be crucial in promoting the widespread adoption of the framework. One approach could be to require WLC assessments as part of building consent applications, especially in high-risk seismic regions. For larger residential projects or those with public access, local councils may require the submission of WLC analysis findings, such as 30-year cost projections, as part of the planning documents. By folding WLC assessments into regulations, the framework can standardise lifecycle cost evaluations across the industry and promote more sustainable and resilient design practices.

Lastly, support from policies and incentives is likely to be crucial for motivating the widespread adoption of the WLC framework. Government agencies or public-private partnerships could tie specific housing grants or incentives to meeting minimum WLC compliance standards. For example, programs like KiwiBuild could require developers to monitor and report on energy, maintenance, and resilience costs over a 30-year period to qualify for financial support or increased density allowances. Furthermore, the framework could align with existing sustainability certification programs such as Green Star, facilitating integration into ongoing efforts to improve the environmental performance of residential buildings.

By following these steps, stakeholders in New Zealand's residential construction sector can effectively integrate the WLC framework into their projects, ensuring a focus on lasting financial and environmental sustainability. The framework serves as a solid tool for evaluating costs, predicting future financial responsibilities, and making informed choices that balance initial expenditures with long-term savings.

Table 7.13: Tailored WLC Framework Structure with Levels 1–5, Including Localised Risk Factors and Additional Cost Elements

s		Level 2		Level 3		Level 4		Level 5	
		1	Non-Construction Costs	1.1	Acquisition Costs	1.1.1	Site acquisition	1.1.1.1	Foreign exchange
								1.1.1.2	Method of financing
								1.1.1.3	Legislative and economic changes
						1.1.2	Administrative, financial, legal, and marketing expenses	1.1.2.1	Regional and geographical conditions
								1.1.2.2	Taxation
								1.1.2.3	Upfront Acquisition cost
								1.1.2.4	Regulatory compliance
		2	Life Cycle Costs	2.1	Construction, Renewal, and Maintenance Costs	2.1.1	Demolition, site preparation, and formation	2.1.1.1	Building resilience to natural hazards
								2.1.1.2	Regulatory compliance
								2.1.1.3	Taxation
						2.1.2	Substructure/ Structure	2.1.2.1	Materials availability
								2.1.2.2	Material durability
								2.1.2.3	Material quality
								2.1.2.4	Material selection
								2.1.2.5	Serviceability of materials
								2.1.2.6	Demand and supply of materials
								2.1.2.7	Construction Quality
								2.1.2.8	Construction technology
								2.1.2.9	Comparability with other building systems
								2.1.2.10	Seismic Resilience
								2.1.2.11	Fire resistance
								2.1.2.12	Wind bracing upgrades
								2.1.2.13	Weather Resilience
								2.1.2.14	Climate Conditions/ Geographical variations
						2.1.3	Architectural works / Non-structural works	2.1.4.1	Consideration of design alternatives
								2.1.4.2	Shape of facility
								2.1.4.3	Efficiency of materials/equipment
								2.1.4.4	Flood mitigation
								2.1.4.5	Design efficiency
								2.1.4.6	Coastal erosion allowances
								2.1.4.7	Insurance premiums for high-risk zones
						2.1.4	Services and equipment	2.1.5.1	Building automation and smart systems
								2.1.5.2	Renewable energy system
								2.1.5.3	Installation practice/ quality

								2.1.5.4	Stormwater upgrades	
								2.1.5.5	Technology depreciation	
						2.1.5	External and ancillary works	2.1.6.1	Water management system	
								2.1.6.2	Building orientation and solar gain	
								2.1.6.3	Greenstar rating	
						2.1.6	Preliminaries and constructors' site overheads	2.1.7.1	Effectiveness of on-site communication and coordination	
								2.1.7.2	Availability of skilled labour	
						2.1.7	Risk allowances	2.1.8.1	Unforeseen circumstances	
								2.1.8.2	Level of uncertainty	
								2.1.8.3	Continuity of supply chain	
						2.1.8	Post-completion loose furniture, fittings, and equipment	2.1.9.1	Residual value	
				2.2	Operation Costs	2.2.1	Cleaning, utilities, waste management	2.2.1.1	Building occupancy type	
								2.2.1.2	Occupancy behaviour	
								2.2.1.3	Estimated annual occupancy hours	
						2.2.2	Security, ICT, site overheads	2.2.2.1	Building security system	
								2.2.2.2	Health and wellbeing	
								2.2.2.3	Acoustic performance	
						2.2.3	Maintenance and replacement costs	2.2.3.1	Maintenance frequency	
								2.2.3.2	Replacement frequency	
								2.2.3.3	Resistance to wear and tear	
								2.2.3.4	Building maintenance technologies	
						2.2.4	Energy and sustainability costs	2.2.4.1	Energy-saving measures	
								2.2.4.2	Renewable resources used	
								2.2.4.3	Environmental cost	
								2.2.4.4	Carbon sequestration	
								2.2.4.5	Green Building Certification Cost	
				2.3	End-of-Life Costs	2.3.1	Disposal inspection, decommissioning	2.3.1.1	Environmental impact evaluation,	
								2.3.1.2	Sustainable deconstruction practices	
						2.3.2	Demolition and reclamation cost	2.3.2.1	Risk allowances,	
								2.3.2.2	Insurance and risk mitigation	
						2.3.3	Site reinstatement	2.3.3.1	Government incentives and subsidies	
								2.3.3.2	Taxation	
		3	Income			3.0.1	Rental Income			
						3.0.2	Disposals			
		4	Externalities			4.0.1	Social impact costs	4.0.1.1	Community displacement	
								4.0.1.2	Infrastructure burden	
								4.0.1.3	Public health impacts	

						4.0.2	User costs	4.0.2.1	Travel time,	
								4.0.2.2	Accessibility issues	
								4.0.2.3	Long-term affordability	

Note: The cost component for each factor in the above framework is provided in Appendix 14.

From an implementation perspective, establishing a national WLC database would be a vital enabler. Such a repository would centralise cost data, material performance insights, and location-specific benchmarks, supporting risk-adjusted financial modelling. This would also enable benchmarking against international systems, such as the UK's Building Cost Information Service (BCIS) and Australia's National Construction Code (RICS, 2020; GBCA, 2021), thereby elevating New Zealand's lifecycle assessment standards. The framework also supports integration into regulatory mechanisms. Mandating WLC assessments for developments in high-risk zones could be complemented by financial incentives such as tax benefits, grants, or reduced insurance premiums. These policy interventions would promote adoption and encourage developers and property owners to invest in long-term resilience and sustainability (NZ Treasury, 2019).

In summary, this section emphasises the tailored WLC framework's strategic and practical relevance to the New Zealand context. While Section 6.6.4 lays out the structural and theoretical foundation, this section demonstrates how the model can be applied, adapted, and institutionalised to enhance decision-making in residential construction.

7.7 Practical and Policy Implications

The enhanced WLC framework developed in this study represents a robust decision-support instrument for stakeholders within New Zealand's residential construction sector. It provides developers and design consultants with a systematic methodology for critically assessing the long-term cost implications associated with early-stage decisions regarding materials, energy systems, and resilience features. This capability facilitates more informed trade-offs between initial capital investment and life-cycle affordability.

Local councils, regulatory bodies, and policymakers, such as the Ministry of Business, Innovation and Employment (MBIE), are well-positioned to leverage the framework to incorporate lifecycle considerations into planning approvals, subsidy design, and compliance regimes. The emphasis on factors such as seismic resilience and energy performance aligns with contemporary national objectives outlined under the Building for Climate Change programme. Furthermore, the modular architecture of the framework enables prospective integration with advanced tools such as Building Information Modelling (BIM), digital twins, and green certification systems (e.g., Green Star NZ).

By actualising long-term cost planning within the context of region-specific risks, the proposed framework contributes to enhanced housing affordability, durability, and climate resilience across New Zealand's residential building inventory.

7.8 Research Limitation

This study acknowledges several key limitations. First, the proposed Whole-life Costing (WLC) framework is conceptual and has not yet undergone empirical validation, such as through case studies, pilot testing, or longitudinal application. These activities are planned as part of future research to assess and refine their real-world performance.

Second, although the framework was informed by expert and stakeholder input to ensure contextual relevance, such qualitative data inevitably reflect a degree of subjectivity and variability in perspectives. Broader engagement and replication with diverse participant groups could strengthen the robustness of the insights.

Third, the development process was constrained by data gaps in current lifecycle cost information, particularly for long-term maintenance expenses, the financial impacts of regulatory changes, and the quantification of social externalities. While the framework highlights the need for improved data infrastructure, effective implementation is likely to depend on ongoing data acquisition, curation, and calibration.

Finally, the use of a system dynamics (SD) approach, though valuable for mapping complex interdependencies, required simplifying assumptions that may omit specific real-world nuances and nonlinearities. Model accuracy is therefore benefit from iterative updating as more empirical evidence and regional datasets become available.

These limitations underscore that the current framework should be viewed as a validated-by-experts design prototype, requiring further testing, refinement, and integration with empirical datasets before it can be confidently deployed at scale.

7.9 Conclusion

The primary aim of this study was to develop a refined Whole-life Costing (WLC) framework specifically tailored to New Zealand's residential construction sector, addressing current gaps in national standardisation, data quality, sector applicability, and resilience considerations. This goal was pursued in response to the distinctive environmental, seismic, and regulatory challenges that influence long-term housing costs in New Zealand.

To achieve this aim, we undertook a multi-stage methodology. First, a comprehensive review and comparative analysis of international LCC/WLC frameworks identified strengths and weaknesses relevant to hazard-prone residential environments. Second, sector-specific requirements were gathered through stakeholder engagement, ensuring the framework incorporated New Zealand's unique seismic risk profiles, climatic conditions, and socio-economic factors. Third, system dynamics modelling, causal loop diagrams, and centrality analysis were applied to map interdependencies between lifecycle cost drivers and to prioritise high-leverage variables, such as seismic resilience, material durability, and energy efficiency. These methodological steps informed the creation of a structured, modular, and nationally standardised WLC framework designed for both rigour and practical usability.

The resulting framework provides a dynamic decision-making tool for lifecycle planning in the residential sector, offering actionable insights for developers, designers, policymakers, and other stakeholders. Beyond its contributions to academic discourse, this framework represents a significant innovation over prior WLC approaches by integrating system dynamics modelling, sector-specific resilience variables, and a full lifecycle scope for the New Zealand residential context. This combination of features presents new opportunities for integrating lifecycle thinking into housing policy and practice, provided that it is validated through further applied research. By enabling resilient design and material selection that considers maintenance, it has the potential to achieve lifecycle savings of approximately 15–25% in high-risk seismic zones when early-stage investments are strategically informed.

To foster industry adoption, we recommend piloting the framework within public housing initiatives, such as Kāinga Ora projects, and fostering collaborations between organisations like MBIE, NZIQS, and BRANZ to produce digital templates and training resources. Future research should focus on validation through case studies, integration with BIM platforms, and development of streamlined tools for smaller developers.

As New Zealand continues to face challenges related to housing affordability and resilience, adopting a lifecycle-based cost framework is timely and necessary. The methodology and tools presented here provide a replicable roadmap for embedding long-term cost considerations into residential construction, supporting more equitable, sustainable, and disaster-resilient housing outcomes.

Chapter 8: Validating a Whole-life Costing Framework for Residential Buildings in New Zealand: A Stakeholder-Based Evaluation

8.1 Prelude

This chapter presents the final phase of this doctoral study: the validation of the Whole-life Costing (WLC) framework developed for residential buildings in New Zealand. In earlier chapters, this research identified the key factors influencing WLC estimation, as discussed in Chapter 4. Chapter 5 examined their dynamic relationships using system dynamics. Chapter 6 designed a tailored WLC framework specifically for New Zealand's residential sector. While these steps addressed theoretical and structural gaps in existing approaches, a crucial step remained: confirming that the proposed framework is practical, relevant, and usable within the industry. New Zealand currently lacks a standard WLC framework for residential construction. There is a recognised value in such tools for improving cost predictability, sustainability, and decision-making. Global models exist but are often too generic, designed for commercial or infrastructure projects, and do not account for local construction practices, regulatory conditions, seismic risks, and climate variability. This gap underscores the need to validate the tailored framework with key industry stakeholders to ensure it aligns with real-world needs and practices.

To address this, Research Question 3 guided this phase: "What improvement in the WLC framework makes it suitable for New Zealand residential buildings?"

This chapter reports on a validation study based on stakeholder input from quantity surveyors, project managers, facilities managers, commercial managers, and government representatives. Using semi-structured interviews and thematic analysis, the study assessed the framework's relevance, usability, clarity, and potential for industry integration. The insights gathered confirmed the framework's applicability and provided recommendations for refining its structure, improving its digital readiness (for BIM integration), and boosting its adoption in public and private sector residential projects. This work has also been shared through a conference paper titled "Validating a Whole-life Costing Framework for Residential Buildings in New Zealand: A Stakeholder-Based Evaluation," submitted to the Global Design and Infrastructure (GDI) 2025 Conference. This submission reflects the broader contribution of the research to international discussions on improving cost management practices in residential construction.

The findings in this chapter ensure that the developed WLC framework goes beyond theoretical design to become a practical, evidence-based tool for long-term cost planning and sustainable residential construction in New Zealand. The following section introduces the background and objectives of this validation study, outlining its role in consolidating the outcomes of the entire research journey.

8.2 Introduction

Whole-life Costing (WLC) is a fundamental approach in construction economics that assesses the total cost of ownership of a building throughout its entire lifecycle, encompassing design, construction, operation, maintenance, and disposal stages (Ashworth & Higgs, 2023). It provides critical insight for long-term economic sustainability and informed decision-making, especially in residential construction, where lifecycle impacts are substantial (Hromada et al., 2021; Trusson, 2019). However, despite its recognised importance internationally, New Zealand currently lacks a dedicated, comprehensive WLC framework explicitly tailored for its residential sector and aligned with the needs of key stakeholders such as quantity surveyors, asset managers, and procurement professionals (Samarasekara, Purushothaman, & Rotimi, 2024).

Current WLC approaches often employ general methods that do not fully account for New Zealand's unique construction features, regulations, and market conditions. Additionally, these frameworks often fail to align with modern construction methods, which limits their effectiveness in today's rapidly changing industry (Omotayo et al., 2024; Zanni et al., 2019a). The rise of new construction technologies presents significant opportunities to enhance WLC processes. These technologies allow for more accurate, transparent, and collaborative cost management throughout the project lifecycle (Hellmuth, 2022; Sacks et al., 2018). Integrating WLC improves scenario analysis, lifecycle optimisation, and enhances communication among project participants. This leads to more sustainable and cost-effective residential construction practices (Ahmad & Thaheem, 2017).

This paper highlights a key gap in New Zealand's residential construction sector: there is no complete WLC framework that suits modern practices and addresses local construction specifics. Despite the recognised benefits of WLC for sustainable and cost-effective building management, existing methods mainly rely on general strategies that overlook New Zealand's regulations, market conditions, and the use of modern tools. This study confirms a Whole-life Costing (WLC) framework tailored for New Zealand's residential construction sector. It ensures the framework meets current industry needs for sustainable and cost-effective building practices. The validation process assesses the practical relevance, clarity, and potential for integration of the framework.

8.3 Literature Review

Whole-life Costing (WLC) is a comprehensive cost management approach that considers the total cost of ownership of a built asset over its entire lifecycle, including planning, design, construction, operation, maintenance, and disposal (Ashworth & Higgs, 2023). Unlike traditional costing methods that only address initial capital expenditures, WLC supports decision-making based on long-term financial and performance outcomes (Trusson, 2019). In residential construction, this method is beneficial for improving affordability, durability, and sustainability (Hromada et al., 2021). Despite growing global interest, WLC is still not widely adopted due to issues with data availability, inconsistencies in methodology, and a lack of tools tailored to local construction conditions (Omotayo et al., 2024). Globally, WLC and Life Cycle Costing (LCC) frameworks vary significantly in scope and quality. In New Zealand, the application of WLC has been primarily confined to infrastructure projects, with little to no adaptation for residential buildings (Samarasekara, Purushothaman, & Rotimi, 2024). A recent comparative study involving 19 countries revealed that New Zealand's current WLC framework lacks consideration of critical local factors, particularly geographical characteristics (GC), adverse weather, and seismic risk, all of which have measurable impacts on residential construction costs (Samarasekara, Purushothaman, Rotimi, et al., 2024).

Additionally, the research of Samarasekara, Purushothaman, Rotimi, et al. (2024) exhibits several practical limitations of current global frameworks. These limitations include the exclusion of key lifecycle components such as disposal, residual value, and externalities, which are essential for comprehensive analysis. Furthermore, there is an absence of a national database or formalised methodology to guide consistent WLC analysis, leading to potential inconsistencies and gaps in data. These omissions reduce the comprehensiveness of cost assessments and hinder accurate long-term financial planning. Moreover, without a formalised national methodology or database, WLC analysis remains inconsistent and difficult to standardise across projects and organisations.

The usability and impact of WLC frameworks depend significantly on alignment with stakeholder needs, especially those of quantity surveyors, asset managers, and procurement professionals (Kishk et al., 2003). Literature indicates that WLC tools that are developed without meaningful input from practitioners in these fields often remain underutilised. This underutilisation is primarily due to the tools lacking practical relevance to everyday workflows and insufficient training provided to users (El-Haram et al., 2002). For successful implementation and widespread adoption, these frameworks must accurately reflect the actual workflows of stakeholders, adhere to relevant regulatory constraints, and incorporate the decision-making criteria that guide their professional activities. In the context of New Zealand, where residential construction projects tend to be fragmented among various public and private sector actors, the absence of such alignment has been a significant barrier. This disconnect has contributed to the poor adoption of lifecycle costing methods within the industry, limiting the potential benefits these methods could provide (Samarasekara, Purushothaman, Rotimi, et al., 2024).

Recognising these limitations, Samarasekara et al. (Samarasekara, Purushothaman, & Rotimi, 2024) developed a novel WLC framework tailored to the specific characteristics of New Zealand's residential sector, which is included in Table 7.13. That framework addressed the influence of adverse weather, geographical variability, and seismic risks while also laying the foundation for future BIM integration. However, the proposed framework has not yet been empirically validated. To ensure practical relevance and industry alignment, it is essential to assess the framework's usability, clarity, and digital compatibility through expert feedback from industry professionals.

This paper directly addresses this need by conducting a validation study that focuses on stakeholders. The research aims to evaluate the clarity, practicality, and context of the framework. The findings provide recommendations based on evidence to improve the model, helping ensure its relevance for industry practitioners and its effectiveness in enhancing whole-life cost estimation for residential buildings in New Zealand.

8.4 Method

This study employs a qualitative research design to assess the relevance, usability, and suitability of a Whole-life Costing (WLC) framework developed for the New Zealand residential construction sector. The framework was developed in earlier research to consider local factors, such as seismic risk, regional climate differences, and construction practices, that affect lifecycle costs. The current phase of the study examines the effectiveness of the framework in practice and whether it meets industry expectations.

To achieve this, purposive sampling helped identify suitable participants who have significant experience in whole-life cost estimation and residential project delivery in New Zealand. Participants needed at least five years of professional experience in the construction sector, with direct involvement in roles such as cost consultancy, project management, asset management, facilities management, or public sector procurement. The final group included five experts from both public and private organisations, providing diverse perspectives across regulatory, operational, and consultancy settings.

Data collection involved semi-structured interviews conducted remotely using Microsoft Teams. Each interview lasted approximately 20 to 30 minutes and was audio-recorded and transcribed verbatim with the participant's consent. The semi-structured format allowed for a consistent set of core questions while giving participants the freedom to elaborate on their insights and share relevant experiences. Interview questions aimed to evaluate the completeness and clarity of the framework, its fit with current industry practices, the usefulness of its cost categorisation, and any barriers or supports for its implementation.

After data collection, a thematic analysis was performed using the six-phase approach outlined by Braun and Clarke (2006). This process involved becoming familiar with the data, creating initial codes, identifying and reviewing themes, and refining them for reporting purposes. NVivo software helped support systematic coding, improve traceability, and ensure consistency throughout the analysis. The validation study focused on three main dimensions of the framework. First, it examined contextual relevance, evaluating how well the framework addresses environmental, regulatory, and economic aspects specific to New Zealand's residential construction sector. Second, it examined usability and clarity from the perspective of practitioners who are likely to use the framework in real-world situations. Finally, it considered the practical challenges and support needed for adopting the framework.

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC) under reference number 24/206. The methodological approach offered a thorough and relevant basis for assessing the WLC framework, ensuring that the findings could lead directly to improvements in the model and support its alignment with the needs of industry professionals involved in residential cost estimation.

8.5 Results

The qualitative data from five participants, PM (Project Manager), GA (Government Authority Employee), CM (Commercial Manager), QS (Quantity Surveyor), and FM (Facilities Manager), were analysed using NVivo software. The analysis addressed key research questions related to WLC estimation in New Zealand residential buildings. Participants demonstrated varying levels of familiarity with WLC in residential settings. Three out of five participants had direct experience using WLC in residential projects. This was especially true for the FM and QS, who noted their active involvement in lifecycle and sustainability-focused initiatives. The other 40%, CM and GA, had a general understanding of construction but limited exposure to WLC in residential settings. They saw it as a developing or less-used concept.

Table 8.1 summarises the key challenges in WLC estimation as pointed out by participants from five professional roles. Three participants mentioned the underestimation or omission of operational and maintenance costs. The FM noted the gap between design and operations teams, while the PM expressed concerns about the limited awareness among clients, GA, and FM. Specific challenges varied by role, including poor documentation quality and a lack of training in estimation (CM), the absence of a standard methodology (PM, QS), and the neglect of social and intangible costs (GA). The QS also pointed out that current costing methods are reactive and inflexible.

Table 8.1: Challenges in Current WLC Estimation Methods

Challenges	PM	GA	CM	QS	FM
Absence of standard methodology	✓			✓	
Lack of post-occupancy cost tracking	✓	✓			✓
Limited client awareness	✓				
Exclusion of social and intangible costs		✓			
Lack of Education and Training in Estimation			✓		
Poor Quality of Project Documentation			✓		
Reactive and Inflexible Costing Methods				✓	
Disconnect Between Design and Operations Teams					✓

Note. QS = Quantity Surveyor; PM = Project Manager; CM = Commercial Manager; GA = Government Authority Representative; FM = Facilities Manager

All five participants agreed on the need for a standardised framework for WLC estimation in the New Zealand residential construction sector. PM and QS believed that a consistent structure would facilitate benchmarking, enhance communication among project teams, and minimise estimation errors. FM added that such a framework would clarify the connection between design choices and long-term operational impacts, which is often lacking in current practices. GA and CM emphasised the potential for a standard framework to serve as a contractual reference or compliance tool, especially in public sector housing or sustainability-focused projects. Most respondents suggested that the framework should follow international standards, such as ICMS, but be adjusted to fit local practices. Several also recommended testing the framework on government-led housing projects to show its value and effectiveness in real-world situations.

Participants examined the framework's cost categorisation closely. Most agreed that it was comprehensive, particularly in differentiating between capital, operational, and end-of-life costs. The key points raised by participants are summarised in Table 8.2.

Table 8.2. Summary of Participant Feedback on Cost Factors and Framework Coverage

Cost Factor / Theme	Included in Framework	PM	GA	CM	QS	FM
Capital, operational, and end-of-life separation	Yes	✓	✓	✓	✓	✓
Indirect operational costs (e.g., security, ICT licences)	No					✓
Tenant turnover costs	No		✓			
Energy tariff escalation	No		✓			
Disposal-phase costs (e.g., environmental levies, carbon tax)	Partially	✓		✓	✓	
Moisture-related deterioration / regional climate effects	Partially			✓		✓
Social value metrics	No		✓			
Smart metering/energy optimisation systems	No				✓	
Construction material price volatility (timber, plasterboard)	No	✓				

Note. QS = Quantity Surveyor; PM = Project Manager; CM = Commercial Manager; GA = Government Authority Representative; FM = Facilities Manager

Participants shared important feedback on how well the proposed WLC framework fits with the specific environmental and economic conditions unique to New Zealand's residential sector. Table 8.3 summarises the Quote-to-Question Mapping for Applicability to the NZ Context.

Table 8.3. Participants' comments on applicability

Participant	Quote / Comment	Mapped Question(s)	Suggested NVivo Node
PM	The framework effectively addresses seismic risk, which is crucial for NZ.	Q8	Applicability to NZ: Seismic Risk
CM	Seismic strengthening and repair cycles vary between regions and should be explicitly included.	Q8	Applicability to NZ: Regional Construction Economics
QS	High UV exposure in coastal regions accelerates material degradation, which needs to be modelled.	Q8, Q7	Applicability to NZ: Environmental Wear
FM	Regional weather patterns and microclimates heavily influence maintenance and renewal cycles.	Q8, Q9	Applicability to NZ: Regional Climate Variation
PM	Labour productivity and cost indices differ significantly between Canterbury and Wellington, especially after seismic events.	Q9	Applicability to NZ: Regional Construction Economics
QS	Include UV-related deterioration metrics to improve cost forecasting accuracy.	Q7	Framework Refinement: Material Performance Factors
FM	Region-specific climate files and local data inputs should support the framework.	Q8, Q4	Framework Refinement: Regional Climate Variation
PM	Seismic factors are well addressed, but regional recovery costs (e.g., in Canterbury) should also be taken into consideration.	Q9	Applicability to NZ: Regional Construction Economics

Note. QS = Quantity Surveyor; PM = Project Manager; CM = Commercial Manager; GA = Government Authority Representative; FM = Facilities Manager

The overall structure and purpose of the WLC framework received positive feedback, but participants expressed concerns about its usability. The suggestions are shown in Table 8.4.

Table 8.4. Participants' feedback on usability and practical implementation

Suggestion	Description	Participant
Dashboard Interface	Include drop-down menus and cost templates to streamline use	GA, QS
Reduce Manual Input	Manual data entry may reduce adoption for small projects	CM
Prepopulated Data & Models	Embed datasets and scenario modelling to ease learning	FM
Example Case Studies	Develop case studies for practical illustration	PM
Simplification & Support	Overall, there is a need for simpler tools to increase effectiveness	All

Note. QS = Quantity Surveyor; PM = Project Manager; CM = Commercial Manager; GA = Government Authority Representative; FM = Facilities Manager

Participants agreed that connecting the framework to the International Construction Measurement Standards (ICMS) would enhance credibility and facilitate international comparisons. QS pointed out the potential to boost investor confidence, especially for projects that involve offshore funding. PM suggested mapping each part of the framework directly to ICMS codes and creating a standardised glossary based on ICMS and RICS terms. GA mentioned that using international case studies would aid in establishing global relevance while also keeping local applicability. This feedback supports the view that international alignment serves as both a quality standard and a way to promote wider acceptance and compatibility.

In addition to the thematic insights, participants offered several suggestions for future research and innovation. CM and FM recommended exploring how the WLC framework can integrate with BIM tools to automate quantity extraction and scenario analysis. PM suggested creating a national database of post-occupancy cost data, which could significantly improve the accuracy of WLC estimates over time. GA mentioned the possibility of using machine learning to predict maintenance intervals and cost increases based on regional factors. Together, these ideas indicate a growing interest in digitising and implementing WLC through innovative technologies and collaboration across the industry.

8.6 Discussion

The validation interviews confirmed the importance of a tailored Whole-life Costing (WLC) framework for New Zealand's residential construction sector. The findings are best understood through three main dimensions: contextual relevance, practical usability, and digital readiness. These dimensions collectively influence the framework's potential for real-world use and integration into digital construction workflows.

Participants consistently affirmed that the framework effectively addresses New Zealand-specific environmental and economic factors. These include seismic risks, climate-related wear, and regional variations in labour and material costs. The explicit inclusion of factors such as UV-induced degradation, microclimate effects, and post-seismic repair cycles ensures that the framework is suitable for the local context. This relevance not only improves lifecycle cost estimation but also boosts the framework's credibility among practitioners in New Zealand. However, participants suggested adding tenant turnover costs, fluctuating material prices, and social value metrics to reflect the changing realities of residential construction in New Zealand. This feedback emphasises the need for a flexible framework that evolves in response to stakeholder insights and regulatory changes, ensuring relevance in a shifting policy and environmental landscape.

While participants generally viewed the framework as thorough, they expressed concerns about its practical application in typical project workflows. Many called for simplification through digital dashboards, automated templates, and illustrative case studies. Without these tools, the framework could be underused due to its perceived complexity, especially in smaller projects with limited resources. Participants across all roles supported the framework's clarity, particularly its structure of separating capital, operational, and end-of-life costs. However, calls for greater standardisation in terminology surfaced, such as aligning with ICMS and RICS definitions, along with more precise guidance for mapping local data to framework components. These improvements would enhance clarity and facilitate comparisons across projects.

The framework's link to BIM workflows was seen as crucial. Most participants agreed that digital integration is vital for real-time cost tracking, data exchange, and scenario planning. Suggestions included embedding the framework into BIM tools to automate quantity extraction and lifecycle simulations, which could boost efficiency and user engagement, and overcome adoption barriers and accuracy issues. Some recommend using BIM for regional simulations and prepopulated models to cut manual work. Aligning with digital construction supports industry digitalisation and enhances the framework's role in future BIM-WLC integration. Challenges include financial short-termism, fragmented incentives, lack of cost databases, and training. To overcome these challenges, stakeholders suggested collaboration, government mandates, pilot projects, and incorporating lifecycle costing into regulations and procurement to encourage sectoral change.

8.7 Conclusion

This study achieved its aim by confirming a Whole-life Costing (WLC) framework for New Zealand's residential construction sector through stakeholder engagement. Key findings highlighted the framework's relevance and comprehensiveness, addressing often-overlooked costs such as maintenance, disposal, environmental damage, and regional economic changes specific to New Zealand's unique conditions. Limitations identified include the need to incorporate indirect operational costs and improve usability through simpler templates and illustrative case studies. The practical implications emphasise the framework's importance for consistent, long-term cost planning and informed decision-making in both public and private residential projects. Socially, it emphasises the need to consider broader lifecycle costs and their impacts on communities. Recommendations include connecting the framework with Building Information Modelling (BIM) to enhance collaboration and transparency in cost estimation. Future studies should test the framework in real-life projects, develop BIM-compatible templates, and expand participant involvement to capture diverse perspectives on long-term value in residential development.

Chapter 9: Discussion and Conclusion

This chapter presents the discussion and conclusion of the study. It begins by critically interpreting the findings in relation to the research objectives, existing literature, and the New Zealand residential construction context. The discussion highlights the theoretical, methodological, and practical implications of the research. The chapter then concludes by synthesising the key findings, outlining the study's contributions, acknowledging its limitations, and identifying directions for future research.

9.1 Discussion

This chapter reviews and reflects on the findings from Chapters 3 to 8, considering the study's goals and the broader research themes of residential construction frameworks, relationships, economic parallels, and contributions to knowledge. The research investigated global factors influencing whole-life costing (WLC), analysed their dynamics in New Zealand's residential sector, developed a refined WLC framework, and validated it through input from stakeholders, thereby filling a significant gap in both literature and practice by creating a context-specific and practical lifecycle cost framework for New Zealand's residential sector.

Taken together, the findings across Chapters 5 to 8 addressed the research objectives outlined in Chapter 1. Chapter 5, 'Interrelations of the Factors Influencing the Whole-Life Cost Estimation of Buildings: A Systematic Literature Review', responded primarily to Objective 1 by identifying and explaining the interrelationships among global WLC factors. Chapter 6, 'A System Dynamics Approach to Evaluating Factors Influencing Whole-life Cost Estimation for Residential Buildings in New Zealand', addressed Objective 2 by examining these factors in the New Zealand residential context and refining them for local application. Chapter 7, 'A System Dynamics Framework for Whole-life Costing in Seismic and Climate-Sensitive Residential Construction in New Zealand', responded to Objective 3 by developing a New Zealand-specific WLC framework that incorporated seismic and climate-related risks. Chapter 8, 'Validating a Whole-life Costing Framework for Residential Buildings in New Zealand: A Stakeholder-Based Evaluation', supported Chapter 7 by validating the developed framework with industry stakeholders and identifying areas for refinement and future development. This chapter discusses these outcomes in an integrated way, highlighting their theoretical, methodological, and practical implications.

Chapter 5 established that while WLC principles are standardised globally through guidelines like ISO 15686-5, the prioritisation of cost factors depends on context and is influenced by specific national conditions (ISO, 2017). In New Zealand, factors such as seismic resilience, climatic variability, and changing regulatory requirements make it insufficient to adopt foreign models directly. This finding aligns with the Treasury's Whole of Life Costs Guidance, which stresses the need for WLC approaches that incorporate local regulatory and operational realities (treasury.govt.nz, 2015). Therefore, the framework suggested in Chapter 7 builds on these global principles and adapts them for the residential sector in New Zealand, incorporating considerations for building service life, ongoing maintenance demands, and the country's affordability challenges. This tailored approach gives stakeholders a more effective tool for lifecycle financial planning in residential construction.

A key contribution of Chapter 6 was the application of system dynamics to model the relationships among WLC factors. Unlike traditional static models, system dynamics acknowledges feedback loops, time delays, and emerging behaviours in complex systems (Sterman, 2002). This perspective highlighted how policy changes, like adjustments to insulation or seismic codes, create ripple effects on initial capital costs, long-term energy use, and maintenance schedules. Similarly, climate-related pressures, particularly in coastal areas, influence decisions regarding material durability and renewal timelines, underscoring the interconnectedness of cost factors throughout a building's life. By employing a systems approach, this study demonstrates that lifecycle costing should reflect the adaptive and changing nature of residential construction economics, rather than treating costs as a one-time calculation.

In reflecting on the weighting process used in Chapter 6, it is important to clarify the rationale for the ratings applied in the Analytic Hierarchy Process (AHP). The study adopted the standard 1–9 AHP scale, in which 1 represents equal importance, and 9 represents extreme importance between two factors, because this scale is widely accepted and intuitive for expert judgement. The specific scores assigned to each factor were derived from a frequency-based procedure that linked numerical values to evidence from both the systematic literature review and the semi-structured interviews. Factors that appeared more frequently in the reviewed studies, or were mentioned by a larger number of interviewees, received higher scores to reflect stronger academic or practitioner consensus. Where a factor was supported by both sources, the higher of the two scores was retained, ensuring that either robust literature evidence or strong industry agreement was sufficient to classify it as highly important. This approach strengthened the transparency and methodological robustness of the weighting process and, by extension, the prioritisation of factors in the WLC framework.

The economic findings of this research also have relevance beyond New Zealand. Although the study focuses on a local context, this chapter situates its insights within a broader economic framework. Regions like Japan and California, which also face seismic risks and resilience-driven design requirements, show similar cost increases and maintenance needs, providing valid points for comparison (Haapio & Viitaniemi, 2008). In New Zealand, the leaky homes crisis, which has cost the country approximately NZD 11 billion in repairs, highlights the financial impact of ignoring lifecycle interdependencies (Library, 2002). These examples underscore the importance of incorporating resilience and whole-of-life thinking into residential construction frameworks, as failures in these areas can result in substantial unplanned costs over time.

In this context, the 'tipping points' in the economic considerations of the framework refer to the conditions under which a higher-performing but more expensive option becomes preferable to a cheaper, lower-performing alternative over the building's life. These tipping points occur when additional upfront investment in resilience or performance (for example, enhanced seismic detailing, durable cladding, or improved thermal performance) is offset by reductions in long-term maintenance, repair, and failure-related costs, as well as avoided social and economic disruption. Rather than specifying a single numerical break-even value, the framework highlights these tipping points conceptually by showing how changes in key cost drivers, construction, operation, maintenance, and hazard-related losses, can shift the balance between short-term affordability and long-term economic sustainability.

The Chapter 8 validation, however, also revealed several areas that require further exploration and development. These areas, which were identified as future research directions, include the integration of data forecasting models, BIM adoption, and regional climate-based modules.

1. Material Evaluation: While material evaluation is a critical part of sustainable construction, it does not directly influence the monetary aspect of WLC. During the validation process, it was confirmed that material evaluation is essential from a sustainability and resilience perspective. However, it does not need to be included as a direct cost factor in the WLC framework.

2. Compliance and Regulatory Integration: The inclusion of compliance and regulatory integration within the framework was validated through stakeholder feedback, with no significant modifications required, as it was already considered in item 2.1.1.2 of Table 7.13.

3. Forecasting and Predictive Models: While forecasting and predictive models are not fully integrated into the current WLC framework, the framework does allow for future research in this area. Currently, the framework focuses on providing a robust, context-specific model for residential buildings in New Zealand, taking into account key cost drivers such as seismic risks, climate factors, and operational life expectancy. However, the integration of forecasting methods that incorporate tools such as GeoNet maps or similar New Zealand-specific methods is identified as a critical area for further development. The framework lays the foundation for future work that could incorporate these geospatial and environmental data sources into long-term cost predictions. For instance, incorporating real-time data from GeoNet maps, which track seismic risk and fault lines, could significantly improve the accuracy of seismic risk assessments in long-term cost projections. Similarly, methods that integrate climatic data, environmental hazards, and regional geospatial information could be developed to enhance cost forecasting for residential buildings, ensuring more reliable future predictions as these factors evolve over time.

4. BIM Integration: Another significant area identified during the validation process is the integration of Building Information Modelling (BIM). BIM has the potential to enhance real-time cost tracking, improve data collection accuracy, and provide a platform for informed decision-making throughout the building lifecycle. While BIM adoption is a growing trend, it remains a future research focus as the full integration of

BIM with the WLC framework will require more research and development, including aligning BIM tools with lifecycle cost data.

5. Regional and Climate-Based Modules: Given New Zealand's unique geographical and climate conditions, incorporating regional and climate-based modules into the WLC framework is another area for future research. The validation process confirmed that incorporating seismic risks, extreme weather, and location-specific factors would enhance the robustness and adaptability of the framework. Developing these modules will enhance the framework's applicability to regions with specific environmental challenges.

This study makes several important contributions to knowledge. It introduces the first WLC framework specifically designed for New Zealand's residential construction sector, bridging the gap between international lifecycle costing principles and local application. It broadens the methodological focus of WLC research by using system dynamics, offering a detailed approach to modelling the feedback loops and interdependencies that influence cost outcomes. Additionally, by validating the framework with professionals, the study ensures that it aligns with industry practices and is ready for integration into digital tools, such as Building Information Modelling (BIM), which can support real-time cost tracking and scenario analysis throughout a building's lifecycle (Eastman, 2011). This practical validation enhances the framework's credibility and potential for adoption in an industry that is increasingly relying on technology-based decision-making tools.

Placing this research within the broader discussion on WLC reveals that it becomes clear that, while the framework is tailored for New Zealand's residential sector, its principles and systems-oriented design can be applied to other construction fields, including commercial buildings and infrastructure. The integration of feedback-based modelling and alignment with international standards, such as ISO 15686, ensures that the framework adds value to global lifecycle costing practices while also being sensitive to local needs. This way, the study lays a foundation for both national policy development and international knowledge sharing on cost-effective, sustainable construction.

The findings also carry important theoretical and methodological implications. Theoretically, the study advances whole-life costing knowledge by demonstrating the need for context-specific adaptation and by framing WLC as a dynamic, feedback-driven process rather than a static calculation. Methodologically, the integration of systematic literature review, qualitative inquiry, Analytic Hierarchy Process, and system dynamics offers a robust and replicable approach for analysing complex cost interdependencies. These insights reinforce the value of adopting systems-oriented approaches in lifecycle cost research, particularly in contexts characterised by environmental uncertainty and regulatory complexity.

In summary, this research advances lifecycle cost management by combining solid concepts with practical applications. It places New Zealand's residential construction issues in a global perspective, showing that WLC is more than just a financial task; it's a dynamic process shaped by regulatory changes, environmental factors, and socio-economic realities. By doing so, it provides a solid foundation for informed financial planning, effective policymaking, and sustainable housing outcomes, making a substantial contribution to both academic research and industry practice.

9.2 Conclusion

This thesis has explored the factors affecting Whole-life Costing (WLC) in New Zealand's residential construction sector. It looked at how these factors are connected through system dynamics modelling and created a framework for more precise and context-sensitive lifecycle cost estimation. The primary objective was to develop a robust, practical, and theoretically grounded WLC framework that aligns with New Zealand's specific regulatory, environmental, and economic conditions while adhering to international best practices. By effectively meeting the four research objectives outlined in Chapters 4 to 7, this study addresses the central research question: How can Whole-life Costing be adapted and utilised to enhance lifecycle cost estimation for residential buildings in New Zealand?

The first objective was to identify specific factors and their connections that impact whole-life cost estimation of residential buildings globally. This was achieved through a thorough literature review and the identification of factors in Chapter 4. The review revealed that while WLC principles are well-established internationally (ISO 15686-5, 2008), their application in the residential sector, particularly in New Zealand, is still limited. The study identified a wide range of cost drivers, including those related to acquisition, construction, maintenance, operations, and end-of-life phases, as well as contextual factors such as regulatory changes, climate-related wear and tear, and affordability issues. These findings served as the basis for developing the framework.

The second objective focused on understanding the system dynamics of the factors that affect the accuracy of WLC estimation in New Zealand. This was addressed in Chapter 5. Using system dynamics modelling (Sterman, 2000), the study mapped out feedback loops and causal relationships between cost factors. It showed that lifecycle costs result from complex, interacting systems rather than simple additive elements. The model clearly illustrated reinforcing and balancing loops, providing insights into the impacts of regulatory changes, trade-offs between initial capital costs and long-term savings, and the influence of climate on material durability and maintenance schedules. While it primarily focused on qualitative aspects, the model was designed to be expandable for quantitative simulations, which would allow future scenario testing and predictive analysis.

The third objective was to develop a WLC framework to make it suitable for residential buildings in New Zealand. This was tackled in Chapter 6. Building on the identified cost factors and their dynamic relationships, the research developed a tailored WLC framework that integrates international standards (ISO 15686) with New Zealand-specific conditions, including seismic requirements, regional climate variations, and socio-economic factors. This framework represents a noteworthy step in aligning global WLC principles with local construction needs, providing a useful tool for decision-makers. Importantly, its modular design allows for adaptation to other building types, such as commercial and infrastructure projects, without compromising its core structure, making it relevant beyond the residential construction sector.

Framework validation is crucial to propose necessary improvements to the WLC framework to make it suitable. Therefore, validation has been carried out through input from stakeholders. This was accomplished in Chapter 7. Feedback was gathered from five industry professionals, including quantity surveyors, project managers, policymakers, and commercial managers, who represent essential roles in the residential construction lifecycle. Their feedback confirmed the framework's relevance, practicality, and adaptability for industry purposes. Participants highlighted its potential for integration with digital technologies, such as Building Information Modelling (BIM), which allows for real-time cost tracking and scenario analysis throughout the building lifecycle. This validation process enhanced the framework's credibility and support for its practical use. Interestingly, the validation process did not result in significant modifications to the initial framework. This indicates that the framework was already well-structured and fit for purpose, accurately reflecting the cost drivers that impact the long-term sustainability of residential buildings in New Zealand.

9.2.1 Significance of the Study

This thesis makes several important contributions to both academic research, industry practitioners, government and policymakers, builders and homeowners. It introduces the first WLC framework specifically designed for New Zealand's residential construction sector, filling a significant gap in the literature and practice. It brings methodological innovation by integrating system dynamics into WLC modelling, offering a richer, systems-focused view on cost behaviour over time. It provides insights grounded in empirical evidence, validated by industry professionals, ensuring the framework addresses real-world challenges and meets the needs of decision-making. By aligning the framework with international standards, such as ISO 15686, while considering local factors, the study bridges the gap between domestic application and global comparability, contributing to the international conversation on lifecycle cost management.

9.2.1.1 Significance for academia

For academia, the study advances whole-life costing research in three main ways. First, it extends WLC scholarship into a context that is both under-represented and technically challenging: seismic- and climate-sensitive residential construction in New Zealand. Second, it demonstrates the value of combining systematic literature review, qualitative inquiry, Analytic Hierarchy Process, and system dynamics within a single integrated research design for WLC studies. Third, the resulting conceptual framework and causal loop structures provide a replicable methodological template that can be adapted to other building types and international settings, supporting comparative and cross-context research on lifecycle costs.

9.2.1.2 Significance for industry practitioners

For industry practitioners such as quantity surveyors, project managers, facilities managers, and developers, the framework offers a structured and transparent way to integrate lifecycle thinking into day-to-day decisions. It identifies and organises the most influential cost factors over the building life, including those related to seismic resilience, climate exposure, and maintenance, enabling practitioners to move beyond initial capital cost and consider long-term financial implications. The framework can support cost planning, procurement strategies, value engineering, facilities management, and asset management. Although it has not yet been fully integrated into digital platforms such as BIM, it provides a clear conceptual foundation for the development of future digital tools that can enable more informed, auditable, and adaptive cost decisions across the project lifecycle

9.2.1.3 Significance for government and policymakers

For government agencies and policymakers, the study provides an evidence-based tool for assessing the long-term cost consequences of regulatory and policy decisions. The framework can support analysis of how changes in building codes, energy-efficiency requirements, or resilience standards affect not only upfront construction costs but also operating, maintenance, and retrofit costs over time. By highlighting the feedback loops among regulation, performance, and lifecycle expenditure, the research can assist in developing policies, incentives, and guidance that promote economically sustainable and resilient housing, and it offers a structured basis for integrating WLC considerations into public procurement and housing programmes.

9.2.1.4 Significance for builders and homeowners

For builders and homeowners, the findings underline the practical value of viewing housing decisions through a whole-of-life cost lens rather than focusing solely on initial price. The framework helps reveal how choices around materials, design, and performance standards influence future costs related to energy use, maintenance, and resilience to hazards. This perspective can support builders in communicating the long-term benefits of higher-performing, resilient housing solutions, and it equips homeowners and prospective buyers with a clearer understanding of the trade-offs between upfront affordability and ongoing cost burdens. In doing so, the study contributes to more informed, sustainable housing decisions at the household level as well as across the wider residential market.

9.2.2 Research Limitation

While this study has successfully met its primary goal of developing a whole-life costing (WLC) framework for New Zealand residential buildings, several limitations should be acknowledged. These limitations do not undermine the value of the research but provide important context for interpreting the findings and identifying directions for further work.

First, the study adopted a qualitative, interpretivist design with a purposive sample of 22 interviewees and 5 expert validators. This approach generated rich, context-specific insights into WLC practices and perceptions; however, it also limits the statistical generalisability of the findings to the wider construction industry. The views captured may not fully represent all stakeholder groups or regions within New Zealand.

Second, the Analytic Hierarchy Process (AHP) and system dynamics modelling relied heavily on expert judgement. The assignment of factor weights and the specification of causal links and feedback loops are inherently subjective and could vary if a different panel of experts were involved. Although efforts were made to ensure consistency and transparency in these processes, the resulting structure and prioritisation of factors should be interpreted as one well-justified configuration rather than the only possible representation.

Third, New Zealand-specific WLC data remain sparse, particularly for long-term operation, maintenance, seismic retrofits, and climate-related impacts. As a result, some cost components and relationships had to be informed by secondary literature, indicative estimates, and international benchmarks. This reliance on indirect data sources may reduce the precision of certain estimates and limit the extent to which the framework can presently be used for detailed numerical prediction.

Fourth, the proposed framework is conceptual and currently supported by causal loop diagrams rather than full quantitative system dynamics simulations or extensive case-study applications. It has not yet been embedded in digital platforms such as BIM or CostX, nor has it been numerically tested on real residential projects. Consequently, its performance as a decision-support tool in live project environments remains to be empirically demonstrated.

Finally, the scope of the study is restricted to standalone two-storey family homes in New Zealand, with environmental and social costs treated at a relatively high level. The framework is therefore not directly generalisable to multi-unit residential developments, commercial buildings, or non-New Zealand contexts without careful adaptation and additional validation. Together, these limitations highlight the need for further empirical testing, data refinement, sectoral extension, and digital integration, which are addressed in the subsequent recommendations for future research.

9.2.3 Future Research

Building on the limitations and contributions of this study, several avenues for future research are recommended to refine and extend the proposed WLC framework.

First, further work should adapt and validate the framework across a wider range of building types and project contexts. Extending the framework to multi-unit residential developments, commercial buildings, and infrastructure projects would enable assessment of its transferability and scalability, and would reveal sector-specific cost drivers that may require additional refinement.

Second, there is significant potential to strengthen the framework through deeper integration of New Zealand's seismic hazard information. Future studies should incorporate GeoNet's spatial seismic hazard data, including peak ground acceleration and spectral accelerations, to enable location-specific modelling of earthquake resilience and associated lifecycle costs across different regions. This work could be enhanced by developing automated data pipelines or application programming interfaces (APIs) that feed GeoNet data and geotechnical site classifications directly into WLC tools, supporting compliance with NZS 1170.5 and improving the accuracy of earthquake-related cost estimates.

Third, advancing from conceptual causal loop diagrams to fully operational quantitative models represents an important next step. Future research should develop and test quantitative system dynamics simulations that use the proposed framework to explore cost trajectories under varying regulatory settings, climate change scenarios, and economic conditions. Such simulations would provide more robust forecasts, sensitivity analyses, and scenario comparisons, strengthening the framework's role as a decision-support tool.
Fourth, there is a need to develop and trial digital prototypes that operationalise the framework in practice. A proof-of-concept software tool could embed the WLC framework within an interactive platform that integrates prepopulated regional climate and seismic datasets, live connections to cost databases, and user-friendly scenario-modelling interfaces. Subsequent work should also explore interoperability with Building Information Modelling (BIM) so that lifecycle cost information can be linked to, and updated alongside, evolving design and construction data throughout a project's life.

Finally, future studies should broaden stakeholder participation beyond the expert group used in this research. In particular, future research should engage financiers, homeowners/end-users, and insurers, alongside facilities managers and additional industry practitioners, because these groups control critical cost drivers such as financing terms, occupancy behaviour, and risk premiums. Involving these stakeholders in further validation exercises and longitudinal case studies would enrich understanding of how the framework performs in real projects and how lifecycle cost information influences decision-making. This expanded engagement would support progressive refinement of the framework and its successful uptake across New Zealand's residential construction sector and beyond.

In conclusion, this thesis has developed and validated a whole-life costing framework that is specifically tailored to New Zealand's residential construction sector and responsive to seismic and climate-related risks. By integrating systematic literature review, empirical inquiry, and system dynamics modelling, the study has advanced understanding of how key cost factors interact over the building lifecycle and has provided a structured basis for more informed, long-term decision-making. Although the framework is subject to the methodological and contextual limitations outlined above, it offers a robust platform for future empirical testing, digital implementation, and extension to other building types and regions. Taken together, these contributions position whole-life costing as a dynamic, context-sensitive process that can support more sustainable, resilient, and economically sound housing outcomes in New Zealand and beyond

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Appendices

Appendix 1: Ethical Approval (Stage 1) – Semi-structured Interviews

24 July 2024
Mahesh Babu
Faculty of Design and Creative Technologies

Dear Mahesh

Ethics Application: **24/206 An evidence-based framework for Whole-life Cost Analysis of Residential Buildings in New Zealand**

Thank you for submitting your application for ethical review. We are pleased to advise that a subcommittee of the Auckland University of Technology Ethics Committee (AUTEC) approved your ethics application **in stages**, subject to:

1. Clarification whether a number of professionals need to be from the same organisation and whether clients need to be of those organisations;
2. Clarification of how the "client" participant group are identified, contact details obtained and recruited; Please note that research is opt in and therefore potential participants do not have to decline (C.3.5.3);
3. How is confidentiality maintained (H.1) or will participants be offered the opportunity to be identified to acknowledge their professional standing. If this opportunity is offered please include this in the Information Sheet and a specific yes/no option in the Consent Form;
4. Provision of where the Consent Forms will be stored (H.11). Please note that the Data management Tool is not a data storage device but a document (H.9);
5. Provision of how the consent forms will be destroyed (H.12);
6. Provision of what ways the participants may experience discomfort or risk (I.1.4); Is it not unlikely given that no sensitive topics are discussed, the Information Sheet says that there is no risk;
7. Provision of an assurance that no participant will have a supervisory and managerial relationship with the researcher;
8. AUTEC recommend sending the Consent Form to potential participants when the Information Sheet is sent;
9. Amendment of the Invitation email as follows;
    a. Inclusion of the researcher's name in the introduction;
    b. Revision of " My next research phase involves interviews with experts on the subject." To include what the subject is;
    c. Revision to include what the second interview is validating;
    d. Removal of the confidentiality paragraph;
    e. Removal of "the "Should any member wish to participate..." as the participants will be contacting the researcher directly and a third party should not be providing participants details;
    f. Inclusion of the AUTEC approval number;
10. Amendment f the advertisement as follows:
    a. Inclusion of the AUT logo and the AUTEC approval number;
    b. Add the word "years after "5+"
11. Revision of the Consent Form to use the AUTEC exemplar;
12. Removal of contact details being kept for future use as there was no information about this in the EA1 or provision of a rationale for doing so;

13. Amendment of the Information Sheet as follows;
    a. Inclusion of the researcher's name in the introduction;
    b. Remove the statement about exclusion criteria from the "How was I identified" section.
    c. Removal of "anonymised" as interviews are not an anonymous form of data collection;
    d. Revision of the first page to not be a letter but an introduction paragraph that leads into the Information Sheet;
    e. Revision of how to agree as the participant will already have the Consent Form;
    f. Revision for repetition of information;
    g. Removal of the offer of counselling;
    h. Removal of "anonymisation" of data as the data is deidentified; Revision of the feedback section to be no more than a paragraph.
    i.

An amendment is required for the stage 2 interviews as a framework is being discussed that is not yet developed.

Please provide a response to the conditions in a memo and attach any altered documents, such as the Information Sheet, Consent Forms, Survey.

A revised EA1 is not required unless specifically requested in the conditions.

Please reference the application number and study title in all correspondence.

The Committee is always willing to discuss with applicants the points that have been made. There may be information that has not been made available to the Committee, or aspects of the research may not have been fully understood.

When the conditions have been met, you will be notified of the full approval of your ethics application. Full approval is not effective until all the conditions have been met. Data collection may not commence until full approval has been confirmed. If these conditions are not met within six months, your application may be closed, and a new application will be required if you wish to continue with this research.

If you have any enquiries about this application, please contact us at ethics@aut.ac.nz.

(This is a computer-generated letter for which no signature is required)
The AUTEC Secretariat
Auckland University of Technology Ethics Committee
Cc: herath.samarasekara@autuni.ac.nz; funmi.rotimi@aut.ac.nz; Ali GhaffarianHoseini

Appendix 2: Participant's Information Sheet (Stage 1)

Date Information Sheet Produced:

20 Aug 2024

Project Title

An evidence-based framework for Whole-life Cost Analysis of Residential Buildings in New Zealand

Introduction

My name is Herath Mudiyanselage Samadhi Nayanathara Samarasekara, and I am pursuing a PhD at the Auckland University of Technology (AUT) within the Faculty of Design and Creative Technologies. I am conducting a research study as part of my doctoral degree requirements, and I am writing to invite you to participate in this research. This study aims to develop a comprehensive whole-life cost (WLC) framework tailored specifically for residential buildings in New Zealand. The overarching goal is to enhance cost estimation accuracy and promote long-term economic sustainability in the construction industry.

What is the purpose of this research?

This research aims to develop a comprehensive whole-life cost (WLC) framework tailored specifically for residential buildings in New Zealand. The aim is to enhance cost estimation accuracy and promote long-term economic sustainability within the construction industry. This research will engage key stakeholders, such as clients, end-users, architects, engineers (both services and structural), quantity surveyors, project managers, facility managers, and government authorities, to gather insights and expertise.

Through semi-structured interviews, participants will contribute to identifying key factors influencing WLC estimation, understanding system dynamics specific to the New Zealand context, and proposing improvements to existing frameworks. The research seeks to address New Zealand's unique geographical characteristics, including seismic resilience and adverse weather conditions.

The specific objectives of this study include:

Determining the specific factors and their interrelationships that impact whole-life cost estimation of residential buildings globally.

Establishing the system dynamics of elements that affect the accuracy of whole-life cost estimation for residential buildings in New Zealand.

Proposing improvements required in the current WLC framework to make it suitable for residential buildings in New Zealand.

The expected outcome is a robust WLC framework that enhances informed decision-making among stakeholders, promotes sustainable building practices, and optimizes the long-term economic performance of residential construction projects. This research's findings may be used for academic publications and presentations, contributing to the advancement of global standards in WLC assessment methodologies.

How was I identified and why am I being invited to participate in this research?

You were identified and invited to participate in this research because you are a key stakeholder in the residential construction industry in New Zealand. Your expertise and insights are invaluable to achieving the objectives of this study, which aims to develop a comprehensive whole-life cost (WLC) framework tailored specifically for residential buildings in New Zealand.

The recruitment and selection process involved identifying and mapping key stakeholders based on the stages outlined in the RIBA Plan of Work. These key stakeholders include clients, end-users, architects, structural engineers, services engineers, civil engineers, quantity surveyors, planning/regulatory authorities, project managers, site engineers, and facility managers. You have been selected because your role and experience align with the inclusion criteria for this study, which focuses on professionals directly involved in the consultant and construction teams, as well as those involved in the management and regulatory aspects of residential building projects.

The inclusion criteria for this study are:

Professionals with experience in the residential construction industry in New Zealand.

Individuals who are involved in roles such as client, architect, engineer (services or structural), quantity surveyor, project manager, facility manager, or planning/regulatory authority.

Participants who comprehensively understand the cost estimation and lifecycle management of residential buildings.

You have received this Information Sheet because your expertise and role make you an ideal candidate to contribute to the development of a robust WLC framework for New Zealand residential buildings. Your participation will help enhance cost estimation accuracy, promote sustainable building practices, and optimize the long-term economic performance of residential construction projects.

How do I agree to participate in this research?

To agree to participate in this research, you will need to complete a Consent Form. If you decide to participate, please contact me at herath.samarasekara@autuni.ac.nz, and I will provide you with the Consent Form and further instructions.

Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, you will be offered the choice between having any data identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

Please do not hesitate to contact me if you have any questions or need further information about the study or the Consent Form. Thank you for considering this invitation to participate in my research. Your contributions will be highly valuable and greatly appreciated.

What will happen in this research?

Your participation in this research will involve contributing your expertise and insights through semi-structured interviews. The purpose of these interviews is to gather detailed information on the factors influencing whole-life cost (WLC) estimation, the system dynamics specific to the New Zealand context, and potential improvements to existing WLC frameworks for residential buildings.

Here is what the project involves and what you will need to do:

Scheduling the Interview: Once you agree to participate, we will schedule a convenient time for the interview. The interview will be conducted using Microsoft Teams, so you can participate from any location with internet access.

Duration of the Interview: Each interview is expected to last approximately 45-60 minutes. I will ensure that the time is used efficiently and respectfully.

Interview Topics: During the interview, you will be asked questions about your experience and insights related to:

Specific factors and their interrelationships impact WLC estimation of residential buildings globally.

System dynamics of elements that affect the accuracy of WLC estimation in New Zealand.

Improvements are needed in the current WLC framework to make it suitable for New Zealand residential buildings.

Confidentiality and Data Use: All information you provide will be kept confidential and used solely for the purposes of this research. Your identity will be deidentified in all publications and presentations resulting from this research. Data will be stored securely and only accessed by my supervising team and me.

This study will not involve a control group, as it focuses solely on gathering qualitative insights from key stakeholders in the construction industry.

What are the discomforts and risks?

Participating in this research involves minimal discomfort and risks. However, it is important to outline any potential issues so that you are fully informed:

Time Commitment: The interview will take approximately 45-60 minutes. While I will do my best to accommodate your schedule and make the process as convenient as possible, this time commitment may be a minor inconvenience.

Privacy and Confidentiality: Although every effort will be made to protect your privacy and keep your responses confidential, discussing your professional experiences and insights may cause discomfort. Rest assured that all information you provide will be deidentified and securely stored. Only myself and my supervising team will have access to the data.

Technical Issues: As the interviews will be conducted using Microsoft Teams, there is a slight risk of technical issues such as poor internet connection or software malfunctions. We will provide support to resolve any technical difficulties promptly.

No significant physical or psychological risks are associated with participating in this study. Your participation is entirely voluntary, and you can withdraw at any time without any negative consequences.

If you have any concerns or need further information about potential discomforts or risks, please get in touch with me. Thank you for considering this invitation to participate in my research. Your contributions will be highly valuable and greatly appreciated.

How will these discomforts and risks be alleviated?

To alleviate the minimal discomforts and risks associated with participating in this research, several measures have been put in place:

Time Management: We understand that your time is valuable. The interview will be scheduled at a time that is convenient for you, and we will ensure that it is conducted efficiently. The expected duration is [[45-60 minutes, and we will stick to this timeframe to respect your schedule.

Privacy and Confidentiality: Your privacy is paramount to us. All information you provide will be kept confidential and deidentified in all research outputs. Data will be securely stored and only accessible to my supervising team and me. If discussing certain topics causes discomfort, you can skip any questions or terminate the interview at any time.

Technical Support: To mitigate potential technical issues during the Microsoft Teams interview, we will provide technical support to help resolve any connectivity or software problems promptly. We will also conduct a brief test call before the interview to ensure everything works smoothly.

What are the benefits?

Participating in this research offers several benefits, both for you as a participant and for the broader construction industry in New Zealand:

Contribution to Knowledge: Your insights and expertise will contribute to developing a comprehensive whole-life cost (WLC) framework tailored specifically for residential buildings in New Zealand. This framework aims to enhance cost estimation accuracy and promote long-term economic sustainability in the construction industry.

Professional Impact: By participating, you will have the opportunity to share your professional experiences and influence the creation of a robust tool that could improve decision-making processes, promote sustainable building practices, and optimise economic performance in residential construction projects.

Enhanced Industry Standards: This study's findings aim to contribute to global standards in WLC assessment methodologies. Your participation helps set benchmarks and improve practices that could benefit the entire construction industry in New Zealand.

Personal Development: Participating in research can be a valuable learning experience, offering new perspectives and insights that could be applied in your professional practice.

This research is part of my PhD study at Auckland University of Technology (AUT) and will assist me in obtaining this qualification. The outcomes of this study will be used for academic publications and presentations, further contributing to the body of knowledge in the field of construction management.

How will my privacy be protected?

Protecting your privacy and ensuring confidentiality are paramount in this research study. Here's how your privacy will be safeguarded:

Confidentiality of Data: All information collected during the interviews will be strictly confidential. Only myself, as the researcher, and my supervising team will have access to the raw data. Any personal identifiers (such as your name, contact details, and specific project details) will be securely stored separately from the interview data. These identifiers will be used solely for the purpose of scheduling and communication related to the study.

Identification of Participants: To further protect your privacy, all data used in any publications or presentations resulting from this research will be presented using a coding system. Your name and other identifying information will not be included in any reports or academic outputs. Instead, pseudonyms or general descriptors may illustrate points made during the study.

Opportunity to be identified by name to acknowledge your professional contributions: Confidentiality of your responses will be strictly maintained throughout the study. However, we also offer you the opportunity to be identified by name to acknowledge your professional contributions to this research. If you choose to be identified, your name and professional details may be mentioned in the study's publications and presentations. **Please indicate your preference on the Consent Form.**

Secure Storage: Data collected during the interviews will be stored securely on cloud storage with encryption. Only authorised personnel (myself and my supervising team) will have access to this data.

What are the costs of participating in this research?

Participating in this research involves minimal costs, primarily in terms of your time:

Time Commitment: The main cost of participating in this research is the time spent during the interview. Each interview is expected to last approximately 45-60 minutes. I understand your time is valuable, and we will ensure the interview is conducted efficiently and respectfully.

No Financial Costs: There are no financial costs associated with participating in this research. You will not be required to pay any fees or incur any expenses related to your involvement.

Other Considerations: There are no other anticipated costs, such as travel or materials. The interview will be conducted remotely using Microsoft Teams so that you can participate from the comfort of your location.

What opportunity do I have to consider this invitation?

You have one month to consider this invitation. This timeframe allows you ample opportunity to review the Information Sheet, ask any questions, and decide whether you wish to participate in the research.

During this period, please take the time to carefully read through the details provided, consider your availability for the interview, and assess any potential impacts on your schedule. If you decide to participate or have any queries during this time, you can contact me. I am here to provide further information and support as needed.

Will I receive feedback on the results of this research?

Yes, you will receive feedback on the results of this research. Participants will be provided with a summary of the findings, typically in a one or two-page document that outlines key insights and conclusions. After completing data analysis and the final report, I will concisely summarise the research findings, highlighting key themes and implications derived from participant contributions. If you have provided your contact details and expressed interest in receiving feedback, I will send the summary directly to you via email. A URL to access the summary online will be provided if the research is conducted without revealing identities. The summary of findings will be made available within a reasonable timeframe after data analysis and report writing, which will be communicated to participants early in the research process.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should first be notified to the Project Supervisor.

Dr. Mahesh Babu Purushothaman
Mahesh.babu@aut.ac.nz
+(64) 9 921 9666 Ext. 5805
Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz*, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Herath Mudiyanselage Samadhi Nayanathara Samarasekara
Herath.samarasekara@autuni.ac.nz
+(64) 21 0845 1003
Project Supervisor Contact Details:

Dr. Mahesh Babu Purushothaman
Mahesh.babu@aut.ac.nz
+(64) 9 921 9666 Ext. 5805

Dr. Funmilayo Ebun Rotimi
Funmilayo.ebun.rotimi@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *typing the date final ethics approval was granted, and reference number AUTEC 24/206.*

Appendix 3: Interview Questions (Stage 1)

Appendix I: Interview Protocol

Title of the Research: An Evidence-based Framework for Whole-life Cost Analysis of Residential Buildings in New Zealand

Researcher(s): Herath Mudiyanselage Samadhi Nayanathara samarasekara

Institution: Auckland University of Technology, Faculty of Design and Creative Science

Purpose of the Study:

This study aims to develop a WLC framework that considers all elements to improve the estimation accuracy of residential buildings for long-term economic sustainability. The objectives of the thesis are as follows.

4. To determine the specific factors and their interrelationship that impact residential buildings' global whole-life cost estimation.
5. To establish the system dynamics of the elements that affect the accuracy of the whole-life cost estimation of residential buildings in New Zealand.
6. To propose the improvements required in the WLC framework to make it suitable for residential buildings in New Zealand

Interview Procedure:

1. Introduction:

- Greet the participant and introduce yourself.
- Provide a brief overview of the study.
- Explain the purpose of the interview and the stages of the interview.
- Assure the participant of confidentiality and anonymity.
- Obtain informed consent, including permission to record the interview.
- Participants' identities will be anonymised in the transcriptions and any publications resulting from the research.
- Any potentially sensitive information disclosed during the interview will be handled with the utmost confidentiality.

Stage 1 – Data collection for the Objective 1 and 2

2. Warm-Up Questions:

- Can you tell me a little bit about yourself?
- How did you become interested in this topic/area?
- Can you describe your experience and expertise in whole-life cost estimation for residential buildings?

3. Main Interview Questions:

3.1 Indicative Questions for Objective 1:

- From your perspective, what factors influence whole-life cost estimation for residential buildings?
- How do you prioritise these factors when conducting cost estimations for residential building projects?
- Can you provide examples of how different factors interact and affect the overall accuracy of whole-life cost estimation?
- In your opinion, which factors significantly impact whole-life cost estimation, and why?

- How do economic conditions, market trends, and regulatory requirements in different countries influence the cost estimation process for residential buildings?
- Have you observed geographical variations in cost estimation methodologies and outcomes for residential building projects?
- What challenges do you encounter when estimating whole-life costs for residential buildings, and how do you address these challenges?
- How do advancements in construction technology, sustainable practices, and building materials impact the global accuracy of whole-life cost estimation?

After addressing the above questions, XX number of distinct factors will be identified. A systematic analysis of their dynamics is imperative to elucidate the interplay among these variables. This necessitates formulating a distinct set of inquiries to achieve this secondary aim. In this phase, the International Cost Management Standard (ICMS) framework will serve as the guiding principle for delineating pertinent questions.

3.2 Indicative Questions for Objective 2:

Part 1 – System dynamics-related questions

- What factors interact positively or negatively influence the WLC of NZ Residential Buildings?
- Have you noticed any patterns where changes in one area, like project decisions or stakeholder interactions, lead to changes in overall cost estimates for residential buildings in New Zealand?
- How do you think a better understanding of how different factors interact could improve the accuracy of cost estimation for residential buildings in New Zealand?
- Considering the interrelationships, how do you rank the factors influencing the accuracy of cost estimates for residential buildings in New Zealand?

Part 2 – Framework related questions

- Can you provide an overview of the current framework or methodologies used for whole-life cost estimation in residential building projects in New Zealand?
- What are the key components or elements included in the existing WLC framework for residential buildings in New Zealand?
- How are costs typically categorised or segmented within the current WLC framework (e.g., construction, maintenance, operational costs)?
- Are there any specific tools, software, or models commonly utilised for whole-life cost estimation in residential building projects in New Zealand?
- How do stakeholders typically collaborate or engage in the whole-life cost estimation process for residential buildings in New Zealand?
- What are the primary challenges or limitations associated with the current WLC framework for residential buildings in New Zealand?
- Are there any notable differences or variations in whole-life cost estimation practices among different regions or sectors within New Zealand?
- How do factors such as project size, complexity, or building type influence the application of the WLC framework for residential buildings in New Zealand?
- Have any recent developments or initiatives aimed at improving or refining the WLC framework for residential buildings in New Zealand?
- Based on your experience or expertise, what areas or aspects of the existing WLC framework do you believe require the most significant improvements or enhancements better to suit the needs of New Zealand residential building projects?

4. Stage 1 Interview closeout

- Do you have any final thoughts or anything else you want to share?
- Thank the participant for their time and contribution.

- Reiterate the confidentiality of the data and how it will be used.
- Inform the participant about the next steps in the research process and how they can access the results if they are interested.

Stage 2 – Validation interview for the Objective 3

After designing a framework based on the identified system dynamics, the next stage involves validation. This process entails conducting validation interviews as part of the semi-structured interview process. These interviews serve to confirm the accuracy and applicability of the framework developed. Through validation interviews, we aim to ensure that the framework effectively represents the system dynamics identified earlier and adequately addresses the factors influencing the accuracy of cost estimates for residential buildings in New Zealand. This iterative process allows for refinement and enhancement of the framework, ensuring its practical utility for industry practitioners. The validation questions have been designed to cover six categories as follows. Interviewees are informed that the framework is still being developed.

- Understanding the framework
- Framework components
- Feasibility and implementation
- Validation and feedback
- Future consideration
- Conclusion

Stage 2 Questions for Validation of the Framework (Under Development)

5.1. Understanding the Framework: a. Given that the framework aims to improve the accuracy of whole-life cost estimation for residential buildings in New Zealand, what are your initial thoughts on its current objectives and components, even as they continue to evolve?
b. How do you perceive the framework's potential relevance and applicability to real-world scenarios in residential building construction in New Zealand, considering it is still in development?

5.2. Framework Components: a. Let's discuss the specific elements included in the framework as it stands. Which components do you believe are most critical for enhancing the accuracy of whole-life cost estimation for residential buildings?
b. Are there any elements that you feel are missing from the current version of the framework that should be included to ensure comprehensive coverage of factors influencing cost estimation accuracy?

5.3. Feasibility and Implementation: a. From your perspective, how feasible do you think it will be to implement this evolving framework in practice within the residential building construction industry in New Zealand?
b. What potential challenges or barriers do you foresee in implementing the framework in its current state, and how would you suggest addressing them?

5.4. Validation and Feedback: a. Do you believe the framework, as it is currently conceived, adequately addresses the dynamic nature of factors affecting whole-life cost estimation for residential buildings in New Zealand?
b. Based on your expertise and experience, do you have recommendations or suggestions for refining or enhancing the framework as it develops?

5.5. Future Considerations: a. Looking ahead, how do you envision the framework evolving to adapt to changes in the residential building construction industry and advancements in technology or industry practices?
b. Are there any additional research areas or topics that you think should be explored to complement or support the implementation of the framework in its developmental phase?

5.6. Conclusion: a. Thank you for your valuable insights and contributions today. Before we conclude the focus group session, is there anything else you want to add or discuss regarding the developing framework?

b. Do you have any final thoughts or recommendations concerning the framework for improving whole-life cost estimation accuracy for residential buildings in New Zealand as it continues to evolve?

6. Recording and Data Management

In adherence to rigorous recording and data management protocols, all interviews will be meticulously documented and stored to ensure the integrity and confidentiality of participant responses. Each interview session will be captured using state-of-the-art recording devices, such as digital audio recorders or secure online platforms of Microsoft Teams. Simultaneously, comprehensive notes will be taken to capture nuanced details and critical insights.

After the interviews, recordings will be transcribed verbatim, maintaining fidelity to the original dialogue. These transcripts and supplementary notes will be securely stored using a sensitive data management protocol that will be filled out and stored during the active data collection stage on https://autuni-my.sharepoint.com. After the analysis, the management protocol will be securely stored in the AUT by the applicant as an encrypted folder. Auckland University of Technology provides a data management tool (DMP) for researchers to store information and download a PDF version when needed. This tool allows the researcher to set the information to private, making it completely secure and unable to be accessed by the public except the researcher and the supervisors.

DMP tool link: https://aut.ac.nz.libguides.com/RDM/plan#s-lg-box-22281170

Data will be secured for six years from obtaining them.

Appendix 4: Ethical Approval (Stage 2) – Validation Interviews

29 May 2025

Mahesh Babu

Faculty of Design and Creative Technologies

Dear Mahesh

Re: Ethics Application: **24/206 An evidence-based framework for Whole-life Cost Analysis of Residential Buildings in New Zealand**

Thank you for your responses to AUTEC's conditions for the next phase of your research.

Stage 2 of the research (validate the developed framework through participant interviews) has been approved.

Non-Standard Conditions of Approval

1. Clarify which of the AUT cloud storage facility is being used for data storage.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact the Secretariat at ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat

Auckland University of Technology Ethics Committee

Cc: herath.samarasekara@autuni.ac.nz; funmi.rotimi@aut.ac.nz; Ali GhaffarianHoseini

Appendix 5: Participant's Information Sheet (Stage 2)

Date Information Sheet Produced:

23 May 2025

Project Title

An evidence-based framework for Whole-life Cost Analysis of Residential Buildings in New Zealand

Introduction

My name is *Herath Mudiyanselage Samadhi Nayanathara Samarasekara*, and I am a doctoral candidate at the Auckland University of Technology (AUT) in the Faculty of Design and Creative Technologies. I am conducting this research as part of my PhD requirements and would like to invite you to take part in a validation interview for the study.

The purpose of this research is to develop a tailored whole-life cost (WLC) framework for residential buildings in New Zealand. This framework is designed to enhance cost estimation accuracy and promote long-term economic sustainability in the construction industry.

What is the purpose of this research?

This research aims to develop a comprehensive whole-life cost (WLC) framework tailored specifically for residential buildings in New Zealand. The aim is to enhance cost estimation accuracy and promote long-term economic sustainability within the construction industry. This research will engage key stakeholders, such as clients, end-users, architects, engineers (both services and structural), quantity surveyors, project managers, facility managers, and government authorities, to gather insights and expertise.

The research actively engages a diverse array of stakeholders, encompassing clients, end-users, architects, both services and structural engineers, quantity surveyors, project managers, facility managers, and regulatory authorities. This engagement is facilitated through a framework validation interview. The specific objectives of this study are as follows:

Determining the specific factors and their interrelationships that impact whole-life cost estimation of residential buildings globally.

Establishing the system dynamics of elements that affect the accuracy of whole-life cost estimation for residential buildings in New Zealand.

Proposing improvements required in the current WLC framework to make it suitable for residential buildings in New Zealand.

The expected outcome is a robust WLC framework that enhances informed decision-making among stakeholders, promotes sustainable building practices, and optimizes the long-term economic performance of residential construction projects. This research's findings may be used for academic publications and presentations, contributing to advancing global standards in WLC assessment methodologies.

Why you have been invited?

You are invited to participate because you are a recognised stakeholder in New Zealand's residential construction sector. Your expertise provides critical insight into the factors that shape cost estimation and lifecycle management.

You were selected based on these criteria:

Relevant professional experience in New Zealand's residential construction sector.

Involvement in roles such as client, architect, engineer (services or structural), quantity surveyor, project manager, facility manager, or regulatory authority.

Understanding of cost estimation and lifecycle practices for residential projects.

Your input is vital to ensure the framework reflects practical, industry-aligned realities.

How can you agree to participate in this research?

To agree to participate in this research, you will need to complete a Consent Form. If you decide to participate, please get in touch with me at herath.samarasekara@autuni.ac.nz, and I will provide you with the Consent Form and further instructions.

Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. Suppose you choose to withdraw from the study. In that case, you will be offered the choice between having any data identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

Please do not hesitate to contact me with any questions or further information about the study or the Consent Form. Thank you for considering this invitation to participate in my research. Your contributions will be highly valuable and greatly appreciated.

What will happen in this research?

A copy of the proposed framework is attached to this document for your review before the interview.

Here is what your involvement will include:

Review of the Proposed Framework:
You are encouraged to review the attached framework and overview document in advance to prepare for the discussion.

Scheduling the Interview:
Upon agreeing to participate, we will schedule a convenient time for the interview. It will be conducted online via Microsoft Teams, allowing you to participate from a location of your choice.

Focus of the Interview:
During the interview, you will be invited to:

Provide feedback on the structure, components, and logic of the proposed WLC framework.

Evaluate the framework's practicality, clarity, and alignment with industry needs.

Identify strengths, weaknesses, or gaps in the framework.

Suggest modifications or enhancements based on your experience.

Confidentiality and Data Use:
All information you share will remain confidential and be used solely for research. Your responses will be deidentified in any publications or presentations. Data will be securely stored and accessed only by me and my academic supervisors.

This research phase is essential for ensuring that the final framework is grounded in real-world practice, reflects stakeholder expertise, and is suitable for industry adoption.

What are the discomforts and risks?

Participating in this research involves minimal discomfort and risks. However, it is important to outline any potential issues so that you are fully informed:

Time Commitment: The interview will take approximately 20-30 minutes. While I will do my best to accommodate your schedule and make the process as convenient as possible, this time commitment may be a minor inconvenience.

Privacy and Confidentiality: Although every effort will be made to protect your privacy and keep your responses confidential, discussing your professional experiences and insights may cause discomfort. Rest assured that all information you provide will be deidentified and securely stored. Only myself and my supervising team will have access to the data.

Technical Issues: As the interviews will be conducted using Microsoft Teams, there is a slight risk of technical issues such as poor internet connection or software malfunctions. We will provide support to resolve any technical difficulties promptly.

No significant physical or psychological risks are associated with participating in this study. Your participation is entirely voluntary, and you can withdraw at any time without any negative consequences.

If you have any concerns or need further information about potential discomforts or risks, please get in touch with me. Thank you for considering this invitation to participate in my research. Your contributions will be highly valuable and greatly appreciated.

How will these discomforts and risks be alleviated?

To alleviate the minimal discomforts and risks associated with participating in this research, several measures have been put in place:

Time Management: We understand that your time is valuable. The interview will be scheduled at a time that is convenient for you, and we will ensure that it is conducted efficiently. The expected duration is [[45-60 minutes, and we will stick to this timeframe to respect your schedule.

Privacy and Confidentiality: Your privacy is paramount to us. All information you provide will be kept confidential and deidentified in all research outputs. Data will be securely stored and only accessible to my supervising team and me. If discussing certain topics causes discomfort, you can skip any questions or terminate the interview at any time.

Technical Support: To mitigate potential technical issues during the Microsoft Teams interview, we will provide technical support to help resolve any connectivity or software problems promptly. We will also conduct a brief test call before the interview to ensure everything works smoothly.

What are the benefits?

Participating in this research offers several benefits, both for you as a participant and for the broader construction industry in New Zealand:

Influence Industry Practice: Help shape a framework that may become an industry standard.

Professional Recognition: You may choose to be acknowledged by name for your contribution (optional).

Knowledge Sharing: Engage in knowledge exchange with academic and industry stakeholders.

Support Research Advancement: Contribute to raising the standard of WLC practices both in New Zealand and internationally.

This research is part of my PhD study at Auckland University of Technology (AUT) and will assist me in obtaining this qualification. The outcomes of this study will be used for academic publications and presentations, further contributing to the body of knowledge in the field of construction management.

How will your privacy be protected?

Protecting your privacy and ensuring confidentiality are paramount in this research study. Here's how your privacy will be safeguarded:

Confidentiality of Data: All information collected during the interviews will be strictly confidential. Only myself, as the researcher, and my supervising team will have access to the raw data. Any personal identifiers (such as your name, contact details, and specific project details) will be securely stored separately from the interview data. These identifiers will be used solely for the purpose of scheduling and communication related to the study.

Identification of Participants: To further protect your privacy, all data used in any publications or presentations resulting from this research will be presented using a coding system. Your name and other identifying information will not be included in any reports or academic outputs. Instead, pseudonyms or general descriptors may illustrate points made during the study.

Opportunity to be identified by name to acknowledge your professional contributions: Confidentiality of your responses will be strictly maintained throughout the study. However, we also offer you the opportunity to be identified by name to acknowledge your professional contributions to this research. If you choose to be identified, your name and professional details may be mentioned in the study's publications and presentations. **Please indicate your preference on the Consent Form.**

Secure Storage: Data collected during the interviews will be stored securely on cloud storage with encryption. Only authorised personnel (myself and my supervising team) will have access to this data.

What are the costs of participating in this research?

Participating in this research involves minimal costs, primarily in terms of your time:

Time Commitment: The main cost of participating in this research is the time spent during the interview. Each interview is expected to last approximately 20-30 minutes. I understand your time is valuable, and we will ensure the interview is conducted efficiently and respectfully.

No Financial Costs: There are no financial costs associated with participating in this research. You will not be required to pay any fees or incur any expenses related to your involvement.

Other Considerations: There are no other anticipated costs, such as travel or materials. The interview will be conducted remotely using Microsoft Teams so you can participate from the comfort of your location.

What opportunity do you have to consider this invitation?

You have two weeks to consider this invitation. This timeframe allows you ample opportunity to review the Information Sheet, ask any questions, and decide whether you wish to participate in the research.

During this period, please take the time to carefully read through the details provided, consider your availability for the interview, and assess any potential impacts on your schedule. You can contact me if you decide to participate or have any queries during this time. I am here to provide further information and support as needed.

Will you receive feedback on the results of this research?

Yes, you will receive feedback on the results of this research. Participants will be provided with a summary of the findings, typically in a one or two-page document that outlines key insights and conclusions. After completing data analysis and the final report, I will concisely summarise the research findings, highlighting key themes and implications derived from participant contributions. If you have provided your contact details and expressed interest in receiving feedback, I will send the summary directly to you via email. A URL to access the summary online will be provided if the research is conducted without revealing identities. The summary of findings will be made available within a reasonable timeframe after data analysis and report writing, which will be communicated to participants early in the research process.

What do you do if you have concerns about this research?

Any concerns regarding the nature of this project should first be notified to the Project Supervisor.

Dr. Mahesh Babu Purushothaman

Mahesh.babu@aut.ac.nz

+(64) 9 921 9666 Ext. 5805

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz*, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Herath Mudiyanselage Samadhi Nayanathara Samarasekara

Herath.samarasekara@autuni.ac.nz

+(64) 21 0845 1003

Project Supervisor Contact Details:

Dr. Mahesh Babu Purushothaman

Mahesh.babu@aut.ac.nz

+(64) 9 921 9666 Ext. 5805

Dr. Funmilayo Ebun Rotimi

Funmilayo.ebun.rotimi@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *typing the date final ethics approval was granted, and reference number AUTEC 24/206*.

Appendix 4: Interview Questions (Stage 2)

Title of the Research: An Evidence-based Framework for Whole-life Cost Analysis of Residential Buildings in New Zealand

Researcher(s): Herath Mudiyanselage Samadhi Nayanathara samarasekara

Institution: Auckland University of Technology, Faculty of Design and Creative Science

Purpose of the Study: To validate the tailored WLC framework, ensuring it meets practical needs, captures critical cost factors, and is applicable to New Zealand's residential construction sector.

Interview Procedure:

- Greet the participant and introduce yourself.
- Provide a brief overview of the study.
- Explain the purpose of the interview and the stages of the interview.
- Assure the participant of confidentiality and anonymity.
- Obtain informed consent, including permission to record the interview.
- Participants' identities will be anonymised in the transcriptions and any publications resulting from the research.
- Any potentially sensitive information disclosed during the interview will be handled with the utmost confidentiality.

Interview Questions

Section 1: General Understanding and Relevance

1. Awareness and Importance of WLC in NZ Residential Construction:
    - How familiar are you with Whole-life Cost (WLC) estimation in New Zealand's residential sector?
    - In your experience, what are the key challenges or gaps in current WLC estimation methods?
    - Do you think a standardised WLC framework is needed for NZ residential buildings? Why or why not?
2. Perception and Relevance of the Tailored Framework:
    - After reviewing the proposed WLC framework, does it effectively capture the critical components required for WLC estimation in NZ residential buildings?
    - How does this framework compare with existing methods? What improvements, if any, does it offer?

Section 2: Comprehensiveness and Content Validation

3. Coverage of Cost Categories:
    - Does the framework sufficiently cover all relevant cost categories, including initial, operational, maintenance, replacement, and end-of-life costs?
    - Are there any key cost components or influencing factors that should be added or emphasised more? (e.g., climate-related risks, material supply fluctuations, regulatory impacts)
4. Consideration of NZ-Specific Factors:

- Does the framework appropriately account for factors unique to NZ, such as local construction practices, seismic risks, weather conditions, and regulatory requirements?
- Are there any distinctive challenges in NZ residential construction that the framework does not currently address?

Section 3: Usability and Practicality

5. Practicality and User Experience:
    - How practical and user-friendly do you find the framework for real-life application?
    - Would it be adaptable to different project scales and types (e.g., standalone homes, multi-unit developments)?
6. Data Availability and Implementation Challenges:
    - Are there any concerns about data availability for applying this framework effectively (e.g., operational costs, maintenance schedules, climate impact data)?
    - What do you see as the biggest barriers to adopting this framework in typical residential projects?

Section 4: Alignment with ICMS and Global Best Practices

7. Integration with ICMS and International Standards:
    - Do you see value in aligning this framework with ICMS principles? If so, how?
    - Are there specific ICMS components that should be emphasised or adapted for NZ's residential sector?
8. Suggestions for Refinement and Adoption:
    - What modifications or enhancements would you suggest improving the framework's effectiveness and usability?
    - How do you think this framework could be successfully implemented in NZ (e.g., through government policies, industry training, BIM integration)?

Section 5: Final Thoughts and Collaboration Opportunities

9. Overall Impact and Future Potential:
    - Do you think this framework can improve cost planning, sustainability, and value-for-money outcomes in NZ's residential construction sector?
    - Do you have any additional feedback, concerns, or insights?

After the interviews, recordings will be transcribed verbatim, maintaining fidelity to the original dialogue. These transcripts and supplementary notes will be securely stored using a sensitive data management protocol that will be filled out and stored during the active data collection stage on https://autuni-my.sharepoint.com. After the analysis, the management protocol will be securely stored in the AUT by the applicant as an encrypted folder. Auckland University of Technology provides a SharePoint folder for researchers to store information and download a PDF version when needed. This tool allows the researcher to set the information to private, making it completely secure and unable to be accessed by the public except the researcher and the supervisors.

Data Storage Link: https://autuni.sharepoint.com/sites/Tuia/SitePages/Research-data-management.aspx

Data will be secured for six years from obtaining them.

Appendix 5: Consent Form

Project Title:	***An Evidence-based Framework for Whole-life Cost Analysis of Residential Buildings in New Zealand***
Project Supervisor:	***Dr. Mahesh Babu Purushothaman***
Researcher:	***Herath Mudiyanselage Samadhi Nayanathara Samarasekara***

○ I have read and understood the information provided about this research project in the Information Sheet dated 23 May 2025.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study, then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Confidentiality and Acknowledgment:

- I agree to have my responses kept confidential. Yes○ No○
- I agree to be identified by name to acknowledge my professional contributions to this research. Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date :

Approved by the Auckland University of Technology Ethics Committee 21 May 2025 AUTEC Reference number 24/206

Note: The Participant should retain a copy of this form.

Appendix 6: Factors Influencing WLC

Item	Author	Origin	Year	Factors																																																		
				Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below ground	Construction technology	Energy saving measures and cost	Shape of facility	Estimated annual occupancy hours	Gross floor Area	Location	Context or purpose determined by stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront acquisition cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/ Renewal cost	Disposal/end-of-life cost	Demand and supply of materials	Materials availability/ Service Life	Real cost	Nominal Cost	Time value of money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental impact evaluation	Green building certification cost	Variations in Various cost	Replacement frequency	Maintenance frequency	Consideration of design alternatives	Renewable resources used	Level of uncertainty	Risk Allowances	Waste management cost	Continuity of supply chain	Seismic Resistance	Fire Resistance	Insurances
1	(AbouHamad & Abu-Hamd, 2019)	Egypt	2019	✓	✓						✓										✓		✓	✓	✓		✓			✓	✓	✓		✓			✓	✓			✓			✓	✓				✓	✓				
2	(Ade-Ojo & Fasuyi, 2013)	Nigeria	2013																	✓	✓	✓	✓	✓	✓												✓	✓						✓	✓									
3	(Aderogba et al., 2022)	Nigeria	2022								✓	✓		✓		✓					✓	✓	✓	✓	✓					✓	✓								✓	✓	✓									✓				
4	(Ashtiani & Muench, 2022)	USA	2022													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓	✓			✓	✓												
5	(Ashworth & Perera, 2015)	UK	2015	✓	✓							✓					✓			✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓				✓					
6	(Aziz, 2012)	Malaysia	2012		✓															✓	✓	✓	✓	✓	✓					✓	✓	✓																						
7	(BAKARE, 2018)	Nigeria	2018																		✓	✓	✓	✓	✓																									✓				
8	(Ballesty, 2021)	Australia	2021			✓					✓		✓	✓									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓			✓						✓					
9	(BCIS, 2008)	UK	2008														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓	✓											✓				✓
10	(BCIS, 2012)	UK	2012	✓	✓	✓	✓				✓			✓			✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						✓	✓				✓					
11	(Bekas et al., 2015)	Greece	2015					✓												✓	✓	✓	✓	✓	✓					✓	✓	✓																						
12	(Bernard et al., 2013)	France	2013																																																			
13	(Boussabaine & Kirkham, 2008)	UK	2008	✓		✓	✓	✓	✓	✓	✓	✓											✓	✓						✓	✓	✓	✓	✓	✓		✓												✓					
14	(BRANZ, 2016)	NZ	2016	✓			✓					✓						✓			✓	✓	✓	✓	✓												✓	✓																
15	(CACQS, 2016)	Canada	2016																		✓	✓	✓	✓	✓					✓																								
16	(Chau et al., 2007)	Hong Kong	2007																								✓														✓													
17	(Ćirović et al., 2014)	Serbia	2014														✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓					✓	✓						✓	✓									
18	(Colli et al., 2020)	France	2020																		✓		✓	✓	✓					✓			✓								✓									✓				
19	(Dafeamekpor et al., 2021)	Ghana	2021									✓			✓					✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓																
20	(De Jong & Arkesteijn, 2014)	Netherlands	2014	✓							✓									✓	✓	✓	✓	✓	✓		✓										✓							✓	✓									
21	(Dong et al., 2023)	China	2023										✓																												✓													
22	(dsr.wa.gov.au, 2005)	Australia	2005	✓		✓	✓	✓		✓	✓			✓							✓		✓	✓	✓					✓	✓							✓								✓	✓							
23	(Ebrahimi et al., 2014)	Malaysia	2014													✓	✓	✓			✓	✓	✓	✓	✓		✓					✓																		✓				
24	(El Hadidi et al., 2022)	Egypt	2022	✓	✓						✓	✓	✓					✓			✓		✓	✓	✓												✓	✓						✓	✓					✓				
25	(El-Haram et al., 2002)	UK	2002																	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓															✓				
26	(Estébanez et al., 2015)	UK	2015																		✓	✓	✓	✓	✓																								✓					

27	(Estevan et al., 2018)	EU	2018		✓			✓									✓			✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓		✓		✓									✓				
28	(Fairey et al., 2004)	UK	2004										✓				✓				✓	✓	✓	✓	✓		✓																											
29	(FIFE)	UK	2023														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓													✓			
30	(Figueiredo et al., 2021)	Australia	2021							✓			✓	✓		✓	✓			✓		✓	✓	✓	✓																													
31	(Goh, 2016)	Singapore	2016	✓						✓										✓	✓	✓	✓	✓	✓												✓	✓						✓	✓									
32	(Gov.au, 2021)	Australia	2021																	✓	✓		✓	✓	✓					✓	✓	✓																						
33	(Gov.ca, 2012)	Canada	2012																	✓	✓		✓	✓	✓					✓				✓		✓		✓										✓						
34	(Henjewele et al., 2012)	UK	2012	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓																										✓					
35	(Hossaini et al., 2015)	Canada	2015	✓	✓								✓							✓	✓		✓	✓	✓																✓						✓					✓	✓	
36	(Hunter et al., 2005)	UK	2005	✓								✓									✓		✓	✓							✓	✓					✓	✓																
37	(ICMS, 2021)	UK	2021	✓	✓	✓	✓				✓			✓			✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						✓	✓				✓					
38	(ISBD, 2021)	Saudi Arabia	2021																	✓	✓	✓	✓	✓	✓					✓																								
39	(Izobo-Martins et al., 2018)	Nigeria	2018	✓	✓	✓	✓	✓	✓	✓	✓												✓																						✓									
40	(Janjua et al., 2019)	Australia	2019	✓																																		✓																
41	(Jansen et al., 2020)	Netherlands	2022																		✓	✓	✓	✓	✓		✓			✓	✓						✓	✓												✓				
42	(Johansson, 2001)	UK	2001	✓	✓	✓	✓				✓										✓		✓	✓	✓		✓	✓																						✓				
43	(Junior et al., 2022)	Switzerland	2022																														✓	✓	✓																			
44	(Khatri & Moore, 2017)	Australia	2017																								✓														✓		✓											
45	(Kishk et al., 2003)	UK	2003														✓			✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓										✓	✓					
46	(Manewa et al., 2009)	UK	2009										✓								✓		✓	✓	✓					✓	✓	✓					✓	✓						✓	✓									
47	(Manewa, 2009)	Netherlands	2009				✓														✓		✓	✓	✓															✓	✓									✓				
48	(Meng & Harshaw, 2013)	UK	2013																		✓	✓	✓	✓	✓												✓	✓																
49	(Mills, 2014)	China	2014										✓	✓			✓				✓	✓	✓	✓	✓																									✓	✓			
50	(Moges et al., 2017)	Canada	2017														✓				✓	✓	✓	✓	✓					✓	✓							✓			✓													
51	(Motooka et al., 2005)	Japan	2005	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓			✓	✓	✓	✓	✓	✓		✓																											
52	(Nalaya, 2021)	Nigeria	2021																	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓						✓	✓				✓					
53	(Nasereddin & Price, 2021)	Jordan	2021																																							✓												
54	(OECD, 2022)	Hungary	2022																✓	✓	✓	✓	✓	✓	✓		✓			✓	✓																							
55	(OGC, 2007)	UK	2007	✓		✓					✓	✓					✓			✓	✓	✓	✓	✓	✓		✓			✓	✓	✓																	✓					✓
56	(Onukwube, 2006)	Nigeria	2006																		✓	✓	✓	✓	✓												✓	✓																
57	(Paganin et al., 2020)	Italy	2020																	✓	✓	✓	✓	✓	✓										✓						✓													
58	(Parameswaran et al., 2019)	Sri Lanka	2019									✓									✓		✓	✓	✓																													
59	(Park, 2009)	South Korea	2009	✓	✓	✓	✓				✓	✓					✓				✓	✓	✓	✓	✓													✓											✓	✓				
60	(Perera et al., 2009)	Canada	2009																	✓	✓	✓	✓	✓	✓						✓			✓				✓	✓				✓											
61	(Phillips et al., 2007)	UK	2007					✓													✓		✓																															
62	(QABAJA, 2017)	Saudi Arabia	2017																	✓	✓	✓	✓	✓	✓					✓			✓																					
63	(QTC, 2016)	Australia	2016																		✓	✓	✓	✓	✓			✓	✓		✓																							
64	(Rahim et al., 2016)	Malaysia	2016	✓	✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓																													

65	(RICS, 2016)	UK	2016														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓	✓											✓				✓
66	(RICS, 2021)	UK	2021	✓	✓	✓					✓	✓		✓						✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓	✓					✓	✓	✓			✓	✓				
67	(Ristimäki et al., 2013)	Finland	2013			✓		✓	✓			✓		✓						✓	✓	✓	✓	✓	✓					✓	✓																							
68	(Schneiderova-Heralova, 2018)	Czech Republic	2018																	✓	✓		✓	✓	✓																													
69	(SCI-Network, 2011a)	UK	2011														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓																							
70	(SCSI, 2022)	Ireland	2022																	✓	✓	✓	✓	✓	✓				✓	✓	✓				✓		✓	✓																
71	(SFT, 2016)	UK	2021													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓			✓	✓						✓	✓					
72	(Shabha, 2003)	UK	2003																		✓		✓	✓	✓		✓										✓	✓						✓	✓									
73	(Shankar Kshirsagar et al., 2010)	USA	2010																	✓	✓	✓	✓	✓	✓					✓	✓																		✓					
74	(Silvestre et al., 2013)	Portugal	2013															✓		✓	✓	✓	✓	✓	✓					✓		✓									✓													
75	(Sohlenius & Johansson, 2002)	UK	2002																	✓	✓	✓	✓	✓	✓																													
76	(Sterner, 2000)	Sweden	2000																											✓	✓																							
77	(Teshnizi et al., 2018)	Canada	2018		✓											✓	✓				✓		✓	✓	✓					✓							✓	✓																
78	(treasury.govt.nz, 2015)	NZ	2015																	✓	✓	✓	✓	✓	✓					✓	✓						✓	✓																
79	(Vasishta et al., 2023)	USA	2023													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓	✓			✓	✓												
80	(Wang, 2016b)	China	2016																	✓		✓	✓	✓	✓					✓	✓																							
81	(Wang, 2018)	China	2018														✓			✓	✓	✓	✓	✓	✓																													
82	(Withanage et al., 2019)	Sri Lanka	2019																		✓	✓	✓	✓	✓		✓			✓	✓						✓	✓																
83	(Zahirah et al., 2013)	UK	2013				✓						✓				✓				✓	✓	✓	✓	✓		✓													✓														
84	(Zanni et al., 2019b)	UK	2019																	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓						✓	✓				✓					
	Totals			**21**	**16**	**14**	**13**	**10**	**6**	**7**	**17**	**14**	**10**	**11**	**1**	**8**	**28**	**9**	**4**	**41**	**71**	**56**	**77**	**74**	**72**	**1**	**25**	**9**	**10**	**45**	**41**	**25**	**21**	**21**	**13**	**1**	**34**	**37**	**8**	**4**	**16**	**4**	**3**	**14**	**15**	**2**	**2**	**3**	**16**	**16**	**2**	**1**	**1**	**3**

Appendix 7: Retrieved Articles

Item	Author	Title	Origin	Year
1	(AbouHamad & Abu-Hamd, 2019)	Framework for construction system selection based on life cycle cost and sustainability assessment.	Egypt	2019
2	(Ade-Ojo & Fasuyi, 2013)	Cost-In-Use: A panacea for sustainable building development in Nigeria	Nigeria	2013
3	(Aderogba et al., 2022)	Mass Residential Housing Projects and Sustainable Construction Practices	Nigeria	2022
4	(Ashtiani & Muench, 2022)	Using construction data and whole-life cycle assessment to establish sustainable roadway performance benchmarks	USA	2022
5	(Ashworth & Perera, 2015)	Cost Studies of Buildings	UK	2015
6	(Aziz, 2012)	Comparing Conventional to Industrialized Building System Construction Costing: A Case Study of School Building Projects	Malaysia	2012
7	(BAKARE, 2018)	AN INVESTIGATION ON COMPARATIVE USE OF LIGHT GAUGE STEEL CONSTRUCTION OVER CONCRETE WORKS DEPARTMENT OF CIVIL ENGINEERING	Nigeria	2018
8	(Ballesty, 2021)	Life Cycle Cost Analysis Information Paper	Australia	2021
9	(BCIS, 2008)	Standardised Method of Life Cycle Costing for Construction Procurement	UK	2008
10	(BCIS, 2012)	elemental Standard Form of Cost Analysis	UK	2012
11	(Bekas et al., 2015)	Life Cycle Analysis and Optimisation of a Steel Building	Greece	2015
12	(Bernard et al., 2013)	Product Lifecycle Management for Society	France	2013
13	(Boussabaine & Kirkham, 2008)	Whole-lifecycle costing: risk and risk responses	UK	2008
14	(BRANZ, 2016)	study Report SR350 New Zealand whole-building whole-of-life framework: Development of reference office buildings for use in early design.	New Zealand	2016
15	(CACQS, 2016)	Cost Managemnt Best Practice Guide. T. C. A. o. C. Q. Surveyors	Canada	2016
16	(Chau et al., 2007)	Environmental impacts of building materials and building services components for commercial buildings in Hong Kong	Hong Kong	2007
17	(Ćirović et al., 2014)	FINANCIAL VALUATION OF CONSTRUCTION INVESTMENT IN SERBIA.	Serbia	2014
18	(Colli et al., 2020)	Investigating eco-efficiency procedure to compare refurbishment scenarios with different insulating materials	France	2020
19	(Dafeamekpor et al., 2021)	Theoretical framework for assessing self-help housing projects affordability. Sustainable Education and Development	Ghana	2021
20	(de Jong & Arkesteijn, 2014)	Life cycle costs of Dutch school buildings	Netherlands	2014
21	(Dong et al., 2023)	Life Cycle Sustainability Assessment of Building Construction: A Case Study in China.	China	2023

22	(dsr.wa.gov.au, 2005)	A guide for sport and recreation facilities owners and managers	Australia	2005
23	(Ebrahimi et al., 2014)	Lifecycle framework for sustainable residential buildings in Malaysia.	Malaysia	2014
24	(El Hadidi et al., 2022)	EVALUATION OF A BUILDING LIFE CYCLE COST (LCC) CRITERIA IN EGYPT USING THE ANALYTIC HIERARCHY PROCESS (AHP)	Egypt	2022
25	(El-Haram et al., 2002)	Development of a generic framework for collecting whole-life cost data for the building industry.	UK	2002
26	(Estébanez et al., 2015)	An Integrated Aerospace Requirement Setting and Risk Analysis Tool for Life Cycle Cost Reduction and System Design Improvement.	UK	2015
27	(Estevan et al., 2018)	Life Cycle Costing State of the art report	EU	2018
28	(Fairey et al., 2004)	Financial analysis and investment appraisal.	UK	2004
29	(FIFE)	whole-life costing (+ CO2) user guide	UK	2023
30	(Figueiredo et al., 2021)	Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP	Australia	2021
31	(Goh, 2016)	Designing a whole-life building cost index in Singapore.	Singapore	2016
32	(Gov.au, 2021)	Whole-of-Life Costing Guideline.	Australia	2021
33	(Gov.ca, 2012)	Next Generation Fighter Capability: Life Cycle Cost Framework.	Canada	2012
34	(Henjewele et al., 2012)	Analysis of factors affecting value for money in UK PFI projects.	UK	2012
35	(Hossaini et al., 2015)	AHP-based life cycle sustainability assessment (LCSA) framework: a case study of six-storey wood frame and concrete frame buildings in Vancouver.	Canada	2015
36	(Hunter et al., 2005)	A whole-life costing input tool for surveyors in UK local government.	UK	2005
37	(ICMS, 2021)	ICMS: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions	UK	2021
38	(ISBD, 2021)	Guidance Note for the use of Lifecycle Cos?ng (LCC) in Procurement of Goods and Works Contract for IsDB- financed Projects.	Saudi Arabia	2021
39	(Izobo-Martins et al., 2018)	Architects' View on Design Consideration that Can Reduce Maintenance Cost.	Nigeria	2018
40	(Janjua et al., 2019)	Sustainability assessment of a residential building using a life cycle assessment approach	Australia	2019
41	(Jansen et al., 2020)	A circular economy life cycle costing model (CE-LCC) for building components.	Netherlands	2022
42	(Johansson, 2001)	A MODULARISATION APPROACH TO HOUSING.	UK	2001
43	(Junior et al., 2022)	Product Lifecycle Management. Green and Blue Technologies to Support Smart and Sustainable Organizations	Switzerland	2022

44	(Khatri & Moore, 2017)	Achieving Low Life Cycle Cost.	Australia	2017
45	(Kishk et al., 2003)	Whole-life costing in construction: a state of the art review.	UK	2003
46	(Manewa et al., 2009)	The paradigm shift towards whole-life analysis in adaptable buildings.	UK	2009
47	(Manewa, 2009)	Towards economic sustainability through adaptable buildings	Netherlands	2009
48	(Meng & Harshaw, 2013)	The application of whole-life costing in PFI/PPP projects	UK	2013
49	(Mills, 2014)	Smart and Sustainable Built Environment	China	2014
50	(Moges et al., 2017)	Review and recommendations for Canadian LCCA guidelines.	Canada	2017
51	(Motooka et al., 2005)	Small House Projects in Japan Housing Experiments for Open-Building Concept.	Japan	2005
52	(Nalaya, 2021)	WHOLE-LIFE COSTING PRACTICES EMPLOYED BY DESIGN TEAMS OF BUILDING CONSTRUCTION PROJECTS IN ABUJA, NIGERIA	Nigeria	2021
53	(Nasereddin & Price, 2021)	Addressing the capital cost barrier to sustainable construction	Jordan	2021
54	(OECD, 2022)	life-Cycle Costing in Public Procurement in Hungary.	Hungary	2022
55	(OGC, 2007)	Whole-life costing and cost management (Achieving Excellence in Construction Procurement Guide	UK	2007
56	(Onukwube, 2006)	Whole–Life Costing and Cost Management Framework for Construction Projects in Nigeria.	Nigeria	2006
57	(Paganin et al., 2020)	An integrated decision support system for the sustainable evaluation of pavement technologies.	Italy	2020
58	(Parameswaran et al., 2019)	Analysing the Impact of Location Factors on Building Construction Cost in Sri Lanka.	Sri Lanka	2019
59	(Park, 2009)	Whole-life performance assessment: Critical success factors.	South Korea	2009
60	(Perera et al., 2009)	Life cycle costing in sustainable public procurement: A question of value.	Canada	2009
61	(Phillips et al., 2007)	The development of a tender analysis support tool for use in social housing best value procurement.	UK	2007
62	(QABAJA, 2017)	APPLICATION LIFE CYCLE COST ANALYSIS IN THE BUILDING SECTOR IN SAUDI ARABIA.	Saudi Arabia	2017
63	(QTC, 2016)	Whole-Of-Life Costing: A quick guide for elected officials and staff.	Australia	2016
64	(Rahim et al., 2016)	Implementation of life cycle costing in enhancing value for money of projects.	Malaysia	2016
65	(RICS, 2016)	Life Cycle Costing	UK	2016
66	(RICS, 2021)	NRM3: Order of cost estimating and cost planning for building maintenance works	UK	2021

67	(Ristimäki et al., 2013)	Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design.	Finland	2013
68	(Schneiderova-Heralova, 2018)	Life Cycle Cost Optimisation Within Decision Making on Alternative Designs of Public Buildings.	Czech Republic	2018
69	(SCI-Network, 2011)	Whole-life Costing	UK	2011
70	(SCSI, 2022)	Guide to Life Cycle Costing	Ireland	2022
71	(SFT, 2016)	Whole-life Appraisal Tool For the Built Environment.	UK	2021
72	(Shabha, 2003)	A low-cost maintenance approach to high-rise flats	UK	2003
73	(Shankar Kshirsagar et al., 2010)	Suitability of life cycle cost analysis (LCCA) as asset management tools for institutional buildings.	USA	2010
74	(Silvestre et al., 2013)	From the new European Standards to an environmental, energy and economic assessment of building assemblies from cradle to cradle	Portugal	2013
75	(Sohlenius & Johansson, 2002)	A framework for decision-making in construction–based on Axiomatic Design.	UK	2002
76	(Sterner, 2000)	Lifecycle costing and its use in the Swedish building sector	Sweden	2000
77	(Teshnizi et al., 2018)	Lessons learned from life cycle assessment and life cycle costing of two residential towers at the University of British Columbia.	Canada	2018
78	(treasury.govt.nz, 2015)	The whole of Life Costs Guidance	NZ	2015
79	(Vasishta et al., 2023)	Comparative life cycle assessment (LCA) and life cycle cost analysis (LCCA) of precast and cast–in–place buildings in the United States.	USA	2023
80	(Wang, 2016)	The application of the life cycle cost concept in government procurement.	China	2016
81	(Wang, 2018)	Life Cycle Cost Management of Fixed Assets in Chinese Power Grid Enterprises.	China	2018
82	(Withanage et al., 2019)	Financial viability of using green roofing in residential buildings.	Sri Lanka	2019
83	(Zahirah et al., 2013)	Soft cost elements that affect developers' decision to build green.	UK	2013
84	(Zanni et al., 2019)	Standardisation of whole-life cost estimation for early design decision-making utilising BIM.	UK	2019

Appendix 8: Pairwise Comparison

Appendix 1: The pairwise score table

	Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below ground	Construction technology	Energy saving measures and cost	Shape of facility	Estimated annual occupancy hours	Gross floor Area	Location	Context or purpose determined by stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront acquisition cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/ Renewal cost	Disposal/end-of-life cost	Demand and supply of materials	Materials availability/ Service Life	Real cost	Nominal Cost	Time value of money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental impact evaluation	Green building certification cost	Variations in Various cost	Replacement frequency
Building Type/ functionality	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Building Element/ orientation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
No of floors/ Height/ level above and below ground	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Construction technology	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Energy saving measures and cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Shape of facility	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Estimated annual occupancy hours	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Gross floor Area	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Location	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Context or purpose determined by stakeholders	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Design Inputs	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Method of financing	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Carbon sequestration	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Government regulations/ fees	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	1.67	5.00	5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67
Environmental cost	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Externalities	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Upfront acquisition cost	2.33	2.33	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	1.00	0.78	1.00	0.78	0.78	0.78	7.00	2.33	7.00	7.00	1.00	1.40	2.33	2.33	2.33	7.00	7.00	1.40	1.40	7.00	7.00	2.33	7.00	7.00	2.33
Construction Cost	3.00	3.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	1.00	1.00	9.00	3.00	9.00	9.00	1.29	1.80	3.00	3.00	3.00	9.00	9.00	1.80	1.80	9.00	9.00	3.00	9.00	9.00	3.00
Residual Value	2.33	2.33	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	1.00	0.78	1.00	0.78	0.78	0.78	7.00	2.33	7.00	7.00	1.00	1.40	2.33	2.33	2.33	7.00	7.00	1.40	1.40	7.00	7.00	2.33	7.00	7.00	2.33
Maintenance Cost	3.00	3.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	1.00	1.00	9.00	3.00	9.00	9.00	1.29	1.80	3.00	3.00	3.00	9.00	9.00	1.80	1.80	9.00	9.00	3.00	9.00	9.00	3.00
Operation Cost/ Renewal cost	3.00	3.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	1.00	1.00	9.00	3.00	9.00	9.00	1.29	1.80	3.00	3.00	3.00	9.00	9.00	1.80	1.80	9.00	9.00	3.00	9.00	9.00	3.00
Disposal/end-of-life cost	3.00	3.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	1.00	1.00	9.00	3.00	9.00	9.00	1.29	1.80	3.00	3.00	3.00	9.00	9.00	1.80	1.80	9.00	9.00	3.00	9.00	9.00	3.00
Demand and supply of materials	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Materials availability/ Service Life	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Real cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Nominal Cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Time value of money	2.33	2.33	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	1.00	0.78	1.00	0.78	0.78	0.78	7.00	2.33	7.00	7.00	1.00	1.40	2.33	2.33	2.33	7.00	7.00	1.40	1.40	7.00	7.00	2.33	7.00	7.00	2.33
Discount Rate	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	1.67	5.00	5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67
Income generated from the asset	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Taxation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00

	Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below ground	Construction technology	Energy saving measures and cost	Shape of facility	Estimated annual occupancy hours	Gross floor Area	Location	Context or purpose determined by stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront acquisition cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/ Renewal cost	Disposal/end-of-life cost	Demand and supply of materials	Materials availability/Service Life	Real cost	Nominal Cost	Time value of money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental impact evaluation	Green building certification cost	Variations in Various cost	Replacement frequency
Inflation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Rate of interest	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Foreign Exchange	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building Life	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	1.67	5.00	5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67
Period of Analysis	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	1.67	5.00	5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67
legislative, statutory, or economic changes	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Technology and Tools	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Environmental impact evaluation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Green building certification cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Variations in Various cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Replacement frequency	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Maintenance frequency	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Consideration of design alternatives	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Renewable resources used	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Level of uncertainty	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Risk Allowances	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Waste management cost	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Continuity of supply chain	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Seismic Resistance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Fire Resistance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Insurances	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building occupancy type	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building Age	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Insurance and risk mitigation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Construction quality	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Water management system	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building automation and smart system	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building resilience to natural hazards	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Renewable energy system	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Supply chain resilience and cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building maintenance technologies	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33

	Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below ground	Construction technology	Energy saving measures and cost	Shape of facility	Estimated annual occupancy hours	Gross floor Area	Location	Context or purpose determined by stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront acquisition cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/ Renewal cost	Disposal/end-of-life cost	Demand and supply of materials	Materials availability/Service Life	Real cost	Nominal Cost	Time value of money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental impact evaluation	Green building certification cost	Variations in Various cost	Replacement frequency
Building orientation and solar gain	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building occupancy behaviours	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Building security system	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Health and wellbeing	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Government incentives and subsidies	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Technology depreciation	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Type of Materials and quality	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	1.67	5.00	5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67
Regional and geographical condition	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00
Cost vs Benefits	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Greenstar Rating	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Material Durability	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Installation practice	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Comparability with other building systems	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Acoustic performance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Resistance to wear and tear	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Efficiency of materials/ equipment	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Unforeseen circumstances	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Effectiveness of on-site communication and coordination between teams	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
Availability of skilled labour	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33
	61.33	61.33	184.00	184.00	184.00	184.00	184.00	61.33	184.00	184.00	61.33	184.00	184.00	36.80	61.33	184.00	26.29	20.44	26.29	20.44	20.44	20.44	184.00	61.33	184.00	184.00	26.29	36.80	61.33	61.33	61.33	184.00	184.00	36.80	36.80	184.00	184.00	61.33	184.00	184.00	61.[illegible]

Appendix 1: The pairwise

	Maintenance frequency	Consideration of design alternatives	Renewable resources used	Level of uncertainty	Risk Allowances	Waste management cost	Continuity of supply chain	Seismic Resistance	Fire Resistance	Insurances	Building occupancy type	Building Age	Insurance and risk mitigation	Construction quality	Water management system	Building automation and smart system	Building resilience to natural hazards	Renewable energy system	Supply chain resilience and cost	Building maintenance technologies	Building orientation and solar gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination	Availability of skilled labour
Building Type/ functionality	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Building Element/ orientation	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
No of floors/ Height/ level above and below ground	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Construction technology	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Energy saving measures and cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Shape of facility	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Estimated annual occupancy hours	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gross floor Area	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Location	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Context or purpose determined by stakeholders	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Design Inputs	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Method of financing	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Carbon sequestration	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Government regulations/ fees	1.67	5.00	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Environmental cost	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Externalities	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Upfront acquisition cost	2.33	7.00	7.00	7.00	2.33	2.33	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Construction Cost	3.00	9.00	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Residual Value	2.33	7.00	7.00	7.00	2.33	2.33	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Maintenance Cost	3.00	9.00	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Operation Cost/ Renewal cost	3.00	9.00	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Disposal/end-of-life cost	3.00	9.00	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Demand and supply of materials	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Materials availability/ Service Life	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Real cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nominal Cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Time value of money	2.33	7.00	7.00	7.00	2.33	2.33	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Discount Rate	1.67	5.00	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Income generated from the asset	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Taxation	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

	Maintenance frequency	Consideration of design alternatives	Renewable resources used	Level of uncertainty	Risk Allowances	Waste management cost	Continuity of supply chain	Seismic Resistance	Fire Resistance	Insurances	Building occupancy type	Building Age	Insurance and risk mitigation	Construction quality	Water management system	Building automation and smart system	Building resilience to natural hazards	Renewable energy system	Supply chain resilience and cost	Building maintenance technologies	Building orientation and solar gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination	Availability of skilled labour
Inflation	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Rate of interest	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Foreign Exchange	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Life	1.67	5.00	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Period of Analysis	1.67	5.00	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
legislative, statutory, or economic changes	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Technology and Tools	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Environmental impact evaluation	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Green building certification cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Variations in Various cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Replacement frequency	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Maintenance frequency	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Consideration of design alternatives	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Renewable resources used	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Level of uncertainty	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Risk Allowances	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Waste management cost	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Continuity of supply chain	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Seismic Resistance	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fire Resistance	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Insurances	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building occupancy type	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Age	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Insurance and risk mitigation	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Construction quality	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Water management system	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building automation and smart system	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building resilience to natural hazards	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Renewable energy system	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Supply chain resilience and cost	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building maintenance technologies	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	Maintenance frequency	Consideration of design alternatives	Renewable resources used	Level of uncertainty	Risk Allowances	Waste management cost	Continuity of supply chain	Seismic Resistance	Fire Resistance	Insurances	Building occupancy type	Building Age	Insurance and risk mitigation	Construction quality	Water management system	Building automation and smart system	Building resilience to natural hazards	Renewable energy system	Supply chain resilience and cost	Building maintenance technologies	Building orientation and solar gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination	Availability of skilled labour
Building orientation and solar gain	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building occupancy behaviours	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building security system	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Health and wellbeing	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Government incentives and subsidies	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Technology depreciation	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Type of Materials and quality	1.67	5.00	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Regional and geographical condition	1.00	3.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Cost vs Benefits	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greenstar Rating	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Material Durability	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Installation practice	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Comparability with other building systems	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Acoustic performance	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Resistance to wear and tear	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Efficiency of materials/ equipment	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unforeseen circumstances	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Effectiveness of on-site communication and coordination between teams	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Availability of skilled labour	0.33	1.00	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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Appendix 9: Normalised Weights

Factor	Normalised Weight
Disposal/end-of-life cost	0.048913043
Operation Cost/ Renewal cost	0.048913043
Maintenance Cost	0.048913043
Construction Cost	0.048913043
Residual Value	0.038043478
Upfront acquisition cost	0.038043478
Time value of money	0.038043478
Building Life	0.027173913
Period of Analysis	0.027173913
Government regulations/ fees	0.027173913
Discount Rate	0.027173913
Technology depreciation	0.027173913
Environmental impact evaluation	0.016304348
Building Element/ orientation	0.016304348
Maintenance frequency	0.016304348
Inflation	0.016304348
Taxation	0.016304348
Risk Allowances	0.016304348
Waste management cost	0.016304348
Insurance and risk mitigation	0.016304348
Building security system	0.016304348
Type of Materials and quality	0.016304348
Income generated from the asset	0.016304348
Building Type/ functionality	0.016304348
Replacement frequency	0.016304348
Materials availability/ Service Life	0.016304348
Environmental cost	0.016304348
Gross floor Area	0.016304348
Design Inputs	0.016304348
Nominal Cost	0.005434783
No of floors/ Height/ level above and below ground	0.005434783
Building resilience to natural hazards	0.005434783
Renewable energy system	0.005434783
Supply chain resilience and cost	0.005434783
Building maintenance technologies	0.005434783
Building orientation and solar gain	0.005434783
Building occupancy behaviours	0.005434783
Energy saving measures and cost	0.005434783
Health and wellbeing	0.005434783
Government incentives and subsidies	0.005434783
Construction technology	0.005434783
Cost vs Benefits	0.005434783
Regional and geographical condition	0.005434783

Water management system	0.005434783
Greenstar Rating	0.005434783
Material Durability	0.005434783
Installation practice	0.005434783
Comparability with other building systems	0.005434783
Acoustic performance	0.005434783
Resistance to wear and tear	0.005434783
Efficiency of materials/ equipment	0.005434783
Unforeseen circumstances	0.005434783
Effectiveness of on-site communication and coordination between teams	0.005434783
Building automation and smart system	0.005434783
Building Age	0.005434783
Construction quality	0.005434783
Context or purpose determined by stakeholders	0.005434783
Demand and supply of materials	0.005434783
Externalities	0.005434783
Rate of interest	0.005434783
Foreign Exchange	0.005434783
Carbon sequestration	0.005434783
Method of financing	0.005434783
legislative, statutory, or economic changes	0.005434783
Technology and Tools	0.005434783
Green building certification cost	0.005434783
Variations in Various cost	0.005434783
Location	0.005434783
Shape of facility	0.005434783
Consideration of design alternatives	0.005434783
Renewable resources used	0.005434783
Level of uncertainty	0.005434783
Estimated annual occupancy hours	0.005434783
Continuity of supply chain	0.005434783
Seismic Resistance	0.005434783
Fire Resistance	0.005434783
Insurances	0.005434783
Building occupancy type	0.005434783
Real cost	0.005434783
Availability of skilled labour	0.005434783

Appendix 10: Relationship Polarity Table

Appendix 3: The Pairwise Relationships

	Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeho	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/End-of-Life Cost	Demand and supply of materials	Materials availability/ Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance
Building Type/ functionality		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Element/ orientation	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
No of floors/ Height/ level above and below ground	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Construction Technology	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Energy Saving Measures and Cost	(+)	(+)	(+)	(+)		(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
Shape of Facility	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Estimated annual occupancy hours	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Gross Floor Area	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)
Location	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Context or Purpose Determined by Stakeholders	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Design Inputs	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Method of financing	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)		(-)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Carbon sequestration	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Government regulations/ fees	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Environmental cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)			(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Externalities	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Upfront Acquisition Cost	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(-)	(+)	(+)	(+)	(+)		(+)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)
Construction Cost	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Residual Value	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Maintenance Cost	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Operation Cost/Renewal Cost	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Disposal/End-of-Life Cost	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Demand and supply of materials	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Materials availability/ Service Life	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Real Cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Nominal Cost	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)		(-)	(-)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(-)
Time Value of Money	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)		(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Discount Rate	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)		(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Income generated from the asset	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Taxation	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Inflation	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)		(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Rate of Interest	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)		(-)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

	Building Type/functionality	Building Element/orientation	No of floors/ Height/ level above and below	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeho	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/ End-of-Life Cost	Demand and supply of materials	Materials availability/Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance
Foreign Exchange	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)		(-)	(-)	(+)	(-)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Building Life	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Period of Analysis	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
legislative, statutory, or economic changes	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(-)		(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Technology and Tools	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Environmental Impact Evaluation	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Green Building Certification Cost	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)		(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Variations in Various Costs	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)		(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Replacement Frequency	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Maintenance Frequency	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(-)
Consideration of Design Alternatives	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)		(-)	(-)	(-)	(-)	(-)	(-)
Renewable Resources Used	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)
Level of Uncertainty	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)
Risk Allowances	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)
Water Management System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)
Continuity of Supply Chain	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)
Seismic Resistance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	
Fire Resistance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Insurance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)
Building Occupancy Type	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Age	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Insurance and risk mitigation	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)
Construction Quality	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Waste Management Cost	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(-)	(-)	(+)
Building Automation and Smart System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Resilience to Natural Hazards	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Renewable Energy System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Supply chain resilience and cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Maintenance Technologies	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Orientation and Solar Gain	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Occupancy Behaviors	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Security System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Health and Wellbeing	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

	Building Type/functionality	Building Element/orientation	No of floors/ Height/ level above and below	Construction Technology	EnergySaving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeho	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/ End-of-Life Cost	Demand and supply of materials	Materials availability/ Service Life
Government Incentives and Subsidies	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Technology Depreciation	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Type of Materials and Quality	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Regional and Geographical Condition	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Cost vs Benefits	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Greenstar Rating	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Material Durability	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Installation Practice	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Comparability with Other Building Systems	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Acoustic Performance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Resistance to Wear and Tear	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Efficiency of Materials/Equipment	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Unforeseen Circumstances	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Effectiveness of On-site Communication and Coordination	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Availability of Skilled Labour	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance
Government Incentives and Subsidies	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Technology Depreciation	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Type of Materials and Quality	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Regional and Geographical Condition	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Cost vs Benefits	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Greenstar Rating	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Material Durability	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Installation Practice	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Comparability with Other Building Systems	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Acoustic Performance	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Resistance to Wear and Tear	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Efficiency of Materials/Equipment	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Unforeseen Circumstances	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Effectiveness of On-site Communication and Coordination	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Availability of Skilled Labour	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

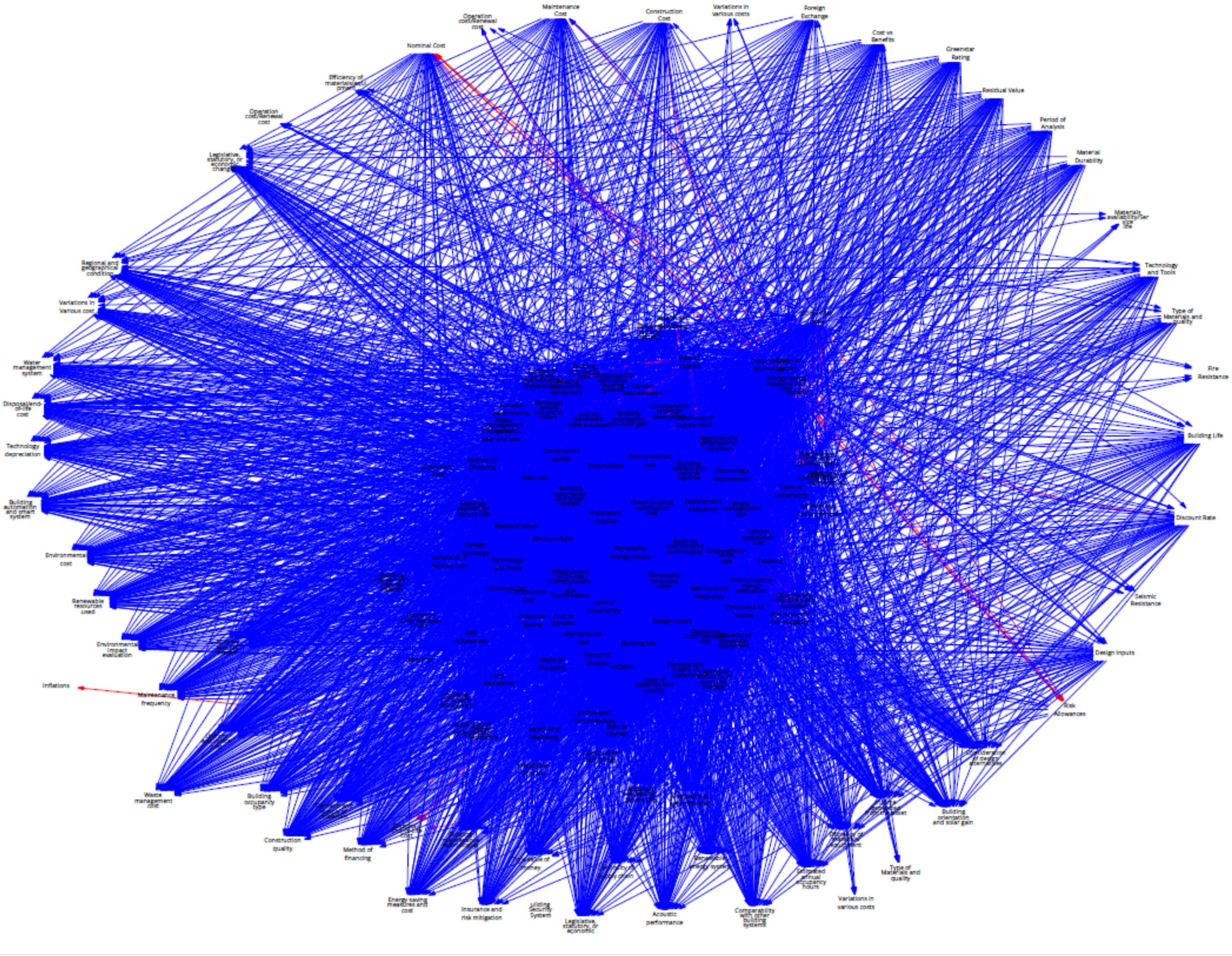
Appendix 3: The Pairwise Relationships

	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supply chain resilience and cost	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication an	Availability of skilled labour
Building Type/ functionality	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Element/ orientation	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
No of floors/ Height/ level above and below ground	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Construction Technology	(+)	(+)	(+)	(-)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Energy Saving Measures and Cost	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(-)	(+)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)
Shape of Facility	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Estimated annual occupancy hours	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Gross Floor Area	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Location	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Context or Purpose Determined by Stakeholders	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Design Inputs	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Method of financing	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Carbon sequestration	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Government regulations/ fees	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Environmental cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Externalities	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(+)
Upfront Acquisition Cost	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(+)	(-)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(+)	(+)
Construction Cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Residual Value	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Maintenance Cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Operation Cost/Renewal Cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Disposal/End-of-Life Cost	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(+)
Demand and supply of materials	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Materials availability/ Service Life	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Real Cost	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Nominal Cost	(-)	(+)	(-)	(+)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(+)	(+)
Time Value of Money	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
Discount Rate	(-)	(-)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)
Income generated from the asset	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)
Taxation	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Inflation	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Rate of Interest	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supply chain resilience and cost	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and	Availability of skilled labour
Foreign Exchange	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(+)
Building Life	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Period of Analysis	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
legislative, statutory, or economic changes	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Technology and Tools	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Environmental Impact Evaluation	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Green Building Certification Cost	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)	(+)	(-)
Variations in Various Costs	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Replacement Frequency	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Maintenance Frequency	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Consideration of Design Alternatives	(-)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(+)	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Renewable Resources Used	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Level of Uncertainty	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Risk Allowances	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Water Management System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Continuity of Supply Chain	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Seismic Resistance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Fire Resistance		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Insurance	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Occupancy Type	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Age	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Insurance and risk mitigation	(+)		(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Construction Quality	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Waste Management Cost	(-)	(-)	(-)	(+)	(+)	(+)		(-)	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(+)	(+)	(+)
Building Automation and Smart System	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Resilience to Natural Hazards	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Renewable Energy System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Supply chain resilience and cost	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Maintenance Technologies	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Orientation and Solar Gain	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Occupancy Behaviors	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Building Security System	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	
Health and Wellbeing	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supply chain resilience and cost	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication an	Availability of skilled labour
Government Incentives and Subsidies	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Technology Depreciation	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)	(+)		(+)	(+)	(+)
Type of Materials and Quality	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Regional and Geographical Condition	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Cost vs Benefits	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)
Greenstar Rating	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)			(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Material Durability	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Installation Practice	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)
Comparability with Other Building Systems	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)
Acoustic Performance	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)
Resistance to Wear and Tear	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)
Efficiency of Materials/Equipment	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)
Unforeseen Circumstances	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)
Effectiveness of On-site Communication and Coordination	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)
Availability of Skilled Labour	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	

Appendix 11: Causal Loop Diagram


Nominal Cost
Operation cost/Renewal cost
Maintenance Cost
Construction Cost
Variations in various costs
Foreign Exchange
Cost vs Benefits
Greenstar Rating
Residual Value
Period of Analysis
Material Durability
Technology and Tools
Type of Materials and quality
Fire Resistance
Building Life
Discount Rate
Seismic Resistance
Design Inputs
Risk Allowances
Building orientation and solar gain
Type of Materials and quality
Variations in various costs
Comparability with other building systems
Acoustic performance
Legislative, statutory, or economic
Insurance and risk mitigation
Energy saving measures and cost
Method of financing
Construction quality
Building occupancy type
Waste management cost
Inflations
Maintenance frequency
Environmental impact evaluation
Renewable resources used
Environmental cost
Building automation and smart system
Technology depreciation
Disposal/end-of-life cost
Water management system
Variations in Various cost
Regional and geographical condition
Operation cost/Renewal cost

Appendix 12: Linkage Weight Matrix

	Building Type/ functionality	Building Element/ orientation	No of floors/ Height/ level above and below ground	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/End-of-Life Cost	Demand and supply of materials	Materials availability/ Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives
Building Type/ functionality	0.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Building Element/ orientation	1.00	0.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
No of floors/ Height/ level above and below ground	0.33	0.33	0.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Construction Technology	0.33	0.33	1.00	0.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Energy Saving Measures and Cost	0.33	0.33	1.00	1.00	0.00	1.00	-1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	-0.33	-0.33	1.00
Shape of Facility	0.33	0.33	1.00	1.00	1.00	0.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	-0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Estimated annual occupancy hours	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Gross Floor Area	1.00	1.00	3.00	3.00	3.00	3.00	3.00	0.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Location	0.33	0.33	1.00	1.00	-1.00	1.00	1.00	0.33	0.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Context or Purpose Determined by Stakeholders	0.33	0.33	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	0.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	-0.33	-0.33	1.00
Design Inputs	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Method of financing	0.33	0.33	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.33	0.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	-0.33	0.33	-0.33	-1.00	-1.00	-0.20	-0.20	0.00	-1.00	0.33	1.00	-1.00	-0.33	-0.33	1.00
Carbon sequestration	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	0.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Government regulations/ fees	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	0.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	-1.67	-5.00	-5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67	1.67	5.00
Environmental cost	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.00	0.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Externalities	0.33	0.33	1.00	-1.00	-1.00	-1.00	-1.00	-0.33	-1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	-1.00	0.33	1.00	1.00	-0.33	-0.33	1.00
Upfront Acquisition Cost	2.33	2.33	7.00	-7.00	-7.00	-7.00	7.00	-2.33	-7.00	7.00	2.33	-7.00	7.00	1.40	2.33	7.00	0.00	0.78	-1.00	0.78	0.78	0.78	-7.00	2.33	7.00	7.00	1.00	1.40	-2.33	2.33	2.33	7.00	7.00	-1.40	-1.40	7.00	7.00	2.33	7.00	-7.00	2.33	2.33	7.00
Construction Cost	3.00	3.00	9.00	9.00	-9.00	9.00	9.00	3.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	1.29	0.00	1.29	1.00	1.00	1.00	9.00	3.00	9.00	9.00	1.29	1.80	3.00	3.00	-3.00	-9.00	-9.00	1.80	1.80	9.00	9.00	3.00	9.00	9.00	3.00	3.00	9.00
Residual Value	2.33	2.33	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	2.33	-7.00	7.00	1.40	2.33	7.00	1.00	0.78	0.00	0.78	0.78	0.78	-7.00	2.33	7.00	7.00	1.00	1.40	2.33	2.33	-2.33	-7.00	-7.00	1.40	1.40	7.00	7.00	2.33	7.00	7.00	2.33	2.33	7.00
Maintenance Cost	3.00	3.00	9.00	9.00	-9.00	9.00	9.00	3.00	9.00	9.00	3.00	-9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	0.00	1.00	1.00	-9.00	3.00	9.00	9.00	1.29	1.80	-3.00	3.00	-3.00	-9.00	-9.00	-1.80	-1.80	9.00	9.00	3.00	9.00	9.00	3.00	3.00	-9.00
Operation Cost/Renewal Cost	3.00	3.00	9.00	9.00	-9.00	9.00	9.00	3.00	9.00	9.00	3.00	-9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	0.00	1.00	-9.00	3.00	9.00	9.00	1.29	1.80	-3.00	3.00	-3.00	-9.00	-9.00	-1.80	-1.80	9.00	9.00	3.00	9.00	9.00	3.00	3.00	9.00
Disposal/End-of-Life Cost	3.00	3.00	9.00	9.00	9.00	9.00	-9.00	3.00	9.00	9.00	3.00	-9.00	9.00	1.80	3.00	9.00	1.29	1.00	1.29	1.00	1.00	0.00	-9.00	3.00	9.00	9.00	1.29	1.80	-3.00	3.00	-3.00	-9.00	-9.00	-1.80	-1.80	9.00	-9.00	3.00	9.00	9.00	-3.00	-3.00	9.00
Demand and supply of materials	0.33	0.33	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	0.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	-1.00	0.33	1.00	1.00	-0.33	-0.33	1.00
Materials availability/ Service Life	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	0.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Real Cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	0.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Nominal Cost	0.33	0.33	1.00	-1.00	-1.00	-1.00	-1.00	-0.33	-1.00	-1.00	-0.33	-1.00	-1.00	-0.20	-0.33	-1.00	-0.14	-0.11	0.14	-0.11	-0.11	-0.11	-1.00	-0.33	-1.00	0.00	-0.14	-0.20	0.33	-0.33	0.33	1.00	1.00	0.20	0.20	1.00	-1.00	-0.33	-1.00	1.00	-0.33	-0.33	1.00
Time Value of Money	2.33	2.33	7.00	7.00	-7.00	7.00	7.00	2.33	7.00	-7.00	-2.33	7.00	7.00	1.40	2.33	7.00	-1.00	-0.78	-1.00	-0.78	-0.78	-0.78	7.00	-2.33	-7.00	-7.00	0.00	1.40	2.33	2.33	-2.33	-7.00	-7.00	1.40	1.40	7.00	7.00	2.33	7.00	7.00	2.33	2.33	7.00
Discount Rate	1.67	1.67	5.00	5.00	-5.00	5.00	-5.00	1.67	5.00	-5.00	-1.67	5.00	5.00	1.00	1.67	5.00	-0.71	-0.56	-0.71	-0.56	-0.56	-0.56	5.00	-1.67	-5.00	-5.00	-0.71	0.00	1.67	1.67	-1.67	-5.00	-5.00	1.00	1.00	5.00	-5.00	1.67	5.00	5.00	-1.67	-1.67	5.00
Income generated from the asset	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	0.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Taxation	1.00	1.00	3.00	-3.00	-3.00	-3.00	3.00	-1.00	-3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	0.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Inflation	-1.00	-1.00	-3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	-1.00	1.00	0.00	-3.00	-3.00	-0.60	-0.60	3.00	3.00	1.00	3.00	-3.00	1.00	1.00	-3.00
Rate of Interest	-0.33	-0.33	-1.00	1.00	1.00	1.00	1.00	0.33	1.00	-1.00	-0.33	-1.00	-1.00	-0.20	-0.33	-1.00	-0.14	-0.11	0.14	-0.11	-0.11	-0.11	-1.00	-0.33	-1.00	-1.00	-0.14	-0.20	0.33	-0.33	-0.33	0.00	-1.00	0.20	0.20	1.00	1.00	-0.33	-1.00	1.00	0.33	0.33	1.00

	Building Type/ functionality	Building Element/ orientation	No of floors/Height/ level above and below ground	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/End-of-Life Cost	Demand and supply of materials	Materials availability/ Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives
Foreign Exchange	-0.33	-0.33	-1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	-0.33	0.33	-0.33	-1.00	0.00	-0.20	-0.20	1.00	-1.00	0.33	1.00	-1.00	-0.33	-0.33	1.00
Building Life	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	0.00	1.67	1.67	5.00	5.00	0.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67	1.67	5.00
Period of Analysis	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	-1.67	5.00	5.00	1.00	0.00	5.00	5.00	1.67	5.00	5.00	1.67	1.67	5.00
legislative, statutory, or economic changes	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	-0.33	0.33	0.33	1.00	1.00	-0.20	-0.20	0.00	1.00	0.33	1.00	-1.00	0.33	0.33	1.00
Technology and Tools	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	0.00	0.33	1.00	1.00	0.33	0.33	1.00
Environmental Impact Evaluation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	0.00	3.00	3.00	1.00	1.00	3.00
Green Building Certification Cost	0.33	0.33	1.00	-1.00	1.00	-1.00	-1.00	-0.33	-1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	-1.00	0.33	0.00	1.00	-0.33	-0.33	1.00
Variations in Various Costs	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.00	1.00	1.00	0.33	1.00	0.00	0.33	0.33	1.00
Replacement Frequency	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	-3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	-3.00	1.00	3.00	3.00	0.43	0.60	-1.00	1.00	-1.00	-3.00	-3.00	-0.60	-0.60	3.00	3.00	1.00	3.00	3.00	0.00	1.00	3.00
Maintenance Frequency	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	-3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	-3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	0.00	3.00
Consideration of Design Alternatives	0.33	0.33	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	-1.00	0.33	1.00	1.00	-0.33	-0.33	0.00
Renewable Resources Used	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Level of Uncertainty	0.33	0.33	1.00	-1.00	1.00	-1.00	1.00	-0.33	-1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Risk Allowances	1.00	1.00	3.00	-3.00	-3.00	-3.00	3.00	-1.00	-3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	3.00	3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Water Management System	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Continuity of Supply Chain	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	0.00	0.33	0.33	1.00
Seismic Resistance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Fire Resistance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Insurance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Occupancy Type	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Age	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Insurance and risk mitigation	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Construction Quality	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	-0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Waste Management Cost	0.33	0.33	1.00	1.00	1.00	-1.00	-1.00	-0.33	-1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	-1.00	0.33	1.00	1.00	-0.33	-0.33	1.00
Building Automation and Smart System	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Resilience to Natural Hazards	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Renewable Energy System	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Supply chain resilience and cost	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Maintenance Technologies	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Orientation and Solar Gain	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Building Occupancy Behaviors	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	-1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	-1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00

	Building Type/ functionality	Building Element/ orientation	No of floors/Height/ level above and below ground	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated annual occupancy hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeholders	Design Inputs	Method of financing	Carbon sequestration	Government regulations/ fees	Environmental cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/End-of-Life Cost	Demand and supply of materials	Materials availability/ Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income generated from the asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	Legislative, statutory, or economic changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Costs	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives
Building Security System	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Health and Wellbeing	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Government Incentives and Subsidies	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Technology Depreciation	0.33	0.33	1.00	-1.00	-1.00	-1.00	1.00	-0.33	-1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Type of Materials and Quality	1.67	1.67	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	0.71	0.56	0.71	0.56	0.56	0.56	5.00	1.67	5.00	5.00	0.71	1.00	1.67	1.67	-1.67	-5.00	-5.00	1.00	1.00	5.00	5.00	1.67	5.00	5.00	1.67	1.67	5.00
Regional and Geographical Condition	1.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	0.43	0.33	0.43	0.33	0.33	0.33	3.00	1.00	3.00	3.00	0.43	0.60	1.00	1.00	-1.00	-3.00	-3.00	0.60	0.60	3.00	3.00	1.00	3.00	3.00	1.00	1.00	3.00
Cost vs Benefits	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Greenstar Rating	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Material Durability	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Installation Practice	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Comparability with Other Building Systems	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Acoustic Performance	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Resistance to Wear and Tear	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Efficiency of Materials/Equipment	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Unforeseen Circumstances	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	1.00	1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Effectiveness of On-site Communication and Coordination	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00
Availability of Skilled Labour	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.14	0.11	0.14	0.11	0.11	0.11	1.00	0.33	1.00	1.00	0.14	0.20	0.33	0.33	-0.33	-1.00	-1.00	0.20	0.20	1.00	1.00	0.33	1.00	1.00	0.33	0.33	1.00

	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supplychain resilience and cost	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination between teams	Availability of skilled labour
Building Type/ functionality	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	-3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Building Element/ orientation	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
No of floors/ Height/ level above and below ground	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Construction Technology	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Energy Saving Measures and Cost	1.00	1.00	0.33	0.33	1.00	-1.00	-1.00	1.00	-1.00	-1.00	0.33	1.00	1.00	1.00	-1.00	1.00	1.00	-1.00	1.00	-1.00	1.00	0.33	1.00	-1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	1.00
Shape of Facility	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Estimated annual occupancy hours	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	0.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gross Floor Area	3.00	-3.00	-1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Location	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Context or Purpose Determined by Stakeholders	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	0.33	1.00	-1.00	1.00	-1.00	1.00	1.00	-1.00	-1.00	-1.00	1.00	0.33	-1.00	-1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Design Inputs	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	-3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Method of financing	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	0.33	1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	0.33	1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Carbon sequestration	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Government regulations/ fees	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Environmental cost	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Externalities	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	-0.33	1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Upfront Acquisition Cost	7.00	7.00	2.33	-2.33	-7.00	7.00	7.00	-7.00	7.00	-7.00	2.33	-7.00	-7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	-7.00	2.33	-7.00	7.00	1.40	-2.33	7.00	7.00	-7.00	7.00	-7.00	-7.00	-7.00	7.00	7.00	7.00	7.00
Construction Cost	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	-9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Residual Value	7.00	7.00	2.33	2.33	7.00	7.00	7.00	7.00	7.00	-7.00	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	1.40	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Maintenance Cost	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	-9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Operation Cost/Renewal Cost	9.00	9.00	3.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	3.00	9.00	9.00	1.80	3.00	9.00	9.00	-9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Disposal/End-of-Life Cost	-9.00	-9.00	-3.00	-3.00	-9.00	-9.00	-9.00	-9.00	-9.00	9.00	3.00	9.00	-9.00	-9.00	-9.00	-9.00	9.00	-9.00	-9.00	-9.00	-9.00	3.00	-9.00	-9.00	1.80	3.00	-9.00	-9.00	-9.00	-9.00	9.00	-9.00	-9.00	-9.00	-9.00	9.00	9.00
Demand and supply of materials	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.33	1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	0.33	1.00	-1.00	1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Materials availability/ Service Life	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	-3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Real Cost	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nominal Cost	-1.00	-1.00	-0.33	0.33	1.00	-1.00	-1.00	1.00	-1.00	1.00	-0.33	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.33	1.00	-1.00	-0.20	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	1.00	-1.00	-1.00	1.00	1.00
Time Value of Money	7.00	7.00	2.33	2.33	7.00	7.00	7.00	7.00	7.00	7.00	2.33	7.00	7.00	7.00	7.00	7.00	-7.00	7.00	7.00	7.00	7.00	-2.33	7.00	7.00	1.40	2.33	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	-7.00
Discount Rate	-5.00	-5.00	-1.67	-1.67	-5.00	-5.00	-5.00	-5.00	-5.00	5.00	-1.67	5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-1.67	-5.00	-5.00	1.00	1.67	-5.00	-5.00	5.00	-5.00	5.00	-5.00	-5.00	-5.00	-5.00	5.00	-5.00
Income generated from the asset	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	-3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.00	3.00
Taxation	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	-1.00	3.00	3.00	3.00	3.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00
Inflation	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Rate of Interest	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	-0.33	1.00	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	-0.20	0.33	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supply chain resilience and cost	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination between teams	Availability of skilled labour
Foreign Exchange	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	0.33	1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	0.33	-1.00	-1.00	1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	1.00	1.00
Building Life	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	-5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Period of Analysis	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	1.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
legislative, statutory, or economic changes	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Technology and Tools	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Environmental Impact Evaluation	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Green Building Certification Cost	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	0.33	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	-0.33	-1.00	-1.00	-0.20	-0.33	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00
Variations in Various Costs	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Replacement Frequency	-3.00	-3.00	-1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Maintenance Frequency	3.00	3.00	1.00	1.00	3.00	-3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Consideration of Design Alternatives	-1.00	-1.00	-0.33	-0.33	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.33	1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	0.33	1.00	-1.00	1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Renewable Resources Used	0.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Level of Uncertainty	1.00	0.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	-0.33	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00
Risk Allowances	3.00	3.00	0.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	-1.00	3.00	3.00	3.00	3.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00
Water Management System	3.00	3.00	1.00	0.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Continuity of Supply Chain	1.00	1.00	0.33	0.33	0.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Seismic Resistance	1.00	1.00	0.33	0.33	1.00	0.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fire Resistance	1.00	1.00	0.33	0.33	1.00	1.00	0.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Insurance	1.00	1.00	0.33	0.33	0.00	1.00	1.00	0.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Occupancy Type	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	0.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Age	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Insurance and risk mitigation	3.00	3.00	1.00	1.00	0.00	3.00	3.00	0.00	3.00	3.00	0.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Construction Quality	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Waste Management Cost	1.00	1.00	0.33	-0.33	-1.00	1.00	-1.00	-1.00	-1.00	1.00	0.33	1.00	0.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.20	-0.33	1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00
Building Automation and Smart System	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Resilience to Natural Hazards	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Renewable Energy System	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Supply chain resilience and cost	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	-1.00	0.33	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Maintenance Technologies	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Orientation and Solar Gain	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Building Occupancy Behaviors	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Water Management System	Continuity of Supply Chain	Seismic Resistance	Fire Resistance	Insurances	Building Occupancy Type	Building Age	Insurance and risk mitigation	Construction Quality	Waste Management Cost	Building Automation and Smart System	Building Resilience to Natural Hazards	Renewable Energy System	Supplychain resilience and cost
Building Security System	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Health and Wellbeing	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00
Government Incentives and Subsidies	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Technology Depreciation	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	-1.00	1.00	1.00	1.00	1.00	1.00
Type of Materials and Quality	5.00	5.00	1.67	1.67	5.00	5.00	5.00	5.00	5.00	5.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00
Regional and Geographical Condition	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00
Cost vs Benefits	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Greenstar Rating	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Material Durability	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Installation Practice	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Comparability with Other Building Systems	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Acoustic Performance	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Resistance to Wear and Tear	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Efficiency of Materials/Equipment	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Unforeseen Circumstances	1.00	1.00	0.33	0.33	1.00	1.00	1.00	0.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Effectiveness of On-site Communication and Coordination	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00
Availability of Skilled Labour	1.00	1.00	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00

	Building Maintenance Technologies	Building Orientation and Solar Gain	Building occupancy behaviours	Building security system	Health and wellbeing	Government incentives and subsidies	Technology depreciation	Type of Materials and quality	Regional and geographical condition	Cost vs Benefits	Greenstar Rating	Material Durability	Installation practice	Comparability with other building systems	Acoustic performance	Resistance to wear and tear	Efficiency of materials/ equipment	Unforeseen circumstances	Effectiveness of on-site communication and coordination between teams	Availability of skilled labour
Building Security System	1.00	1.00	1.00	0.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Health and Wellbeing	3.00	3.00	3.00	3.00	0.00	3.00	3.00	0.60	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Government Incentives and Subsidies	1.00	1.00	1.00	1.00	0.33	0.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Technology Depreciation	1.00	1.00	1.00	1.00	0.33	1.00	0.00	0.20	-0.33	1.00	1.00	1.00	1.00	-1.00	1.00	1.00	0.00	1.00	1.00	1.00
Type of Materials and Quality	5.00	5.00	5.00	5.00	1.67	5.00	5.00	0.00	1.67	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Regional and Geographical Condition	3.00	3.00	3.00	3.00	1.00	3.00	3.00	0.60	0.00	3.00	3.00	-3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Cost vs Benefits	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Greenstar Rating	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Material Durability	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Installation Practice	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Comparability with Other Building Systems	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Acoustic Performance	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Resistance to Wear and Tear	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00
Efficiency of Materials/Equipment	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Unforeseen Circumstances	1.00	1.00	1.00	1.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Effectiveness of On-site Communication and Coordination	1.00	1.00	1.00	0.00	0.33	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
Availability of Skilled Labour	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00

Appendix 13: Literature Matrix

Author(s)	Year	Title	Key Contributions	Relationship to this study
Abdullah, A. S., et al.	2025	*A geographic information system-based flood risk assessment comprehensive model utilising a multi-criteria decision analysis technique*	Proposed a GIS-based model for flood risk assessment in construction, emphasising the integration of multi-criteria decision analysis.	This study employed similar multi-criteria approaches to incorporate climate risks into WLC frameworks.
Akiyama, M., et al.	2020	*Toward life-cycle reliability-risk- and resilience-based design and assessment of bridges and bridge networks*	Introduced a resilience-based framework for assessing infrastructure risks, focusing on earthquake, tsunami, and corrosion hazards.	This study extended resilience-based approaches into residential building design, particularly in seismic regions.
ASCE & ENO	2014	*Life Cycle Cost Analysis*	Provided guidelines for conducting life cycle cost analysis (LCCA) in civil engineering projects.	This study built on LCCA by incorporating system dynamics and adapting it for residential buildings with regional considerations.
ASTM	2020	*Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*	Developed a standardised approach to LCCA for assessing the long-term costs of building systems.	This study referenced ASTM's framework by integrating New Zealand-specific risks, including seismic activity and climate change.
Bao, Z.	2023	*Developing circularity of construction waste for a sustainable built environment in emerging economies*	Focused on circular economy strategies for reducing construction waste and promoting sustainability in emerging economies.	This study incorporated similar sustainability principles but with a focus on WLC and resilience in the New Zealand context.
Crielaard, L., et al.	2024	*Refining the causal loop diagram: A tutorial for maximising the contribution of domain expertise in computational system dynamics modelling*	Emphasised the importance of domain expertise in system dynamics modelling, particularly for causal loop diagrams (CLDs).	This study used CLDs to model WLC factors, enhancing them with New Zealand-specific data and risks.
DGNB	2022	*Important Facts about DGNB Certification*	Described the DGNB certification system for sustainable building, which includes environmental and social criteria.	This study integrated these criteria into a WLC framework tailored for New Zealand's residential buildings.
Goh, B. H.	2016	*Designing a whole-life*	Developed a cost index	This study adapted the

		building cost index in Singapore	for building life-cycle management specific to Singapore's building sector.	index to New Zealand's residential buildings, taking into account the country's unique seismic and climate risks.
Goh, B. H., & Sun, Y.	2016	*The development of life-cycle costing for buildings*	Explored the development and application of life-cycle costing in building projects, focusing on long-term economic considerations.	This study expanded on this by integrating regional factors, such as seismic resilience and climate impacts.
ISO	2017	*ISO 15686-5: Buildings and Constructed Assets—Service Life Planning—Part 5: Life Cycle Costing*	Standardised life-cycle costing for buildings, focusing on systematic cost management and service life planning.	This study followed the ISO standard while incorporating context-specific factors, such as seismic and climate-related risks, relevant to New Zealand.
Jaques, R. A., et al.	2015	*Valuing sustainability and resilience features in housing*	Focused on valuing sustainability features in residential buildings, specifically in the context of New Zealand.	This study considered sustainability and resilience, emphasising their role in whole-life costing for New Zealand homes.
Kallio, H., et al.	2016	*Systematic methodological review: developing a framework for a qualitative semi-structured interview guide*	Developed a framework for semi-structured interviews in qualitative research, focusing on systematic data collection.	This study employed a similar qualitative framework to conduct expert interviews, validating cost-driving factors in New Zealand's residential buildings.
Lakshmanan, N., et al.	2008	*Experimental investigations on the seismic response of a base-isolated reinforced concrete frame model*	Investigated the seismic response of reinforced concrete frames, focusing on base-isolation techniques.	This study incorporated seismic resilience as a key cost driver, aligning with findings from Lakshmanan et al. on seismic risk management.
Lehmann, S.	2013	*Sustainable building design and systems integration: combining energy efficiency with material efficiency*	Discussed the integration of energy efficiency and material efficiency in sustainable building design.	This study integrated energy efficiency and material durability as central factors influencing the WLC of residential buildings.
Lim, J., et al.	2025	*Evaluating green building certification criteria for small health care centres in the Jakarta area – from GREENSHIP to Puske-GREENSHIP framework*	Evaluated the criteria for green building certifications, focusing on health care centres.	This study incorporated similar certification criteria into the WLC framework for New Zealand's residential sector.
Liu, J., et al.	2023	*Life cycle cost modelling and economic*	Reviewed life cycle cost modelling in wind	This study incorporated similar life cycle cost

		analysis of wind power: A state of art review	power, offering insights into renewable energy systems.	models, focusing on the residential sector and integrating energy-efficient technologies and renewable systems.
MBIE	2013	*Total cost of Ownership: An Introduction to Whole-life cost*	Introduced guidelines for considering whole-life cost in public procurement for infrastructure.	This study extended these principles to residential buildings in New Zealand, incorporating seismic and climate risks into cost estimations.
Memon, F. A., et al.	2015	*Energy and carbon implications of water saving micro-components and greywater reuse systems*	Investigated the energy and carbon savings associated with water-saving systems.	This study extended water-saving systems into a broader WLC framework, focusing on their impact on long-term building costs in New Zealand.
Minami, K.	2003	*Whole-life cost of post offices in Japan, based on a survey of actual conditions and consideration of investment correction*	Explored the whole-life cost of post offices in Japan, particularly regarding investment correction.	This study extended these cost estimation techniques to the residential sector in New Zealand, incorporating local seismic risks.
Nasereddin, M., & Price, A.	2021	*Addressing the capital cost barrier to sustainable construction*	Discussed how to overcome the capital cost barrier in sustainable construction practices.	This study addressed similar barriers by incorporating long-term WLC considerations and seismic resilience into New Zealand's residential building practices.
NIWA	2022	*Climate change and possible impacts for New Zealand*	Provided an overview of potential climate change impacts specific to New Zealand.	This study directly incorporated the climate risks identified by NIWA into the WLC framework for residential buildings.
Opsahl, T., et al.	2010	*Node centrality in weighted networks: Generalizing degree and shortest paths*	Expanded the understanding of centrality in social networks, focusing on weighted connections.	This study applied centrality analysis to model the dynamic interactions of cost drivers in residential buildings.
Page, M. J., et al.	2021	*The PRISMA 2020 statement: an updated guideline for reporting systematic reviews*	Provided updated guidelines for conducting systematic literature reviews.	This study adhered to the PRISMA guidelines to conduct a systematic review of factors influencing WLC in residential buildings.
Purushothaman, M. B., & Aguas, A. B.	2025	*Cognitive biases that shape the drivers and barriers to embracing green construction practices*	Explored cognitive biases affecting the adoption of green construction practices.	This study incorporated insights from cognitive biases to analyse barriers to WLC adoption in New Zealand's

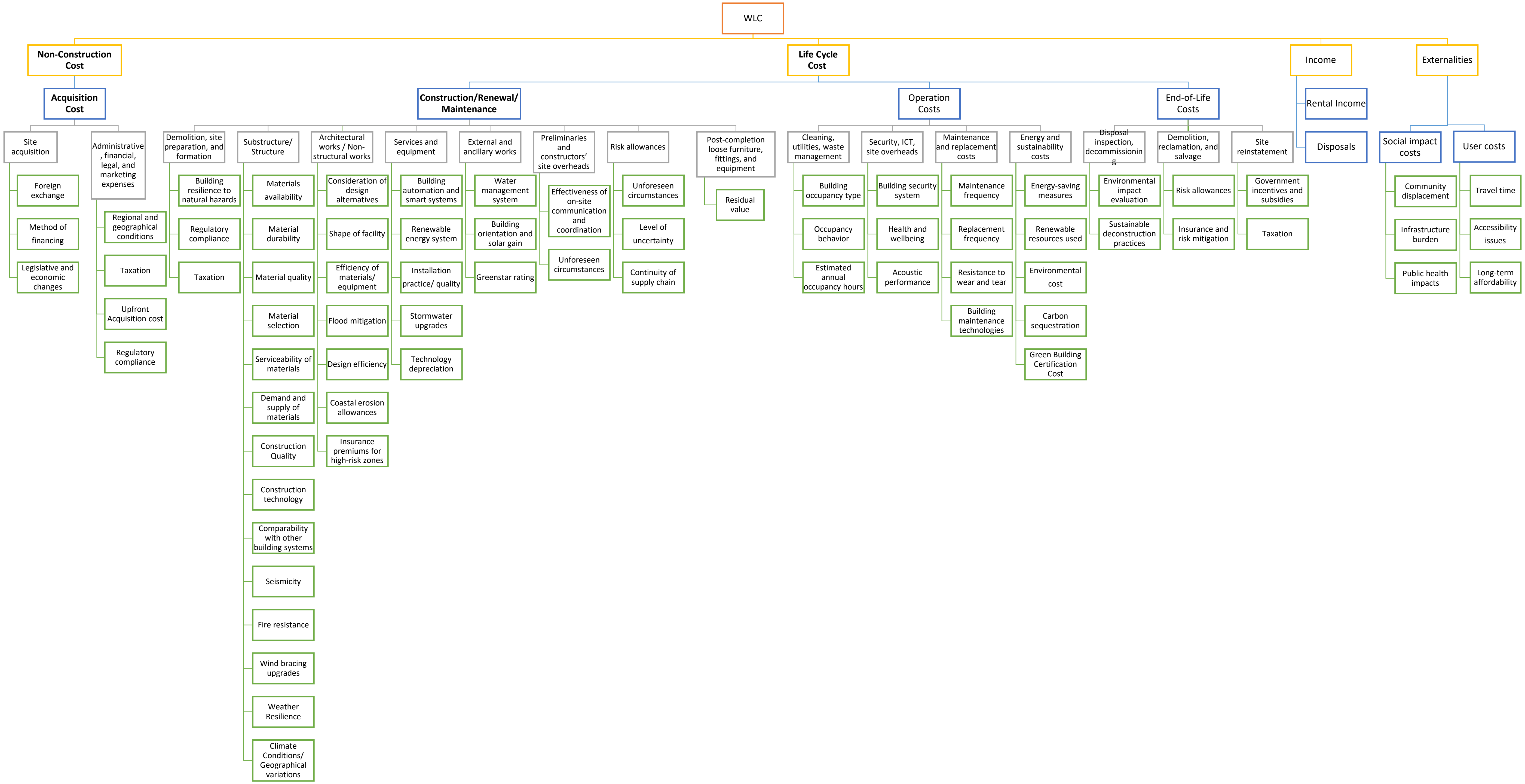
				residential sector.
QTC	2019	*Whole-Of-Life Costing: A QUICK REFERENCE GUIDE FOR ELECTED OFFICIALS AND STAFF*	Provided a practical guide to understanding and applying whole-of-life costing in public projects.	This study followed similar guidelines, applying WLC specifically to residential buildings in New Zealand.
RICS	2016	*Life Cycle Costing*	Provided a comprehensive guide to life cycle costing in construction, with an emphasis on cost management.	This study adapted RICS guidelines, focusing on the integration of system dynamics for residential buildings in New Zealand.
Rolfstam, M., & Petersen, O. H.	2014	*Denmark. In Public Procurement, Innovation and Policy: International Perspectives*	Focused on public procurement and innovation in Denmark, with an emphasis on lifecycle considerations.	This study built on these principles, incorporating regional factors like seismic resilience and climate change into the WLC framework for New Zealand.
Seetharaman, A., et al.	2017	*The impact of property management services on tenants' satisfaction with industrial buildings*	Explored the role of property management in tenant satisfaction in industrial buildings.	This study extended these findings by focusing on lifecycle cost factors in residential buildings, with a particular emphasis on long-term sustainability and resilience.
Sterman, J.	2002	*System Dynamics: systems thinking and modelling for a complex world*	Provided a comprehensive approach to system dynamics, focusing on modelling and feedback loops.	This study adopted system dynamics and causal loop diagrams (CLDs) to model the dynamic interactions of cost drivers in the WLC of residential buildings.
treasury.govt.nz	2015	*Whole of Life Costs Guidance*	Guided considering whole-of-life costs for public procurement in New Zealand.	This study incorporated this guidance to model long-term costs for residential buildings, taking into account seismic and climate-related risks.
UKSI	2015	*The Public Contracts Regulations 2015/102*	Provided regulations for public procurement, emphasising lifecycle costs and sustainability.	This study aligned with UKSI's regulations by applying lifecycle cost modelling to residential buildings in New Zealand.
USGBC	2019	*LEED v4.1 Building Design and Construction Beta Guide*	Provided a guide to LEED v4.1 for building design and construction, focusing on sustainability.	This study incorporated LEED v4.1 criteria for building sustainability and applied them to the WLC framework for New Zealand homes.
USGBC	2021	*LEED v4.1 Reference Guide for Building*	A comprehensive guide for achieving	This study followed LEED criteria for

	Design and Construction	LEED certification in building projects, focusing on green building standards.	sustainability and integrated them into the whole-life costing model for New Zealand's residential sector.

Appendix 14: Cost Components of the Factors in the WLC Framework according to BCIS (2012); (ICMS, 2019; RICS, 2016, 2021)

Non-Construction Cost	**Acquisition Cost**	**Site Acquisition**	**All payments required to acquire the site, excluding physical construction**
		Administrative, financial, legal, and marketing expenses	All other expenses associated with project realisation, from inception to putting into use, excluding physical construction
Life Cycle Cost	Construction, renewal, and maintenance cost	Substructure	All the load-bearing work underground or underwater up to and including the lowest floor slabs and basement sides and bottom, including related waterproofing and insulation
		Structure	All the load-bearing work, including non-load-bearing components, services, and equipment forming an integral part of composite or prefabricated load-bearing work, excluding those included in Substructure and Architectural works | Non-structural works.
		Architectural works/non-structural works	All architectural and non-load-bearing work, excluding services, equipment, and surface and underground drainage
		Services and Equipment	All fixed services and equipment required [to put the completed project into use for Construction Costs | to sustain the use after completion of construction for Renewal and Maintenance Costs], whether they are mechanical, hydraulic, plumbing, firefighting, transport, communication, security, electrical or electronic, control systems, or signalling excluding external surface and underground drainage, including testing, commissioning and operational licensing and plant upgrades/refurbishment.
		Surface and underground drainage	All underground or external surface drainage systems, excluding those inside the basement or underground construction
		External and ancillary works	All work outside the external face of buildings or beyond the construction entity is required to fulfil the project's primary function and is not included in other Groups.
		Preliminaries | Constructors' site overheads | general requirements	Constructors' site management, temporary site facilities, site services, mobilisation, demobilisation, and other expenses not directly related to a particular group but commonly required to be shared by all Groups.
		Risk Allowances	A quantitative allowance is set aside as a precaution against risks and future needs, allowing for the uncertainty of outcomes. This may include an allowance for optimism bias and a contingency sum.
		Taxes and Levies	Mandatory costs taxed or levied in connection with any phase of the Project by national governments, states, municipalities, or governmental organisations, whether paid by the Client, the Constructor or the Operator.
		Work and utilities off-site	All payments to government authorities or public utility companies to connect | keep connected public work and utilities to the site, or services diversions, to enable the Project, including related risk allowances, taxes, and levies.
		Production and loose furniture, fittings, and equipment	Those provided for the Project to perform its business function close to or after completion of construction, including related risk allowances, taxes, and levies.
		Construction | Renewal | Maintenance-related consultancies and supervision	Fees payable to Service Providers not engaged by the Constructors, including related risk allowances, taxes, and levies
	Operation costs	Cleaning	Periodic, routine and specialist cleaning of internal and external works.
		Utilities	Fuel, including gas, electricity, fuel oil, solid and other fuel; water and drainage, including water rates, effluents, sewerage drainage and other charges
		Waste Management	Collection, compaction, removal, disposal and recycling of general and toxic waste from the constructed asset
		Security	Physical security (such as access control, CCTV camera, including staff or contractors involved in providing security controls via remote support centres to the constructed asset
		Information and communication technology	Information communications systems (such as public address and communications cabling and IT support services built as a constructed asset, as well as technology used for monitoring assets (i.e., building management systems) and physical sensors
		Operators' site overheads | general requirements	Operators' site management, temporary site facilities, site services, and expenses are not directly related to a particular group but are commonly required to be shared by all Groups.
		Risk Allowances	A quantitative allowance is set aside as a precaution against risks and future needs, allowing for the uncertainty of outcomes. This may include an allowance for optimism bias and a contingency sum.
		Taxes and Levies	Mandatory costs taxed or levied in connection with any phase of the Project by national governments, states, municipalities, or governmental organisations, whether paid by the Client, the Constructor or the Operator.
	End-of-life costs	Disposal inspection	Inspections are carried out in connection with demolition, dilapidations, or other contractual requirements.
		Decommissioning and decontamination	All post-occupation activities are required to render the constructed asset ready for demolition.
		Demolition, reclamation, and salvage	Demolition of the constructed asset at the end-of-life or period of interest, and landfill, recycling or disposal.
		Reinstatement	Dealing with dilapidations, measures to comply
		Constructors' site overheads | general requirements	Constructors' site management, temporary site facilities, site services, and expenses are not directly related to a particular group but are commonly required to be shared by all Groups.
		Risk Allowances	A quantitative allowance is set aside as a precaution against risks and future needs to allow for the uncertainty of outcomes. This may include an allowance for optimism bias and a contingency sum.
		Taxes and Levies	Mandatory costs taxed or levied in connection with any phase of the Project by national governments, states, municipalities, or governmental organisations, whether paid by the Client, the Constructor, or the Operator.
Income	Income from sales/ rental	Third-party income (PFI/PPP)	
		Taxation on income	
Externalities			Costs associated with an asset but not reflected in the transaction costs of the acquisition.

Appendix 15: The five-level WLC hierarchy


WLC
Non-Construction Cost
Life Cycle Cost
Income
Externalities
Acquisition Cost
Construction/Renewal/ Maintenance
Operation Costs
End-of-Life Costs
Rental Income
Disposals
Social impact costs
User costs
Site acquisition
Administrative, financial, legal, and marketing expenses
Demolition, site preparation, and formation
Substructure/ Structure
Architectural works / Non-structural works
Services and equipment
External and ancillary works
Preliminaries and constructors' site overheads
Risk allowances
Post-completion loose furniture, fittings, and equipment
Cleaning, utilities, waste management
Security, ICT, site overheads
Maintenance and replacement costs
Energy and sustainability costs
Disposal inspection, decommissioning
Demolition, reclamation, and salvage
Site reinstatement
Foreign exchange
Method of financing
Legislative and economic changes
Regional and geographical conditions
Taxation
Upfront Acquisition cost
Regulatory compliance
Building resilience to natural hazards
Regulatory compliance
Taxation
Materials availability
Material durability
Material quality
Material selection
Serviceability of materials
Demand and supply of materials
Construction Quality
Construction technology
Comparability with other building systems
Seismicity
Fire resistance
Wind bracing upgrades
Weather Resilience
Climate Conditions/ Geographical variations
Consideration of design alternatives
Shape of facility
Efficiency of materials/ equipment
Flood mitigation
Design efficiency
Coastal erosion allowances
Insurance premiums for high-risk zones
Building automation and smart systems
Renewable energy system
Installation practice/ quality
Stormwater upgrades
Technology depreciation
Water management system
Building orientation and solar gain
Greenstar rating
Effectiveness of on-site communication and coordination
Unforeseen circumstances
Unforeseen circumstances
Level of uncertainty
Continuity of supply chain
Residual value
Building occupancy type
Occupancy behavior
Estimated annual occupancy hours
Building security system
Health and wellbeing
Acoustic performance
Maintenance frequency
Replacement frequency
Resistance to wear and tear
Building maintenance technologies
Energy-saving measures
Renewable resources used
Environmental cost
Carbon sequestration
Green Building Certification Cost
Environmental impact evaluation
Sustainable deconstruction practices
Risk allowances
Insurance and risk mitigation
Government incentives and subsidies
Taxation
Community displacement
Infrastructure burden
Public health impacts
Travel time
Accessibility issues
Long-term affordability