Developing a Decision Support Framework to Facilitate the Demolition versus Deconstruction Decision-Making Process at the End-of-Life Phase of the Building Lifecycle in New Zealand's Construction Industry

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by

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ABSTRACT

The activities of the construction industry during the End-of-Life (EOL) phase of the building lifecycle make a substantial contribution to the generation of Construction & Demolition Waste (C&DW), accounting for more than 50% of the total waste produced. The urgent need to address environmental concerns and the unsustainable practices prevalent in the construction sector has prompted the adoption of deconstruction as an alternative to conventional demolition when buildings reach the end of their service lives. Nevertheless, the decision-making process regarding the selection between traditional demolition and contemporary deconstruction is intricate and influenced by multiple factors. This research aims to identify and analyse the parameters that influence this decision while also developing a decision support platform to optimize the EOL phase of building lifecycle.

Through an extensive review of the relevant literature, five categories of parameters were discerned: Building-related, Cost-related, Material-related, Geographical-related, and Structural-related. A total of 21 parameters were identified within these categories. Verification of these parameters was accomplished through consultations with professionals from the construction industry in New Zealand, thereby confirming their significance in the decision-making process, with particular emphasis on building and cost-related factors. To determine the importance of each parameter both within their respective clusters and overall, a questionnaire survey was conducted. The survey enlisted industry experts with a minimum of five years of experience in demolition, deconstruction, or both. Based on the data collected, a decision-support framework was formulated, enhancing professionals' understanding of the critical factors influencing the decision-making process during the EOL phase. Structural Equation Modelling (SEM) was employed to validate the framework and evaluate the interrelationships among the identified categories. The analysis results indicated that Cost-related parameters exerted the most significant influence on the decision-making process. It was also revealed that Building-related parameters exert significant impacts on all other categories, while Cost-related parameters are influenced by each of the other categories. This research contributes to the construction industry by providing a comprehensive comprehension of the factors that influence the decision between traditional demolition and contemporary deconstruction during the EOL phase. Furthermore, the developed decision support platform can facilitate informed decision-making among professionals, optimizing the EOL phase of the building lifecycle and promoting sustainable practices within the construction industry.

Keywords: Building End-of-Life, Building Lifecycle, EOL, Demolition, Deconstruction.

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ATTESTATION OF 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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LIST OF SYMBOLS AND ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
AHP	Analytic Hierarchy Process
AUTEC	Auckland University of Technology Ethics Committee
AVE	Average Variance Extracted
BIM	Building Information Modelling
BRP	Building-related Parameters
BWPE	BIM-based Whole-life Performance Estimator
C&D	Construction and Demolition
CB-SEM	Covariance-based Structural Equation Modeling
CDF	Cumulative Distribution Function
CDW	Construction and Demolition Waste
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CR	Composite reliability
CRP	Cost-related Parameters
DfD	Design for Deconstruction
DvDD	Demolition versus Deconstruction Decision
EDF	Empirical Distribution Function
EFA	Exploratory Factor Analysis
EOL	End-of-Life
GDP	Gross Domestic Product
GOF	Goodness-of-Fit
GRP	Geographical-related Parameters
KMO	Kaiser-Meyer-Olkin
KS	Kolmogorov-Smirnov
LCA	Life Cycle Assessment
LV	Latent Variable
MCDM	Multi-Criteria Decision Making
MRP	Material-related Parameters
MV	Measured Variable
NZ	New Zealand
NZDAA	New Zealand Demolition and Asbestos Association
OECD	Organisation for Economic Cooperation and Development
PLS-SEM	Partial Least Squares Structural Equation Modeling

R&D	Research and Development
RMSEA	Root Mean Squared Error of Approximation
SEM	Structural Equation Modelling
SLR	Systematic Literature Review
SPSS	Statistical Package for the Social Science
SRMR	Standard Root Mean Squared Residual
SRP	Structural-related Parameters
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

Chapter 1 Introduction

1.1 Overview

This chapter is designed to provide a brief understanding of the thesis. It starts with reviewing previous studies to provide an insight into the importance of this research and why there is a need to perform further research in this field. Then, the gap in the literature is highlighted, followed by the research aim and objectives. Next, the research methods utilised are described before explaining the potential contributions to academia and industry in the construction field of this study. Furthermore, the thesis outline is described briefly, and a summary of the next chapter is addressed.

1.2 Background

It has been revealed that activities in the End-of-Life (EOL) phase of building lifecycle account for over 50% of the total Construction and Demolition Waste (C&DW) resulting from the construction industry (Akinade, Oyedele, Omoteso, et al., 2017). The growing environmental concerns and the currently unsustainable construction industry have triggered the adoption of deconstruction as an alternative method to conventional demolition when buildings come to their end of service lives (Carvalho Machado et al., 2018). Therefore, various studies have been dedicated to investigating the advantages and disadvantages of both deconstruction and demolition (Kühlen et al., 2016; Rios et al., 2015; Shami, 2006). The concept of design for disassembly in the building and construction field was first introduced by Philip Crowther (Crowther, 1999) as “a useful strategy that can be applied to varying extents to increase the future rates of material and component reuse. Subsequently, between 2001 and 2006, different suggestions were put forward to encourage design for disassembly to ease future reusing, recycling, and repurposing of the materials and components of different structural frameworks (Crowther, 2005; Morgan & Stevenson, 2005;

Webster & Costello, 2005). Other studies have been conducted comparing demolition and deconstruction's economic aspects. For instance, based on economic variables, Guy and Ohlsen (Guy & Ohlsen, 2003) developed a tool to estimate the effectiveness and cost of the application of deconstruction compared with the traditional demolition of the wood-framed building's structure.

From the environmental impact perspective, a comprehensive project analysis and quantitative survey have been conducted by Vefago et al. (Vefago & Avellaneda, 2013) to calculate and assess the recyclability inventory of typical EOL building materials. Another study (Akbarnezhad et al., 2014) has estimated the budget, energy consumption, and carbon footprint arising from four possible strategies that could be used at the building's EOL. The study, furthermore, investigated the most economical and environmentally friendly deconstruction methods by developing a framework to assess and compare the effectiveness of different deconstruction strategies on critical factors such as carbon footprint, consumed energy and cost of deconstruction projects. Using building information modelling (BIM), Akbarnezhad et al. (Akbarnezhad & Nadoushani, 2014) have estimated the energy consumption and carbon emissions of concrete recycling.

Moreover, several studies have been conducted to evaluate the effective deconstruction approach. For instance, in 2018, Carvalho et al. conducted a comprehensive analysis to identify the characteristics which could influence the deconstruction potentials for different building projects (Carvalho Machado et al., 2018). In 2015, Akinade et al. (Akinade et al., 2015) proposed a BIM-based Deconstructability Assessment Score (BIM-DAS) model to determine – right from the design stage – whether a building could be deconstructed. In 2017, the same authors discussed the future of Design for Deconstruction (DfD) and its effectiveness by using a BIM-based approach (Akinade, Oyedele, Omoteso, et al., 2017). In the said study, after conducting thematic data analysis, it has been revealed that BIM can provide seven functionalities in an effective DfD process. These functionalities include: a) improving the collaboration between stakeholders, b) visualising the process of deconstruction, c) identifying materials with recoverability potential, d) developing a deconstruction plan, e) simulation and performance analysis of EOL alternatives, f) improving building life management, and g) promoting the ability for collaboration with existing BIM software.

Another study by Hübner et al. (Hübner et al., 2017) investigated the various methods which can be employed in the stage of project planning of building deconstruction, such as strategic and operational planning methods. Coelho and De Brito (Coelho, 2013) have compared conventional demolition and deconstruction technological aspects and concluded

that “with current techniques and transportation methods, only significant separation efforts that result in reuse or recycling of bulk aggregate materials may lead to sizable environmental impact reductions, compared to a conventional demolition scenario”.

Furthermore, several researchers have investigated different simulation techniques in deconstruction planning (Cheng & Ma, 2013), proposing functional mass flow models based on BIM databases. Considering the optimisation of building EOL process, a mathematical multi-objective programming model has been developed by Aidonis (Aidonis, 2019), which proposed an integrated and comprehensive strategy for selecting the appropriate dismantling approach for the EOL of buildings. While previous studies have focused on design concepts for deconstruction, principles for deconstruction from the design stage, introducing a foundation for design for the deconstruction process and also providing a performance assessment for the design stage (Addis, 2008; Akanbi et al., 2019; Guy et al., 2006), little attention has been paid to planning and decision making for the optimal EOL approach for the existing buildings.

1.3 Problem Statement

It has been claimed that the construction sector plays a crucial role in resource and energy consumption (Martínez et al., 2013). The construction industry is renowned worldwide for consuming large amounts of raw materials, water, and energy, production of greenhouse gas emissions, and sending CO_2 into the atmosphere (Dobrovolskienė et al., 2019). By looking at the studies, it comes to know that the construction industry, compared to other sectors, has dropped back in adopting environmental sustainability practices (Ajayi & Oyedele, 2018). In contrast, the detrimental effects of different types of waste on society and the environment are widely studied and addressed (Banihashemi et al., 2018; Lu & Yuan, 2011).

Due to the shortage in land supply and increasing building densities in urban areas (Kühlen et al., 2016), demolition works are highly demanded. While the growth in the number of demolition projects brings in larger volumes of waste, deconstruction activities are proven to unlock different potentials toward a more sustainable industry (van den Berg et al., 2021). Employing deconstruction in building EOL enables material reuse and waste reduction, as well as allowing the capable components and products to re-enter the construction market (Jayasinghe et al., 2019; Nasir et al., 2017).

However, since deconstruction is considered as complicated as the construction process, and it is not always a feasible option for bringing down a building, choosing the appropriate approach, either conventional demolition or deconstruction, is a critical decision. Besides, in theory, it is believed that types of decisions differ from a rational approach to an emotional

one. Algorithmic models, however, are assumed to enhance decision-making by moving the processes from an emotional to a sensible approach (Hossfeld, 2017).

At the same time, Building Information Modeling (BIM) has been developed and has been taking the attention of the Architecture, Engineering & Construction (AEC) sectors since the early 2000s (Ghaffarianhoseini et al., 2017). However, the evidence shows that despite the widespread use of BIM in various stages of a building lifecycle, such as design, construction, and maintenance, its usage in the last stage of the building lifecycle, End-of-Life, is still not a common practice (Akinade, Oyedele, Omoteso, et al., 2017).

Since selecting an appropriate and optimal EOL approach requires a wide range of factors to be taken into consideration (Akbarnezhad et al., 2014), herein, the primary aim of this research is set to be the development of a decision support framework for the End-of-Life stage of building lifecycle, facilitating the decision-making process in choosing the appropriate approach, conventional demolition or deconstruction.

1.4 Research Aim

This research aims to develop a framework to facilitate decision-making at the End-of-Life phase of building lifecycle in New Zealand. To accomplish the research aim, five key objectives have been proposed, and five research questions are originated to be answered.

1.4.1 Objective 1: Identifying the Critical Parameters Influencing the Selection of an Appropriate Approach for the End-of-Life Phase of the Building Lifecycle

As mentioned earlier in this chapter, the End-of-Life phase in the building lifecycle has not been thoroughly investigated compared to the other phases globally, and New Zealand is not an exception. It is necessary to identify the parameters that may affect the professionals' decision on whether to choose demolition or deconstruction, as it could improve the level of their understanding of each approach and the critical factors in this decision-making process.

As a result, the following research question is expected to be answered to achieve this objective:

RQ1: What are the critical parameters influencing the decision on whether a project is worth being deconstructed or demolished conventionally?

1.4.2 Objective 2: Verifying the Collected Parameters from the Literature in the Context of the New Zealand Construction Industry

This objective aims to evaluate whether all the parameters collected from the literature apply in New Zealand's construction industry. By achieving this objective, the following research questions will be answered:

RQ2: Would all the identified parameters be applicable in New Zealand's construction industry?

1.4.3 Objective 3: Developing a Decision Support Framework to Facilitate the Decision-Making Process on EOL Approach Selection

After identifying and verifying the affecting parameters, a decision support framework will be developed. Besides highlighting the critical parameters affecting the decision-making process, the framework also ranks the parameters based on their level of importance. Therefore, the following research question is anticipated to be answered:

RQ3: What would be the most significant parameter affecting the selection of demolition or deconstruction at the EOL phase?

1.4.4 Objective 4: Examining the Impact of Consequential Parameters Influencing the Decision-Making Process Between Conventional Demolition and Deconstruction

This objective aims to examine the contribution of each parameter on professionals' decisions when choosing between conventional demolition and deconstruction. It is essential to study the weight of each parameter since it can be used to illustrate the level of effectiveness of each parameter on the professionals' final decision – demolition versus deconstruction decision (DvDD). To achieve this objective, the following research question is planned to be answered:

RQ4: How significant is each parameter in professionals' decisions when choosing between deconstruction and demolition as the most proper EOL approach?

To achieve this objective, the following hypotheses are tested:

- H1 – BRP have significant impacts on DvDD.
- H2 – CRP have significant impacts on DvDD.
- H3 – MRP have significant impacts on DvDD.
- H4 – GRP have significant impacts on DvDD.
- H5 – SRP have significant impacts on DvDD.
- H6 – BRP have significant impacts on CRP.
- H7 – BRP have significant impacts on MRP.

- H8 – BRP have significant impacts on SRP.
- H9 – MRP have significant impacts on CRP.
- H10 – GRP have significant impacts on CRP.
- H11 – GRP have significant impacts on MRP.
- H12 – SRP have significant impacts on CRP.

1.4.5 Objective 5: Validating the Developed Decision Support Framework using Structural Equation Modelling (SEM)

After examining how significant each parameter can be in the decision-making process, the developed framework will be validated by employing Structural Equation Modelling (SEM). The model will reveal the impacts and relationships of significant parameters. As a result of this, three questions are intended to be addressed:

RQ5: What are the critical categories affecting the decision-making process of the EOL phase?

To conclude, the summary of the research aim, research question and the expected outcomes of the research can be seen in Figure 1.1.

Developing a Decision Support Framework to Facilitate the Decision-Making Process at The End-of-Life Phase of Building Projects in New Zealand's Context

Research Objective 1 Identifying the Critical Parameters Influencing the Selection of an Appropriate Approach for the EoL Phase of Building Projects	**Research Question 1** What are the critical parameters influencing the decision on whether a project is worth being deconstructed or demolished conventionally?
Research Objective 2 Verifying the Collected Parameters from the Literature in the Context of New Zealand's Construction Industry	**Research Question 2** Would all the identified parameters be applicable in New Zealand's construction industry?
Research Objective 3 Developing a Decision Support Framework to Facilitate the Decision-Making Process on EoL Approach Selection	**Research Question 3** What would be the most and least significant parameters affecting the selection of demolition or deconstruction at the EOL phase?
Research Objective 4 Examining the Impact of Consequential Parameters Influencing the Decision-Making Process Between Conventional Demolition and Deconstruction	**Research Question 4** How significant is each parameter in professionals' decisions when choosing between deconstruction and demolition as the most proper EOL approach?
Research Objective 5 Validating the Developed Decision Support Framework using Structural Equation Modelling (SEM)	**Research Question 5** What are the critical parameters affecting the decision-making process of the EOL phase?

Figure 1.1 Research Aim, Questions and Objectives

1.5 Research Contribution

The research proposes a framework that can be effectively employed to improve the End-of-Life phase of a building lifecycle. The developed framework ultimately facilitates the decision-making to choose the appropriate approach for demolishing a building. This will help the construction industry to tackle existing problems regarding not having a systematic process when a building reaches its end and the scepticism of selecting conventional demolition or deconstruction as the EOL approach. The research results are expected to provide insights into the Building End-of-Life phase in New Zealand. To do so, influencing parameters on the demolition versus deconstruction decision (DvDD) to choose conventional demolition or deconstruction will be determined. In addition, the importance level of each category of parameters will be discussed. Consequently, a decision support framework will be provided to facilitate the decision-making on whether conventional demolition or deconstruction would be the most appropriate and optimised approach for the End-of-Life phase of building lifecycle in the New Zealand context.

This research could play an essential role in the EOL phase of the building life cycle as it provides an innovative approach to improve professionals' understanding of the affecting parameters on choosing an appropriate approach. To the author's best knowledge, few research studies have focused on optimising the EOL phase of buildings in New Zealand despite the importance of this topic. By providing inside into the current EOL status in New Zealand, the research results could be used by other researchers as references for future studies.

1.6 An Overview of Research Methods

This research consists of five different phases in which the following methods were used: i) Systematic literature review, ii) Semi-structured interview, iii) Entropy and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), iv) questionnaire survey, v) Structural Equation Modelling (SEM).

A comprehensive **literature review** was carried out to understand the nature of the research gap. The review examined the EOL phase in the building's lifecycle globally and specifically in New Zealand. Further, the two main EOL approaches, conventional demolition and deconstruction, were discussed, focusing on their challenges, alongside their positive and negative aspects. Reviewing the previous studies, the potential parameters affecting the professionals' decision on demolition or deconstruction were sought and are

presented in the subsequent section. In addition, the literature review allowed us to identify a knowledge gap and set a foundation to construct the research aim, objectives, and questions.

Then, **semi-structured interviews** were conducted to validate and localise the collected potential parameters from the literature. The philosophical stance used in this research was pragmatism and utilised a combination of positivism and interpretivism to introduce various perceptions of the research, eventually improving the research's reliability. The semi-structured interviews were conducted between October 2020 and June 2021, and 12 professionals participated in this project phase. The interviews provided a realistic view of the EOL phase of the building's lifecycle in New Zealand and validated the collected data from the literature.

Shannon Entropy and **Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)** were utilised to develop the decision support framework to facilitate decision-making in the EOL phase of the building's life cycle. The Shannon Entropy was used as a tool to calculate the weight of the affecting parameters, and following that, the TOPSIS method was employed to rank the crucial parameters. By the end of this phase, the EOL decision support framework was developed based on the calculated weights and ranks of the parameters.

A **questionnaire survey** was then prepared and distributed to collect data supporting the developed framework. The survey was designed in three sections, including i) background information, ii) rating the parameters, and iii) ranking the parameters. A pilot study was conducted after receiving 30 responses to evaluate the reliability and validity of the instrument, and data collection was stopped after the number of responses reached a satisfactory response rate of 33.23%.

With the use of **Structural Equation Modelling (SEM)**, the developed framework was validated, and the hypothesised structural relationships between the parameters were evaluated. The SEM modelling was conducted in two rounds in which the measurement and structural models were assessed, respectively.

1.7 Thesis Organisation

The structure of this PhD thesis comprises six chapters as outlined below:

Chapter One provides an overview of the research project, initiating with the background of the study. This is followed by the problem statement, justifying the conduction of the current research. Subsequently, the research aim, objectives, and questions

are highlighted. The chapter further discusses how this research contributes to the state-of-art knowledge and industry, followed by an overview of the methods employed in this study.

Chapter Two examines the current studies by implementing a comprehensive literature review. The building End-of-Life fundamentals, particularly definitions, scopes, disciplines, benefits, and challenges of Conventional Demolition and Deconstruction as the two main approaches of EOL, are highlighted, followed by a comparison of the mentioned methods. After illustrating the overall status of EOL in the New Zealand Construction Industry, the potential affecting parameters extracted from the literature is presented in the last section of this chapter.

Chapter Three explains the methodological approach adopted to conduct the study to achieve the research aim. It explains the philosophical stance of the study, followed by exploring different approaches, techniques, and strategies to select the appropriate data collection method. Subsequently, ethical considerations for the research are reported, and the justification for the credibility of the findings is discussed. The chapter then concludes with a summary.

Chapter Four presents the findings of the study to support and validate the research aims and objectives. It highlights the findings from the semi-structured interviews and the results from Entropy and TOPSIS calculations. The analysed data from the questionnaire survey and the results from the SEM modelling are then presented.

Chapter Five synthesises the findings of phases 1 to 4 reported in Chapter 4. The chapter begins with a discussion on the affecting parameters and their ranking based on their level of importance. After that, a decision-support framework is proposed to facilitate decision-making at the End-of-Life phase of building lifecycle. Further, a summary is provided to conclude the discussions.

Chapter Six concludes the research by integrating the findings with the research objectives. After that, the contribution to the knowledge is discussed, followed by recommendations for future researchers and industry practitioners. Lastly, the chapter highlights research limitations.

Chapter 2 Literature Review

2.1 Chapter Introduction

This chapter aims to review previous studies and present a state-of-the-art literature review about the construction industry and building End-of-Life (EOL), conventional demolition, and deconstruction. After reviewing New Zealand's construction industry, the chapter provides descriptions of the main elements of the research, including Building End of Life (EOL), conventional demolition, and deconstruction. Then, after highlighting the current status of EOL in New Zealand, the potential affecting parameters extracted from the literature are presented. Thereafter, possible gaps in the literature for further study, and the outline of the next chapter, are underlined in the summary. Figure 2.1 illustrates an overall content outline for this chapter.

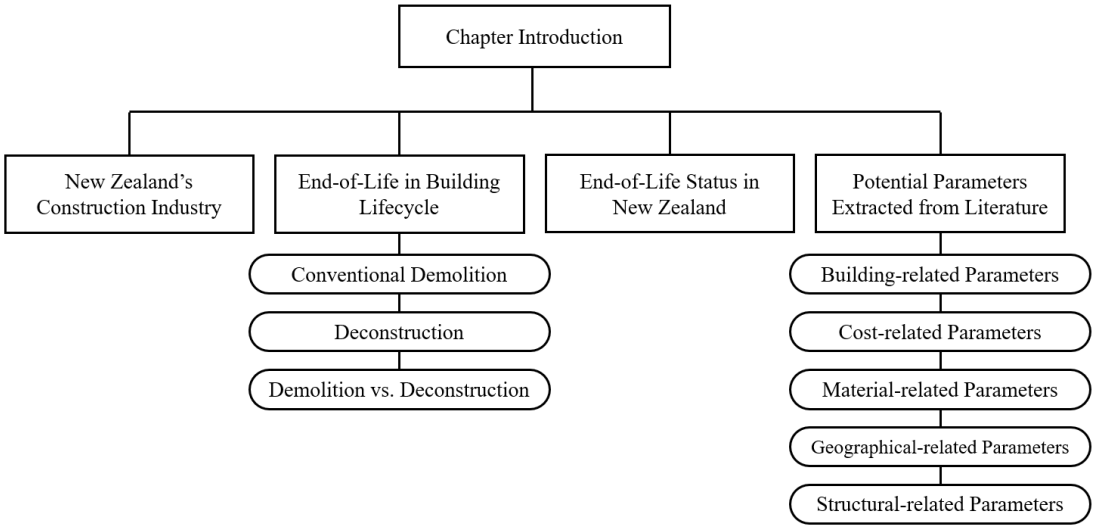

Figure 2.1 Content Outline of Chapter Two

2.2 New Zealand's Construction Industry

It is broadly reported that the construction industry plays a critical role in the domestic economy globally (Sulbaran, 2005). Likewise, the construction industry is one of the major contributors to New Zealand's economy as it is reported to be "the fifth largest industry, produces 6.7 per cent of real gross domestic product (GDP), comprises approximately 70,600 businesses nationwide, and directly employs almost 300,00 people (around 10.5 per cent of the total workforce)" (MBIE, 2022). In New Zealand, construction is defined as the work applied to build, erect, renovate, alter, or improve an existing building for which building consent is required under the Building Act 2004 (Act, 2004).

Although it is crucial to the national development of New Zealand, still different aspects of the construction industry seem to need further improvement. For instance, compared to other OECD (Organisation for Economic Co-operation and Development) countries, the lack of infrastructure development in New Zealand is noticeable due to the low construction productivity (Liu & Wilkinson, 2011). In line with this matter, it has been claimed that (Jaffe et al., 2016) a rise of one per cent in construction productivity could bring about a two per cent improvement in the country's gross domestic product. The constant decrease of productivity trend in the construction industry sector over the years (from 1980 to 2010) has caused the foundation of the Building and Construction Productivity Partnership in 2010 to increase productivity by 20 per cent within a ten-year timeframe. In 2019, after conducting a series of interviews and workshops, Seadon and Tookey (Seadon & Tookey, 2019) provided 10 nodal points and 19 crucial levers for implementation in order to enhance productivity in the construction industry within the New Zealand context. Hereafter, no study has been reported on this topic.

Some studies have attempted to identify the driver factors of New Zealand construction productivity. For instance, it has been mentioned that internal factors, such as workers' capability and efficient management, are the most critical factors, while external ones are neither important nor studied (Durdyev & Mbachu, 2011; Page, 2011). Although productivity in the construction industry has been studied internationally for several years, it has not been focused on the New Zealand market (Jaffe et al., 2016).

When it comes to innovations, the construction industry, undeniably, is still within the less-covered sectors (Noktehdan et al., 2015), and it has been claimed that low construction productivity is due to the scarcity of innovation or defective innovation (Carson & Abbott, 2012). This is while, it has been confirmed that research and development (R&D) expenditure in the construction industry accounts for around 5% of the total expenditure in

the sector (Carson & Abbott, 2012). The results from the recent research and development survey produced by New Zealand Statistics in 2021 (Fig 2.2) confirm that expenditure spent on the construction sector is still within the lowest sectors compared to the others (Statistic, 2021).

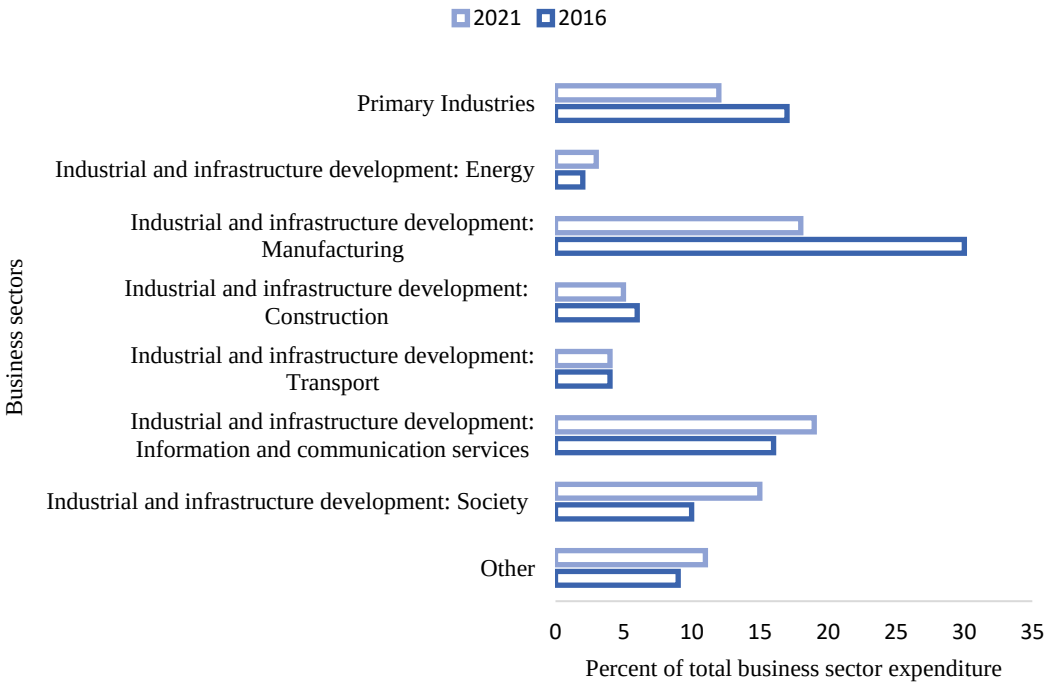

Figure 2.2 Sectors Benefit from Research and Development Expenditure (Statistic, 2021)

Apart from the low level of innovation and productivity, a large amount of waste is considered another unappealing characteristic of New Zealand's construction industry (Hampson et al.), and it has been a major contributor to environmental destruction (Wang, 2014). While it is said that the construction industry introduces 45-65% of disposal waste, it also has been claimed to utilise approximately 40% of energy, 25% of harvested wood, and 17% of water resources resulting in accelerated deforestation (Li et al., 2017).

In summary, the primary challenges faced by the New Zealand construction industry can be identified as the inadequate levels of innovation and productivity, alongside the pressing concern of construction and demolition waste (C&DW). In addressing these challenges, governmental bodies and local authorities hold significant potential to facilitate positive change by promoting the adoption and effective utilisation of innovative solutions within the industry. The following section highlights one of the most controversial topics in the construction industry that has recently been devoted attention by construction professionals and researchers.

2.3 End-of-Life in Building Lifecycle

The life cycle of a building is commonly divided into four distinct stages, namely production, construction, operation, and End-of-Life, although there exist multiple definitions and explanations of these stages (Roh & Tae, 2017; Sanchez et al., 2019). The production stage encompasses the extraction of raw materials and their subsequent conversion into construction materials (Amaral et al., 2020). This phase is of particular concern due to its irreversible impact on non-renewable resources, thereby exacerbating the risk of resource depletion (Bertino et al., 2021). Moreover, the manufacturing process involved in producing construction materials and products is known to consume a substantial amount of energy, rendering it one of the largest energy consumers on a global scale (Mallis et al., 2021). During the construction stage, which involves the participation of numerous stakeholders, a significant expenditure of energy and materials is incurred to shape the final product (Song et al., 2018). The operational phase of a building's lifecycle is recognised as the most extensive stage, encompassing activities such as utilisation, reuse, maintenance, and refurbishment, all aimed at prolonging the building's lifespan (Giorgi et al., 2019). However, this stage also entails significant environmental consequences, as it has been reported to contribute substantially to the emission of carbon dioxide CO_2 (Ramon et al., 2023). Lastly, the End-of-Life stage pertains to the period and processes involved in the safe removal of a building at the conclusion of its useful lifespan (John & Buchanan, 2013).

Research findings indicate that activities occurring during the End-of-Life phase of building lifecycle contribute to more than half of the total Construction and Demolition Waste (CDW) generated by the construction industry (Akinade, Oyedele, Omoteso, et al., 2017). The growing environmental concerns and the unsustainable nature of the present construction industry have spurred the adoption of deconstruction as an alternative to conventional demolition when buildings have reached their full lifecycle potential (Carvalho Machado et al., 2018).

Traditionally, two approaches are commonly employed for managing the End-of-Life of buildings: Conventional Demolition and Deconstruction (Fig. 2.3). The former involves the complete dismantling of a structure without any specific purpose, often resulting in the deposition of materials in landfills. In contrast, the latter approach aims to divert waste away from landfills by emphasising practices such as reusing, repurposing, recovering, and other post-end-of-life strategies (Akinade et al., 2015)

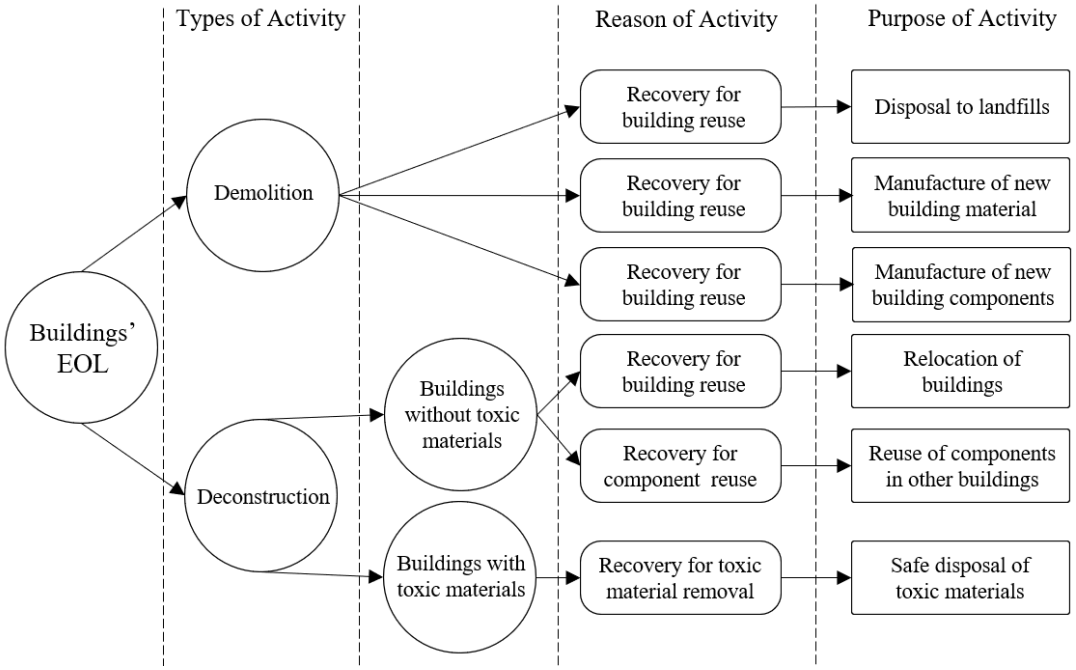

Figure 2.3 Building End-of-Life Types and Purposes (Akinade et al., 2015)

Due to the economic and environmental advantages associated with sustainable construction practices, professionals in the Architecture, Engineering, and Construction (AEC) industry have shifted their attention from the traditional method of EOL demolition to the contemporary approach of deconstruction. However, it has been demonstrated that sustainable EOL practices, including deconstruction, are characterised by significant labor requirements and time consumption, which can considerably impact the project's schedule and budget (Quéheille et al., 2022).

2.3.1 Conventional Demolition

2.3.1.1 Definition

In the literature, the concept of demolition has been defined from various perspectives. For example, Aidonis et al. (Aidonis, 2019) characterises demolition as the systematic dismantling of buildings, commencing from the roof and progressing downwards, with the aim of permanently removing the structure within a short timeframe. In contrast, Zaman et al. (Zaman et al., 2018) define demolition as a method that employs heavy machinery to swiftly demolish buildings, often disregarding the volume of waste generated. Another study has been conducted and explained that the demolition approach employs different types of machinery, equipment, and even explosion or manual techniques to deconstruct buildings, referring to it as "the process of destroying or collapsing down of large buildings after their useful life" (Menon & Jayaraj, 2017). Furthermore, Ngwepe and Aigbavboa (Ngwepe &

Aigbavboa, 2015) defines demolition as a technique that involves the complete removal of a building by pulling down its structure without any specific purpose.

Conventional demolition, commonly referred to as "top-down," is a widely used term to describe the typical demolition approach. As the terminology suggests, this method involves initiating the demolition process by dismantling the roof and subsequently progressing downwards until completion on the ground (Poon et al., 2001). Essentially, the demolition activities follow a vertical downward axis (Aidonis, 2019). In practice, various techniques are employed for demolition, and the subsequent section provides a concise overview of these methods.

2.3.1.2 Methods

Demolition techniques display a diverse range of approaches, as evidenced by numerous sources and reports, highlighting their susceptibility to various influencing factors. (Menon & Jayaraj, 2017). According to one study (Ge et al., 2017) there are five distinct methods commonly employed for demolition: implosion, crane and ball, high-reach arm, rope pulling, and strip out. The *Implosion* method (Rathi & Khandve, 2014), involves the utilisation of explosives to induce the structural collapse of the building. However, this approach is accompanied by substantial noise, dust, and vibration. Conversely, the *Crane and Ball* method (Menon & Jayaraj, 2017), employs a massive and weighty ball that is swung into the building structure, resulting in its collapse.

The *High-reach Arm* method (Menon & Jayaraj, 2017), involves equipping a base machine with an extended demolition arm, which comprises a telescopic boom or multiple sections. This technique offers enhanced safety and cleanliness due to its ability to minimise debris and dust generation, thereby mitigating potential health risks to both operators and individuals in the vicinity. On the other hand, the *Rope Pulling* technique (Rao et al., 2019), involves attaching wire ropes and cables to the structural elements of the building, subsequently employing a tractor or winch to exert force and bring about the structural collapse.

An examination of the existing literature reveals that extensive research has been conducted on the principles and implementation of diverse demolition methods (Menon & Jayaraj, 2017; Rašković et al., 2020) Table 2.1 provides an overview of the key distinctions among various demolition methods.

Table 2.1 The Comparison Between Demolition Methods' Principle and Implementation (Menon & Jayaraj, 2017)

Method	Principle	Implementation

Piecemeal Demolition	Following the general form of manual demolition, from top to bottom	• Carried out manually • Tie wires or ropes are used to pull down the building • Need extra safety and caution • Using hammers to break the structure
Mechanical Method	Demolition is done by machines and from top to bottom of the structure	• Carried out by machines • A mechanical plant is lifted to the top of the building • The mechanical plant needs to move within the area
Thermal Lance	Thermal lance operates by thermal cutting high melting materials. The temperature can cut any material at high functioning	• Oxygen passes through the tube using a seamless mild steel tube created by low-carbon rods • Eliminates vibrations and dust problems • Noise can be restricted • Fire danger and the possibility of hazards related to smoke
Saw Cut Method	Includes conventional chain saw and disk saw, wire saw and diamond core stitch drilling	• Accurate in cutting • Good option for alteration • Noise and vibration are minimised • Minimum spread of dust
Water Jet Method	A high-pressure water jet penetrates the pores and cracks of the concrete and builds an internal pressure that exceeds the tensile strength, and causes the concrete to break	• Minimum spread of dust • Fire hazards and vibration are minimised • Produces less sound than a hammering does • Less labour-intensive • Good option to cut contours and straight lines
High reach Demolition	Work is done from the ground and is applicable for various attachments in different types of structures	• Minimum distortion • Fewer risk factors • Work from the ground • Reliable and Quick • Controlled operation • Suitable for tall buildings where other methods are not possible
Cutting and Lifting	First, the structure is cut into individual pieces; then the pieces are lifted or assembly by crane onto the ground	• Suitable to remove architectural elements, canopies, balconies • After removing structural elements, they need to be secured by connected tie wires or temporary supports

		• After cutting, the elements need to be lowered to the ground in a controlled manner
Soundless Chemical Demolition Agents (SCDA)	The energy of SCDAs is generated when the chemical material is mixed with water and starts hydration	• Limited amount of noise • No toxic fumes or vibration • No risk of premature explosion • Suitable for small-scale demolition projects
Implosion	The process of using explosives to make the building's structure collapse	• By weakening or removing critical components and supports, the building will fall under its weight • Fastest method • Applicable to tall and multi-storeyed buildings • Risky, since minor carelessness results in colossal damage

2.3.1.3 Demolition Benefits

Demolition, particularly when facilitated by machinery, is often regarded as the swiftest and most indiscriminate form of destruction (Shami, 2006). Kibret et al. (Kibert & Languell, 2000), support this claim by asserting that demolition offers rapid execution, cost-effectiveness, and reduced labor requirements, making it an advantageous option for projects constrained by tight timelines.

Furthermore, an advantageous aspect of demolition lies in its longstanding presence within the construction industry, which has led to the development of legislation, guidelines, and established health and safety protocols (Yu et al., 2017). Consequently, one can have confidence that reputable demolition companies possess the requisite licenses, knowledge, and training to ensure compliance with all pertinent local laws and regulations.

2.3.1.4 Demolition Challenges

Evidence shows that conventional demolition can introduce a different set of challenges. First and most importantly, the negative environmental impacts of demolition have been reported by various studies (Gálvez-Martos et al., 2018; Ge et al., 2017; Shami, 2006). It is claimed that demolition methods are largely responsible for generating high noise, dust, and vibration. When demolition is used as the EOL approach, the materials and components become unrecoverable and will eventually be sent to landfills (Akinade et al., 2015). Transferring debris to landfills may lead to severe environmental effects, such as soil contamination (Tatiya et al., 2018). From the social and economic perspective, demolition does not contribute to community employment and education since it is carried out using heavy machines and the labour who are not necessarily required to be trained (Menon & Jayaraj, 2017).

Apart from the general drawbacks directed to conventional demolition, every method has its own weaknesses. Table 2.2 illustrates the challenges related to each demolition method briefly.

Table 2.2 Summary of Challenges Related to Popular Demolition Methods

Method	Negative Aspects
Implosion	• Inability to separate the construction component and material • Not suitable for knocking down one part of a whole property • Produces noise, vibration, and dust • High rate of health and safety risks
Crane and ball	• Limited in terms of height • Inability to separate the construction component and material • Not suitable for knocking down one part of a whole property • Produces noise, vibration and dust
High reach arm	• Limited in terms of height • Not suitable for irregular structure • Not suitable for knocking down one part of a whole property • Produces noise, vibration, and dust
Rope pulling	• Requires large spaces around the building • Inability to separate the construction component and material • Not suitable for knocking down one part of a whole property • Produces noise, vibration, and dust
Selective Demolition or Strip out	• Takes more time • May be the most expensive

2.3.2 Deconstruction

2.3.2.1 Definition

Deconstruction is defined as 'the construction in reverse' (Shami, 2006), meaning that the very last-place materials and components during the construction process will be the very first to be detached and removed from the building. Unlike demolition, which focuses on removing the building fast (Shami, 2006), deconstruction aims to promote efficient recovery of building components by increasing the chance of reusing, recycling or repurposing the materials and components (Akinade, Oyedele, Omoteso, et al., 2017).

It is also claimed that (Carvalho Machado et al., 2018) the concept of deconstruction has emerged as an alternative method for traditional demolition when environmental concerns have been raised due to its high waste generation rates. Building deconstruction also has been known as selective demolition, meaning that a building is carefully dismantled with the aim of reutilising, recovering or recycling the construction materials (Guy, 2006). Other

researchers (Diyamandoglu & Fortuna, 2015) have interpreted deconstruction as “the process of disassembling a physical structure to its components in reverse order with minimal damage so that they maintain their original physical properties and structural integrity”.

2.3.2.2 Deconstruction Benefits

Deconstruction represents a wide range of economic, environmental and social benefits. It has been claimed that (Shami, 2006) up to 75% of demolition waste can be decreased by implementing deconstruction since retrieved materials can be reused or recycled. As a result, it saves the landfill space used for the debris of demolished buildings on a yearly basis. Other researchers also have highlighted deconstruction as a practical approach to diminish Construction and Demolition (C&D) debris by reducing landfill loads (Dantata et al., 2005) and an approach to promote natural resource preservation (Kibert et al., 2003).

Deconstruction also provides the clients and contractors with the opportunity to reduce their dependency on new building components and materials, which will reduce the required amount of energy needed to produce new materials. It has been found that deconstruction contributes to less water and air pollution, fewer pollutants from heavy machinery, reduced noise pollution, higher job creation and expanded community involvement in the process, to name a few (Anuranjita et al., 2017).

Table 2.3 Summarised Benefits of Deconstruction

Category	Benefit
Economical	Reducing the dependence on new building components and materials
	Decreasing the requirement for extracting virgin resources
	Allowing materials to be reused or recycled and so promoting the circular economy
	Offering controlled waste management
Environmental	Reducing the pollution released into the atmosphere and watercourses
	Resulting in less embodied energy compared to a new building
	Decreasing the requirement for extracting virgin materials from natural resources
	Saving energy due to fewer loads transported to the site
	Decreasing the amount of debris that ends up in the landfill
Social	Providing more local businesses and job opportunities
	Minimising disturbances such as noise, vibration and dust

2.3.2.3 Deconstruction Challenges

Although providing a wide range of benefits, deconstruction is still not a common practice since various challenges are related to its implementation (Rios et al., 2015). The skepticism of buyers to purchase used materials with unknown published quality due to

varying quality assessments from unreliable sources is an essential technical issue (EPA, 2008). The lack of rules and standards to regulate the construction process with used materials (Kibert et al., 2000) and the possible damage of materials on-site due to scarcity of appropriate training (Nakajima & Russell, 2014) can be mentioned as other technical issues. Another noteworthy point is the need for innovative automated separation and dismantling of building elements, such as self-controlling machines or robots (Kühlen et al., 2016).

Time constraint is another fact that hinders deconstruction implementation (Grothe & Neun, 2002). It has been affirmed that the time needed for disassembly may vary from three to eight times that of conventional demolition (WASTE, 2002). As a result, deconstruction may not be considered an appropriate alternative method to demolition in situations where time is a critical factor. On the other hand, the cost could be another challenge (Kibert et al., 2000). A common belief among professionals is that deconstruction cost is higher than conventional demolition and disposal, while some studies (Ciarimboli & Guy, 2007; WASTE, 2002) have claimed this cannot be true in all cases. Some variables that would affect the deconstruction cost include a) labour costs, b) transportation fees, c) material storage before transferring to the destination, d) materials conditions, and e) landfill fees.

Furthermore, the lack of measuring methods for estimating deconstruction's benefits exists (Liu, 2009; Srour et al., 2012). According to (Chong & Hermreck, 2010), the lack of proper methods will result in underestimating the recycling process, and deconstruction benefits cannot be measured appropriately. It also has been affirmed that there still is a shortage of quantitative studies in the deconstruction field (Rios et al., 2015). The overview of the deconstruction challenges are summarised in Table 2.4.

Table 2.4 Summarised Challenges of Deconstruction

Category	Challenges	Reference
Technical	Need for innovative technology	(Couto & Couto, 2010; Kibert et al., 2000; Munroe et al., 2006)
	Need for training	(Couto & Couto, 2010; Munroe et al., 2006)
	Safety risks for workers	(Munroe et al., 2006)
	Lack of methods for measuring the benefits	(Couto & Couto, 2010)
	Uncertain quality of recovered material	(Kibert et al., 2000)
Organisational	Long and timely schedules	(Couto & Couto, 2010; Kibert et al., 2000)
	Storages issues	(Couto & Couto, 2010)
	Lack of professional experts	(Munroe et al., 2006)

Economical	Increase in cost	(Couto & Couto, 2010; Kibert et al., 2000)
	Lack of developed market	(Couto & Couto, 2010)
Legal	Lack of rules and regulations for used materials	(Kibert et al., 2000; Munroe et al., 2006)

2.3.3 Conventional Demolition vs. Deconstruction

Research studies in the literature have investigated the leading principles and main differences between the different techniques of building EOL (Aidonis, 2019). The first vivid difference between the two previously mentioned approaches can be found in their aims; where the primary goal of demolition as a traditional building removal strategy is the complete disposal of materials with little consideration on material reuse or recovery, however, deconstruction can be an environmental friendly option by focusing on minimising disposal by materials and components recovery, reuse and repurpose (Akinade et al., 2015). In contrast to deconstruction, demolition does not support an efficient recovery process and is considered a hindrance to reverse logistics (Coelho & de Brito, 2011b). On the other hand, deconstruction has been nominated as a method to decrease the resulting environmental impacts of demolition operations because of maintaining the embodied energy and providing more recovery options (Chau et al., 2017).

Furthermore, health and safety risks are common in conventional demolition due to the absence of a systematic extraction and the existence of harmful materials (Bloomfield et al., 2015). Apart from general safety risks, the presence of contaminated substances needs special consideration since they can cause severe health problems in the long run. In deconstruction, however, these concerns have been mainly controlled (Saghafi & Teshnizi, 2011).

From another perspective, deconstruction tends to be a labour-intensive process, given its selective dismantling nature. It can take weeks to harvest materials from a structure, whereas demolition can be completed in as little as a day. Accordingly, demolition does not socially benefit communities as it mainly depends on machinery, while deconstruction provides new employment opportunities for the local workforce thanks to its labour intense nature (Shami, 2006).

The comprehensive comparison between conventional demolition and deconstruction, extracted from the previous studies, is given in Table 2.5.

Table 2.5 Summarised Comparison between Demolition and Deconstruction

Aspect	Demolition	Deconstruction	Reference
Aim	Rapidly removing buildings or structures which generate a pile of waste, ending in landfills	Systematically dismantling materials and components from a building to increase the chance of reusing, recycling or remanufacturing	(Balogun et al., 2022; Tatiya et al., 2018)
Environmental	Severe effects on the environment due to the transfer of waste products to landfills	Environmentally beneficial technique because of material reuse and recovery	(Shami, 2006; Tatiya et al., 2018)
	During the planning and operations, special considerations are needed to prevent the spread of hazardous materials	Avoids consuming a great deal of energy and harvesting new material. Promotes the preservation of natural resources	(Tatiya et al., 2018)
	During site clearance, more waste is created. Noise and dust are not controlled.	Greater attention is paid to the protection of the local site. Less noise and dust are produced.	(Balogun et al., 2022; Tatiya et al., 2018)
	A significant amount of waste is sent to landfills	Minimise the amount of waste up to 75% since most material is collected for recycling and reuse	(Balogun et al., 2022; Tatiya et al., 2018)
Social	Does not benefit communities as it is mainly dependent on machines and equipment	Offering new job opportunities for the local workforce as it is mainly labour-intensive	(Balogun et al., 2022; Shami, 2006; Tatiya et al., 2018)
	Practitioners need to be trained in dust, noise, and machinery operations	Practitioners need to be trained in the process and duration of deconstruction	(Tatiya et al., 2018)
Organisational	Quick and generally more economical for contractors and clients	Takes longer and is more costly, however, adds other benefits which may result in reduced cost	(Balogun et al., 2022; Shami, 2006; Tatiya et al., 2018)
	Intensive planning on machine operation is required	Intensive planning on labour training and working plans is required	(Tatiya et al., 2018)
	A small number of workforces is needed	A large number of workforces is needed	(Shami, 2006; Tatiya et al.,

				2018)
Technical		Large and heavy machine tools are used to accelerate the work speed	To detach material and components in good condition, hand tools and small equipment are mainly used	(Balogun et al., 2022; Shami, 2006; Tatiya et al., 2018)
Other	Site survey	Site survey consists of material, structure, construction method, adjacent buildings, hazardous material, etc.	More intensive surveys of the structure, material categories, components and their connections, hazardous material and access to the location are required	(Tatiya et al., 2018)
	Safety Plan	Focusing on workforce safety, vehicles, pedestrians, adjacent properties, etc.	Workforce safety is a more controversial issue since they primarily work inside the building	(Tatiya et al., 2018)
	Suitability	All types of structures are capable of being demolished	Not all types of structures and buildings are good candidates for deconstruction	(Tatiya et al., 2018)
	Site Security	Attention to workers' safety, the general public, and surrounding structures' safety.	Besides public and workers' safety, on-site material security is essential since collected material is vulnerable to theft.	(Tatiya et al., 2018)

2.4 End-of-Life Status in New Zealand

In New Zealand, around 850,000 tons of construction and Demolition (C&D) waste is directed to landfills annually (Zaman et al., 2018). Few studies have been conducted considering the EOL phase of buildings in New Zealand's construction industry. In 2018, Atiq U. Zaman et al. (Zaman et al., 2018) analysed a case study named 'whole house reuse' to highlight both opportunities and challenges of deconstruction in New Zealand. They have affirmed that deconstruction provides various potentials for material reuse and recovery and a wide range of environmental benefits. However, under the ongoing socioeconomic and environmental policy settings, and due to the difference between labour cost and resale value of the collected items and materials, deconstruction viability is highly affected. The study concluded that materials recovered from deconstruction might not be economically workable. However, a systematic national approach for employing deconstruction seems to offer significant benefits – such as more socioeconomic points and environmental benefits related to carbon footprint reduction and energy savings over conventional demolition disposal.

Apart from a lack of understanding and awareness regarding the potential benefits of deconstruction, other tangible barriers contribute to the lack of widespread adoption of deconstruction in New Zealand. These barriers have been investigated by different studies and discussed in different reports (Anggadjaja, 2014; Bohne & Eirik Rudi, 2014; Chini et al., 2014; Durmisevic & Binnemars, 2014; Earle et al., 2014; Kuehlen et al., 2014; Nakajima, 2014; Nakajima & Russell, 2014; Storey et al., 2005). The results of these studies are highlighted in Table 2.6.

Table 2.6 Barriers to Implement Deconstruction in New Zealand (Nakajima & Russell, 2014; Storey et al., 2005)

Category	Identified Barriers
Technical issues	Lack or insufficiency of documentation on existing properties
	Unfair competition between reused and imported materials
	Increased implementation of non-reversible construction, technology, etc.
	Issues with Design for Disassembly due to the seismically active region of NZ
	More complex and less economically rewarding material recovery due to new construction systems
Legislation	Lack of attention to waste reduction on behalf of the central government and local councils
	Confusion about government legislation related to environmental responsibilities
	Lack of systematic measurement of local waste
Liability	Lack of standard grading system for reused material and structural components

	The emphasis of current standard specifications on using new materials
C&D Industry	Lack of networking and communication between professionals in the C&D industry
	The fact that demolition is a low-profit industry in general
	Lack of understanding of the benefits achieved by choosing deconstruction over demolition
Economic issues	The fact that some new raw materials are cheap
	Strict legislation on Health and Safety
	Low rates of tipping
	The requirement of a more skilled workforces compared with demolition
	Ignoring the long-term benefits of deconstruction due to the first increase in cost
	Marketplace, the intention of 'as fast as possible.'
New Zealand's Market	Issues with NZ's small population and geographic isolation
	The high cost of storage and transport of collected materials and components
	Undeveloped and undefined some retrieved materials
	Inability to guarantee the quality of collected materials
Design for Deconstruction	The slow movement towards considering design for deconstruction
	Existing buildings are designed without considering deconstruction
	Lack of training about design in terms of increasing the deconstruct-ability of buildings
	Lack of understanding of the benefits and opportunities associated with deconstruction
	Lack of lessons learned from previous case studies in New Zealand

The positive aspects of deconstruction have also been discussed in New Zealand's construction industry. Since deconstruction aims for a circular economy, it has been claimed that the environmental benefits of this method are two-fold (Bertino et al., 2021); First, natural resource harvesting is minimised, thereby a reduction in demand for new materials. Accordingly, this leads to fewer gas emissions, adverse environmental effects, and air and water pollution. Second, deconstruction reduces the amount of waste that goes to landfills as components and materials are rescued for reuse or recycling efforts. Providing training for professionals and offering new job opportunities, deconstruction also can promote social benefits to New Zealand's construction industry.

Looking into disposal and recycling activities such as C&D waste management in New Zealand, it can be seen that various strategies and regulations have been compiled. Table 2.7 illustrates an overview of the legislative/ regulatory and strategy/policy conditions of New Zealand.

Table 2.7 Strategies Associated with C&D Management and Recycling in New Zealand (Zaman et al., 2018)

Policy / Strategy / Legislation	Brief Outline / Area of Relevance
The Litter – Act 1979	Provides procedures to control and abate litter, especially on a large scale of waste
The Resource Management Act 1991	Responsible for controlling the environmental impacts of waste facilities. Contains different sections on the principles of 'The Treaty of Waitangi.'
Health and Safety and Employment Act 1992	Avoids work-related harms, interacting with C&D operations, recycling and waste collection, disposal, etc.
Hazardous Substances and New Organisms Act 1996	Compiles regulations on how to control the whole lifecycle of manufactured chemicals. Includes context related to copper, chromium, arsenic, timber, preservative chemicals, etc
Ozone Protection Act 1996	Interacts with the waste & recycling industry through the subject chemicals' existence in the products
The Local Government Act 2002	Gives importance to waste collection and discharging as a task required to be covered by a local authority
The Climate Change Response Act 2002	Enables New Zealand ETS (Emissions Trading Scheme), including the GHG emissions from landfills
The Building Act 2004	Includes sustainability concepts, including the systematic and sustainable implementation of materials
The Waste Minimisation Act 2008	Encouraged waste reduction and minimising waste disposal by considering a levy on waste directed to landfills
The New Zealand Waste Strategy |2002–2010	Represented a comprehensive and proactive approach to waste strategies towards a broader crucial sustainable development
The New Zealand Waste Strategy | 2010–ongoing	Strives for two goals: minimise the harmful impacts of waste and enhance the effectiveness of resource reuse

2.5 Classification of Related Studies

Demolition and deconstruction have been studied by different researchers in the past few years; as a result, promising progression can be spotted in this field, both in academia and industry. Between 2001 and 2006, different guidelines were established to encourage designers to employ attributes that can extend a building's lifecycle and increase the utilisation of construction materials resulting from a building's deconstruction (Crowther, 2005; Morgan & Stevenson, 2005; Webster & Costello, 2005). Likewise, a life cycle assessment methodology

focused on material reuse was developed to quantify the embodied energy and carbon emissions spread when reusing the structures (Tingley & Davison, 2012). In addition, a parametric Life Cycle Assessment (LCA) model with the capability of studying the end-of-life of any building was developed by Qu´eheille et al. (Quéheille et al., 2022). This model could be utilised as a decision-making support tool to plan the demolition or deconstruction of a building considering the environmental impact of this process. It has been concluded that the resulting impacts and the best scenario to minimise the environmental impact are greatly case-dependent, meaning that deconstruction does not necessarily perform better than conventional demolition for all case studies and criteria.

Bertino et al. (Bertino et al., 2021) established a set of recommendations to improve the level of sustainability for the EOL stage of buildings. The primary aim of these suggestions was to enable a wide range of their application on construction systems and materials. These recommendations include "reduction of building complexity, smart choice of materials, and access to the deconstruction information."

Other studies have considered the economic aspects of conventional demolition and deconstruction. Based on economic variables, Guy and Ohlsen (Guy & Ohlsen, 2003) have developed a software application to estimate the effectiveness and cost of deconstruction compared with the traditional demolition of wood-framed buildings structures. Another study (Coelho, 2013) has compared conventional demolition and deconstruction by conducting an economic analysis while discussing their technological aspects. Although deconstruction was not entirely justified within the established conditions of the case study, some deconstruction scenarios did present economic benefits. A life cycle assessment (LCA) concluded that separation efforts that result in recycling or reusing bulk aggregate materials could reduce the environmental impacts.

From the environmental impact point of view, comprehensive project analysis and quantitative surveys have been conducted by a group of researchers (Vefago & Avellaneda, 2013) to calculate and assess the recyclability inventory of typical EOL building materials. Another study by Akbarnezhad et al. (Akbarnezhad et al., 2014) has estimated the budget, energy consumption and carbon footprint arising from four possible strategies that could be used at the building's EOL. In addition, the study has further searched for the most economical and environmentally friendly deconstruction method appropriate for a particular building by employing building information modelling.

Another group of researchers (Vitale et al., 2017), using an "attributional life cycle assessment", have quantified the environmental impacts of each stage of the Building End-of-Life phase. In this study, after conducting a sensitivity analysis, the results have shown the

advantages of a proper selective demolition which increases the quantity and quality of the residues and safe disposal. The research also highlights that recycling reinforced steel has a significant positive environmental impact. Similarly, Martínez et al. (Martínez et al., 2013) performed a study to distinguish the required procedures in the environmental assessment of the building's end-of-life in terms of identifying those variables that considerably affect the consumption of energy, as well as greenhouse gas emissions. The researchers have found that in selective demolition, there are a couple of environmental aspects, including transporting waste from the demolition work to the target plant and transporting the non-recyclable components to the final landfill. Another aspect was the fuel consumption of the equipment used for the demolition work.

In order to evaluate the effective deconstruction approach, several studies have been dedicated over the past few years. In 2018, Carvalho et al. (Carvalho Machado et al., 2018) conducted a comprehensive analysis of the related guidelines to identify the characteristics influencing the deconstruction potentials for different building projects. In 2015, Akinade et al. (Akinade et al., 2015) proposed a BIM-based Deconstructability Assessment Score model to determine – right from the design stage – whether a building could be deconstructed. In 2017, the same researchers discussed the future of Design for Deconstruction (DfD) and its effectiveness using a BIM-based approach (Akinade, Oyedele, Omoteso, et al., 2017). After conducting thematic data analysis, this study revealed that BIM could provide seven functionalities in the DfD process. These functionalities will assess DfD in the following: a) improving the collaboration between stakeholders, b) visualising the process of deconstruction, c) identifying materials with recoverability potential, d) developing a deconstruction plan, e) simulation and performance analysis of EOL alternatives, f) improving building life management, and g) promoting the ability for collaboration with existing BIM software. Accordingly, another study attempted to quantify the impact of Design for Disassembly using BIM and network analysis. A group of other researchers investigated the methods employed in project planning of building deconstruction (Hübner et al., 2017). In 2018, Akanbi et al. (Akanbi et al., 2018) developed a BIM-based Whole-life Performance Estimator (BWPE) to estimate the amount of recoverable structural components based on BIM databases.

Coelho and de Brito (Coelho, 2013) have quantitatively compared deconstruction approaches using case studies. Two other research projects (Kourmpanis et al., 2008; Liu et al., 2005) studied various combinations of deconstruction processes and different management strategies of deconstruction material. They tried to evaluate them qualitatively; however, they did not provide a decision support system. A group of other researchers (Abdullah & Anumba, 2002), using a multicriteria analysis, has developed a decision support system to select the best demolition method for buildings; yet, deconstruction has not been included in this study. The

deconstruction optimisation models have been discussed by Gollenbeck (Gollenbeck, 2008), but their applicability in buildings has not been covered in the study.

Recent studies show that the application of Building Information Modelling (BIM) shifts from the design process to retrofitting projects. Several researchers have investigated simulation techniques in deconstruction planning (Cheng & Ma, 2013), proposing functional mass flow models based on BIM databases. Akbarnezhand et al. also (Akbarnezhad et al., 2014) have developed a framework to assess and compare the effectiveness of different deconstruction strategies on critical factors such as carbon footprint, consumed energy and cost of deconstruction projects.

Considering the optimisation of building EOL processes, a mathematical multiobjective programming model has been developed by (Aidonis, 2019); however, it has not been done into the further extent, in terms of taking advantage of a digitised process. While several previous studies are focusing on design concepts for deconstruction, principles for deconstruction right from the design stage, introducing a foundation for design for the deconstruction process and also providing a performance assessment for the design stage (Akinade, Oyedele, Ajayi, et al., 2017; Guy et al., 2006), no attention has been paid to planning and decision-making for the optimal EOL approach for the already existing buildings.

Since the previous cost prediction techniques for deconstruction were not accurate and essentially transplanted from that for demolition, a recent study (Tatiya et al., 2018) conducted by Tatiya et al. has developed a model to predict the cost of building deconstruction by implementing AI algorithms. The results of this study indicate that the model provides a high prediction accuracy of 95%. Looking at health and safety issues, Bloomfield and his colleagues (Bloomfield et al., 2015) have investigated the risks of deconstruction. Hitting with heavy machinery, gas and electricity services, hazardous substances, manual lifting, and handling have been considered potential hazards of the deconstruction process.

After reviewing the literature comprehensively and thematic analysis, an overview of the related studies in terms of their scope, key points, and year and country of the study has been achieved. Thematic analysis is a detailed assessment of the literature, which, using an appropriate coding scheme, will identify units of meaning from the content of the literature and will classify them into meaningful categories (Akinade, Oyedele, Omoteso, et al., 2017). The findings resulting from this analysis are listed in Table 2.8.

Table 2.8 Classification of the Recent Related Studies

Authors	Year	Origin	Focus of the Paper			Paper Key Points	Ref
			EOL	Dem	Dec		
Balogun et al	2022	Global			✓	Developing a framework – considering technical, economic, legal, operational and social factors – to highlight deconstruction feasibility	(Balogun et al., 2022)
Qu´eheille et al	2022	France	✓			Suggesting a Life Cycle Assessment (LCA) model for estimating the environmental impacts of the EOL of any building	(Quéheille et al., 2022)
Bertino et al	2021	Global		✓	✓	Facilitating the utilising of the circular economy by proposing main principles for deconstruction as an alternative to demolition	(Bertino et al., 2021)
Antunes et al	2021	Portugal	✓			Presenting a generic database of the environmental impacts of the EOL, considering promoting the reuse and recycling of the CDW flows	(Antunes et al., 2021)
Charef et al	2021	Global	✓			Facilitating the adoption of the circular economy by investigating the barriers to implementing EOL management of assets	(Charef et al., 2021)
Aidonis et al	2019	Global	✓			Developing a mathematical multiobjective programming model to optimise the building end-of-life process	(Aidonis, 2019)
Charef et al	2019	Global				Developing a theoretical framework for the building lifecycle in a BIM environment to convert a linear system to a circular economy	(Charef et al., 2019)
Akanbi et al	2019	Global	✓			Providing a system for analysing the disassembly and deconstruction potential of buildings to promote the EOL performance of building designs	(Akanbi et al., 2019)
Jayasinghe et al	2019	Global	✓			Exploring the collaboration between PEoLB concepts (post-end-of-life of a building) and operations to reach sustainability	(Jayasinghe et al., 2019)
Machado et al	2018	Global			✓	Identifying the related attributes to design for deconstruction (DfD) and examining the impact of each attribute on the applicability of a deconstruction	(Carvalho Machado et al., 2018)
Akanbi et al	2018	Global	✓			Developing a BIM-based Whole-life Performance Estimator (BWPE) model to estimate the amount of recoverable structural components	(Akanbi et al., 2018)
Akinade et al	2018	Global	✓			Promoting a BIM-enabled model to estimate the reusability and recyclability performance of the concrete, timber and steel	(Crowther, 2005)
Tatiya et al	2018	Global			✓	Developing a novel model to predict the cost of building deconstruction by implementing AI algorithms	(Tatiya et al., 2018)
Akinade et al	2017	Global		✓	✓	Avoid demolition and achieve sustainability through BIM-enabled approach	(Akinade, Oyedele,

						for the design for deconstruction	Omoteso, et al., 2017)
Hubner et al	2017	Global			✓	Providing an extended overview of the literature and potential methods for deconstruction planning	(Hübner et al., 2017)
Akinade et al	2017	Global	✓			Enhancing the effectiveness of the material recovery using design for deconstruction (DfD) and the factors affecting DfD	(Akinade, Oyedele, Ajayi, et al., 2017)
Chinda	2017	Germany, Thailand		✓	✓	Considering the critical factors affecting the RL (reverse logistics) applications for demolition waste management	(Chinda, 2017)
Kim et al.	2017	Korean		✓		Introducing a demolition waste estimation technique to support the management and planning of the building design	(Kim et al., 2017)
Chau et al.	2017	Hong Kong	✓			Management strategies in adopting deconstruction to achieve the optimum energy saving at the end-of-life of buildings	(Chau et al., 2017)
Chinda et al	2016	Global		✓	✓	Exploring key factors, including technology, time and cost affecting the RL decision-making to develop a decision-making hierarchy model	(Chinda & Ammarapala, 2016)
Wu et al.	2016	China		✓		Proposing a quantitative documentation guide on demolition in terms of decision making for recycling	(Wu et al., 2016)
Nasir et al	2016	Global			✓	Investigating the potential advantages in the circular economy compared to linear SCM in the construction industry	(Nasir et al., 2017)
Akinade	2015	Global			✓	Proposing a BIM-based assessment score model to determine, right from the design stage, whether a building could be deconstructed	(Akinade et al., 2015)
Bloomfield et al.	2015	Australia			✓	Exploring the health and safety risks related to the deconstruction process of buildings	(Bloomfield et al., 2015)
Fauzey et al.	2015	Malaysia		✓		Identifying, prioritising and assessing the environmental, health and safety risks related to demolition work	(Fauzey et al., 2015)
Akbarnezhad et.al	2014	Global			✓	Developing a framework to assess the effectiveness of deconstruction strategies on critical factors such as carbon footprint, consumed energy, etc	(Akbarnezhad et al., 2014)
Cheng et al	2013	Global		✓		Presenting a BIM-based system to estimate and plan for demolition and renovation (D&R) waste	(Cheng & Ma, 2013)
Coelho et al.	2011	Portugal		✓	✓	Comparison between selective and conventional demolition, in terms of economic perspective	(Coelho & de Brito, 2011b)
Saghafi et al.	2011	Iran			✓	Investigating the importance and determinants, as well as the benefits of building deconstruction in Iran	(Saghafi & Teshnizi, 2011)

2.6 Potential Parameters Extracted from Literature

To develop the decision-support framework, there is a need for a list of parameters affecting decision making when choosing an EOL approach. Reviewing the literature allowed the identification of 18 parameters, which were grouped into 6 categories based on their essence. The summary of the findings of the parameters is presented in Table 2.9.

Table 2.9 Summary of Potential Affecting Parameters on Professionals' Decisions

Category	Parameter	Refs.
Building-related Parameters	Building age	(Bertino et al., 2021; EPA, 2016; Guy & Ohlsen, 2003; Kibert & Languell, 2000; Tatiya et al., 2018)
	Building Height	(Akbarnezhad et al., 2014; Guy & Ohlsen, 2003)
	Building Condition	(Akinade, Oyedele, Ajayi, et al., 2017; EPA, 2016; Tatiya et al., 2018)
	Design Complexity	(Bertino et al., 2021; EPA, 2016; Guy & Ohlsen, 2003; Tatiya et al., 2018)
	Hazardous materials	(Basta et al., 2020; Carvalho Machado et al., 2018; Crowther, 2005; EPA, 2016; Guy, 2001, 2006; Tatiya et al., 2018)
Cost-related Parameters	Labour Cost	(Balogun et al., 2022; Dantata et al., 2005; Guy & Ohlsen, 2003; Huuhka et al., 2015)
	Equipment Costs	(Carvalho Machado et al., 2018; Nakajima & Russell, 2014)
	Transportation Costs	(Balogun et al., 2022; Kibert & Languell, 2000)
	Disposal Costs	(Dantata et al., 2005; Guy & Ohlsen, 2003)
Recyclability Parameters	Material and Component Potentials	(Akanbi et al., 2019; Akinade, Oyedele, Ajayi, et al., 2017; Akinade et al., 2015; Carvalho Machado et al., 2018; Kanters, 2018; Tatiya et al., 2018)
	Recycling Market	(Gorgolewski, 2006; Grothe & Neun, 2002; Hradil et al., 2019; Srour et al., 2012; Tatiya et al., 2018)

Reusability Parameters	Material and Component Potentials	(Akanbi et al., 2019; Akinade, Oyedele, Ajayi, et al., 2017; Carvalho Machado et al., 2018; Tatiya et al., 2018)
	Secondary Market	(Gorgolewski, 2006; Grothe & Neun, 2002; Hradil et al., 2019; Srour et al., 2012; Tatiya et al., 2018)
Geographic-related Parameters	Geographical Location (city, suburb, etc.)	(Akbarnezhad et al., 2014; Srour et al., 2012)
	Building Area	(Densley Tingley, 2013; Kibert & Languell, 2000; Tatiya et al., 2018)
	Site/ Building Accessibility	(Carvalho Machado et al., 2018; Densley Tingley, 2013; Kibert & Languell, 2000; Tatiya et al., 2018; Tingley & Davison, 2012)
Structural-related Parameters	Recoverability of Structure Type	(Chini & Balachandran, 2002; Guy & Ohlsen, 2003; Kibert & Languell, 2000; Webster & Costello, 2005)
	Recoverable Materials	(Basta et al., 2020; Bertino et al., 2021; Tatiya et al., 2018)

2.6.1 Building-related Parameters

This category includes a set of parameters mainly related to the physical characteristics of the buildings. For instance, when choosing between demolition and deconstruction, the layout of the building must be taken into account to ensure the necessary access for heavy machinery in the case of demolition and components manoeuvring in the case of deconstruction (Carvalho Machado et al., 2018). It also has been mentioned that hazardous materials need to be identified and appropriately treated as it reduces the risk of contamination of the materials and components for reutilisation, and the potential risks to the health of workforces in either approach (Crowther, 2005).

2.6.2 Cost-related Parameters

This is another area with much emphasis on parameters related to expenditure and price. The parameters under this category highlight to decision-makers what cost-related parameters must be taken into consideration when choosing between demolition and deconstruction. For example, transporting the components and materials from the site to the storage or from the storage to the recycling facility or market inevitably impose extra costs, which should not be underestimated (Balogun et al., 2022). Another parameter under this category includes the cost

to employ more labour in the case of deconstruction since this approach utilises less heavy equipment (Balogun et al., 2022).

Moreover, disposal costs are another factor that differs from one approach to another. For example, Dantata et al. (Dantata et al., 2005) explain that in demolition, the rate for unsorted waste is almost 1.5 times that of in the case of deconstruction.

2.6.3 Reusability and Recyclability Parameters

These categories of parameters explain the factors that directly relate to the materials and components. Considering these factors is essential, as it was mentioned that a material's recyclability determines whether or not the materials used in a building are suitable for recycling or reuse (Carvalho Machado et al., 2018). It also has been mentioned that, when evaluating the feasibility of deconstruction as an EOL approach for a project, it is essential to consider whether the presence of markets for reused or recycled materials (Ueda et al., 2003).

2.6.4 Geographical-related Parameters

When deciding on a proper EOL approach, it is crucial to consider the geographical aspects, such as location, as there might be situations where access to skilled workers and the availability of special technologies are limited (Carvalho Machado et al., 2018). Location also determines other important aspects, such as the condition of the site at different times of the year (Densley Tingley, 2013).

2.6.5 Structural-related Parameters

It is worth mentioning that the type and complexity of the structure also play important roles in the decision making on either demolition or deconstruction. For example, looking at the complexity of the structure, the number of connections, as well as the access to the parts and connections impact the deconstruction time (Carvalho Machado et al., 2018). Additionally, the feasibility of the deconstruction option for removing a building can be determined based on the different types of materials of the structure. For instance, wooden structures' beams, joists and lintels can be dismantled and either used in a new structure or repurposed for another use (Bertino et al., 2021).

2.7 Summary

The literature review was carried out to understand the state-of-art of building EOL, conventional demolition and deconstruction. This chapter provided insights into New Zealand's construction industry and its current EOL status. After reviewing the recent related studies, a list of potential affecting parameters on professionals' decisions when choosing between demolition

and deconstruction was presented. The literature review confirmed that low innovation and productivity levels and the high amount of C&DW are the major issues in New Zealand's construction industry. It also has been seen that EOL has not been thoroughly studied and investigated in New Zealand compared to the other phases of a building lifecycle.

Although it has been confirmed that deconstruction can be considered an appropriate alternative method to demolition, there are still doubts and challenges associated with utilising it. The lack of understanding of the factors influencing their decisions has also been seen as a hindrance for professionals to consider deconstruction as the EOL approach. Hence, the primary aim of this research is set to develop a decision support framework for the EOL stage of the building lifecycle. The next chapter describes the methodological approaches and the research design used in this study to accomplish the research aim and fill the identified gap.

Chapter 3 Research Methodology

3.1 Chapter Introduction

The extensive review of the literature in the previous chapter emphasised the importance of utilising deconstruction as an alternative method to conventional demolition. The literature also confirmed the need for a systematic framework in order to facilitate the decision-making process at the End-of-Life phase and noted the knowledge gap. This chapter introduces and explains in detail the methodological approach and the utilised methods to highlight the process of filling the identified gap and answering the research questions.

The chapter initiates by providing a definition of research, followed by an overview of the scientific research philosophies. After discussing different research approaches and strategies, various research designs are explained with a rationale for the chosen strategies and design for this study. Thereafter, the data collection methods and process and the ethical considerations are discussed. Further, the chapter concludes with a summary of the discussed contents.

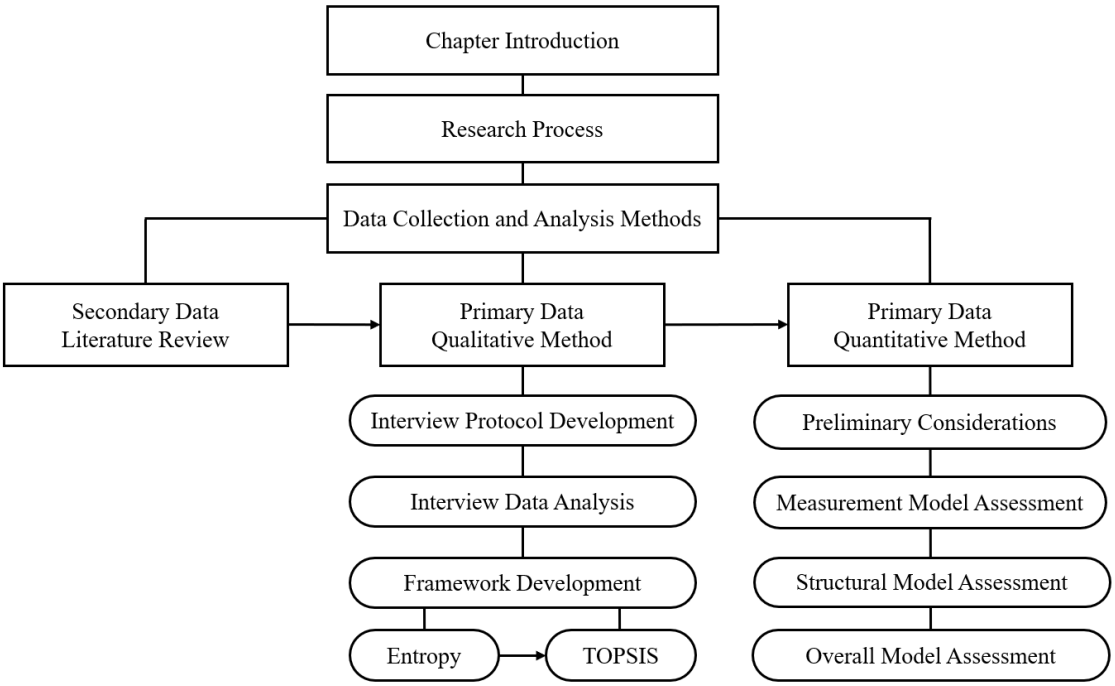

Figure 3.1 Content Outline of Chapter Three

3.2 Research Process

When starting a research project, several considerations need to be taken into account through which the research study can be carried out effectively and efficiently. These considerations are summarised and illustrated in Saunder's Research Onion (Saunders et al., 2015).

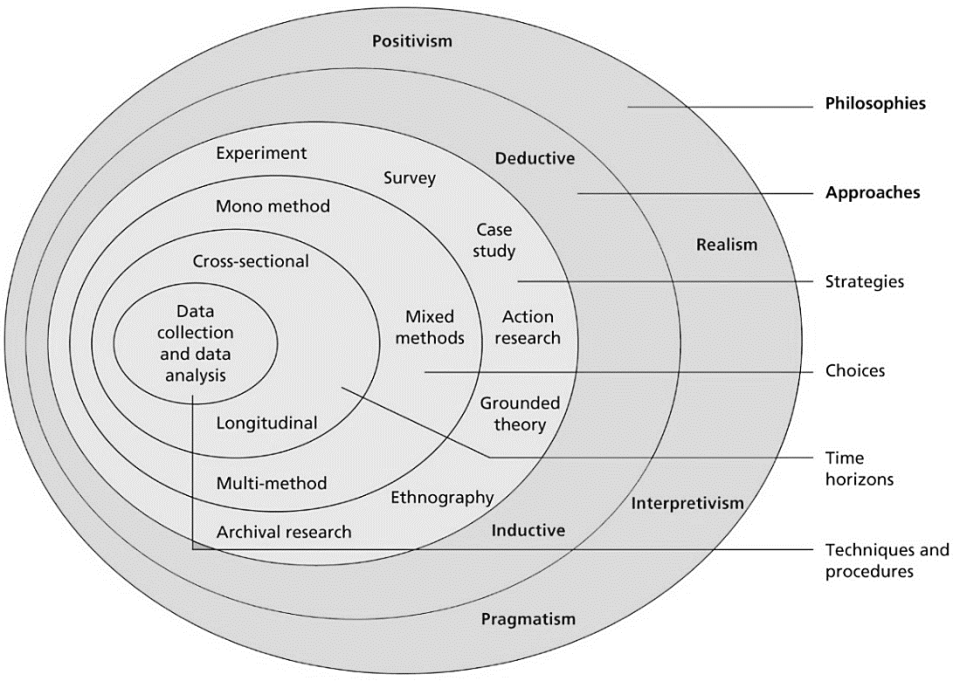

Figure 3.2 Research Onion (Saunders et al., 2009)

Research philosophy is the first consideration as per the research onion. It refers to a set of beliefs and assumptions about knowledge development, including data collection, interpretation and analysis of the collected data (Al-Zefeiti & Mohammad, 2015). The assumption developed from the research philosophy determines how the research study will be undertaken, which includes methodological choice, research strategy, data collection techniques and analysis procedures (Saunders et al., 2009). There are four types of research philosophies – *positivism, interpretivism, realism, and pragmatism*.

The positivism addresses natural scientific issues, whereas the interpretivism focus on social science issues (Ryan, 2018). The pragmatism paradigm, however, can address both natural scientific and social science issues by integrating the two abovesaid philosophies within the scope of one research study (Goldkuhl, 2012). On the other hand, it has been claimed that research in the construction management field is situated between natural science and social science (Love et al., 2002). Hence, the pragmatism philosophy is deemed to be an appropriate paradigm for this study as it aims to develop a decision support framework to assist professionals, within the construction management field, when choosing between demolition and deconstruction methods at EOL phase.

Furthermore, pragmatism allows research to first introduce multiple research questions, and then integrate multiple research approaches, strategies and methods (Yvonne Feilzer, 2010). In order to fulfil the aim of this study, multiple research questions were needed to be introduced. Moreover, the lack of robust literature about the selected topic reinforced the necessity of implementing combining research methods to ensure the transparency, accuracy and reliability of data collection. Hence, pragmatism considered a proper research philosophy for this study.

The next layer of the onion is the **research approach**, defined as "the path of conscious scientific reasoning" (Spens & Kovács, 2006). It is believed that selecting a research approach primarily depends on the adopted research philosophy (Jamshed, 2014). There are three types of research approaches – *inductive, deductive,* and *abductive*.

The deductive research approach is described as a "theory testing process", which initiates with "an established theory or generalization, and seeks to test whether the theory applies to specific instances" (Spens & Kovács, 2006), and it is criticised for its lack of clarity on the selection of theories via developing hypotheses (Saunders et al., 2016). On the other hand, inductive approach is a "theory development process", which begins with the observation of particular cases and aims to "establish generalizations about the phenomenon under investigation" (Spens & Kovács, 2006), and it is criticised since "no amount of empirical data will necessarily enable theory-building" (Saunders et al., 2016).

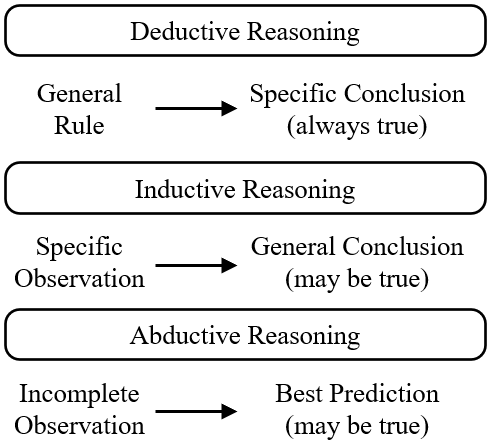

Figure 3.3 Deductive, Inductive and Abductive Reasoning (Dudovskiy, 2019)

This study adopted the abductive approach in order to benefit from, and overcome the weaknesses of, both inductive and deductive reasoning. This approach considered appropriate since (i) it started by observing or exploring defined facts (the parameters affecting the decision-making process when choosing between demolition and deconstruction) which led to (ii) derive statements serving as hypotheses (the parameters may affect one another) which (iii) in respect to the collected and analysed data, then resulted in a decision support framework.

The third layer is **research strategy**, defined as the "technique being used to reach the goal of the research by linking the philosophy, approach, and methodological choice" (Mardiana, 2020). There are different types of research strategies – *survey, experiment, action research, case study, grounded theory, ethnography, and archival research*.

Having chosen abductive reasoning , the survey strategy was considered appropriate for this study since it allows data collection and analysis by applying inductive and deductive approaches through semi-structured qualitative interviews and questionnaire tools (Al-Ababneh, 2020). Considering the exploratory nature of the research and investigating research questions that have not previously been studied in-depth, the interview was the most, if not the only, feasible way to collect initial data (Doody & Noonan, 2013). Afterwards, a questionnaire with the ability to collect a great deal of data from a large population was chosen since, to the best of the author's knowledge, the type of data needed to fulfil research objectives was not available in reviewed published sources; therefore, it was required to be gathered for this research specifically.

The next layer of the research onion is shown as the **choices**. The choices depend on how the research is conducted and its information is collected (Skobe, 2012). Mainly, there are three choices – *mono-methods, mixed methods, and multi-methods.*

Considering this study's research aim and objectives, employing an integrated qualitative and quantitative research design method seemed necessary to best understand the research topic. Hence, the sequential exploratory research design was deemed to be appropriate for this study, and this can be justified as follow:

First, it has been claimed that "what" and "how" questions are more likely to be answered using a mixed-method research design (Creswell & Creswell, 2017). On the other hand, literature confirmed that there had not been much focus on the EOL phase of the building lifecycle in New Zealand. Therefore, qualitative research, such as semi-structured interviews, could allow the researcher to deeply explore the research problem within the industry context. Meanwhile, quantitative research, such as questionnaire surveys, was considered a proper method to ensure the reliability of collected data, as suggested by (Bashir et al., 2008). Additionally, developing a framework to facilitate the decision-making process at the End-of-Life phase is complex by its nature as it involves wide-ranging affecting parameters. Thus, qualitative research can be considered appropriate for such a project as it could provide rich insight into a specific phenomenon (Merriam & Tisdell, 2015). Nevertheless, due to its limitations, such as a small sample size and potential bias in responses, quantitative research is suggested to be coupled with qualitative research design to overcome these limitations (Asenahabi, 2019).

The fifth layer, **time horizon**, explains the timeframe relevant to the research (Sahay, 2016), highlighting the time available and spent carrying out the research project. There are two types of time horizons – *cross-sectional and longitudinal*.

A cross-sectional study involves gathering data just once over a period of days, weeks, or months (Setia, 2016). On the other hand, longitudinal studies are repeated over an extended period, often several years or even decades. This type of study involves collecting data from the same group of individuals at different points in time to examine changes or trends over time (Caruana et al., 2015).

The cross-sectional time horizon was selected for this study since, considering the research aim, research objectives could be achieved by collecting data from a given population. Meaning that, in order to develop the intended decision support framework, the affecting parameters on professionals' decision-making process could be collected from the experts in the New Zealand construction industry. Defining participant selection criteria resulted in a limited population from which data collection could be completed in a short time frame of a doctoral research. Moreover, fulfilling the research objectives of this study was not dependent on neither observing trend changes nor manipulating variables. Hence, it concluded that cross-sectional timeline is appropriate for conducting this research study.

The last layer of the research onion is the techniques and procedures involved in conducting the research. Herein, the researcher justifies the specific procedures for collecting and analysing data (Richey & Klein, 2014). Regardless of the approach, two different types of data can be collected in any research project – *primary and secondary data*.

3.3 Data Collection and Analysis Methods

To fulfil the research aim and objectives of this study, both primary and secondary data were collected and analysed. In the first place, secondary data was collected and reviewed through a systematic literature review. Afterwards, the mixed-method research design was utilised in this study to collect primary data. The sequential exploratory research process started with qualitative research followed by quantitative research, employing semi-structured interviews and questionnaire surveys, respectively, as the data collection methods.

3.3.1 Secondary Data - Literature Review

The research design engaged the application of a systematic literature review, first to explore and evaluate the previous studies relevant to the research topic and then to establish affecting parameters on the decision-making process at the EOL phase of the building lifecycle.

A systematic literature review (SLR) is a well-structured and transparent approach to research synthesis which provides a comprehensive and unbiased process for tracking down studies relevant to a research topic (Higgins et al., 2019). According to Aromataris and Pearson (Aromataris & Pearson, 2014), SLR is widely accepted due to its explicit features, such as " clearly articulated objectives and questions, inclusion and exclusion criteria, comprehensive search to identify all relevant studies, appraisal of the quality of included studies, and presentation and synthesis of the findings extracted". Furthermore, SLR has been reported to be gaining popularity among engineering and management research areas (Alaka et al., 2018).

How systematic reviews are carried out may vary from one study to another as the utilised methods are dependent on the questions being asked and the preference of researchers (Aromataris & Pearson, 2014). The SLR for this study was conducted following the 5-step procedure suggested by Aromataris and Pearson (Aromataris & Pearson, 2014). These steps include: (i) reviewing research questions and determining search keywords, (ii) selecting databases and searching for relevant studies, (iii) selecting studies and assessing them critically, (iv) extracting and synthesising data, and (v) interpreting and reporting the findings.

The first step before initiating the SLR involved developing the research questions. Doing so would help the researcher to fulfil the research objectives within the defined scope. In spite of

varying opinions on research databases, the Scopus and Web of Science databases are acknowledged as accurate and reliable resources for SLR procedure (Martín-Martín et al., 2018). As such, the current study utilised these two databases to strengthen their reliability and accuracy. As it has been claimed that its coverage is "impressively broad and includes the most important scholarly publishers' archives" (Jacsó, 2005), Google Scholar was used as a supplementary tool to ensure no relevant literature was overlooked.

Identifying and selecting proper keywords plays a vital role in conducting a successful literature review. Hence, a two-step search words was conducted to ensure selecting appropriate research keywords. In the first step, "building deconstruction" and "building demolition", the two main components of the research, were used for a preliminary literature search to identify the proper cluster of words. The search resulted in a total of five keywords, including "building" as the only keyword in the first cluster, and "end-of-life", "EOL", "demolition", "deconstruction" as the four keywords in the second cluster.

In the next stage, Boolean search, as a "practical retrieval method" of searching (Li et al., 2021), was implemented to capture research studies relevant to each particular keyword by applying the union 'OR' and the intersections of the keywords using the union 'AND' for an exclusive concentration on the main objective of the research. The intersection of the two clusters generated different group of keywords. The utilised terms were broad enough not to limit the search yet narrow enough to address the research questions. According to the initial search results, very few relevant articles were published prior to the year 2000. Hence, the timespan for the literature search was considered 2000 to 2022, correspondingly, 1166 studies were found.

Study selection was conducted in two stages. During the first stage, titles and abstracts of each identified study were screened while applying exclusion criteria. The exclusion criteria were determined as (i) the studies in any language other than English, (ii) the studies outside the research timeframe and scope, and (iii) the studies with unreliable sources/ publishers. If any exclusion criteria were satisfied with certainty, the study was not moved forward for further processing; total remaining studies at this stage recorded as 805. During the second stage, the introduction, discussion and conclusion parts of the selected studies were screened considering the inclusion criterion, which was studies covering building EOL or at least one of two EOL approaches – *demolition and deconstruction*. At this point, irrelevant research studies, including those within fields other than construction, such as human or medical science, and studies focusing on irrelevant topics, were identified and excluded from the study. Given that the main aim of the study was not thoroughly investigated before, 43 research studies were perceived to be relevant and appropriate for full-text screening.

Subsequently, data analysis was conducted using content analysis. Content analysis is regarded as an objective approach that allows researchers to systematically sort, compare and classify information (Neuendorf, 2017). It has been reported as a beneficial approach when "summarising the key elements in a large amount of data" (Mikkonen & Kääriäinen, 2020). In this study, the content analysis started with developing meaningful themes and coding, through which the codes were assigned to the content addressing similar points. The themes were defined based on the five different groups of parameters being discussed, including building-related, cost-related, material-related, geographical-related, and structural-related categories of parameters. Further, each parameter was assigned a code based on their relevance to each theme.

The complete procedure of the literature review conducted in this study is illustrated in Figure 3.3, and the findings resulting from this stage are presented in Chapter 2.

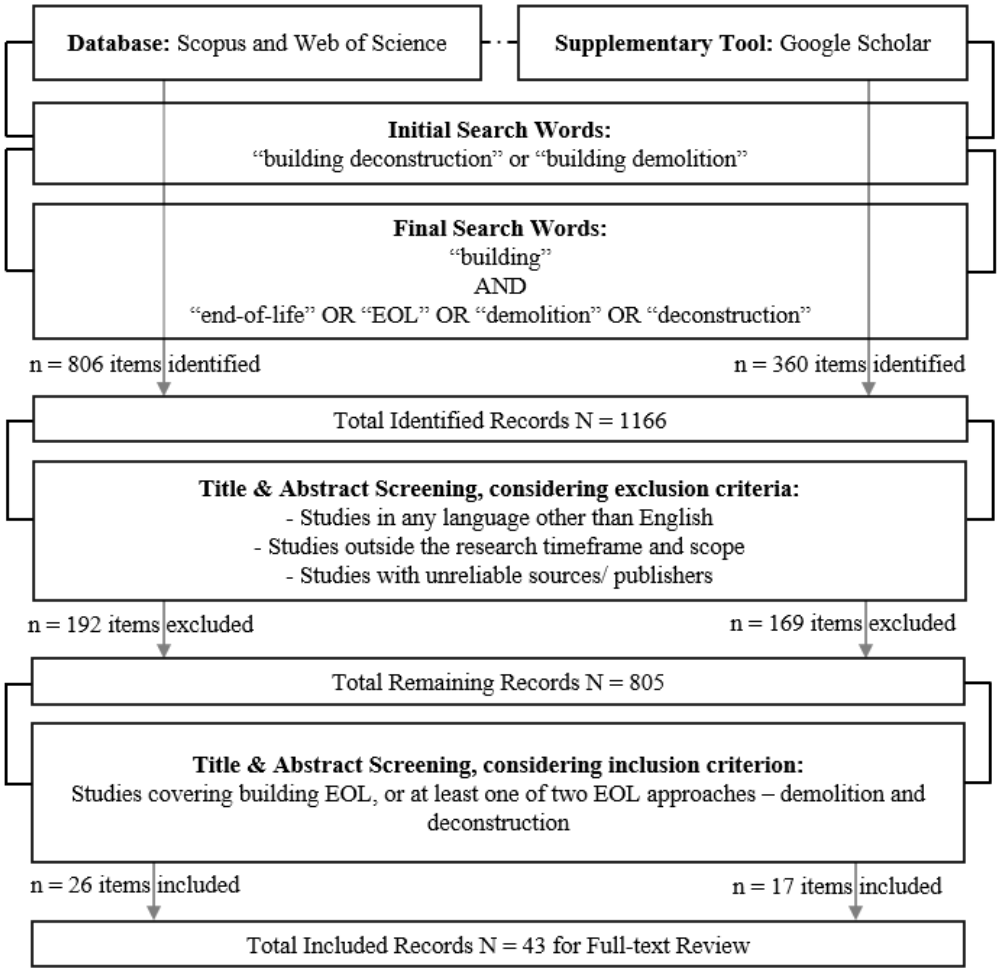

Figure 3.4 Systematic Literature Review Framework

3.3.2 Primary Data – Qualitative Method

The primary objective of the qualitative research of this study was to validate and localise the collected parameters from the literature. Semi-structured interviews were carried out to deepen the understanding of the affecting parameters on the decision-making process at the End-of-Life phase of the building lifecycle.

Being embedded in interpretivism, in-depth qualitative interviewing provides quality and effective contextualisation of issues (Knight & Ruddock, 2009). The premise of the interpretive view is based on subjective reality, where individuals interpret their environment in accordance with their own set of ideas and values (Fellows & Liu, 2021). The subjective experiences and the particular circumstances surrounding participants' interpretations of reality provide breadth and depth to the studied topic (Thomas, 2003). Additionally, semi-structured interview was considered appropriate due to its prevailing benefit of providing "deep, rich observational data" (Adriaanse et al., 2010; Onwuegbuzie & Leech, 2005). By "allowing respondents the freedom to actively engage in sharing their views in their terms" (Galletta, 2013), semi-structured interviews provide comparable and reliable qualitative data.

3.3.2.1 Interview Protocol Development

Semi-structured interviews were carried out using an interview schedule (Appendix F) containing statements and questions divided into three sections. The first section explained the research and its primary purpose. The following section included questions about the background of the participants. The final section highlighted the table of parameters extracted from the literature and sought interviewees' opinions about each parameter. The schedule was mainly used as a guide; however, interviewees were allowed to answer freely and bring forward new ideas.

3.3.2.1.1 Participant Selection

According to Denscombe (Denscombe, 2017), familiarity and sound judgement are the two factors resulting in precise participant selection in research. Typically, participants in qualitative interviews are selected based on the extent of their familiarity with the phenomena being studied (Robson, 2002). Herein, construction professionals in management roles were identified as the most likely to be proper participants for this study since, with higher authority and decision-making power, they are considered key role-players in the decision-making process at the EOL phase. Therefore, the primary criteria for selecting interviewees were substantial construction industry experience and a managerial position in the New Zealand construction sector.

To recruit the participants, a combination of two alternative sampling methods was employed (see Figure 3.5). Initially, purposeful sampling was adopted to guarantee that the desired criteria

were met. Due to the lack of professionals within the EOL field, snowball sampling was subsequently used to identify and recruit more participants. According to previous studies, using multiple sampling methods in a given study is relatively commonplace (Teddlie & Yu, 2007; Tongco, 2007).

The first interviewees were identified and approached using the New Zealand Demolition and Asbestos Association (NZDAA) website and search engines such as LinkedIn. The NZDAA website provides business support, guidance, training, and specialist representation. The available directory on the website was used to identify and invite demolition and/or deconstruction experts. LinkedIn, an effective professional networking media with a large population of business professionals (Albrecht, 2011; Schneiderman, 2016), was also used to recruit more interviewees. Afterwards, recommendations for locating more participants were provided by initially engaged interviewees.

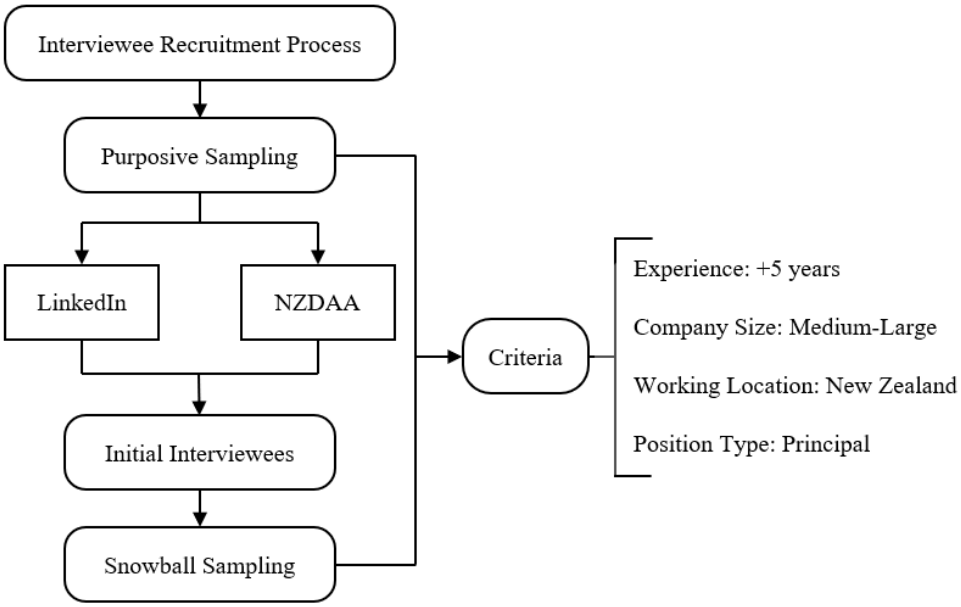

Figure 3.5 Interviewee Recruitment Process

3.3.2.1.2 Interview Procedure

Semi-structured interviews were carried out between October 2020 and June 2021 using two powerful telecommunication tools, Zoom and Skype. Distance interviewing was chosen over face-to-face interviewing due to the restrictions caused by the Covid-19 pandemic during the timeline of this study. Moreover, it has been cited that Internet-based communication methods bring about new opportunities by enabling researchers to contact participants without distance restriction in a cost-effective and time-efficient way, enhancing the diversity of the samples (Lo Iacono et al., 2016; Oliffe et al., 2021).

While audio recorded, interviews lasted between 40 to 50 minutes on average. Afterwards, the audio recordings were transcribed verbatim for further analysis. In total, twelve interviews were conducted and determined sufficient for the exploratory phase of the study since no substantially new ideas had emerged between the ninth and the twelfth interviews (Galvin, 2015; Guest et al., 2006). According to the results achieved by other researchers (Crouch & McKenzie, 2006; Kvale & Brinkmann, 2009), and previous qualitative studies in the field of construction (Hurlimann et al., 2018; Sacilotto & Loosemore, 2018), the sample size of 12-15 is appropriate to achieve the saturation.

3.3.2.2 Interview Data Analysis

As described by Saunders et al. (Saunders et al., 2016), qualitative data analysis involves investigating collected data to evaluate respondents' knowledge, experiences and opinions towards the main research objectives. Among a variety of proposed approaches, such as grounded theory, content analysis and thematic analysis, thematic analysis was determined appropriate for this study since it has been claimed as "a foundational method for qualitative analysis" that produces accurate and informative findings (Braun & Clarke, 2006). According to Creswell (Creswell & Poth, 2016), thematic analysis allows for the methodical organisation of data in order to identify key patterns concerning research questions and objectives. Besides, thematic analysis, as claimed by Thomas and Harden (Thomas & Harden, 2008), allows for the discovery of themes that provide a more profound understanding of under-researched topics. The following steps introduced by Braun and Clarke (Braun & Clarke, 2006) were executed to analyse the collected data thematically.

Data Transcription and Organisation: Transcribing collected data involves the process of converting auditory data into written text with the purpose of facilitating repeated reading (Braun & Clarke, 2006). Herein, the twelve audio recordings from interview sessions were transcribed fully and transferred to NVIVO software for further analysis. As a powerful qualitative data analysis computer software package, NVIVO is widely utilised due to its efficiency, transparency and simple application (Hoover & Koerber, 2009).

Data Familiarisation and Code Generations: This stage involved extensive reading and grouping of data in preparation for categorising and sorting them into themes. Codes indicate common and critical words representing participants' opinions on a specific matter. Comparing codes across all interviewees' responses provides clarity to collected data and ensures consistency of themes (Creswell, 2014).

Themes Establishment: According to Thomas and Harden (Thomas & Harden, 2008), themes refer to specific patterns in qualitative data that represent the primary or fundamental principles of the study. This stage involved the development of distinctive concepts (themes)

related to the research aim and objectives, which demands the researcher's judgement (Braun & Clarke, 2006).

Validity and Reliability Assurance: In order to promote the validity and reliability of the findings, various strategies were employed. Initially, the participants with a wide range of characteristics were engaged to ensure the maximum possible demographic diversity. As cited by Merriam and Tisdell (Merriam & Tisdell, 2015), variation in participants' demographic allows the study findings to be effectively transferred to the readers. Data saturation was achieved by detailed questioning and adequate engagement, as well as spending sufficient time with each respondent (Merriam & Tisdell, 2015).

The transcripts and generated codes were reviewed to avoid potential errors during the transcribing stage and ensure that the codes were accurately grouped and consistent throughout all the interviews (Gibbs, 2018; Longhofer et al., 2012). Afterwards, the grouped, coded and theme-based data was returned to the respondents for assessment, validation, and verification of the trustworthiness of what had been discussed, recorded and transcribed; this process has been defined as member checking (Birt et al., 2016). Ultimately, the findings were compiled and presented in Chapter 4.

3.3.2.3 Framework Development

By conducting semi-structured interviews, the collected parameters from the literature were validated and localised. At this stage, Shannon Entropy proceeding Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were used to specify the rank of each parameter and ultimately to develop the decision support framework to facilitate the decision-making process on EOL approach selection.

TOPSIS was utilised as it is a reliable and well-established multi-criteria decision analysis method for objectively and systematically evaluating options by assigning a weighting value to each criterion (Olson, 2004). The TOPSIS method adheres to the principle that the preferred alternative "should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution" (Syamsudin & Rahim, 2017). In this method, both "the distance to the positive ideal solution and the distance to the negative ideal solution" are taken into account by considering the "relative proximity to the positive ideal solution" (Rahim et al., 2018). TOPSIS method, owing to its concept, is straightforward and easy to understand, provides efficient computation (T. Ding et al., 2016), and "can measure the relative performance of the alternatives decision" (Rahim et al., 2018). Based on the corresponding steps of TOPSIS, it is required to determine the weight of each criterion.

Typically, subjective fixed weight methods such as Delphi method, survey method, and analytic hierarchy process method (AHP) are used to determine index weights. According to Li et al. (Li et al., 2011), the application of such methods could result in "deviations of indexes' weights due to subjective factors". Whereas, objective fixed weight methods such as Shannon entropy, due to relying on the inherent information of indexes for calculating indexes' weights, could effectively avoid human errors and provide outcomes that are more in line with reality (Jozi et al., 2012). Hence, integrating entropy and TOPSIS could effectively enhance the accuracy and reliability of outcomes. Additionally, the literature confirms that the entropy method is frequently utilised in measuring the index/ attribute weight for the TOPSIS method (Aras et al., 2017; L. Ding et al., 2016; Kaynak et al., 2017; Yang et al., 2018)

The entropy weight method was first proposed in 1948 by Shannon (Shannon, 1948) to "measure the uncertainty of the signal in the information source" (Chen, 2021). Shannon entropy plays a crucial role in information theory, hence its choice is appropriate as it "provides an objective weighting that fully exploits the information of the data itself" (Karagiannis & Karagiannis, 2020). Particularly, the entropy method grants more weight to parameters with more significant variation among all the decision-making units since they provide more considerable discrimination and are more valuable in decision-making (Karagiannis & Karagiannis, 2020). Accordingly, parameters with relatively less variation across decision-making units are assigned lower weights.

The process of determining the objective weight of the affecting parameters on the decision-making of the EOL approach using the Shannon entropy can be summarised as follows:

Step 1: Normalising the decision matrix. Suppose that the initial decision matrix of $A = (X_{ij})_{mxn}$ including m alternative and n criteria are generated, the matrix hence is normalised using Equation (1).

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \qquad i = 1, 2, \dots, m, \qquad j = 1, 2, \dots, n \tag{1}$$

Step 2: Calculating the entropy for each index using Equation (2).

$$E_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln(P_{ij}), \qquad j = 1, 2, \dots, n \tag{2}$$

Step 3: Calculating the degree of deviation of essential information for each index using Equation (3).

$$D_j = \left| 1 - E_j \right|, \qquad j = 1, 2, \dots, n \tag{3}$$

where D_j calculates the degree of deviation of crucial information for the jth criteria.

Step 4: Calculating the entropy weight of each criterion using Equation (4).

$$w_j = \frac{D_j}{\sum_{j=1}^{n} D_j}, \qquad j = 1, 2, \dots, n \tag{4}$$

where w_j represents the importance weight of the jth criteria.

The TOPSIS method was first developed in 1981 by Hwang and Yoon (Hwang et al., 1981) and is an abbreviation for Technique for Order Preference by Similarity to the Ideal Solution. As one of the most popular Multi-Criteria Decision Making (MCDM) methods, TOPSIS assists decision-makers with organising the issues to be addressed, as well as analysing, comparing and ranking the alternatives (Shih et al., 2007). Accordingly, an appropriate alternative(s) will be selected. The primary theory of TOPSIS derives from "the concept of a displaced ideal point from which the compromise solution has the shortest distance" (Shih et al., 2007).

Hwang and Yoon (Hwang et al., 1981) further suggest ranking the alternatives based on the shortest distance from the ideal solution and the farthest from the negative ideal solution. TOPSIS concurrently evaluates the distances to both positive and negative ideal solutions, and "a preference order is ranked according to their relative closeness, and a combination of these two distance measures" (Shih et al., 2007). In reality, TOPSIS is a utility-based technique that directly evaluates each alternative based on the data (weights) in the evaluation matrices (Cheng et al., 2002).

According to Uyun et al. (Uyun & Riadi, 2013), TOPSIS provides four main advantages, including (i) a sound logic representing the rationality of human decision, (ii) a numeric value that simultaneously considers both positive and negative ideal alternatives, (iii) a straightforward computation process that can be simply implemented into a spreadsheet, and (iv) ability to measure the relative performance of decision alternatives in a simple mathematical format. These advantages have made TOPSIS a prominent MCDM technique in comparison to other similar methods, such as the analytical hierarchical process (AHP). Moreover, the literature confirms that the TOPSIS method has been successfully utilised in different disciplines, such as transportation (Janic, 2003), manufacturing (Milani et al., 2005), human resource management (Chen & Tzeng, 2004), and quality control (Yang & Chou, 2005). In the construction field, researchers have also made great use of TOPSIS. For instance, Gandhi et al. (Gandhi et al., 2018) utilised the TOPSIS method for ranking the drivers affecting the integration of lean and green manufacturing. In another study by Vinodh and Swarnakar (Vinodh & Swarnakar, 2015), the TOPSIS method was employed to determine the most practical Lean Six Sigma (LSS) projects for an automotive parts manufacturing business.

Kabirifar and Mojtahedi (Kabirifar & Mojtahedi, 2019), employed TOPSIS for ranking Engineering, Procurement, and Construction (EPC) pivotal activities across extensive residential construction projects.

Due to its successful application in similar previous studies (Alptekin & Alptekin, 2017; Sun & Yu, 2021) and its workability and effectiveness for ranking critical indicators (Dehdasht et al., 2020; Gandhi et al., 2018; Kabirifar & Mojtahedi, 2019), the TOPSIS method was considered appropriate for this study. The procedure of the TOPSIS method can be summarised in a series of steps as follows:

Step 1: Calculating the normalised decision matrix using Equation (5).

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \qquad i = 1, 2, \dots, m, \qquad j = 1, 2, \dots, n \tag{5}$$

Step 2: Calculating the weighted normalised decision matrix using Equation (6).

$$\sum_{j=1}^{n} w_j = 1 \tag{6}$$

$$v_{ij} = w_j n_{ij}, \qquad i = 1, 2, \dots, m, \qquad j = 1, 2, \dots, n$$

where w_j is the weight of the jth criterion.

Step 3: Calculating the positive-ideal and negative-ideal solutions, using Equations (7) and (8) respectively.

$$A^+ = \{v_1^+, \dots, v_n^+\} = \left\{\left(max v_{ij} \mid i \in I\right), \quad \left(min v_{ij} \mid i \in i \in J\right)\right\} \tag{7}$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \left\{\left(min v_{ij} \mid i \in I\right), \quad \left(max v_{ij} \mid i \in i \in J\right)\right\} \tag{8}$$

where I is associated with deconstruction, and J is associated with demolition.

Step 4: Calculating the separation value – the distance of each alternative from the ideal and negative ideal solutions, using Equations (9) and (10), respectively.

$$d_i^+ = \left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2\right\}^{\frac{1}{2}}, \qquad i = 1, 2, \dots., m \tag{9}$$

$$d_i^- = \left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2\right\}^{\frac{1}{2}}, \qquad i = 1, 2, \dots., m \tag{10}$$

Step 5: Determining the relative closeness to the ideal solution using Equation (11).

$$R_i = \frac{d_i^-}{\left(d_i^+ + d_i^-\right)}, \qquad i = 1, 2, \dots, m \tag{11}$$

since $d_i^- \geq 0$ and $d_i^+ \geq 0$, then $R_i \in [0, 1]$

3.3.3 Primary Data – Quantitative Method

The quantitative research design was chosen to further examine the qualitative phase findings. The primary objective of the quantitative design for this study was to examine the impact of each parameter influencing the decision-making process between conventional demolition and deconstruction, in addition to validating the developed decision support framework using Structural Equation Modelling (SEM). The following sections comprehensively explain the quantitative design process and the techniques utilised.

3.3.3.1 Survey Protocol Development

3.3.3.1.1 Questionnaire Development

No survey can reach a high level of acceptance without a well-structured and well-designed questionnaire (Roopa & Rani, 2012). Developing a survey questionnaire in construction involves several steps to ensure that questions effectively gather the desired information. The first step is determining the required information to meet the research objective. The precise definition of the research problem and the key research questions that the questionnaire will address play an important role in increasing the questionnaire's effectiveness. Referring to the research questions that are aimed to be answered by the designed questionnaire, and the quantitative nature of analysis in this stage, the formal standardised questionnaire style was selected. All the questions were structured to meet the research objectives. Also, a high level of care was undertaken for the wording structure of the questions to minimise the chance of unanswered questions. The questionnaire comprised three main sections: background information, rating the parameters, and ranking the parameters. In the first section, demographic data were collected, including the respondents' years of experience in the New Zealand construction industry and the position(s) they have held or already holding. It also examined the number of conventional demolition and deconstruction projects they have been involved in. The respondents were also asked how familiar they are with the deconstruction's benefits and how they would rate the overall profitability of deconstruction compared to demolition. This section ended with a question asking how likely it is for the respondents to choose deconstruction over conventional demolition.

In the second section, the five categories of parameters are investigated as listed in Table 3.1, examining their level of importance when the professionals are supposed to decide on either conventional demolition or deconstruction. When choosing between demolition and deconstruction to bring down a building, the respondents were asked how effective each parameter is in their decision. All the parameters were evaluated on the five-point Likert scale, where 1 = not at all effective, 2 = slightly effective, 3 = moderately effective, 4 = very effective, and 5 = extremely effective. A five-scale Likert scale was considered appropriate as it provides respondents with sufficient freedom of thought, and minimises chance of error by uniformity in item response choices (Dawes, 2008). The participants rated each factor's level of importance in their final decision when choosing between demolition and deconstruction. Finally, in the third and last section, the respondents were asked to rank the parameters within their clusters so that the parameters with the higher priority are placed first.

Table 3.1 List of Identified Parameters

Identified Parameters	Code
Building-Related Parameters	(BRP)
Building Age	BRP1
Building Height	BRP2
Building Area/Volume	BRP3
Building Accessibility	BRP4
Material & Component Condition	BRP5
Layout Design Complexity	BRP6
Hazardous Materials	BRP7
Cost-Related Parameters	(CRP)
Labour Cost	CRP1
Tools and Machinery Costs	CRP2
Transportation Costs	CRP3
Disposal Costs	CRP4
Management Costs	CRP5
Material-Related Parameters	(MRP)
Material Reusability Potentials	MRP1
Material Recyclability Potentials	MRP2
Secondary Market	MRP3
Recycling Market	MRP4
Geographic-Related Parameters	(GRP)
Project Location (city, suburb, etc.)	GRP1
Topography of the Site	GRP2
Access to Site	GRP3

Structural-Related Parameters	(SRP)
Type of Structure (Steel, Timber, etc.)	SRP1
Complexity (framing, Junctions, etc.)	SRP2

The questionnaire was developed on the Qualtrics platform and was self-administered anonymously. Qualtrics is a powerful online survey tool, especially for studies based on questionnaires, since "scalar, open-ended, and multiple-choice items are easily added and edited using the platform's graphical interface" (Permut et al., 2019). It is widely used in academia as it allows collected data to be exported and transferred to Statistical Package for the Social Science (SPSS) (Lamberts et al., 2019).

3.3.3.1.2 Pilot Study

A pilot study was conducted to ensure the appropriate wording of the questionnaire, as well as to evaluate the reliability and validity of the instrument. To conduct a pilot study for a questionnaire, a smaller sample size should be selected to test the questionnaire. This strategy identifies any potential issues with the questionnaire before the data collection starts (Lackey & Wingate, 1997). It is especially important for large or complex surveys to ensure that the questions are clear, concise, and relevant to the intended population (Thabane et al., 2010). Therefore, the pilot study was conducted on the first 30 responses. These responses were assessed to ensure the questionnaire's reliability, validity, and feasibility. The criteria, such as ordering the question, wording, and question flow, were re-checked. Based on the preliminary pilot study results, the validity and reliability of the questionnaire were confirmed.

3.3.3.1.3 Validity and Reliability

Validity and reliability are two critical aspects of quantitative research that ensure the accuracy and consistency of the study's results (Heale & Twycross, 2015). Validity refers to the extent to which the research measures what it intends to measure. In other words, it is the degree to which the research instrument, such as a survey questionnaire, accurately measures a concept or construct (Sürücü & MASLAKÇI, 2020). On the other hand, reliability is the degree to which a research instrument consistently measures the same construct over time and across different participants. It measures the consistency and stability of the instrument's results (Heale & Twycross, 2015).

Herein, the reliability and internal consistency of the collected data through the questionnaire were assessed in two rounds; first, at the pilot study stage with 30 responses, and then once the data collection was completed. To do so, the Cronbach's alpha, KMO and Bartlett's Test of Sphericity methods were measured. A commonly accepted range for Cronbach's alpha is a value of 0.70 or above, based on the work by Taber in 2018 (Taber, 2018). If the alpha value is lower

than 0.70, it could indicate a low number of questions, poor interrelatedness between items, or heterogeneous constructs, as noted in the study by Cortina (Cronbach, 1951). Besides, a KMO value greater than 0.5 (Field, 2013) and a significance level for the Bartlett's test lower than 0.05 (Shrestha, 2021) indicate the appropriateness of the collected data for further statistical analysis. The results are presented in Chapter 4, section 4.3.2.

3.3.3.2 Descriptive Analysis

Descriptive analysis, also referred to as descriptive statistics or analytics, is a method used to describe and summarise data points or features of a dataset. It provides a way to organise and present data in a constructive manner, allowing for a clear understanding of the patterns, trends, and characteristics of the data (Sloman, 2010).

In the descriptive analysis, statistical techniques are used to generate summaries of the data, such as measures of central tendency (mean, median, mode), measures of dispersion (range, variance, standard deviation), and graphical displays (histograms, box plots, scatter plots) (Fisher & Marshall, 2009). These summaries help to reveal the key features of the data, such as its distribution, shape, and spread. Descriptive analysis is often the first step in data analysis, as it allows researchers to gain insights into the data before applying more advanced statistical techniques such as SEM. Herein, all the data points and features were analysed as a function of three questionnaire sections: demographic, rating and ranking.

3.3.3.3 Model Development (PLS-SEM)

After analysing the data descriptively, the collected data were analysed inferentially. Inferential analysis is a statistical approach that enables researchers to draw conclusions and make predictions about a larger population based on a smaller sample of data (Blaikie, 2003). Unlike descriptive statistics, which simply summarise and describe data (Hahs-Vaughn & Lomax, 2013), inferential statistics use probability and statistical methods to analyse data and draw conclusions that can be generalised to a larger population (Byrne, 2007). Through inferential statistics, researchers can determine the likelihood that their findings are representative of the population as a whole (Sutanapong & Louangrath, 2015). This allows making predictions and drawing inferences about phenomena of interest with a degree of confidence based on the sample data which have been collected.

In this study, Structural Equation Modeling (SEM) was adopted as an inferential statistical technique to confirm the decision-making framework developed earlier. Since this research stage aims to examine and validate the variables and their relationships, SEM was considered an appropriate method in which the relationship between 21 factors and 5 categories can be systematically analysed.

Structural Equation Modeling (SEM) is a statistical technique used to analyse the relationships between multiple variables in a complex system (Baumgartner & Homburg, 1996). It involves creating a model representing the hypothesised relationships between these variables and testing it using empirical data. The SEM model typically consists of two components: a measurement model and a structural model (Krajangsri & Pongpeng, 2017). The measurement model specifies how the observed variables (indicators) are related to the underlying latent variables (factors) that are hypothesised to cause them. The structural model specifies how the latent variables are related to one another, allowing for the testing of causal hypotheses. To construct an SEM model, researchers were advised to first identify the variables of interest and determine their hypothesised relationships based on theory or prior studies, and then collect the data on these variables and statistical software to estimate the model's parameters, including factor loading, intercepts, and path coefficients (Lowry & Gaskin, 2014). Model fit is assessed by comparing the observed data to the predicted data generated by the model, using goodness-of-fit indices such as the chi-square statistic, the Comparative Fit Index (CFI), and the Root Mean Squared Error of Approximation (RMSEA) (Barrett, 2007). Researchers may then revise the model to improve its fit or modify their theoretical assumptions based on the results. SEM can be employed to demonstrate the path significance for explanatory and confirmatory modelling (Hair Jr et al., 2017). It is worth noting that while SEM can be a powerful tool for understanding complex relationships between variables, it also requires careful consideration of model assumptions, data quality, and sample size (Kline, 2012).

CB-SEM stands for Covariance-based Structural Equation Modeling, one of the two commonly used methods for estimating structural equation models, and the other method is Partial Least Squares Structural Equation Modeling (PLS-SEM) (Hair Jr et al., 2017). Both methods have advantages and limitations, and researchers can choose either based on the nature of their data and research questions.

In **CB-SEM,** researchers estimate the relationships between latent variables by analysing the covariance matrix of observed variables. This method assumes that the data follows a multivariate normal distribution and is suitable for models with a large number of observed variables. CB-SEM is commonly used in social sciences, marketing, and management research (Rigdon et al., 2017).

On the other hand, **PLS-SEM** is a non-parametric method that estimates the relationships between latent variables by finding linear combinations of observed variables with the highest covariance with the latent variables. PLS-SEM is suitable for models with small sample sizes and non-normal data distributions. This approach is practical when there are multiple interrelated variables and when the relationships between these variables are not clearly defined

(Rigdon et al., 2017). It is commonly used in fields such as information systems, engineering, and neuroscience.

One of the main differences between the two methods is how they handle latent variables (Hair Jr et al., 2017). CB-SEM is better suited for factor-based models that assume that the latent variables are measured by multiple indicators. CB-SEM provides a better model for indices and is more appropriate for testing complex models with many latent variables (Afthanorhan, 2013). On the other hand, PLS-SEM is a non-parametric method that is more flexible and requires fewer assumptions (Jannoo et al., 2014). Overall, the choice between PLS-SEM and CB-SEM depends on the specific research questions and the nature of the data. CB-SEM is preferred when testing an established theory with multiple latent variables and indicators, whereas PLS-SEM is more appropriate for exploratory research with small sample sizes and few latent variables (Hair Jr et al., 2017). Thanks to the unique advantages of the PLS-SEM over the CB-SEM, such as its multi-disciplinary coverage for both exploratory and confirmatory research, its effectiveness provides reliable and consistent results regardless of the sample size (F. Hair Jr et al., 2014). Considering the primary aim of this research to develop a decision-making process at the EOL phase of the building lifecycle, as well as the nature, type and complexity of the proposed research, PLS modelling was confidently chosen.

3.3.3.3.1 Preliminary Considerations

In recent years, there has been substantial discussion on whether PLS-SEM is more or less suited for different situations under different conditions (Goodhue et al., 2012; Khan et al., 2019; Marcoulides & Saunders, 2006). In the following, the critical considerations before implementing PLS-SEM are explained.

(i) Normal Distribution: Although some studies have specifically mentioned the PLS-SEM's appropriateness for addressing skewed data (Hair et al., 2012), it also has been cited that extremely skewed data can cause "inflated standard bootstrap error", which decreases the statistical power (Hair Jr, Hult, Ringle, & Sarstedt, 2021). Hence, researchers are suggested to examine the degree to which data are not normally distributed using normality tests, such as Kolmogorov–Smirnov.

The Kolmogorov-Smirnov (KS) test is a non-parametric statistical test used to determine if a sample comes from a population with a specific probability distribution (Justel et al., 1997). The KS test calculates the maximum distance between the empirical distribution function (EDF) of the sample and the cumulative distribution function (CDF) of the population, known as the KS statistic. The KS test can be used for any probability distribution, which may be normal, uniform, or exponential. To perform the KS test, the sample is first sorted in ascending order, and the EDF is calculated by dividing the number of observations less than or equal to each

value by the total number of observations. The CDF of the population distribution is then calculated based on the assumed distribution (Steinskog et al., 2007). The KS statistic is the maximum absolute difference between the EDF and CDF. The KS test is commonly used to test for normality, where the null hypothesis is that the sample comes from a normal distribution (Steinskog et al., 2007). The results of KS test are presented in Chapter 4, section 4.3.4.1.

(ii) Correlation Coefficient: Before performing SEM, it is essential to "examine whether the sign and size of the correlation coefficients match the theoretical empirical expectations" (Kang & Ahn, 2021). If they vary from anticipated, the analytical findings based on these data are invalid. In this research, Pearson's correlation coefficient and Chi-square tests are adopted.

Pearson's correlation coefficient, also known as Pearson's r, is a statistical measure used to determine the strength and direction of the linear relationship between two continuous variables (Cohen et al., 2009). It ranges from -1 to 1, with a value of 0 indicating no correlation, a value of 1 indicating a perfect positive correlation, and a value of -1 indicating a perfect negative correlation. The chi-square test is used to determine if there is a significant association or relationship between two categorical variables (Ugoni & Walker, 1995). It tests whether the observed frequencies of the categories in the two variables are significantly different from what would be expected if the two variables were independent. The correlation matrix resulted from Pearson's chi-square test is presented in Chapter 4, section 4.3.4.1.

(iii) Factor Analysis: Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) are both statistical techniques used in factor analysis, a statistical method used to identify underlying factors influencing observed data (Thompson, 2004). Exploratory factor analysis (EFA) is a statistical method used to analyse the relationships among a large set of variables and identify underlying factors that explain the correlations among them (Williams et al., 2010). EFA aims to identify a smaller set of summary variables, called factors, that explain the correlations among a larger set of observed variables (Watkins, 2018). These factors are latent variables that are not directly observable but inferred from the observed variables. EFA assumes that there are underlying factors that are responsible for the correlations among the observed variables. The factors are identified based on the degree to which each observed variable is correlated with each factor (Cudeck, 2000). On the other hand, CFA is used to verify the factor structure of a set of observed variables. In CFA, the researcher has a priori assumptions about the number and nature of the underlying factors and seeks to confirm these assumptions using statistical analysis (Roberts, 1999).

In summary, EFA is used to explore and develop hypotheses about the underlying structure of a set of observed variables. The Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of

Sphericity are two statistical tests commonly used in exploratory factor analysis to assess the suitability of data for factor analysis (Field, 2013).

The KMO test is a statistical method used to assess the suitability of data for factor analysis by measuring the sampling adequacy for each variable (Hadi et al., 2016). The test evaluates the strength of partial correlation between variables and determines how well the variables explain each other. The KMO test is useful for researchers and data analysts in determining whether the data collected is appropriate for factor analysis and can provide valuable insights into the underlying relationships between variables. The KMO test returns a value between 0 and 1, where higher values indicate better suitability of the data for factor analysis (Field, 2013). According to Shrestha (Shrestha, 2021), KMO values between 0.8 and 1 indicate that the sample is adequate for factor analysis, while values less than 0.6 indicate that the sample is not adequate and remedial action is needed. Most studies consider a KMO value of at least 0.5 acceptable, while values closer to 1.0 are considered ideal (Kaiser, 1974).

Bartlett's test of sphericity is performed to compare the observed correlation matrix of the variables to the identity matrix and test the hypothesis that the correlation matrix is an identity matrix (Tobias & Carlson, 1969). In other words, it tests whether the variables are uncorrelated from each other. If the p-value of the test is less than 0.05, then the null hypothesis is rejected, and it can be concluded that the variables are not uncorrelated and, thus, related to each other (Shrestha, 2021). The results from KMO and Bartlett's tests are presented in Chapter 4, section 4.3.4.1.

Once all the considerations are assessed, and the assumptions are confirmed, PLS-SEM can be performed following a three-step process – *assessing the measurement model, assessing the structural model, and assessing the overall model.*

3.3.3.3.2 Assessment of Measurement Model

Assessing the measurement model is an essential step in evaluating the effectiveness of the PLS-SEM approach. By evaluating the measurement models, researchers can gain insight into the effectiveness of their statistical model and make any necessary adjustments. In order to assess the measurement model, three different measures, namely reliability, convergent and discriminant validity, must be evaluated (Hair et al., 2019).

Reliability

Evaluating the reliability of a PLS-SEM measurement model involves assessing the internal consistency and indicator reliability. This was achieved through various statistical techniques, including Cronbach's alpha, composite reliability, and factor loading (Hair Jr et al., 2020). By evaluating the reliability of the measurement model, a high level of confidence can be ensured

that the results are valid and reliable and can make sound inferences based on the data (Hair Jr, Hult, Ringle, Sarstedt, et al., 2021).

Cronbach's alpha is a statistical measure commonly used to evaluate the reliability or consistency of a set of items in a scale or test. It assesses how well the items in a scale or test measure the same underlying construct or concept (Zeller, 2005). Cronbach's alpha ranges from 0 to 1, with values closer to 1 indicating higher internal consistency and reliability of the test. A value of 0.7 or higher is generally considered acceptable for research purposes. The value for alpha was calculated using the following formula (Cronbach, 1951):

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} S_i^2}{S_t^2}\right) \quad (12)$$

where a is the Cronbach's alpha value, k is the number of questions, Si^2 is variance of the questions' scores and the St square is total score variance of the questions.

Composite reliability (CR) is a statistical measure used to assess the internal consistency of a set of scale items intended to measure the same construct (Bacon et al., 1995). The composite reliability coefficient indicates the degree to which the scale items are reliable indicators of the underlying construct (Peterson & Kim, 2013). In addition to Cronbach's Alpha, the composite reliability was also measured to strengthen the reliability of the constructs. The CR value was calculated using the following formula suggested by Hair et al (Hair et al., 2006):

$$CR = \frac{(\sum \lambda)^2}{(\sum \lambda)^2 + (\sum \delta)} \quad (13)$$

whereby, λ represents the factor loadings for individual factor, and δ is the error term for each individual factor. According to Hair et al (Hair et al., 2006), the minimum acceptable threshold for CR is considered 0.7, showing the internal consistency of the constructs.

Factor loading is a statistical term used in factor analysis to describe the relationship between a variable and a factor. It measures the degree to which a variable is associated with a particular factor, representing the amount of variance in the variable that can be explained by the factor (Gagne & Hancock, 2006). The factor loading ranges from -1 to 1, with higher values indicating a stronger relationship between the variable and factor. The loadings can be used to identify which variables are most important for a particular factor and to simplify complex data sets by reducing the number of variables (Anderson & Gerbing, 1982).

Validity

In partial least squares structural equation modelling (PLS-SEM), assessing both convergent and discriminant validity is essential for ensuring the accuracy and reliability of the model (Henseler et al., 2015).

Convergent Validity is defined as "the extent to which multiple indicators represent a common construct" (Hamann et al., 2013), and is determined by evaluating average variance extracted (AVE) (Henseler et al., 2009). The average variance extracted (AVE) is a statistical measure used to determine the amount of variance captured by a construct in relation to the amount of measurement error in the construct (Cheung & Wang, 2017). AVE is a measure of convergent validity as it quantifies the proportion of the variance in a construct that is accounted for by its indicators. According to the study by Hair et al. (Hair, 1998) the AVE value more than 0.5 can be considered as the acceptable range to claim the extent to which the observed indicators are related to their underlying construct. This indicates that the construct is capturing a substantial amount of the variance in the items that make up the construct and is not simply measuring measurement error or other irrelevant factors. The AVE value is calculated using the formula shown below:

$$AVE = \frac{\sum \lambda^2}{n} \tag{14}$$

whereby, λ represents the factor loadings for individual factor and n is the total number of factors.

Discriminant validity is a statistical concept that assesses the degree to which two different constructs or measures are truly distinct. Specifically, discriminant validity is concerned with determining whether two constructs or measures that are supposed to be distinct are unrelated (Zaiţ & Bertea, 2011). To evaluate the discriminant validity, two techniques were used; the Fornell-Larcker-Criterion which was performed on the constructs, and cross-loadings which was performed on the indicators (Henseler et al., 2009).

The Fornell-Larcker criterion is a technique used to evaluate the discriminant validity of constructs in structural equation models (Henseler et al., 2009). The criterion was first introduced by Fornell and Larcker in 1981 (Fornell & Larcker, 1981), and it suggests that discriminant validity can be established if the average variance extracted (AVE) of each construct exceeds the squared correlations with all other constructs. The purpose of the criterion is to determine if two latent variables are distinct from one another, which is important because it indicates that the variables measure unique aspects of a construct rather than overlapping (Zaiţ & Bertea, 2011).

The cross-loadings are concerned with assessing whether the loadings of the indicators on their assigned construct are higher than the loadings of the other indicators on this particular construct. In other words, the loading of an indicator that is assigned to a construct must be the highest within all other indicators (Fornell & Larcker, 1981; Henseler et al., 2009).

The results of assessing internal consistency (composite reliability and Cronbach's alpha) and indicator reliability (factor loadings), as well as convergent validity (AVE) and discriminant validity (Fornell-Larcker-Criterion and cross-loadings) are presented in Chapter 4, section 4.3.4.2.

3.3.3.3.3 Assessment of Structural Model

The assessment of the structural model in PLS-SEM includes assessing the path significance, standard beta coefficient, coefficient of determination (R^2) and its adjusted (R_a^2), and prediction relevance (Q^2).

The Path Significance

The path significance in PLS-SEM represents the strength of the relationship among variables (Mitchell, 1992). Specifically, it represents the change in the dependent variable associated with a unit change in the explanatory variable while holding all other variables in the network constant. Path analysis, a form of SEM, utilises path significance to explore potential causal relationships among variables in a given network. By examining the pattern of path significance, the strength and direction of the relationships between variables and evaluating the model's overall fit to the observed data was determined (Wright, 1934).

Standard Beta Coefficients

The standardised beta coefficient is a measure of the strength of the effect of each independent variable on the dependent variable and is expressed in units of standard deviation (Bring, 1994). A higher absolute value indicates a more substantial effect. On the other hand, the beta coefficient measures the degree of change in the outcome variable for every one-unit change in the predictor variable (Peterson & Brown, 2005). The t-test determines whether the beta coefficient differs significantly from zero, indicating a significant relationship between the predictor and outcome variables (Paternoster et al., 1998).

Coefficient of Determination (R^2)

The coefficient of determination, also known as the explained variance R^2, is a statistical metric that quantifies how well a statistical model fits the data (Nagelkerke, 1991). A high coefficient of determination indicates that the model is able to accurately explain the constructs, while a low coefficient of determination indicates that the model is unable to explain the latent constructs (Henseler et al., 2009). For PLS-SEM, the R-squared values of the latent variables were classified as follows: $R^2 < 0.25$ indicated a very weak relationship, $0.25 \leq R^2 < 0.50$ indicated a weak relationship, $0.50 \leq R^2 < 0.75$ indicated a moderate relationship, and $R^2 \geq 0.75$

indicated a substantial relationship (Chin, 1998). The R^2 values are calculated using the following formula:

$$R^2 = \frac{SSR}{SST} \quad (15)$$

whereby, SSR and SST represents sum of squared of residuals and sum of squared total, respectively.

Adjusted Coefficient Determination (R_a^2)

The adjusted coefficient of determination is a statistical measure used to assess the effectiveness of a multiple regression model in explaining the observed outcomes (Srivastava et al., 1995). It considers the number of independent variables included in the model and adjusts the coefficient of determination (R^2) value accordingly. The adjusted coefficient of determination is useful in preventing the overfitting of the model by penalizing the inclusion of unnecessary independent variables (Liao & McGee, 2003). By implementing the adjusted coefficient of determination, researchers can determine how well the model fits the sample data and make more accurate predictions about the population. The R_a^2 values are calculated using the following formula:

$$R_a^2 = 1 - \frac{(1 - R^2)(N - 1)}{N - p - 1} \quad (16)$$

whereby, R^2 is the sample R-square, N is the toal sample size and p is the number of independent variables.

Prediction Relevance (Q^2)

The prediction relevance (Q^2), or the Stone-Geisser's Q^2 test (Geisser, 1974; Stone, 1974), measures the predictive relevance of the structural model for predicting the indicator of an endogenous construct. A high Q^2 value indicates a good fit of the model and, therefore, a high predictive ability (Ringle et al., 2015). It has been reported that the Q^2 values of 0.35, 0.15 and 0.02 represents the large, medium and small predictive relevance of a particular construction, respectively (Henseler et al., 2009). The Q^2 values are calculated using the below formula:

$$Q^2 = 1 - \frac{SSE}{SSO} \quad (17)$$

whereby, SSE and SSO represents sum of squared prediction error and number of observations, respectively.

3.3.3.3.4 Assessment of the Overall Model

The final stage of performing PLS-SEM involves assessing the model's overall goodness of fit, which is vital in determining how the model fits the observed data (Shevlin & Miles, 1998).

As an essential part of PLS-SEM, numerous methods have been proposed to undertake the assessment of overall model to examine the accuracy of the developed system, namely Standard Root Mean Squared Residual (SRMR) (Steiger, 1980), the Root Mean Squared Error of Approximation (RMSEA) (Jöreskog & Sörbom, 1981), and Goodness-of-Fit (GOF) (Tenenhaus et al., 2005). Knowing the fact that PLS is a variance-based SEM, and referring to the suggestions made by Tenenhaus et al. (Tenenhaus et al., 2005), GOF calculations were used in this study to assess the overall model. This is typically done using measures of goodness of fit, which quantify the discrepancy between the observed data and the model's predictions. The GOF values ranges from 0 to 1, in which the values below 0.1 are considered small, 0.25 is considered medium, and 0.36 is considered large (Tenenhaus et al., 2005). This way, the model can be assessed using the global validation method. A "good" model fit can confirm that a proposed model is plausible and parsimonious (Henseler et al., 2016). The GOF can be calculated based on the AVE values and the average R^2 value(s) as shown in Equation (15):

$$GOF = \sqrt{Average\ R^2 \times Average\ Communality} \quad (18)$$

3.4 Ethics Approval

When conducting research involving human participants, ethical approval is required to "ensure that the privacy, safety, health, social sensitivities and welfare of human participants are adequately protected" (AUTEC, 2023a). Ethics approval for this research was sought from and granted by the Auckland University of Technology Ethics Committee (AUTEC). The process involved preparing the ethics application form, participant information sheets and consent forms. The ethics approval process was carried out individually in two rounds for the interview and questionnaire phases. For each phase, prior to the beginning of data collection, full ethics approval was granted by AUTEC, with application number 20/239.

During the interview and questionnaire stages, it was ensured that participants' confidential information was not disclosed unless consented to (AUTEC, 2023a, 2023b; Petrova et al., 2016). The whole dataset was anonymised, making it impossible for individual responses to be identified. Access to the collected data was restricted to the researcher, and the project information was secured in a password-protected folder. Moreover, no information regarding the research project was used for reasons other than the research objectives of the study (AUTEC, 2023c; Mittelstadt & Floridi, 2016).

3.5 Summary

This chapter presented the research methodology employed in this study to achieve the aim and objectives of the research. Given the nature of the research topic, introduced research questions and objectives, pragmatism philosophy and abductive approach were adopted to carry out the research. This led the study to employment an integration of qualitative and quantitative research designs, utilising semi-structured interviews and questionnaire surveys as data collection methods. Both primary and secondary data were collected and analysed to fulfil the research aim, and this included three stages (i) literature review, (ii) qualitative research, and (iii) quantitative research.

After reviewing the literature, the affecting parameters on the professionals' decision when choosing between demolition and deconstruction at the EOL phase of the building lifecycle were collected. By completing this stage, the first research objective of the study was fulfilled – *RO1: Identifying the critical parameters influencing the selection of an appropriate approach for the EOL phase of building lifecycle*.

Afterwards, semi-structured interviews were conducted with local experts in the field of demolition and deconstruction to confirm and validate the collected parameters from the previous stage. Having reached this point, the second research objective of the study was accomplished – *RO2: verifying the collected parameters from the literature in the context of New Zealand's Construction Industry.*

The collected data from the interviews were then further analysed using Shannon Entropy and TOPSIS methods to develop the decision support framework for the decision-making process at the EOL phase of the building lifecycle, and this resulted in addressing the third research objective of the study – *RO3: developing a decision support framework to facilitate the decision-making process on EOL approach selection.*

The next stage, quantitative research, was designed first to evaluate how important each parameter is in the professionals' decision to decide on demolition or deconstruction and then investigate the potential relationships between the parameters. By implementing PLS-SEM modelling, the developed framework in the previous stages was validated and confirmed. By doing so, the fourth and fifth research objectives were achieved – *RO4: examining the impact of consequential parameters influencing the decision-making process between conventional demolition and deconstruction; RO5: validating the developed decision support framework using Structural Equation Modelling (SEM).*

Chapter 4 Results

4.1 Chapter Introduction

This chapter aims to concisely present the findings from the qualitative and quantitative research designs aligned with the methodological approach and methods explained in the previous chapter. As such, the chapter starts by presenting the findings from the thematic analysis of semi-structured interview data. Consequently, the entropy-based TOPSIS method results are reported, and the decision support framework is developed. Following that, the conceptual model predicting the potential relationships between the constructs (categories of parameters) is designed.

The next section presents the findings of quantitative research descriptively and inferentially. The descriptive analysis examines the demographic profile of the respondents, as well as reports the rating analysis using descriptive statistics. Afterwards, the PLS-SEM is performed to validate the developed conceptual model, and the results are presented according to its 3-step process. Further, the chapter concludes with a summary of the discussed contents.

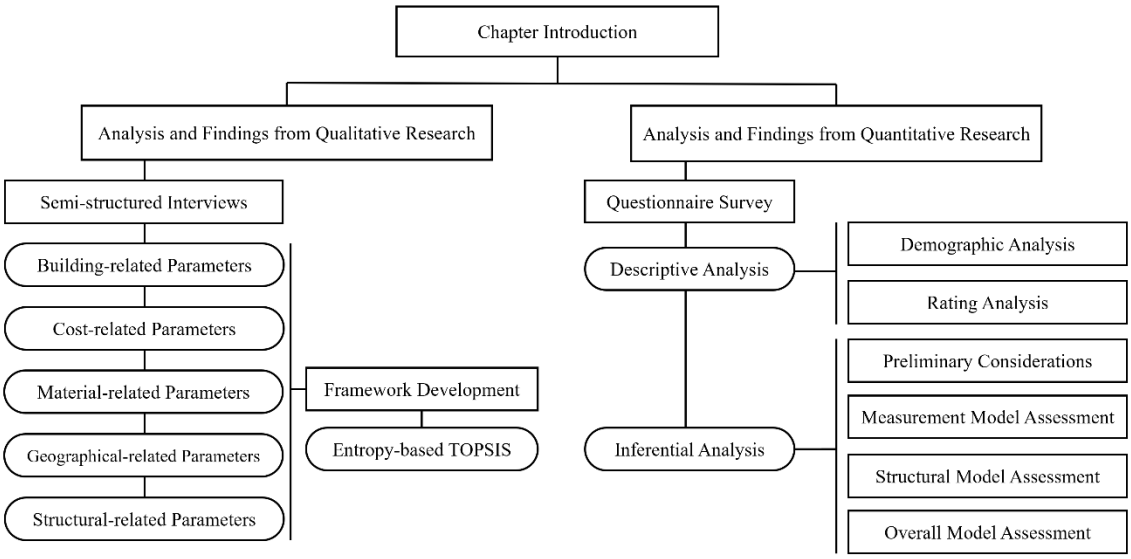

Figure 4.1 Content Outline of Chapter Four

4.2 Analysis and Findings from Qualitative Research

The findings from the qualitative phase are presented in two parts, including the content analysis findings from semi-structured interviews and the results from the Entropy-based TOPSIS calculations.

4.2.1 Semi-Structured Interviews

The twelve audio-recorded interview sessions were analysed after being transcribed verbatim. The background of the interviewees is presented in Table 4.1.

Table 4.1 Demographic Information of Interviews

Interviewee	Position	Years of Experience	Company Size
#01	Project Director	≈ 20	Medium
#02	Managing Director	≈ 30	Large
#03	Site Manager	≈ 12	Medium
#04	Project Manager	≈ 20	Medium
#05	Site Manager	≈ 17	Large
#06	Project Manager	≈ 22	Medium
#07	Project Manager	≈ 15	Large
#08	Executive Manager	≈ 13	Large
#09	Project Manager	≈ 20	Large
#10	Project Director	≈ 18	Large
#11	Project Manager	≈ 06	Medium
#12	Project Manager	≈ 10	Medium

As outlined in Table 4.1, the majority of the interviewees had at least 10 years of experience in the New Zealand construction industry, holding principal positions in medium to large companies. Only one of the interviewees came with 6 years of experience, which was still within the introduced criterion for participant recruitment.

During the interview sessions, the table of parameters extracted from the literature (Table 2.9) was discussed in detail, and the interviewees were asked whether all the categories and parameters are applicable in New Zealand's context. They were also asked whether there are any parameters that, based on their experience, they would suggest being included in or removed from the table. Accordingly, none of the listed parameters was agreed as non-applicable; however, a few changes in the naming and locating of the parameters within the categories have occurred, which will be discussed in the following sections, in line with the five groups of parameters, including building-related, cost-related, material-related, geographical-related, and structural-related categories.

4.2.1.1 Building -related Parameters

After reviewing the interview transcriptions, seven codes were generated and assigned to the building-related category in which each code represented each parameter in this group. The codes included building age, building height, building area/ volume, building accessibility, material and component condition, layout design complexity, and hazardous materials. The following sections discuss the abovesaid parameters in detail.

4.2.1.1.1 Building Age

Interviewees, first, were asked about the *building age* and how it may affect their decision on choosing either conventional demolition or deconstruction at the EOL phase. Interviewee #1 believed "*building age is an important factor to consider because it tells us about different things; for example, the quality of the materials or how the building is built*". "*When it comes to bringing down a building, we consider the age of the building as it helps us determine how we go about the deconstruction or demolition process*", continued interviewee #1.

Building age, as an indicator of how a building was built, was mentioned by a number of participants. "*Age could be important in terms of how the building is built. For example, if a building is built in the era of unreinforced brick masonry, one must be mindful of the deconstruction process as the buildings with such structure do not have much structural rigidity*", claimed interviewee#3. Besides, interviewee #4 also suggested, "the age of the building often determines the Building Code that it was built to".

It was also clear that building age is not an independent factor, as interviewee #5 stated, "*there are probably many things around the age that are linked into other parameters, such as building condition*". Three other interviewees agreed on the same viewpoint. Moreover, deterioration was another point mentioned concerning building age. "*Age results in deterioration; so, with deterioration becomes instability which is an important factor when deciding on demolition or deconstruction*", said interviewee #7.

While most participants believed that building age is considered a critical factor in the decision-making process, interviewee #12 noted, "*it probably does a little bit, but not as much as some other parameters do*". The same interviewee mentioned labour and disposal costs, project location and type of structure as the most important factors, which will be discussed shortly.

4.2.1.1.2 Building Height

Building height, also called building storeys, was the second parameter in the building-related category to be discussed. The first point regarding the height of the building was the necessity of utilising high-reach demolition equipment in high-rise buildings. "*Building height is probably one of the most significant considerations […] a low-rise building, one or two storeys generally is a safe and easy process because you do not have to overreach; so, you do not need extraordinary equipment and safety measure*", said interviewee #1. Besides, it was pointed out by interviewee #3 that "*demolition of low-rise buildings requires less complex equipment, as well as less trained workforce*".

Interviewees #5 and #7 discussed the complexity of work regarding the height of buildings. "*Lower buildings are obviously less complex to either deconstruct or demolish*", and "both demolition and deconstruction across the height make the job more complex", explained interviewees #5 and #7, respectively.

Interviewees also agreed that building height would be a crucial factor when choosing between demolition and deconstruction since higher buildings are riskier to be demolished. "*For probably over 12 storeys buildings, deconstruction would be a safer option as there are many more risks to demolishing the building*", said interviewee #12.

4.2.1.1.3 Building Area/ Volume

Building area, similarly, called *building volume*, initially was categorised under the geographic coordinate category based on what has been found in the literature; however, after reviewing the interview transcriptions and analysing the themes, it was considered best to be categorised under building-related parameters as it describes a building's characteristics.

Interviewees generally believed that building area/ volume influences the decision-making process indirectly rather than directly. "*Building area on its own may not contribute to the*

decision-making process; however, it should be taken into account as, for example, deconstruction of large buildings would take longer, and it does affect the costs of the project", claimed interviewee #2.

Building area could also determine the volume of materials and components used in buildings, and it is a crucial matter when it comes to the transportation and storage of potentially salvageable materials. "*When you have a big building, you will need more transportation and storage capacity to either transfer the waste to disposal sites or relocate the salvageable materials to treatment facilities and storage*", said interviewee #5. Moreover, "*quantifying materials and components in large scale buildings require more time and skilled workforce which both would affect the costs of the project*", claimed interviewee #11.

4.2.1.1.4 Building Accessibility

Similar to the building area, *building accessibility* was also classified under the geographic coordinates category in accordance with the literature. However, interviewees differentiated between access to the building and access to the site. Hence, building accessibility, as an individual item, was added to the building-related parameters category.

As one of the most pivotal building-related parameters, access to the building repeatedly was mentioned influential in deciding the appropriate EOL approach for a building. "*For the buildings within dense urban centres, manoeuvring and operation of big and heavy machinery could be troublesome*", and "*if there is no easy access for machinery, systematic disassembling of the building would be the only option*", claimed interviewee #1 and #6 respectively.

"*Access to the building and the ability to get the scrap materials and parts out of the building safely is a very important factor that makes a big difference in the choices*", claimed interviewee #3, further added by interviewee #10, "*I would say that in any major city in New Zealand, in the CBD suburban area, you would be only able to deconstruct because there are too many residential buildings and complexes nearby and you cannot get the machinery in there*".

4.2.1.1.5 Material and Component Condition

The 'building condition' item in the extracted table of parameters from the literature was advised to be renamed to *material and component condition* as the majority of interviewees believed that "*there are materials and components which define an acceptable or unacceptable condition of a building status*", claimed interviewee #7.

This item possessed a high degree of attention. Interviewee #1 believed "*well-maintained buildings constructed with great workmanships will, of course, offer you better quality materials and components at the end of the building life, and these buildings are the best options for being*

deconstructed". He continued, "*this is because the money you spend for dismantling the building piece by piece can eventually get back to your account by selling the quality parts*". The same point was mentioned by interviewee #4, as he claimed, "*if a building is in pristine condition, it is typically an engineered deconstruction; if a building is damaged, well, we knock it down*". Hence, it could be concluded that the better the condition of the materials and components, the more eager the decision-makers to opt for deconstruction.

Another interviewee pointed out the safety and tolerability considerations. "*The condition of components also can be about the rigidity and stability of the building; if the condition is not good enough so you cannot get yourself in or put equipment on the floor without collapsing, you should go for demolition*", claimed interviewee #8. Moreover, emphasised by interviewee #11 that "*building condition is mainly about how badly the structure and materials of a building have been affected by special conditions like an earthquake, or if it has been a leaky building*".

4.2.1.1.6 Layout Design Complexity

The item regarded as 'design complexity' in the extracted table of parameters from the literature was renamed to *layout design complexity* as more than half of the interviewees specified the layout of the building when addressing complexity.

In the discussion around layout design complexity, interviewee #2 stated, "*it is a very important consideration because when you remove a part of the structure, for example, the whole way that the building deals with loads changes, and so this is why nowadays we are very much using structural engineers to help in the kind of phasing of how we take a building apart*". Moreover, interviewee #5 added "*we have people who would start to demolish part of the building, not realising how critical its load bearing properties were, and then they would find another section of the building might just spontaneously collapse. So, the design complexity is a major consideration, particularly in high-rise buildings*".

Another point was brought up by interviewee #10, saying, "*design complexity can also be about having different materials. For example, when you get marinated of different finishes, it is hard to sort them and sell them all in the secondary market compared to the time that you get a thousand square meters of the same material in one project*". Interviewee #12 also talked about the complexity from the material point of view, claiming: "*the way buildings are designed a large obstacle. Cheap materials, chemical-based adhesives and protective coatings have made many of a building's components useless or too expensive to retreat after removal*".

4.2.1.1.7 Hazardous Materials

Hazardous materials, mainly asbestos, were mentioned as a critical factor; however, they were not a decisive consideration when choosing between demolition and deconstruction.

Interviewee #2 elucidated that "*it does not matter whether you go for demolition or deconstruction; it should be considered at early stages, particularly if the building is over 20 years old*". The point was further stressed by interviewee #4: "*when it is about hazardous materials, especially asbestos, the safety of workers and the surrounding neighbourhoods comes first, then you would think of either demolishing or dismantling it*".

Interviewee #7 concluded the discussion by mentioning that "*asbestos is probably the most hazardous material we come across; specialised workers are needed to go into buildings to remove it before work starts. So, regardless of whether we deconstruct or whether we decide to demolish, asbestos or any other types of toxic materials must be removed safely*". A similar discussion was held with other interviewees, and matching conclusions were drawn.

4.2.1.2 Cost-related Parameters

Five codes were assigned to this category after reviewing the interview transcriptions. The codes were in line with each parameter, including labour costs, tools and machinery costs, transportations costs, disposal costs, and management costs. The parameters are individually discussed in the following sections.

4.2.1.2.1 Labour Costs

Labour cost was frequently mentioned as the category's most critical and decisive cost-related parameter. "*In a situation of deconstruction, to ensure intact material removal, labour and manual work are required; and once removed, the salvaged components and materials require further processing before they can be marketed. On the other hand, demolition is not labour intensive as the whole process can be completed using heavy machines*", stated interviewee #2.

While comparing the labour cost in New Zealand and other countries, interviewee #5 stated: "*deconstruction is a waste of time in the current economy. Demolition is faster and cheaper than deconstruction because machines can take down buildings instead of by hand, and there is no need to separate materials that can be saved from those that cannot. Going for the traditional method (demolition) saves thousands of hours of labour time and is way cheaper than deconstruction*". The high influence of labour cost was also mentioned by interviewee #6: "*while thinking about deconstruction, you must know you have got your cost of labours gone up considerably*".

"*A building can be torn down in a matter of hours (demolition) instead of the days or weeks it takes to take it apart piece by piece (deconstruction), so labour cost is a consideration here*" "*it is a good idea to try to save something, but not if it takes extra weeks and having laboured*

on site. You need to justify the inconvenience against the money you will save" added by interviewee #8 and #11, respectively.

4.2.1.2.2 Tools and Machinery Costs

The *tools and machinery costs* was the next parameter in the cost-related category. Hence, it was mainly compared with labour costs. Interviewee #1 claimed, "*deconstruction is usually a whole lot more labour intensive than equipment intensive; so, I would say, the costs of tools and machinery in deconstruction method is not going to extensively higher than the costs of equipment in demolition*".

"*Deconstruction normally involves labours using hand tools and portable equipment to wreck the building, whereas demolition uses heavy machinery like pushing arms or swinging balls to knock the building down*", said interviewee #6. "*Securing heavy machinery for demolition work may cost more than securing hand tools for dismantling piece by piece, but this is where time comes into play*", continued interviewee #6.

"*It may not be the case now, but as time passes and deconstruction finds its way, there will be special tools and equipment, which definitely cost a lot. Some deconstruction services now use articulating forklifts, conveyor belts, and bobcats to move things around more quickly. Alternatively, removing nails from used wood takes much less time with tools like de-nailing guns*", explained interviewee #12.

4.2.1.2.3 Transportation Costs

From the discussions around *transportation costs,* it could be concluded that the destinations to which materials – either salvaged ones in case of deconstruction or debris in case of demolition – will be sent play the most critical role. Interviewee #3 declared, "*transportation costs can be varied based on a couple of factors, like where the project is, how far it is from the landfill or the warehouse where materials are supposed to be stacked*". "*The volumes of waste, which I believe in the case of demolition is way higher, is another factor that may influence the cost of transportation. But you should not also underestimate the possibility of having two or three destinations in terms of deconstruction, as there would be some materials to be sent to the warehouse, some to be sent to the materials recycling facility, and for sure some to a landfill. Therefore, I believe transportation costs must be involved*", continued interviewee #3.

Regarding comparison, interviewee #9 added, "*we probably have to move the same mass of materials, transferring to either landfills or sorting and recycling facilities; it does not matter which approach you go, you still have this cost*". He added, "*all I am going to say is that it is still effective, but it is not like your labour which is by far the biggest cost*".

4.2.1.2.4 Disposal Costs

After labour costs, the severity of *disposal costs* in deciding between demolition and deconstruction was mentioned second. "*Getting rid of waste costs much money*", affirmed interviewee #5, followed by "*in deconstruction, the maximum amount of materials are targeted for resale and recycling, and it lowers project waste disposal expenses*". The same point was mentioned by interviewee #7, indicating that "*deconstruction allows demolition firms to cut disposal expenses by diverting debris from landfills; no more tipping fee*."

The point about disposing of hazardous debris was brought up by interviewee #9: "*disposal basically is two parts; normal disposal and hazardous waste disposal. The good point of deconstruction is that you avoid having normal disposal costs while the hazardous waste disposal is still there. So, it when choosing between the two approaches, this is something that you would like to think of earlier*".

4.2.1.2.5 Management Costs

During the interview sessions, the participants mutually mentioned *management costs* as another component to be added to the cost-related category. Based on their experiences, deconstruction projects need more coordination between various stakeholders. The management cost, also mentioned as the management fee, compensates the managers for their expertise and time throughout the projects. "*One point which is missing in the cost-related parameter category is the management fee. You cannot expect to manage, supervise, and coordinate a deconstruction project which is much more complex and costs the same as demolition*", explained interviewee #3.

Later on, interviewee #5 also added: "*the cost of management becomes very expensive when deconstruction is going to be happening. This is because such projects normally are more complex compared to the conventional method (demolition). So, if the person in charge is a consultant, you would definitely get charged more*".

According to interviewee #7, management cost could also incorporate other expenses: "*management fee does not only include the money you pay the management crew; you may need to apply for consents, or sometimes you have to deal with the council for demolition or even deconstructing*".

4.2.1.3 Material-related Categories

In accordance with material-related parameters, four codes were defined in this theme which include material recyclability potentials, material reusability potentials, secondary market, and recycling market. The following sections highlight the discussions around the material-related parameters.

4.2.1.3.1 Material Recyclability and Reusability Potentials

Mutually, the *potential for materials and components to be recycled or reused* was among the highly cited parameters when choosing between conventional demolition and deconstruction. "*When there is no chance of recycling or reusing, what is the point of putting time and spending money to deconstruct, right?*" said interviewee #1. Emphasised by interviewee #4: "*the potential of being able to recycle or reuse the material and components is very important; deconstruction is taking me suddenly three times the duration to actually demolish it, and if I cannot get any credence for the recyclable material, why should I spend the time?*"

According to the discussion, an initial building inspection is required to identify potential salvageable components. Buildings that are likely to be suitable candidates for deconstruction were itemised as below:

- Timber framed with unique timber or heavy timber (point suggested by interviewees #1, 4, 5, 7, and 11)
- Buildings with special materials, such as hardwood or native flooring, architectural mouldings, and unique electrical/ plumbing fixtures (point suggested by interviewees #1, 3, 6, 9, 11, 12)
- Commercial buildings with high-quality (point suggested by interviewees #2, 4, 5, 6, 10, 11)

In accordance with what interviewee #11 explained, before beginning the project, creating an inventory of the kinds and amounts of resources to be salvaged, repurposed, or discarded is a critical step allowing decision-makers to make a better judgement on whether deconstruction or demolition is the appropriate approach for the project.

4.2.1.3.2 Secondary and Recycling Market

After the potential for reusability and recyclability of materials, the *market* for salvageable material was the main point of the discussions. It was mentioned by interviewee #3 that "*deconstruction and the market for used building materials are still young*", and a similar point was also raised by interviewees #5, 7 and 11. The statement was emphasised by interviewee #8: "*a project may have recyclability or reusability potentials, but you have got to have a market for it. Even if you have got a market for an item, this value still has to outweigh its costs to recover*".

"*Availability of the market for what you are trying to recycle has a huge impact on whether going for conventional demolition or deconstruction; if a building has a large number of recyclable materials and there is a market for it, then making a decision is pretty easy for us*",

claimed by interviewee #9. Based on what has been discussed with interviewee #12, it could be inferred that, by aligning supply and demand for salvage building materials, a partnership between deconstruction services and reuse retailers, the market's potential could be increased significantly.

Eventually, after analysing the themes and associated codes, the parameters within the two categories of 'recyclability attributes' and 'reusability attributes' in the initial table extracted from the literature were grouped and generated a new category called *material-related parameters*.

4.2.1.4 Geographical-related Parameters

Three codes were identified in this theme, including project location, topography of the site, and access to site. The codes were in line with the parameters within this group and are discussed in the following sections.

4.2.1.4.1 Project Location (city, suburb, etc.)

Most interviewees have affirmed that *project location* plays a critical role in the decision-making processes regarding the EOL approach being used. The first repeatedly mentioned point was about the neighbourhood and possible inconveniences. "*Before you tear down a building, think about how you will deal with the dirt, noise, and dust that will be made*", said interviewee #4.

"*If the project is within a neighbourhood centre with high-density housing, you probably cannot think of anything but deconstructing and dismantling the building piece by piece*". Although you choose the least inconvenient approach, you still need to "*be respectful and notify your neighbours ahead of time that you will be creating some noise and causing a mess*", continued interviewee #6.

Another example given by interviewee #8 explains, "*at the moment, we are working on a project that the site and building accessibility is good, the used materials are good; however, the building itself is surrounded by retirement home villages. They are elderly people that do not want noise, even during the workday they are home. So, every single component has to be deconstructed and not demolished because demolition makes noise*".

The second point about project location was linked to the availability of the resources. Interviewee #3 claimed, "*I think the geographical location makes a difference, whether the job is in Wellington, Auckland or Christchurch, most importantly in terms of having access to resources*". "*Different options might be available in different locations; for example, crushing concrete might not be available in the middle of the North Island. In this case, you may end up just sending the debris to landfill*", emphasised interviewee #7.

The last point regarding this item was the public area and the required precautionary. If the project is adjacent to a public area, there are some special considerations, as was mentioned by interviewee #12, "*where demolition work is adjacent to a public place, and there is a risk of falling debris or hazardous noise, a method of protection should be selected. And if it does not work at all, you have to go for deconstruction*."

4.2.1.4.2 Topography of the Site

After analysing the interview discussions, it was found that the *site's topography*, as an individual code, is another influential factor that is best to be added to the geographical-related category. The process of generating a new code started when interviewee #6 suggested, "*you might be concerned about the challenges of knocking down a building if the project has a particularly steep slope*", and it was more emphasised by interviewee #9, saying, "*once dealing with incline, demolition may cause too much of vibration and destabilise the adjacent lands or properties*".

Apart from landslip and destabilisation, the access of heavy vehicles to the site was another point regarding topography. This point was broadly discussed when discussing the last parameter in this group, access to the site.

4.2.1.4.3 Access to Site

After the site's location, *access to the site* was the next most highlighted within the geographical-related category. Interviewee #2 began: "*access to the site is a major factor to consider; if the site has limited vehicle access, particularly big ones, your choice would be deconstruction, not demolition*". A similar point has been raised by other interviewees as the primary consideration after the location of the site while assessing the geographical-related parameters.

4.2.1.5 Structural-related Parameters

In the table of parameters resulted from the literature review, two items were included under the structural-related category, which mainly addressed points regarding the recoverability potentials. However, after reviewing the interview transcriptions, , it could be concluded that the *type of structure* and its *complexity* are the two most frequently repeated points by the interviewees. Hence, these two items were identified as the two codes assigned to this theme. This justified the two structural-related parameters which are further discussed in the following sections.

4.2.1.5.1 Type of Structure (steel, timber, etc.)

According to interviewee #4, "*surveying the structure to examine the structural system, structural conditions of basements and possible underground tanks can specify for you which approach is suitable*". "*If it is a steel-framed building, very well built and preserved, you do not want to go for demolition and waste all the valuable parts*", added interviewee #5.

Timber, a versatile material widely used in New Zealand construction projects, was mentioned as the highest priority to be salvaged if the quality allows. "*Carefully deconstructing the salvageable timber is the ultimate aim of each deconstruction contractor, but it depends on its quality*" said interviewee #7, and the concept was raised and emphasised by interviewees #9 and #11 as well.

4.2.1.5.2 Complexity (framing, junctions, etc.)

In addition to the type of structure, how *complex* the structure is assembled was acknowledged as a critical factor. "*If the structure is complex and there is no easy access to the elements, deconstruction is technically impossible*", claimed interviewee #9. Moreover, interviewee #12 added, "*if there are countless connections, same or different types, the separation process will be too slow, and deconstruction time increases drastically; in this case, you choose demolition for sure*".

Overall, it could be concluded that the deconstruction time can vary depending on the type of structure, junctions, and fixing used. Hence, the complexity of the structure was mentioned as a significant factor when deciding on the appropriate EOL approach.

4.2.1.6 Updated Table of Parameters

The five main themes, including building-related, cost-related, material-related, geographical-related, and structural-related categories, with a total number of 21 parameters (codes), were defined and analysed. Based on what has been discussed above, the initial table of parameters (Table 2.9) was updated as follows:

Table 4.2 Updated Table of Parameters Affecting the Professionals' Decisions at EOL

Category	Parameter
Building-related Parameters	Building Age
	Building Height
	Building Area/Volume
	Building Accessibility
	Material & Component Condition
	Layout Design Complexity

	Hazardous Materials
Cost-related Parameters	Labour Cost
	Tools and Machinery Costs
	Transportation Costs
	Disposal Costs
	Management Costs
Material-related Parameters	Material Reusability Potentials
	Material Recyclability Potentials
	Secondary Market
	Recycling Market
Geographical-related Parameters	Project Location (city, suburb, etc.)
	Topography of the Site
	Access to Site
Structural-related Parameters	Type of Structure (Steel, Timber, etc.)
	Complexity (framing, Junctions, etc.)

The collected data from interview sessions were then further analysed using an entropy-based TOPSIS to develop the decision-support framework.

4.2.2 Framework Development

At the end of the discussion, the interviewees were requested to evaluate and rank the parameters within their own categories based on their effectiveness in the final decision. This evaluation resulted in constructing an initial decision matrix for each interviewee.

These collected data were then analysed by the entropy based TOPSIS method. As comprehensively explained in Chapter 3, the entropy method was first used to calculate the weights of the parameters. Following the 4-step process of the entropy method explained in section 3.3.2.2, the calculated results are shown in Table 4.3.

Table 4.3 Entropy Weight of Parameters

Scale/ Subscale	Mean	Entropy	Informational load	Weight
BRP	2.42	0.91	0.09	0.47
CRP	2.08	0.96	0.04	0.21
MRP	4.25	0.99	0.01	0.05
GRP	2.92	0.98	0.02	0.10
SRP	2.50	0.97	0.03	016
Building-related Parameters				
BRP1	3.16	0.98	0.02	0.08

BRP2	4.42	0.98	0.02	0.08
BRP3	6.00	0.97	0.03	0.12
BRP4	6.08	0.99	0.01	0.04
BRP5	2.16	0.94	0.06	0.25
BRP6	1.67	0.92	0.08	0.55
BRP7	4.50	0.98	0.02	0.08
Cost-related Parameters				
CRP1	1.66	0.90	0.10	0.45
CRP2	4.17	0.97	0.03	0.14
CRP3	3.67	0.97	0.03	0.14
CRP4	2.42	0.96	0.04	0.18
CRP5	3.00	0.98	0.02	0.09
Material-related Parameters				
MRP1	3.33	0.97	0.03	0.21
MRP2	1.92	0.98	0.02	0.14
MRP3	1.75	0.92	0.08	0.57
MRP4	3.00	0.99	0.01	0.07
Geographical-related Parameters				
GRP1	1.50	0.95	0.05	0.55
GRP2	2.83	0.99	0.01	0.11
GRP3	1.75	0.97	0.03	0.33
Structural-related Parameters				
SRP1	1.75	0.98	0.02	0.4
SRP2	1.25	0.97	0.03	0.6

The TOPSIS method was then applied to rank the parameters, following the 5-step process explained in section 3.3.2.3. The final computed ranks of all the parameters according to their relative closeness are presented in Table 4.4.

Table 4.4 TOPSIS Rank of Parameters

Scale/ Subscale	+ Ideal	− Ideal	Dis. of + Ideal	Dis. of − Ideal	Weight	Rank
BRP	0.05	0.23	0.35	0.48	0.58	2
CRP	0.03	0.11	0.10	0.20	0.67	1
MRP	0.02	0.01	0.02	0.02	0.50	3
GRP	0.04	0.01	0.05	0.07	0.58	2
SRP	0.09	0.02	0.17	0.10	0.37	4
Building-related Parameters						
BRP1	0.06	0.18	0.14	0.39	0.73	2
BRP2	0.25	0.02	0.54	0.36	0.40	4

BRP3	0.01	0.27	0.77	0.36	0.31	7
BRP4	0.09	0.05	0.10	0.10	0.50	3
BRP5	0.03	1.05	1.05	3.15	0.75	1
BRP6	0.76	0.05	2.17	1.02	0.32	6
BRP7	0.25	0.05	0.53	0.26	0.33	5
Cost-related Parameters						
CRP1	0.06	0.31	0.32	0.77	0.71	1
CRP2	0.01	0.05	0.11	0.05	0.31	5
CRP3	0.01	0.05	0.11	0.06	0.35	4
CRP4	0.02	0.10	0.12	0.20	0.62	2
CRP5	0.04	0.02	0.05	0.03	0.37	3
Material-related Parameters						
MRP1	0.07	0.02	0.08	0.14	0.64	1
MRP2	0.06	0.02	0.08	0.10	0.55	2
MRP3	0.31	0.08	0.68	0.37	0.35	4
MRP4	0.03	0.01	0.04	0.04	0.50	3
Geographical-related Parameters						
GRP1	0.28	0.09	0.30	0.54	0.64	1
GRP2	0.03	0.02	0.04	0.01	0.20	3
GRP3	0.15	0.05	0.17	0.22	0.56	2
Structural-related Parameters						
SRP1	0.13	0.06	0.10	0.20	0.66	1
SRP2	0.26	0.13	0.39	0.22	0.36	2

Based on the calculated ranks for the parameters, the decision support framework is developed as follows:

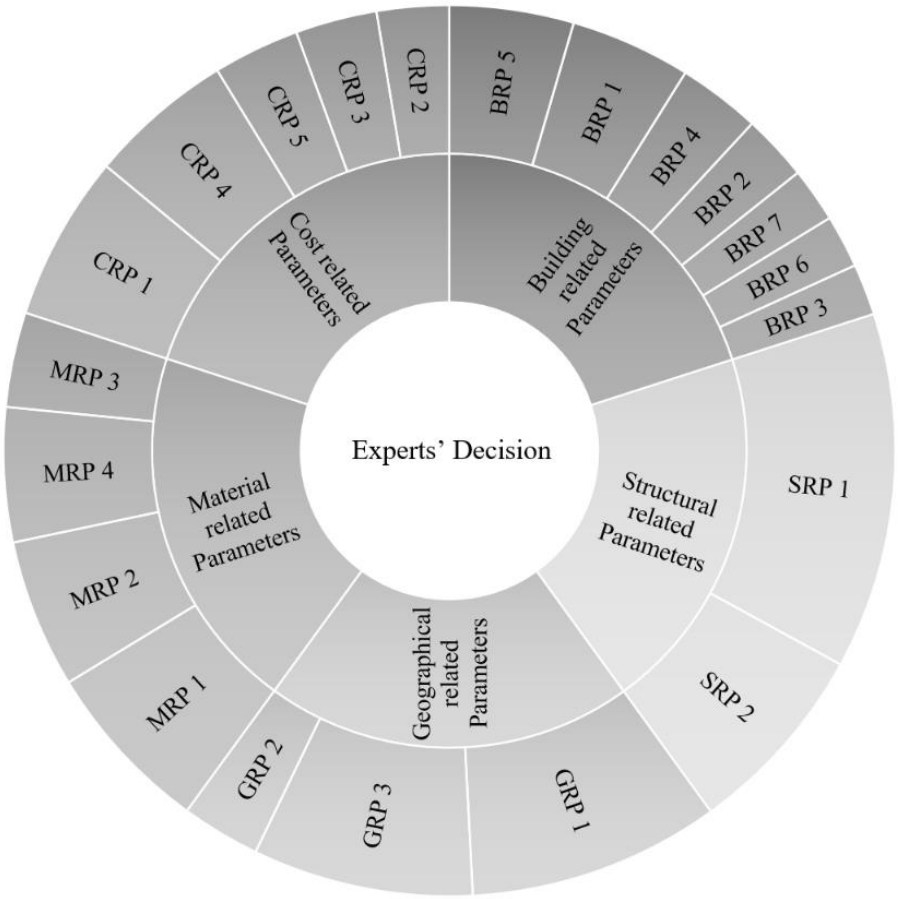

Figure 4.2 Decision Support Framework to Facilitate the Selection of the EOL Approach

The developed framework above highlights the importance of each parameter in the decision-making process; however, it does not explain how the parameters relate to each other. Hence, the quantitative part of the research was designed and performed to strengthen the reliability and validity of the findings from the qualitative part and further explore the potential relationships between the parameters.

In this instance, based on what has been discussed during the interview sessions and interpreted by the researcher, the following hypotheses are constructed:

Table 4.5 List of Hypotheses

Hypothesis	Statement
H1	BRP have significant impacts on DvDD.
H2	CRP have significant impacts on DvDD.
H3	MRP have significant impacts on DvDD.
H4	GRP have significant impacts on DvDD.
H5	SRP have significant impacts on DvDD.

H6	BRP have significant impacts on CRP.
H7	BRP have significant impacts on MRP.
H8	BRP have significant impacts on SRP.
H9	MRP have significant impacts on CRP.
H10	GRP have significant impacts on CRP.
H11	GRP have significant impacts on MRP.
H12	SRP have significant impacts on CRP.

The first five hypotheses were generated from the table of parameters, demonstrating the impacts of each category of parameters, for instance, BRP, on the DvDD when deciding between demolition and deconstruction. Further, hypotheses 6 to 12, which explain the potential impacts of one group of parameters on another, were interpreted and hypothesised based on the discussions with the interviewees.

Hence, the conceptual model highlighting the hypothesised relationships between the categories of parameters and their direct impacts on the DvDD is presented in Figure 4.3.

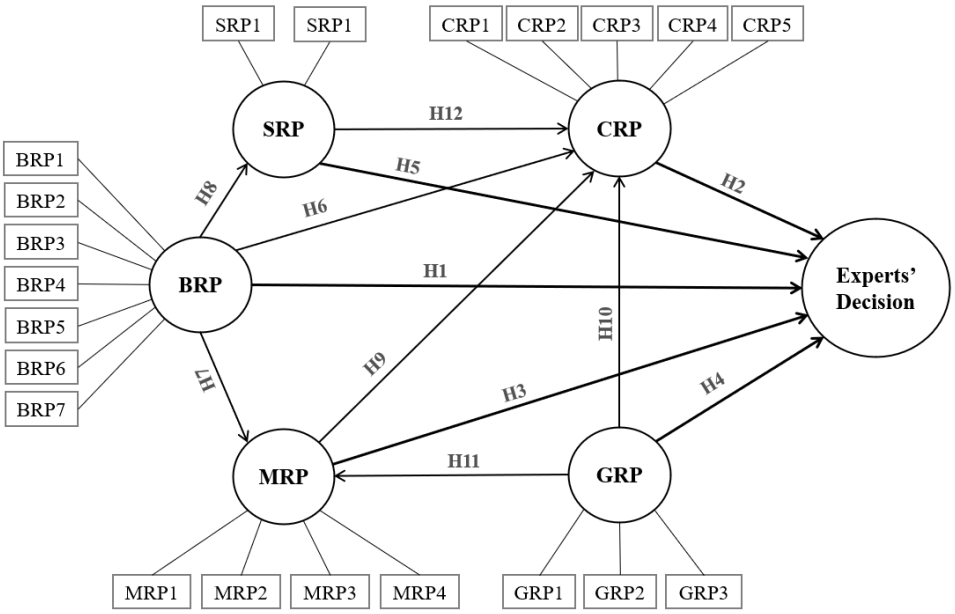

Figure 4.3 Conceptual Model

4.3 Analysis and Findings from Quantitative Research

After developing the conceptual model based on the knowledge obtained from the literature review and the results from the semi-structured interviews, the next stage was to validate the model by assessing it through data collected from quantitative research.

The analysis of the quantitative data collected in this study is presented in two parts; the first section reports the findings from the descriptive analysis, including the demographic and parameter rating analysis. The second section presents the results from the inferential analysis, which includes the steps for developing a PLS-SEM model.

4.3.1 Survey Response Rate

The survey was conducted between October 2021 and August 2022. The link to the online questionnaire was clicked on 617 times, and a total number of 211 responses were recorded. Among them, six received responses were discarded as they had not been completed fully. Considering 205 valid responses, the overall response rate for the questionnaire was calculated at 33.23%. The achieved response rate was considered comparatively high, as it exceeds the typical rate of 20-30% in construction management studies (Akintoye, 2000; Oke & Aghimien, 2018).

4.3.2 Reliability Assessment

As explained in Chapter 3, the reliability and internal consistency of the collected data were assessed by three criteria, including Cronbach's Alpha, KMO and Bartlett's Test of Sphericity. The assessment was carried out twice. The first attempt was at the pilot stage to measure the validity and reliability of the questionnaire. After receiving 30 responses, Cronbach's alpha, KMO and Bartlett's test of sphericity were tested, and the results are presented in Table 4.6 and Table 4.7, respectively.

Table 4.6 Cronbach's Alpha Value (n=30)

Construct	Cronbach's Alpha
BRP	0.776
CRP	0.814
MRP	0.855
GRP	0.903
SRP	0.827

Table 4.7 KMO and Bartlett's Test (n=30)

KMO Measure of Sampling Adequacy	Bartlett's Test of Sphericity		
	Approx. Chi-Square	df	Sig.
0.560	308.828	120	0.000

As shown in Table 4.6, Cronbach's alpha value for all constructs is above the acceptable threshold of 0.7 suggested by Taber (Taber, 2018), emphasising the reliability of the constructs. Table 4.7 highlights the KMO value of 0.560 and the significant Bartlett's test of sphericity with a *p*-value of < 0.0001. Although still within the acceptable range, the low value of KMO resulted from the small sample size at the pilot stage (n=30). According to Hair et al. (Hair et al., 2011), when performing PLS-SEM, the sample size must be "ten times the largest number of structural paths directed at a particular latent construct in the structural model". Therefore, the KMO and Bartlett's test was repeated once the data collection was completed. The results from the second attempt are presented further in section 4.3.4.1.

4.3.3 Descriptive Analysis

4.3.3.1 Demographic Analysis

Demographic analysis in this study was aimed to examine the characteristics of the studied population based on their work experience and position(s) in the construction industry, number of conventional demolition or deconstruction projects they have been involved in, familiarity with deconstruction's benefits, the profitability of the conventional demolition compared to the deconstruction and the possibility of choosing deconstruction over conventional demolition. As mentioned in chapter 3, the demographic analysis was performed to identify patterns and trends within the studied population. A summary of the demographic information obtained from the respondents is shown in Table 4.8.

Table 4.8 Frequency Distribution of Demographic Information (n=205)

Demographic		Frequency	%
Work Experience	1-5 years	19	9.3
	6-10 years	35	17.1
	11-15 years	29	14.1
	16-20 years	49	23.9
	+20 years	73	35.6
Position(s) in the Construction Industry	Project Manager	68	18.1
	Site Manager	71	18.9
	Project Director	22	5.9
	Quantity Surveyor	37	9.8
	Lead Manager	28	7.4
	Company Owner	26	6.9
	Project Engineer	57	15.2
	Builder	49	13.0
	Other	18	4.8

Number of Demolition Projects	1-10 projects	53	25.9
	11-20 projects	30	14.6
	21-30 projects	26	12.7
	31-40 projects	22	10.7
	+40 projects	74	36.1
Number of Deconstruction Projects	1-10 projects	90	43.9
	11-20 projects	37	18.0
	21-30 projects	35	17.1
	31-40 projects	21	10.2
	+40 projects	22	10.7
Familiarity with Deconstruction's Benefits	Not at all familiar	1	0.5
	Slightly familiar	23	11.2
	Moderately familiar	60	29.3
	Very familiar	59	28.8
	Extremely familiar	62	30.2
Profitability of Deconstruction compared to Demolition	Very low	0	0.0
	Low	3	1.5
	Average	34	16.6
	High	66	32.2
	Very high	102	49.8
Possibility of Choosing Deconstruction over Demolition	Not at all likely	2	1.0
	Slightly likely	21	10.2
	Somewhat likely	75	36.6
	Very likely	67	32.7
	Extremely likely	40	19.5

The result reveals a predominance of professionals with over 20 years of working experience in the construction industry. As stated, over 35.6% of the 205 respondents were allocated within this group. This was followed by the respondents with 16-20 and 11-15 years of work experience, equivalent to 23.9% and 14.1% of the total number of respondents, respectively. While 35 respondents have been in the industry for 6 to 10 years, only 19 claimed to have less than 5 years of experience.

As presented in Table 4.7, the second point in the demographic part is the organisational position(s) the respondents hold in the construction industry. The majority of the respondents held management positions, such as site manager and project manager, accounting for 18.9% and 18.1% of the total number of respondents, respectively. This was followed by the project engineers, builders and quantity surveyors with 15.2%, 13% and 9.8% of the total respondents. Lead managers, company owners, project directors and others comprised the minority of the

respondents, with each accounting for less than 10% of the respondents. This distribution reflects the higher contribution level of respondents with principal roles, such as site and project managers.

The next item in the demographic section examines the number of demolition projects respondents were involved in during their work experience. As shown in Table 4.7, respondents with less than 10 projects are 25.9% of the total number of respondents in the study. At the same time, 14.6% of respondents have experience with 11-20 demolition projects. The respondents with 21-30 and 31- 40 demolition projects covered 12.7% and 10.7% of the total respondents, respectively. Lastly, a cumulative total of 36.1% of respondents were involved in more than 40 demolition projects. As observed, 46.8% of the respondents have more than 30 demolition projects in their work history.

The fourth point of consideration within the demographic analysis studies respondents' involvement in deconstruction projects. As presented in Table 4.7, only 10.7% of the respondents were involved in 40+ deconstruction projects, while nearly half (43.9%) were involved in less than 10 deconstruction projects. The table also highlights that respondents with 11-20, 21-30 and 31-40 deconstruction projects in their work history cover 18%, 17.1% and 10.2% of the total number of respondents, respectively.

The next item in the demographic part examines the level of familiarity of the respondents with the deconstruction's benefits. Referring to table 4.7, it can be stated that only 0.5% of the respondents are considered not at all familiar with deconstruction and its benefits; this per cent equals one participant only. This rate increases to 11.2% and 29.3% for respondents with slightly to moderate familiarity. Fifty-nine respondents, equivalent to 28.8% of all respondents, declared that they are very familiar with what advantages deconstruction brings about. Finally, 30.2% of the total respondents claimed to be extremely familiar with the benefits of deconstruction. This means that around 59% of the total respondents have a high level of awareness about deconstruction's benefits.

Further, the sixth point of consideration is the respondents' opinions on the profitability of deconstruction compared to conventional demolition. As stated in Table 4.7, no one considers that the profitability of deconstruction over demolition is very low. Similarly, only 1.5% selected low as their answer for this aspect. The majority of the respondents believed the profitability level of deconstruction, compared to demolition, is above average. This distribution reflects that more than 80% of the respondents gave a high chance of profitability to deconstruction compared to conventional demolition.

The last point, within the demographic questions, examines the preference of respondents to select the deconstruction approach over conventional demolition. As presented in Table 4.7, it

can be claimed that only 1% showed unwillingness to choose deconstruction over demolition. 10.2% of the respondents claimed that it is slightly likely for them to choose deconstruction, while it was more likely for 36.6% of the respondents. It can be further seen that 32.7% and 19.5% of the respondents saw the likelihood of choosing deconstruction over conventional demolition as very likely and extremely likely, respectively.

4.3.3.2 Rating Analysis

In this part, the five categories of parameters were examined in terms of their level of importance. Respondents were asked, in choosing between demolition and deconstruction as an EOL approach to remove a building, to what extent each criterion influences their choice.

Building-related category and its parameters were examined first; see Table 4.9. Among seven parameters categorised under the building-related group, participants ranked material & component condition (BRP5 mean = 4.88 ± 0.415) as the most effective parameters when deciding between demolition and deconstruction. This is followed by building age, building accessibility, building height, hazardous materials, and layout design complexity, with the mean value of 4.77 ± 0.595, 4.30 ± 0.676, 4.09 ± 0.927, 3.89 ± 1.006 and 3.73 ± 0.92, respectively. Building area/ volume, conversely, was selected as the least important parameter in this group (BRP3 mean = 2.99 ± 0.686).

Table 4.9 Descriptive Statistic of Building-related Parameters

Code	Central Tendency		Dispersion		Distribution	
	Mean	Median	Std. deviation	Range	Skewness	Kurtosis
BRP	4.09	4.28	0.456	2.71	-1.906	1.273
BRP 1	4.77	5.00	0.595	4.00	-1.981	1.138
BRP 2	4.09	4.00	0.927	4.00	-0.820	-0.001
BRP 3	2.99	3.00	0.686	4.00	-0.356	0.765
BRP 4	4.30	4.00	0.676	4.00	-1.222	1.512
BRP 5	4.88	5.00	0.415	3.00	-1.098	1.551
BRP 6	3.73	4.00	0.920	4.00	-0.841	-0.850
BRP 7	3.89	4.00	1.006	4.00	-1.290	1.700

The findings, as set out in Table 4.10, indicate that, among the five parameters of the cost-related group, CRP1 and CRP2 have the highest and the lowest mean values of 4.85 ± 0.406 and 3.48 ± 0.683, respectively. Therefore, it can be concluded that labour costs are the most and tools and machinery costs are the least influential factor when deciding on an appropriate EOL approach.

Table 4.10 Descriptive Statistic of Cost-related Parameters

Code	Central Tendency		Dispersion		Distribution	
	Mean	Median	Std. deviation	Range	Skewness	Kurtosis
CRP	4.36	4.40	0.279	2.00	-1.044	1.010
CRP 1	4.85	5.00	0.406	2.00	-1.857	1.927
CRP 2	3.48	3.00	0.683	3.00	0.546	-0.130
CRP 3	4.39	4.00	0.688	3.00	-0.948	0.754
CRP 4	4.63	5.00	0.609	4.00	-1.109	1.895
CRP 5	4.50	5.00	0.669	4.00	-1.480	1.413

As depicted in Table 4.11, MRP1 and MRP2 were given relatively similar significance (mean value = 4.88 and 4.87), meaning that material reusability and recyclability potentials have the highest level of importance when choosing between demolition and deconstruction. Thereafter, MRP4 and MRP3 follow with a fairly close mean value of 4.36 and 4.35, respectively, meaning that recycling and secondary markets are the next two important parameters in this group to be considered.

Table 4.11 Descriptive Statistic of Material-related Parameters

Code	Central Tendency		Dispersion		Distribution	
	Mean	Median	Std. deviation	Range	Skewness	Kurtosis
MRP	4.61	4.50	0.390	2.25	-1.879	1.374
MRP 1	4.88	5.00	0.415	2.00	-1.684	1.920
MRP 2	4.87	5.00	0.440	3.00	-1.781	1.403
MRP 3	4.35	4.00	0.605	3.00	-0.617	0.883
MRP 4	4.36	4.00	0.606	4.00	-0.897	1.310

As shown in Table 4.12, GRP1 has received the highest mean value, equivalent to 4.84 ± 0.617, meaning that the project location is the most effective on DvDD among all three parameters in this category. Following that, GRP3 as access to the site and GRP2 as the topography of the site (mean value = 4.68 ± 0.652 and 3.70 ± 0.808) were the next.

Table 4.12 Descriptive Statistic of Geographic-related Parameters

Code	Central Tendency		Dispersion		Distribution	
	Mean	Median	Std. deviation	Range	Skewness	Kurtosis
GRP	4.40	4.66	0.523	4.00	-1.765	1.095
GRP 1	4.84	5.00	0.617	4.00	-1.563	-1.551
GRP 2	3.70	4.00	0.808	4.00	-1.533	1.060
GRP 3	4.68	5.00	0.652	4.00	-1.559	1.988

As listed in Table 4.13, the reported mean value of 4.87 and 4.38 for SRP1 and SRP2, respectively, indicate that the type of structure is more effective than the complexity of structure on DvDD when choosing between demolition and deconstruction.

Table 4.13 Descriptive Statistic of Structural-related Parameters

Code	Central Tendency		Dispersion		Distribution	
	Mean	Median	Std. deviation	Range	Skewness	Kurtosis
SRP	4.62	4.50	0.517	4.00	-1.849	1.367
SRP 1	4.87	5.00	0.458	4.00	-1.824	1.500
SRP 2	4.38	4.00	0.761	4.00	-1.562	1.641

4.3.4 Model Development

In order to analyse and validate the developed conceptual model, PLS-SEM was adopted. To perform PLS-SEM, a process consisting of three steps was followed as below:

(i) **preliminary considerations;** to check whether the collected data are appropriate for using PLS-SEM,

(ii) **measurement model assessment;** to ensure the reliability and validity of the research instrument,

(iii) **structural model assessment;** to evaluate the hypothesised relationships,

(iv) **overall model assessment;** to evaluate the model fit.

4.3.4.1 Preliminary Considerations

In this section, required preliminary considerations prior to performing PLS-SEM, such as normal distribution of data, the correlation coefficient of scales and goodness-of-fit of data, will be addressed.

4.3.4.1.1 Normal Distribution

The one-sample Kolmogorov-Smirnov test was employed to determine if the data followed a normal distribution and were appropriate for further analysis. As shown in Table 4.14, all the measured p-values are greater than α=0.05. Considering the significant level of 95%, it can be claimed that the data in this study for all the variables are normally distributed.

Table 4.14 One-Sample Kolmogorov-Smirnov Test (n=205)

Variables	Normal Parameters		Test Statistic	Asymp. Sig. (2-tailed)
	Mean	Std. Deviation		
BRP	4.09	0.456	0.679	0.840
CRP	4.36	0.279	0.558	0.928

MRP	4.61	0.390	0.734	0.828
GRP	4.40	0.523	0.783	0.796
SRP	4.62	0.517	0.661	0.835

4.3.4.1.2 Correlation Coefficient

Pearson's chi-square test was used to examine whether there is a significant association between the variables. As shown in Table 4.15, the chi-square independent test confirms the sufficient correlation between variables with a significant level of 95%.

*Table 4.15 Correlation Matrix (n=205, P<0.05 *, P<0.01 **)*

Variables	BRP	CRP	MRP	GRP	SRP
BRP	1	0.400**	0.229**	0.575**	0.465**
CRP	0.400**	1	0.133*	0.250**	0.304**
MRP	0.229**	0.133*	1	0.381**	0.362**
GRP	0.575**	0.250**	0.381**	1	0.601**
SRP	0.465**	0.304**	0.362**	0.601**	1

4.3.4.1.3 Factor Analysis

KMO and Bartlett's tests were used to determine the suitability of data for factor analysis, a statistical technique used to identify underlying factors that explain the interrelationships among the variables. As shown in Table 4.16, it can be seen that the KMO value is equal to 0.79 > 0.6, which reflects that the sample size is adequate in this study; thus, collected data are appropriate for factor analysis. Additionally, the result of Bartlett's test is highly significant at 0.000, which indicate that the correlation matrix is an identity matrix and variables are unrelated. Therefore, it can be concluded that the collected data are suitable for factor analysis.

Table 4.16 KMO and Bartlett's Test (n=205)

KMO Measure of Sampling Adequacy	Bartlett's Test of Sphericity		
	Approx. Chi-Square	df	Sig.
0.790	1936.247	210	0.000

4.3.4.2 Assessment of Measurement Model

The measurement model presents two potential manifestations: either a formative model or a reflective model, or even a hybrid integration of both paradigms (Hulland, 1999). Within the reflective model, it is observed that the Latent Variable (LV) serves as the causal driver for the Measured Variables (MVs), thereby signifying that the MVs represent the 'outcome' of the LV.

The values associated with the connections between an LV and its corresponding MVs are termed ‘factor loadings’, a concept elaborated upon by (Henseler et al., 2009) and (Henseler et al., 2009). On the other hand, within a formative model, the MVs either predict or actively contribute to the occurrence of the LV. In other words, there’s a causal relationship between the MVs and their corresponding LV, where the LV is perceived as being shaped by a combination of its component indicators. In this formative measurement model, the values on the paths connecting each MV to its respective LV represent the significance or impact of each MV on its LV, and they are referred to as “weight coefficients” (Henseler et al., 2009).

The determination of whether indicators should assume a formative or reflective character is intricately tied to “the inherent causal relationship between the indicator and the latent variable (LV)” (Henseler et al., 2009; Hulland, 1999). In the proposed conceptual framework, this relationship is construed as reflective, as evidenced by the directional arrows in the measurement model within Figures 4.4 and 4.5, denoting a path from the latent variable to the measured variables.

The measurement model assessment involves the evaluation of reliability, convergent validity, and discriminant validity. In the following sections the results of each different abovesaid assessment are provided.

4.3.4.2.1 Reliability

As explained in Chapter 3, to examine the reliability of the measurement model, both *internal consistency* and *indicator reliability* were tested.

In order to test the **internal consistency reliability**, composite reliability and Cronbach’s alpha were measured. The composite reliability value ranges from 0 to 1, and its minimum acceptable threshold is considered 0.7 to show internal consistency (Nunnally, 1978). Similarly, Cronbach’s alphas range from 0 to 1, and the minimum acceptable threshold for it to indicate internal consistency is 0.7 (Cheung et al., 2023). The results, as set out in Table 4.17, indicate that the value of the composite reliability and the value of Cronbach’s alpha for all the constructs are above the threshold of 0.7. Hence, it can be concluded that the internal consistency reliability for all the constructs of the study is achieved.

Moreover, to examine the **indicator reliability** for each indicator, the outer loading of each individual indicator on its associated factor was checked. A loading value greater than 0.5 shows the indicator reliability is established (Hair et al., 2006). With the results set out in Table 4.17, the high outer loadings of individual indicators, which ranges between 0.528 and 0.749, signify a sufficient level of indicator reliability.

4.3.4.2.2 Convergent Validity

In order to assess the convergent validity, the Average Variance Extracted (AVE) was measured. The value of AVE ranges between 0 and 1, and its minimum acceptable threshold is considered 0.5 (Fornell & Larcker, 1981; Henseler et al., 2009). As shown in Table 4.17, the AVE values of all the constructs are well above the acceptable threshold, signifying an acceptable level of discriminant validity.

Table 4.17 Internal Consistency reliability , Indicator Reliability , Convergent Validity

Construct	Indicator	λ	α	CR	AVE
BRP		0.619	0.836	0.828	0.739
	BRP 1	0.677			
	BRP 2	0.681			
	BRP 3	0.568			
	BRP 4	0.528			
	BRP 5	0.593			
	BRP 6	0.612			
	BRP 7	0.572			
CRP		0.575	0.844	0.852	0.647
	CRP 1	0.509			
	CRP 2	0.584			
	CRP 3	0.621			
	CRP 4	0.533			
	CRP 5	0.656			
MRP		0.718	0.794	0.779	0.781
	MRP 1	0.749			
	MRP 2	0.672			
	MRP 3	0.558			
	MRP 4	0.719			
GRP		0.651	0.769	0.760	0.711
	GRP 1	0.597			
	GRP 2	0.548			
	GRP 3	0.663			
SRP		0.593	0.725	0.718	0.749
	SRP 1	0.564			
	SRP 2	0.600			

4.3.4.2.3 Discriminant Validity

In order to evaluate discriminant validity, the cross-loadings and Fornell-Larcker-Criterion were measured.

The first discriminant validity measurement was concerned with the evaluation of the loading of the indicators. As shown in Table 4.18, BRP1 to BRP7 have the highest loadings value with their construct, BRP. Similarly, the loadings of all the other indicators on their associated constructs are the highest compared to the other indicators' loadings. Therefore, it can be concluded that the discriminant validity between the constructs is met.

Table 4.18 Cross-Loadings

	BRP	CRP	MRP	GRP	SRP
BRP 1	0.687	0.258	0.077	0.135	0.192
BRP 2	0.519	0.461	0.029	0.040	0.107
BRP 3	0.613	0.246	0.142	0.443	0.156
BRP 4	0.575	0.085	0.178	0.320	0.483
BRP 5	0.620	0.302	0.108	0.028	0.401
BRP 6	0.530	0.301	0.034	0.117	0.236
BRP 7	0.420	0.269	0.294	0.355	0.111
CRP 1	0.126	0.620	0.090	0.128	0.078
CRP 2	0.264	0.412	0.009	0.127	0.212
CRP 3	0.263	0.631	0.182	0.466	0.132
CRP 4	0.274	0.512	0.114	0.301	0.242
CRP 5	0.372	0.437	0.309	0.312	0.376
MRP 1	0.025	0.309	0.607	0.401	0.223
MRP 2	0.050	0.418	0.644	0.322	0.107
MRP 3	0.382	0.261	0.731	0.242	0.105
MRP 4	0.344	0.292	0.780	0.106	0.081
GRP 1	0.179	0.134	0.191	0.790	0.088
GRP 2	0.105	0.360	0.255	0.513	0.016
GRP 3	0.343	0.010	0.203	0.535	0.183
SRP 1	0.017	0.205	0.228	0.295	0.728
SRP 2	0.088	0.249	0.168	0.078	0.630

Furthermore, the discriminant validity was also measured by the Fornell-Larcker-Criterion, where the square roots of the AVE of each construct must be greater than its correlation with other latent variables. The results of the Fornell-Larcker-Criterion matrix for each construct and its indicators are presented in Tables 4.19 to 4.23. According to Hair et. al, discriminant validity

is achieved if the diagonal values in the Fornell Larcker Matrix are higher than those in the same row and column (Hair Jr, Hult, Ringle, & Sarstedt, 2021).

As can be seen in Table 4.19, all the diagonal values are greater than the calculated values in the same row and column. Therefore, it can be claimed that no discriminate validity issue exists for the BRP construct.

Table 4.19 Fornell-Larcker Matrix of the Building-Related Parameters

	BRP 1	BRP 2	BRP 3	BRP 4	BRP 5	BRP 6	BRP 7
BRP 1	0.513						
BRP 2	0.439	0.509					
BRP 3	0.295	0.379	0.481				
BRP 4	0.198	0.229	0.376	0.478			
BRP 5	0.248	0.281	0.338	0.441	0.529		
BRP 6	0.395	0.317	0.306	0.241	0.275	0.456	
BRP 7	0.170	0.243	0.311	0.215	0.472	0.390	0.573

Furthermore, as indicated in Table 4.20, all the diagonal values are greater than the calculated values in the same row and column. Therefore, it can be claimed that the discriminate validity between the CRP and its indicators is satisfied.

Table 4.20 Fornell-Larcker Matrix of the Cost-Related Parameters

	CRP 1	CRP 2	CRP 3	CRP 4	CRP 5
CRP 1	0.471				
CRP 2	0.206	0.496			
CRP 3	0.163	0.255	0.642		
CRP 4	0.239	0.302	0.502	0.581	
CRP 5	0.197	0.266	0.323	0.404	0.648

Referring to Table 4.21, it can be seen that all the diagonal values are greater than the calculated values in the same row and column. Therefore, it can be concluded that discriminant validity is achieved within the MRP and its indicators.

Table 4.21 Fornell-Larcker Matrix of the Material-Related Parameters

	MRP 1	MRP 2	MRP 3	MRP 4
MRP 1	0.782			
MRP 2	0.747	0.423		
MRP 3	0.203	0.175	0.788	
MRP 4	0.205	0.397	0.766	0.745

Similarly, the result in table 4.22 indicates that the diagonal values are greater than the calculated values in the same rows and columns. As a result, it can be claimed that discriminant validity is achieved within the GRP and its indicators.

Table 4.22 Fornell-Larcker Matrix of the Geographic-Related Parameters

	GRP 1	GRP 2	GRP 3
GRP 1	0.453		
GRP 2	0.384	0.462	
GRP 3	0.370	0.307	0.470

Lastly, as shown in table 4.23, it can be noticed that two diagonal values are greater than the value in the same row and columns. This can be taken as an indicator again, which confirms the discriminant validity of SRP and its subscales.

Table 4.23 Fornell-Larcker Matrix of the Structural-Related Parameters

	SRP 1	SRP 2
SRP 1	0.522	
SRP 2	0.405	0.576

The measurement model of the study with 5 constructs and 21 indicators was confirmed after the satisfactory results of reliability, convergent and discriminant validity assessments.

4.3.4.3 Assessment of Structural Model

By assessing the structural model, the significance of the hypothesised relationships between the model constructs and the predictive relevance of the model were examined. The structural model assessment includes assessing the path significance, standard beta coefficient, coefficient of determination (R^2), and predictive relevance (Q^2). The findings from the abovesaid measurements are presented in Table 4.24, depicted in Figures 4.4 and 4.5, and are interpreted in the following.

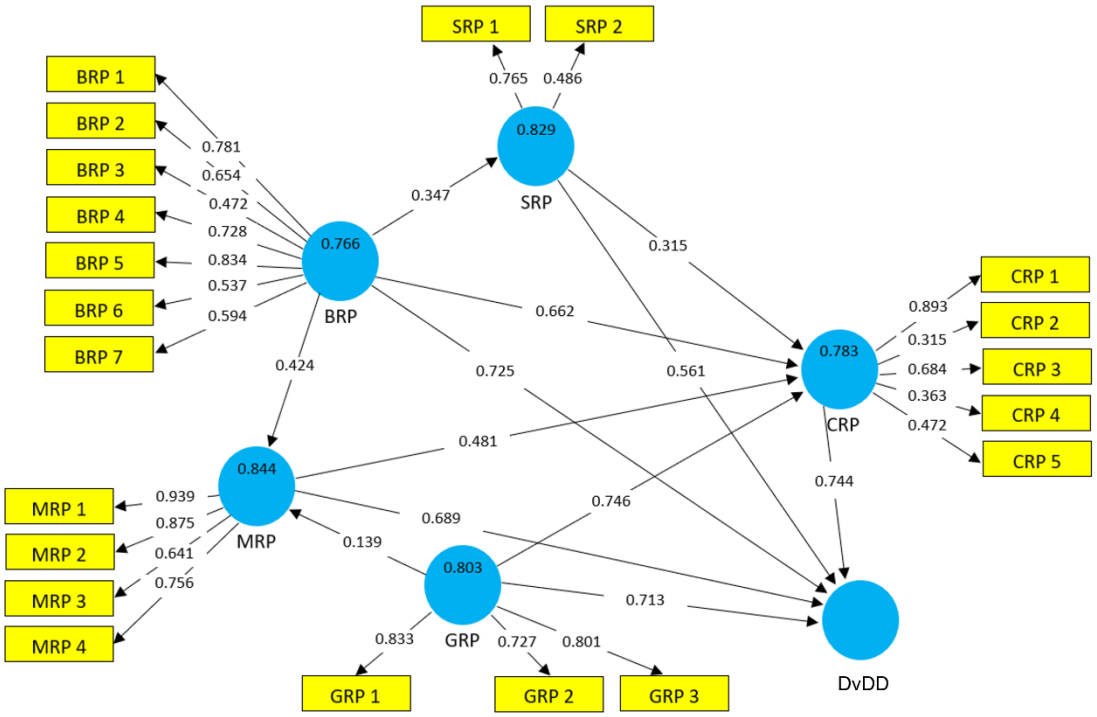

Figure 4.4 Structural Model in the Situation of Path Coefficients

In PLS-SEM, the path significance measures the strength of the relationships among the variables. By performing this command in SmartPLS software, the test statistic, also shown as the *t*-values statistic, is calculated for all the relationships. If the *t*-statistic value is greater than 1.96, the relationship is significant at the 95% confidence level. As reported in Table 4.24 and shown in Figure 4.4, the *t*-statistics values of all the constructs and indicators are above 1.96, while the *p*-values of all the items are below 0.05. The achieved *t*-statistics and *p*-values indicate that the hypothesised relationships between the constructs and their indicators are significant.

Table 4.24 Model Summary

Hypothesis	Variables			Standard Coefficients	Std. Deviation	Test Statistic	Sig. (2-tailed)
	Endogenous	→	Exogenous				
H1	BRP	→	DvDD	0.725	1.069	23.576	0.000
H2	CRP	→	DvDD	0.744	1.085	24.814	0.000
H3	MRP	→	DvDD	0.689	0.998	19.849	0.000
H4	GRP	→	DvDD	0.713	0.844	17.769	0.000
H5	SRP	→	DvDD	0.561	1.265	20.918	0.000
H6	BRP	→	CRP	0.662	0.856	27.417	0.000
H7	BRP	→	MRP	0.424	0.752	15.961	0.000
H8	BRP	→	SRP	0.347	0.831	22.228	0.000
H9	MRP	→	CRP	0.481	1.347	21.785	0.000
H10	GRP	→	CRP	0.746	1.256	17.944	0.000

H11	GRP	→	MRP	0.139	0.905	19.805	0.000
H12	SRP	→	CRP	0.315	1.017	13.711	0.000
	BRP 1	→	BRP	0.781	1.033	18.031	0.000
	BRP 2	→	BRP	0.654	1.312	18.244	0.000
	BRP 3	→	BRP	0.472	0.999	15.652	0.000
	BRP 4	→	BRP	0.728	1.274	19.844	0.000
	BRP 5	→	BRP	0.834	1.049	16.746	0.000
	BRP 6	→	BRP	0.537	0.739	18.341	0.000
	BRP 7	→	BRP	0.594	1.168	17.182	0.000
	CRP 1	→	CRP	0.893	1.160	23.816	0.000
	CRP 2	→	CRP	0.315	1.295	24.942	0.000
	CRP 3	→	CRP	0.684	1.028	25.571	0.000
	CRP 4	→	CRP	0.363	1.212	26.276	0.000
	CRP 5	→	CRP	0.472	1.011	22.075	0.000
	MRP 1	→	MRP	0.939	0.743	29.328	0.000
	MRP 2	→	MRP	0.875	0.844	21.645	0.000
	MRP 3	→	MRP	0.641	0.794	26.304	0.000
	MRP 4	→	MRP	0.756	1.210	24.271	0.000
	GRP 1	→	GRP	0.833	0.894	19.756	0.000
	GRP 2	→	GRP	0.727	1.115	19.241	0.000
	GRP 3	→	GRP	0.801	1.431	19.538	0.000
	SRP 1	→	SRP	0.765	0.970	20.879	0.000
	SRP 2	→	SRP	0.486	0.937	24.552	0.000

Next, the coefficient of determination (R^2), also known as the explained variance, was measured. R^2 ranges between 0 and 1, and according to (Henseler et al., 2009), the values of 0.75, 0.50 and 0.25 are considered substantial, moderate and weak, respectively. The high values of R^2 specify that the values of the constructs predicted by the PLS model are significant. As reported in Table 4.25 and Figure 4.5, the R^2 values for all the constructs are greater than 0.7.

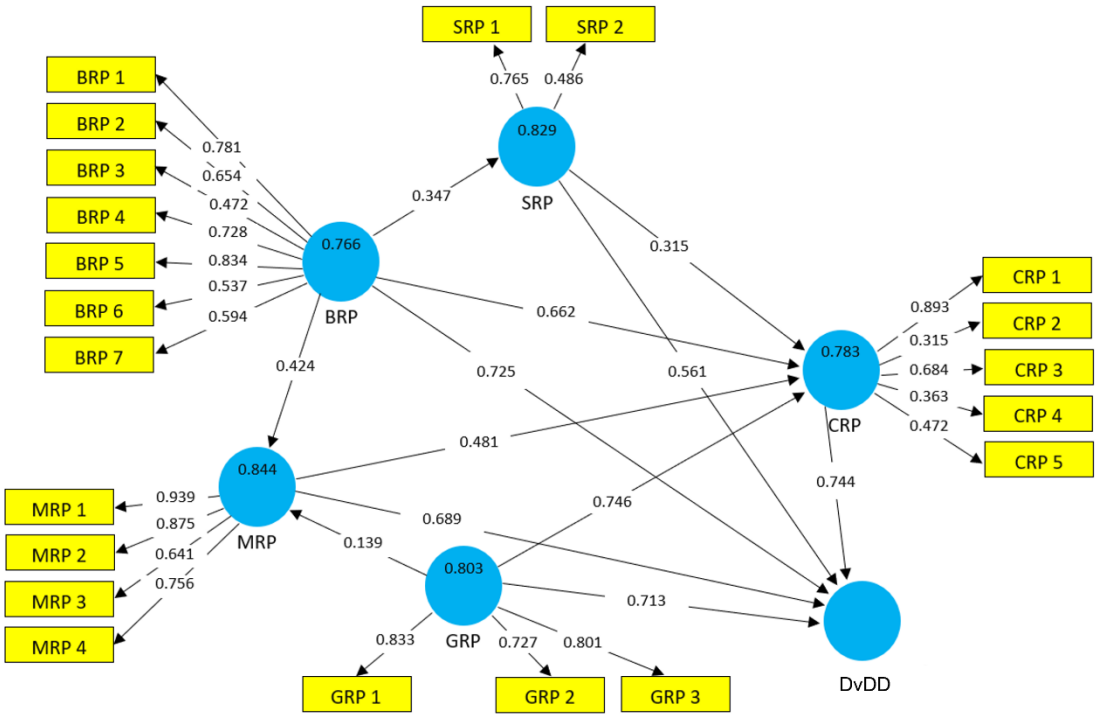

Figure 4.5 Structural Model in the situation of Standard Coefficient

The predictive relevance, or Stone-Geisser Q^2 indicator, evaluates the model's predictive power. The Q^2 values of 0.35, 0.15 and 0.02 indicate large, medium and small predictive relevance, respectively (Wiedenhoft et al., 2019). The higher values of $Q^{2,}$ the better the relevance of the prediction.

Table 4.25 Coefficient of Determination, Predictive Relevance

Endogenous Variable	R^2	R^2_a	Q^2
BRP	0.766	0.760	0.456
CRP	0.783	0.759	0.425
MRP	0.844	0.839	0.439
GRP	0.803	0.795	0.471
SRP	0.829	0.815	0.412

4.3.4.4 Assessment of the Overall Model

Lastly, the accuracy of the two models – measurement and structural – was tested using goodness-of-fit (GOF) criteria, as suggested by Tenenhaus et al. (Tenenhaus et al., 2005). Having the average of R^2 from Table 4.26, the GOF was calculated is follows:

$$GOF = \sqrt{0.807 \times 0.819} = 0.812$$

The measured GOF value of 0.812 indicates that the empirical data fits the model precisely and satisfactory.

4.4 Summary

This chapter presented the findings of the study in two main parts; findings from qualitative research and findings from quantitative research. The data from twelve semi-structured interviews were thematically analysed in the first part and presented with the findings. At this stage, the extracted parameters from the literature were confirmed and validated, and the updated table of parameters was presented. The results from Entropy-based TOPSIS calculations were then presented, from which the decision support framework was developed. Herein, the conceptual model highlighting the potential relationships between the constructs was predicted.

In the next part, the findings from conducted quantitative research were presented in two main sections. First, the collected data were analysed descriptively. The findings at this stage include the demographic profiles of the respondents and the rating analysis, which are explained descriptively. Next, the collected data were further examined inferentially. This section then presented the process of performing PLS-SEM, a multivariate analysis method to validate the conceptual model developed earlier in this chapter. Accordingly, the findings from the 3-step process, including preliminary considerations, measurement and structural model assessment, were presented. A detailed discussion of the findings, together with the validated model, is presented in the next chapter.

Chapter 5 Discussion

5.1 Chapter Introduction

This chapter presents an interpretation and discussion of the qualitative and quantitative research findings conducted in this study, comparing them with the current literature. In the first section, the specific findings and analysis related to the New Zealand End-of-Life are addressed. Moving to the next section, a combination of the findings from the thematic analysis of the semi-structured interviews and entropy based

TOPSIS calculation are discussed and compared with the current body of knowledge. In this section, ranking of the parameters in accordance with their level of importance and the formation of the framework are discussed. Afterwards, where the developed conceptual framework, and the reflecting hypothesised relationships between the groups of parameters, are explained and discussed, the findings from quantitative research used for model validation are explained. The chapter then concludes with an overall summary. Figure 5.1 illustrates the content outline of this chapter.

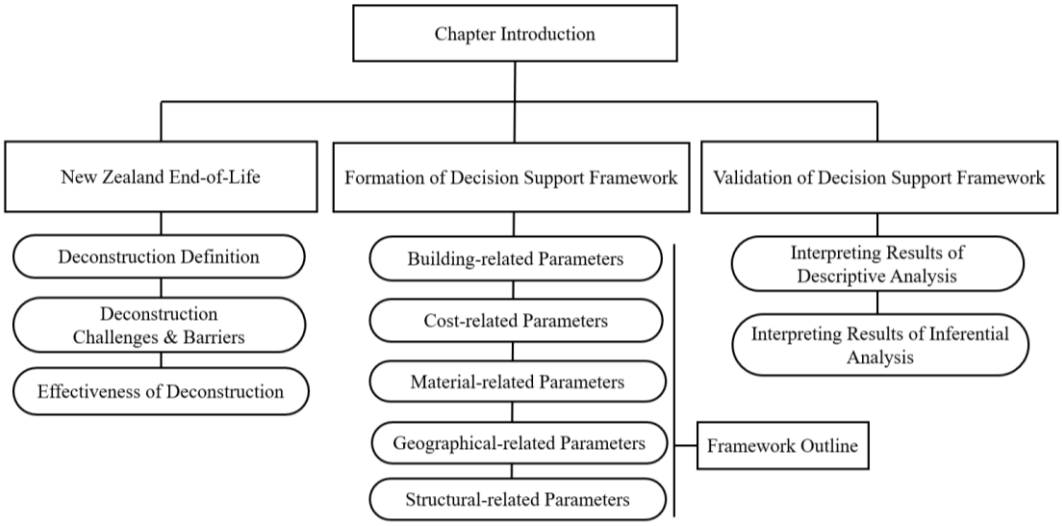

Figure 5.1 Content Outline of Chapter Five

5.2 New Zealand End-of-Life

Sustainability has become a critical concept in the modern world as it seeks to maintain a balance between economic, social, and environmental systems (Correia, 2019). The concept is based on the understanding of natural ecosystems and their continued success. Sustainability recognizes the cyclic nature of growth, decomposition, re-growth, and energy in its immediate and embodied forms (Misopoulos et al., 2021). It aims to create a process that is cyclic, linking resources into an infinite cycle. The current production processes in New Zealand are generally linear in nature, which is not sustainable (Storey et al., 2005). In light of these issues, it is imperative for New Zealand practices to prioritise the adoption of more sustainable production processes that is cyclic in nature.

The construction and demolition (C&D) industry is a significant contributor to the depletion of resources and pollution (Asante et al., 2022). Concrete and timber construction, in particular, have contributed to the depletion of resources, which is becoming increasingly evident in New Zealand (Storey et al., 2005). The current production process of dominant construction materials in the C&D industry is linear (Nasir et al., 2017), which does not contribute to sustainability. To address this issue, the role of deconstruction in the C&D industry is crucial.

Deconstruction is an essential process in the C&D industry as it creates a loop in resource use, consumption, and energy expenditure (Tleuken et al., 2022) since it is the process of dismantling buildings and other structures carefully to salvage reusable materials, such as bricks, concrete, steel, and wood (Menon & Jayaraj, 2017). These materials can then be reused or recycled, thereby reducing waste in landfills, decreasing the depletion of resources, and mitigating pollution.

The potential of deconstruction in shifting the C&D industry to a more sustainable level in New Zealand is significant as it can reduce the need for virgin resources, conserve energy, and create jobs (Zaman et al., 2018). Moreover, deconstruction can also save landfill space, reduce greenhouse gas emissions, and improve air quality (Saghafi & Teshnizi, 2011).

Despite the potential benefits of deconstruction, New Zealand has yet to fully embrace this sustainable practice (Storey et al., 2003), which is supported by the findings from interviews conducted as part of this study. According to the findings of the interviews, the construction and demolition industry in New Zealand is currently considered unsustainable by a majority of the participants, with nine out of twelve interviewees confirming this viewpoint. Additionally, it is becoming increasingly difficult to find landfills that are acceptable to the public, economically feasible, and environmentally sound, as confirmed by the collected data from interview sessions.

Based on the preceding discussion, it is evident that the concept of sustainability is a critical aspect of maintaining balance between economic, environmental, and social systems. To achieve sustainability, New Zealand must embrace a more cyclic approach to production processes. Deconstruction is an approach that can prove crucial to this objective, especially in the construction and demolition industry. Deconstruction can facilitate a loop in resource utilisation, consumption, and energy expenditure, thereby promoting sustainability in New Zealand. The potential benefits of deconstruction are significant and include reduced depletion of resources, pollution mitigation, and enhanced air quality. Consequently, prioritising and facilitating the adoption of deconstruction in the construction and demolition industry is essential for creating a sustainable future for New Zealand. Hence, this study aimed to develop a decision support framework to facilitate the decision-making process between conventional demolition and deconstruction at the EOL phase of the building's lifecycle.

5.2.1 EOL Definitions in New Zealand

According to the interviewees, in New Zealand construction industry, conventional demolition is defined as a widely used process for tearing down of buildings and other structures. It involves the utilisation of heavy machinery such as excavators, bulldozers, and wrecking balls to bring the structure down to its foundation. This accords with the definition given by Menon et al. (Menon & Jayaraj, 2017), saying "demolition is defined as the process of destroying down or collapsing down of large buildings after its useful life" with no further purpose. Another definition to conventional demolition is given by Durmisevic and Noort (Durmisevic & Noort, 2003), as "the process whereby a building is broken up with little or no attempt to recover any of its constituent parts for re-use". The main objective of conventional

demolition is to completely destroy the building, which often results in significant amounts of waste material (Pantini & Rigamonti, 2020).

On the other hand, deconstruction was defined by interviewees as a meticulous process that involves careful dismantling of a building or structure with the aim of salvaging as many materials as possible for reuse, repurposing, or recycling. They believed, it offers a more sustainable and environmentally friendly approach to demolition. It was also mentioned that the materials that can be salvaged through deconstruction may include wood, metal, brick, and other building components such as joinery, hardware, etc. The findings regarding deconstruction are in line with the global views towards deconstruction. For instance, Akinade et al. (Akinade et al., 2020) defined deconstruction as the process which aim to "ensure efficient material flow from the end-of-life to the beginning-of-life". In addition, the quotes from interviewees were in line with views of Quéheille et al. (Quéheille et al., 2022), that deconstruction is a process of the deliberate disassembly of a building or structure to retrieve and repurpose as many construction materials as feasible before starting a renovation or new construction project.

From analysing the interview transcriptions, it could be concluded that the primary difference between conventional demolition and deconstruction lies in their respective focus on waste reduction and resource recovery. While conventional demolition prioritises the quick and efficient destruction of the building, deconstruction aims to minimise waste and recover valuable materials that can be reused or repurposed. According to the interviewees, in New Zealand, where sustainable building practices are increasingly gaining traction, deconstruction has become an increasingly popular option for building owners and contractors who are keen to reduce their environmental impact. By adopting deconstruction approach, EOL practices can contribute towards waste reduction, resource conservation, and sustainable development in the construction industry.

5.2.2 Deconstruction Challenges and Barriers in New Zealand

In interview phase, after discussing general terms and definitions regarding deconstruction and demolition, interviewees were asked if they could elaborate on some of the challenges and barriers faced when it comes to using deconstruction in New Zealand. During the interview sessions, four factors were identified and will be thoroughly discussed in the subsequent sections.

5.2.2.1 Lack of Awareness and Education

During the interview sessions, the interviewees referred to lack of awareness, as well as education, towards deconstruction and its benefit compared to conventional demolition. "One of the key obstacles we encounter is insufficient understanding and knowledge regarding

deconstruction practices. Many professionals in the construction industry have limited knowledge about the benefits and processes involved in deconstruction. It's crucial to raise awareness and provide education on the advantages of deconstruction compared to traditional demolition methods. By increasing understanding and knowledge, we can foster a greater acceptance and uptake of deconstruction practices in New Zealand". Armanda Couto and João Couto's perspective aligns with this finding, as they emphasised that a major obstacle in the UK's construction industry, hindering the wider adoption of deconstruction methods, is the insufficient availability of information, skills, and tools for both deconstruction and designing with deconstruction in mind (Couto & Couto, 2010).

5.2.2.2 Cost and Financial Viability

The interviewees identified financial difficulties and the high cost associated with deconstruction as other challenges impeding its implementation in New Zealand. This assertion is exemplified by the following quote:

"*One of the major hurdles we encounter is the financial aspect. Implementing deconstruction practices in New Zealand can be costly and may pose financial challenges. Compared to traditional demolition methods, deconstruction tends to be more time-consuming and labour-intensive, resulting in higher upfront costs. Additionally, establishing efficient material recovery systems and finding markets for the reclaimed materials can be economically demanding, particularly if the demand for these materials is low. Therefore, while deconstruction offers significant environmental advantages, we need to address the financial viability to make it a more feasible choice for construction professionals and industry stakeholders*" [interviewee #4].

In the existing literature, Rios et al. (Rios et al., 2015) put forth the argument that cost can indeed hinder the successful implementation of deconstruction, with several variables identified as influencing these costs. These variables include: 1) the need for material storage prior to reaching their final destination; 2) increased labour costs; 3) escalated expenses related to workers' insurance; 4) transportation costs associated with debris removal; 5) expenditures linked to the removal of hazardous materials; 6) training expenses; 7) the local and regional market demand for used materials; 8) the condition of the materials being deconstructed; and 9) landfill fees.

5.2.2.3 Regulatory and Permitting Issues

Another challenge identified by the interviewees as a significant impediment to the successful implementation of deconstruction was the presence of regulatory and permitting issues. These issues encompass the complex framework of governmental regulations and approval processes that may not align seamlessly with the principles and requirements of

deconstruction. Such misalignment often leads to difficulties in obtaining the necessary permits and complying with the existing regulations, thereby impeding the widespread adoption of deconstruction projects in New Zealand.

These observations align with the research conducted by Storey et al. (Storey et al., 2005). In their report, the authors thoroughly examine various legislative barriers that hinder the successful utilisation of deconstruction within the New Zealand context. These barriers encompass a range of factors as below:

A) Lack of Priority for C&D Waste Minimization: Some local councils and central government agencies do not prioritize the minimization of construction and demolition (C&D) waste. As a result, there is limited emphasis on developing and implementing legislation that specifically addresses waste reduction and encourages the adoption of sustainable practices, including deconstruction.
B) Unclear Government Legislation on Environmental Responsibility: There is confusion and ambiguity surrounding the existing government legislation pertaining to environmental responsibility in the context of C&D waste management. The lack of clarity regarding the specific regulatory requirements and obligations related to deconstruction practices can create uncertainties and deter stakeholders from actively engaging in sustainable demolition and material recovery efforts.
C) Inconsistencies in Units of Measurement and Limited National Data: The absence of standardised units of measurement for C&D waste data at the local level contributes to inconsistencies and challenges in accurately assessing and monitoring waste generation, diversion, and recycling rates. Furthermore, the availability of comprehensive and reliable national data on C&D waste is severely limited. This scarcity of data poses a significant obstacle in formulating evidence-based policies and regulations to support deconstruction initiatives effectively.
D) Local Council Responsibility without Mandatory Regulation: Waste management, including C&D waste, is primarily the responsibility of local councils in New Zealand. However, there is no mandatory regulation specifically targeting deconstruction practices. This absence of mandatory requirements can lead to inconsistency in approaches and practices across different regions, making it challenging to ensure widespread adoption of deconstruction as a preferred method of demolition and waste management.
E) Voluntary Adherence to NZ Waste Strategy Targets and Goals: The NZ Waste Strategy sets targets and goals for waste reduction, including C&D waste. However, adherence to these targets and goals is voluntary rather than mandatory. This voluntary nature limits

the enforceability and accountability of achieving sustainable waste management outcomes, including the promotion and implementation of deconstruction practices.

5.2.2.4 Lack of Market Demand for Reclaimed Materials

As discussed during the interviews, the successful implementation of deconstruction relies on the existence of markets for the reclaimed materials. If there is a lack of demand for these materials, it can hinder the economic feasibility of deconstruction projects. This point is portrayed in the following quote:

"*One significant challenge we face is the limited market demand for salvaged materials. You see, for deconstruction to be successful, there needs to be a market for the materials we recover from buildings. However, in New Zealand, there might not always be a strong demand for these salvaged materials. This lack of demand causes a barrier to the economic feasibility of deconstruction projects. So, it becomes essential for us to create awareness and stimulate interest in utilising such kind of materials, so promoting a market that can support the sustainable practices of deconstruction*." [interviewee #8].

Storey et al. (Storey et al., 2005) has claimed that in New Zealand, there are two separate market sectors that deal with resource recovery; one sector focuses on architectural components that are unique and rare or have high value, and this market seems to be well-established or in the process of development. On the other hand, there is another sector that deals with materials like concrete, which are available in large quantities but are not highly valued. The later market refers to the reclaimed materials resulting from deconstruction activities. According to Storey and Pedersen (Storey & Pedersen, 2014), the market for these materials in New Zealand is limited. Hence, it can be concluded that the findings from the interview sessions regarding the lack of market demand for reclaimed materials are in agreement with the existing literature.

5.2.3 Effectiveness of Deconstruction in New Zealand

After conducting interviews, it has become evident that deconstruction has the potential to yield significant benefits on a national scale in New Zealand. This is exemplified in the following quotation:

"*Deconstruction is a significant game changer in our journey towards achieving zero waste. When we construct and demolish buildings, we generate the most waste that ends up in landfills. On average, a new house construction can waste around 4.5 tonnes of materials, which is equivalent to 30 years' worth of weekly garbage collections for a person living in Auckland. Auckland Councillors emphasise that it is crucial for the projects to prioritise keeping*

construction materials out of landfills and integrating them into the circular economy." [interviewee #2].

The analysis of the data gathered from the interviewees revealed that the adoption of deconstruction offers a multitude of positive outcomes for both the construction industry and the wider community in New Zealand. These benefits include various dimensions, including environmental, social, and economic aspects.

5.2.3.1 Environmental Benefits

As per the respondents, the foremost environmental advantage of implementing deconstruction was that the requirement for the extraction of fresh raw materials in the building sector is greatly decreased when deconstruction is performed. According to interviewee #7, the lifespan of existing resources can be extended through the process of deconstruction, which involves the methodical disassembly of buildings and the recovery of elements that can be reused. This reduction in the requirement for fresh extraction contributes to the preservation of natural resources and minimises the environmental impacts that are linked with this practise. It can be concluded that, deconstruction makes a contribution to the protection of ecosystems and habitats by minimising the depletion of scarce resources such as minerals and timber. This helps to reduce the negative effects that mining operations have on the land, the water, and the biodiversity of the area. This debate is in line with the current body of research, as Anuranjita et al. (Anuranjita et al., 2017) has pointed out that deconstruction provides clients and contractors with the opportunity to reduce their dependency on new building components and materials. The authors believed that, because of this lessened reliance, there may be a corresponding reduction in the quantity of energy needed for the manufacturing of new materials.

Another notable environmental advantage that deconstruction brings to New Zealand, as emphasised by the interviewees, is waste reduction and diversion from landfills. The volume of waste that would otherwise contribute to the contamination and destruction of the environment is reduced to a minimum when deconstruction is used since it keeps waste from demolition and building out of landfills. This waste diversion lessens the pressure that is placed on landfill capacity, mitigates the release of toxic compounds from decomposing waste, and minimises the greenhouse gas emissions that are generated by practises associated with landfilling waste. In addition, as deconstruction encourages the reusing and recycling of materials, it lessens the need for energy-intensive production processes, which cut down on carbon emissions and other forms of pollution that are harmful to the environment.

The claim above is in line with the results from the study conducted by Rod Sweet (Sweet, 2019), it has been stated that effective deconstruction, followed by recycling and reuse of construction materials such as concrete, bricks, wood, glass, metals, and plastics, can result in

significant reductions in carbon emissions by eliminating the need for additional mining and manufacturing operations that are energy- and carbon-intensive. This strategy is in keeping with the goals established in the Waste Framework Directive issued by the European Commission, which aims to achieve a recovery rate of seventy percent, measured by weight, for waste from building and demolition. Sweet believes that it is possible to significantly reduce the emissions caused by the manufacture of materials if this step is taken.

5.2.3.2 Social Benefits

As expressed by the individuals interviewed, the adoption of deconstruction is seen as a promising approach that can generate substantial social benefits for the New Zealand community. The labour-intensive nature of deconstruction results in the establishment of job opportunities, particularly for individuals with lower levels of ability. This inclusiveness in the workforce has the potential to contribute to the reduction of social inequality and the promotion of economic empowerment for underrepresented groups. This is portrayed in the quote below:

"*I believe that embracing deconstruction as a method can bring some major social benefits for our community. You see, deconstruction requires a lot of labour, which means it creates new job opportunities. And the cool thing is, these jobs are especially great for people who might have lower qualifications or skills. By giving them a chance to work, it makes our society fairer and helps avoiding social inequality*", [interviewee # 8].

Shami (Shami, 2006), similarly, discuss that the provision of training required skills for implementing deconstruction results in an increase in employment opportunities and a stimulation of small business activity, which is accomplished through the sale of recycled materials and the requirement for labour.

In addition to this, interviewees mentioned that deconstruction can act as a foundation for the development of skills and a venue for training. This point was also discussed by (Rios et al., 2015), claiming that forty percent of the workers in an examined case study were female, and all of them had undergone training before beginning their deconstruction task. Hence, Based on the information presented, it becomes evident that individuals' employability can be improved by deconstruction programmes, and as a result, so can their chances of finding work in the construction business. This encourages individuals to continue their education throughout their lives and gives them the tools they need to engage in the economy more effectively (Shami, 2006).

Another social benefits of deconstruction which was discussed in the interview sessions but has not been mentioned in the literature was its potential to contribute to the development of a mature market for reused and recycled materials. Based on the insights of the interviewees, as

the demand for such materials increases, their availability and affordability are likely to improve; "*as more and more people start demanding these recycled materials, they become more readily available and cheaper too*", discussed interviewee #9. "*..., that's a win-win situation for everyone. When building materials become more affordable, it means that construction itself becomes more accessible to a lot more people. And that's a big deal, you know? It means more people can have a place to call home and communities can grow stronger*", continued interviewee #9. Reduced costs of building materials can benefit the wider society by making construction more affordable and accessible, resulting in broader participation in housing and infrastructure development. Another aspect that was addressed referred to the point that a mature market for reused and recycled materials can stimulate economic growth and foster a circular economy, where resources are utilised efficiently, and waste is minimised.

5.2.3.3 Economic Benefits

In accordance with the viewpoints expressed by the interviewees, in comparison to more traditional methods of demolition, deconstruction has the potential to result in cost savings. Interviewees expressed their belief that, through a careful dismantling process and the reclamation of materials, the necessity for acquiring new raw materials is decreased, consequently resulting in reduced construction expenditures. Furthermore, deconstruction mitigates disposal fees by diverting materials away from landfills by repurposing or recycling. Interviewees believed that these financial advantages can be particularly beneficial for construction projects limited budgets, especially in the current challenging economic conditions in New Zealand.

Prior research has also demonstrated comparable economic benefits associated with the implementation of deconstruction. For instance, Balogun et al. (Balogun et al., 2022) claimed that the salvaged materials, which encompass all the recoverable materials from building deconstruction, have the potential to generate economic benefits, such as Cost savings and reduced construction expense and revenue generation from the sale of salvaged materials. Another study conducted by Chini and Bruening (Chini & Bruening, 2003) demonstrates that while deconstruction costs may be higher compared to demolition, the resale of salvaged materials compensates for these expenses, making deconstruction a more economically viable option. The study showcases the findings of a deconstruction project undertaken by the Powell Center for Construction and Environment (PCCE) (Guy & McLendon, 2000) in Gainesville, Florida, which revealed that after salvaging materials, the total costs for deconstruction were less than 30% of demolition costs.

In summary, implementing deconstruction in New Zealand offers significant environmental, social, and economic benefits, according to the information provided. From an environmental perspective, deconstruction lowers the need for extracting fresh raw materials in the building sector, extending the lifespan of existing resources and preserving natural resources. It also contributes to waste reduction and diversion from landfills, minimising irreparable environmental impacts such as contamination and greenhouse gas emissions. Socially, deconstruction creates job opportunities, promoting economic empowerment and reducing social inequality. It also functions as an educational environment, improving employability and skills development for workers. Furthermore, deconstruction can lead to the development of a mature market for reused and recycled materials, making construction more affordable, stimulating economic growth, and encouraging a circular economy. Economically, deconstruction offers cost savings compared to conventional demolition methods, as it reduces the need for new materials and mitigates disposal fees. Overall, deconstruction in New Zealand proves to be effective in achieving multiple benefits across environmental, social, and economic dimensions.

5.3 Formation of Decision Support Framework

As comprehensively discussed in Chapter 2 and based on the discussion provided earlier in this chapter, the significance of the construction industry's contribution to resource and energy consumption, greenhouse gas emissions, and waste production emphasises the need to adopt more sustainable practises. Besides, given the increasing demand for demolition works due to land supply shortages and higher building densities in urban areas, it is crucial to consider resource efficiency. Conventional demolition often results in the loss of valuable resources embedded in buildings, while deconstruction as a more sustainable practice allows for their recovery and reuse, promoting resource efficiency (Bertino et al., 2021; Zaman et al., 2018).

As highlighted in Chapter 2, a limited number of studies have explored practical approaches for optimising the selection between deconstruction and demolition processes of buildings at their end-of-life. This suggests that there is a lack of established methodologies or frameworks to guide decision-makers in determining the most appropriate approach for a given project. Without such guidance, decision-makers may face difficulties in understanding the potential benefits and drawbacks of each option, hindering their ability to make informed choices. In addition, not every building holds the potential for deconstruction, wherein components and materials can be salvaged for reuse, repurpose, or recycling. According to the literature and the collected data from the interview phase, deconstruction potential of buildings depends on various factors. These factors encompass a broad spectrum of elements, including but not

limited to the building characteristics, structural design, material composition, user accessibility, environmental impacts, and end-of-life management strategies. Therefore, it becomes crucial to have a decision support framework that can highlights these factors and their level of importance, helping decision-makers to determine whether deconstruction is a viable option for a particular building. This framework would enable decision-makers to evaluate the feasibility and potential benefits of deconstruction on a case-by-case basis.

Moreover, the literature suggests that while deconstruction offers a wide range of advantages, such as resource conservation and reduced environmental impact, it is also complex, costly, time-consuming, and labour-intensive when compared to conventional demolition (Tatiya et al., 2018). Considering these trade-offs, decision-makers require a structured approach that takes into account crucial parameters to evaluate the overall feasibility and desirability of deconstruction in specific scenarios. A decision support framework can provide a systematic way to consider these factors and assist in making well-informed decisions (Kersten, 2000).

Furthermore, the lack of studies in the context of New Zealand that specifically address the EOL phase of the building lifecycle highlights the need for a specialised decision-making process, confirmed by the conducted literature review. Without a dedicated procedure, decision-makers may face difficulties in navigating the complexities associated with choosing between demolition and deconstruction. Therefore, a decision support framework would help identify critical parameters that influence the decision and provide guidance on how to evaluate and prioritise these parameters in the context of New Zealand’s unique circumstances.

In summary, the development of a decision support framework was deemed necessary to bridge the existing gap in knowledge and practice. Such a framework would enable decision-makers to consider the practical approaches, assess the deconstructability of buildings, and incorporate critical parameters for decision-making in the context of choosing between conventional demolition and deconstruction as the EOL approach. By providing a strategic and structured approach, this framework would facilitate more informed and effective decision-making in the New Zealand construction industry.

In order to develop the outlined decision support framework, the study adopted a holistic approach, incorporating the insights derived from the reviewed literature, semi-structured interviews, and entropy-based TOPSIS calculations. As stated by Mohemad et al. (Mohemad et al., 2010), decision support frameworks are primarily designed to aid evaluators and decision makers in analysing complex processes by offering relevant information and data, with the focus on facilitating informed decisions rather than exclusively selecting the optimal candidate from the available options.

The aim of the decision support framework proposed in this study is to assist decision makers in selecting the most appropriate EOL approach, whether demolition or deconstruction, considering their competencies in varying projects and circumstances. As noted by Schwartz et al. (Schwartz et al., 2018) decision-making frameworks assist in defining and prioritising criteria for decision evaluation – criteria are the standards or measures used to assess the desirability or effectiveness of each alternative. Consequently, it becomes important to identify the affecting parameters on the decision-making process. This justifies the development of the first research objective of the research, as "identifying the critical parameters influencing the selection of an appropriate approach for the end-of-life phase of building lifecycle", and this research objective was accomplished by conducting a systematic literature review, as the first step of the research. Afterwards, the identified parameters needed to be verified by the local professionals in New Zealand. As such, the second objective was set to "verifying the collected parameters from the literature in the context of New Zealand construction industry". The next step of the study, semi-structured interviews, carried out to fulfill this objective.

Furthermore, decision support frameworks aid researchers in selecting the optimal choice by organising and ranking the affecting criteria according to their relative significance (Al-Atesh et al., 2023). This highlights the justification of the third step undertaken in this study, which examined the importance of each parameter in the ultimate decision-making process when selecting between demolition and deconstruction.

After conducting detailed analysis on both collected primary and secondary data, 5 main categories with 21 parameters were established as the main components of the decision support framework. In accordance with the results presented in Chapter 4, the following sections provide detailed discussion on the five categories of parameters, including building-, cost-, material-, geographical-, and structural-related categories.

5.3.1 Building-related Parameters

Seven parameters were studied and included within this category, namely building age, building height, building area/ volume, building accessibility, material and component condition, layout design complexity, and hazardous materials. Subsequently, each of these parameters will be discussed in detail.

BRP1 – Building Age: According to the opinions shared by the interviewees, building age has been specified as one of the most decisive parameters in the decision-making between conventional demolition and deconstruction. It was concluded from the interview results that building age could influence the quantity of salvageable and reusable materials, as well as the quality and durability of them. The materials used to construct older structures, such as

hardwood flooring, brick, and stone, are often more durable and have a longer lifespan than those used in modern construction, making them valuable for reuse in new projects. In such instances, deconstruction would be a better option as it allows for careful dismantling of a building, preserving the valuable materials and reducing the amount of waste that ends up in landfills. Hence, buildings can provide crucial information from which experts can make informed assessments about its potential suitability for either demolition or deconstruction. Furthermore, during the interviews it was noted that the age of a building can offer significant insights into its structural composition, stability, and security, which are essential factors in assessing its suitability for demolition or deconstruction.

Literature also confirms that the age of a building is a crucial aspect to be taken into account when choosing between demolition and deconstruction. A study by Pantini and Rigamonti (Pantini & Rigamonti, 2020) explains that building age can affect the feasibility of deconstruction as older buildings may have structural issues that make deconstruction more difficult and costly. However, the authors argue that even in these cases, deconstruction can still be a more sustainable option than conventional demolition. Coelho and de Brito (Coelho & de Brito, 2011a) highlights the importance of building age in the decision-making process, noting that how building age is an important factor in determining the types and quantities of materials. In their conducted study aimed at developing a cost prediction model for building deconstruction in urban areas, Tatiya et al. (Tatiya et al., 2018) identified building age as a significant predictor influencing the process of building deconstruction.

Further, the outcomes derived from the entropy based TOPSIS calculations provide additional evidence to reinforce the significance of the building age in the decision-making process. It is evident from the results presented in Table 4.4 that building age has been assigned the second-highest rank as a critical parameter, as perceived by the interviewees.

BRP2 – Building height: Based on insights from the interviewees, the height of buildings is considered a pivotal factor within the category of building-related parameters. The participants assert that low-rise structures, typically consisting of one or two storeys, present less complexity during the demolition process due to the absence of high-reach demolition equipment and the reduced need for extensive safety measures. Furthermore, as per the discussions conducted with the interviewees, it can be inferred that the complexity of the work escalates in direct proportion to the height of the building. The deconstruction or demolition of taller buildings requires the engagement of a more proficient and trained workforce alongside the utilisation of specialised equipment. This observation emphasises the requirement for enhanced skills and resources in order to tackle the complexities associated with higher structures.

Drawing upon the existing body of literature, considering building height emerges as a fundamental aspect when selecting the most suitable EOL method. Notably, research regarding the utilisation of "high-reach demolition techniques" underlines that taller structures may require the adoption of more specialised and potentially intricate approaches for effective demolition (Kamrath, 2013). Additionally, the existence of particular regulations governing the demolition of low-rise buildings up to a specific height implies that the height of a structure serves as a critical factor in identifying the appropriate strategy for demolition (*Demolition – Best Practice Guidelines For Demolition in New Zealand*, 2014).

The outcomes of the thematic analysis conducted on semi-structured interviews have demonstrated that the respondents have underscored the significance of the building height in their decision-making process when choosing between demolition and deconstruction. Conversely, the results from the entropy based TOPSIS calculations have indicated that building height ranks as the fourth most significant parameter. Consequently, it can be inferred that building height exerts a considerable influence on the decision-making process; nonetheless, three other parameters belonging to the category, namely the material and component condition, the age of the building, and the accessibility of the structure, assume a greater priority. While Tatiya et al (Tatiya et al., 2018) acknowledge the influence of building storey (also known as building height) on the deconstruction process, they did not extensively explore its relative significance compared to other parameters in their study.

BRP3 – Building area/ volume: The outcomes derived from the interview phase regarding to the relationship between building area and demolition or deconstruction processes reveal several pivotal aspects. During the interview data analysis, it was noted that while building area alone may not emerge as the most influential factor in the decision-making process, it undeniably exerts a noteworthy impact on the costs and logistics of a project.

As expressed by the interviewees, one important consideration is the timeline deconstruction process. As noted, deconstructing a large building will take longer and require more resources than a smaller one. This means that building area must be factored into the planning and budgeting process for a construction project, as it can significantly impact the overall costs and timeline. The interviewees also emphasised the significant influence of building area on the volume of materials and components used in construction. The size of buildings directly correlates with the quantity of materials and components, subsequently influencing transportation and storage demands. As a result, the logistics of a project can be significantly impacted, necessitating thorough consideration during the planning and budgeting stages. Finally, the challenges of quantifying materials and components in large-scale buildings were highlighted. This process requires more time and skilled workforce, which can also affect the

project's costs. Therefore, building area must be considered when assessing the project's capability for either demolition or deconstruction.

The above findings are consistent with those of Chini (Chini, 2001) who argues that the amount of building material that can be salvaged through deconstruction is directly related to the building's area. Using data from case studies, the author found that buildings with larger areas generally have more salvageable materials than smaller buildings. Therefore, when considering whether to deconstruct or demolish a building, the building's area should be a key factor in the decision-making process.

Other studies have also reinforced the significance of building area in the decision-making process between deconstruction and demolition. For instance, Allam & Nik-Bakht (Allam & Nik-Bakht, 2022) conducted a comprehensive analysis and concluded that larger buildings tend to offer higher potential for material salvage through deconstruction compared to smaller structures. Similarly, Bertino et al (Bertino et al., 2021) examined multiple case studies and affirmed that building area directly influences the feasibility and economic viability of deconstruction projects. These collective perspectives from various studies emphasis the agreement regarding the crucial role of building area as a determinant in choosing between deconstruction and demolition methods.

In contrast to the earlier findings, the results of the TOPSIS calculations revealed that building area ranked as the least significant factor among the parameters associated with buildings. This indicates that while building area holds importance as an individual consideration, it does not hold the highest priority when compared to other factors within this particular category.

In summary, the building area holds importance in the planning and implementation of an EOL project. While it may not hold the most importance in the decision-making process, it undeniably exerts a considerable influence on the project's costs, timeline, and logistical intricacies. Thus, a thorough evaluation of a building's characteristics, including its area, becomes crucial when making the choice between conventional demolition and deconstruction methods. By factoring in the building area as part of the comprehensive assessment, decision-makers can make informed decisions that align with the project's goals, optimise resource utilisation, and ensure effective EOL management.

BRP4 – Building Accessibility: The significance of access to buildings in determining the appropriate EOL approach was revealed during the data analysis stage, highlighting by the participants in the interview phase. The arguments propose that access to the building plays a crucial role deciding whether to deconstruct or demolish a building. For instance, it was indicated that, the successful execution of the demolition process is dependent upon the ability

to manoeuvre heavy machinery. Nevertheless, when a building is located in a densely populated urban centre where machine access is limited, disassembling the building in a systematic manner is the only recourse. This statement suggests that access to a building does not simply refer to entry into the building but also encompasses the ability to safely retrieve scrap materials and components from the building. In metropolitan areas such as central business district (CBD) of New Zealand, gaining access to buildings intended for demolition can pose a significant challenge. The existence of neighbouring residential structures and complexes renders the utilisation of bulky machinery infeasible, compelling demolition advocates to instead consider deconstruction as a viable alternative.

According to the data extracted from the literature (Table 2.9), it is evident that the parameter of building accessibility has not been recognised as an independent factor influencing the decision-making process between demolition and deconstruction. This was apparent in the study conducted by Tatiya et al. (Tatiya et al., 2018), where building accessibility was mentioned alongside with the site accessibility. However, the data collected during the interview phase clearly demonstrate that building accessibility and site accessibility impact the decision-making process in distinct ways. Therefore, it is imperative to distinguish between these two parameters and evaluate them separately during the decision-making process.

Furthermore, the assigned rank of 3 to the building accessibility parameter in TOPSIS calculations not only emphasises the significance of this parameter but also reinforces its role as a key consideration for decision-making experts. This ranking indicates that building accessibility carries substantial weight in the decision-making process, further emphasising the critical role it plays in determining whether demolition or deconstruction is the more appropriate course of action for a particular project.

BRP5 – Material and Component Condition: Within the building-related category of parameters, material and component condition was referenced by the interviewees as the most decisive factor when choosing between demolition and deconstruction. As per the discussion made by professionals, buildings that have been constructed with excellent craftsmanship and have been maintained well are considered the most appropriate options for deconstruction. This has been attributed to the fact that such buildings possess better quality materials and components towards the end of their life (Arora et al., 2020), and the expenditure incurred for dismantling the building piece by piece can be recuperated by selling the quality parts. As a result, decision-makers show more enthusiasm for opting for deconstruction when the materials and components are in better condition.

The evaluation of the condition of components is an indispensable factor in choosing between demolition and deconstruction. The stability and firmness of the building hold

significant importance in determining whether it can be dismantled safely or necessitates demolition (Schafer & Bajpai, 2005). In case the condition is poor, there is a possibility of collapsing while entering the building or placing equipment on the floor. Therefore, it is crucial to assess the condition of the components before deciding on the appropriate EOL method.

Literature also highlights the importance of considering material and component condition when selecting an EOL approach. For instance, Akinade et al. (Akinade, Oyedele, Ajayi, et al., 2017) emphasised the importance of considering the condition of the materials and components when deciding on an EOL approach. They note that materials and components that are still in good condition may be suitable for reuse or refurbishment, while those that are damaged or degraded may be more appropriate for recycling or disposal.

The above discussion is in accordance with the outcomes of the TOPSIS calculations. The analysis revealed that the material and component condition parameter held the highest ranking in the building-related category of parameters, thereby marking its greatest significance.

BRP6 – Layout Design Complexity: The analysis of the results implies that the design complexity of a building plays a crucial role in determining the building's load-bearing properties. According to the interviewees, the removal of even a single component of the structure can result in a significant change in the building’s load-bearing capabilities, which in turn necessitates the consideration of how the building will be deconstructed. In the context of high-rise buildings, the importance of design complexity was further emphasised by the participants. They noted that, careful planning of the deconstruction process becomes even more crucial to ensure that the building’s load-bearing properties are not compromised. The demolition of a single section of the building without considering its critical load-bearing properties may result in the spontaneous collapse of another section of the building. Hence, the need for evaluating the design complexity before selecting an EOL approach cannot be overstated.

As per the insights shared by the interview participants, apart from the building’s load-bearing properties, the complexity of materials utilised in its design also earns significant attention. A building with multiple finishes produces difficulties in sorting and reselling these materials in the secondary market. In contrast, selling a thousand square meters of identical material in one project is considerably more straightforward. This aspect emphasises the importance of material standardisation and design complexity before choosing between demolition and deconstruction.

The findings observed in the current study mirror those of the previous studies that have examined the importance of Design for Deconstruction (DfD). According to the literature review conducted by Kanters (Kanters, 2018), design complexity, which they define as the

degree of interdependence between building components and systems, can have a significant impact on the feasibility of deconstruction. Based on the study's findings, buildings with higher levels of design complexity may be more difficult and costly to deconstruct, due to the challenges of disassembling and separating interconnected building components. As a result, the authors suggest that design complexity should be taken into consideration when deciding whether to demolish or deconstruct a building. Another study conducted by Carvalho Machado et al. (Carvalho Machado et al., 2018) further emphasises the importance of design complexity as a critical factor by discussing how it affects the deconstructability of a structure. The study explains complex designs often involve intricate connections, and unique assembly methods, making it difficult to dismantle and extract individual components without causing damage or reducing their value for reuse. The study further elucidates that interconnected building elements, such as integrated mechanical, electrical, and plumbing systems, can complicate the disassembly process, requiring additional effort, specialized tools, and skilled labour.

Contrary to the above findings, the TOPSIS calculations disclosed that layout design complexity was ranked as the 6th most significant factor among the parameters associated with a building's character. This suggests that while design complexity is an important consideration, it does not hold the highest priority compared to other factors within this category; meaning that there are other parameters within the building-related category that hold greater weight in the decision-making process.

BRP7 – Hazardous Materials: Both the literature and the insights provided by the interviewees consistently highlight that the presence of hazardous materials, notably asbestos, is a critical factor that necessitates careful consideration during the process of building removal. However, during the interviews, it was understood that the presence of hazardous materials does not significantly influence the decision-making process regarding demolition or deconstruction. This is because regardless of the chosen technique or approach, it is crucial to handle hazardous materials appropriately:

"it does not matter whether you go for demolition or deconstruction; it should be considered at early stages, particularly if the building is over 20 years old", quoted interviewee #2.

Nonetheless, literature suggests to ensure welfare of workers and the surrounding community, prioritising safety is critical when handling toxic materials (Zoghi et al., 2022). This is applicable regardless of whether the decision is made to demolish or deconstruct the building. According to Guy and McLendon (Guy & McLendon, 2000), whether the choice is to deconstruct or demolish, asbestos is a highly hazardous material that requires specialised workers to remove it safely.

In conclusion, hazardous materials are a critical factor to consider when planning for EOL phase. While it may not be the most decisive factor in choosing between demolition and deconstruction, it should be taken into account at the early planning stages, and the safety of workers and the community must be prioritised. Therefore, it is always important to involve experienced professionals in the process to ensure that hazardous materials are removed safely and responsibly, regardless of whether the decision is to demolish or deconstruct.

The TOPSIS calculations also underscore the above discussion. According to the data presented in Table 4.4, the hazardous material parameter received a ranking of 5 out of 7 parameters within the category of building-related parameters. Therefore, while it remains a significant consideration in the selection of an EOL approach, it does not hold a prominent position in terms of prioritization compared to the other parameters.

Overall Discussion on BRP: Based on the preceding discussion, it becomes evident that building-related category of parameters exerts direct influences on cost-, material- and structural-related parameters. Consequently, the justification for formulating hypotheses H6, H7, and H8 can be derived from this relationship.

Furthermore, based on the findings presented in Table 4.4 and the preceding discussion, it can be deduced that the most decisive factor for decision-makers when selecting between demolition and deconstruction within the building-related category of parameters is the material and component condition. Subsequently, building age, accessibility, height, hazardous materials, and layout design complexity are in descending order of importance in influencing the decision-making process. Lastly, building area appeared as the least consequential parameter in DvDD.

5.3.2 Cost-related Parameters

This category encompasses five parameters that have been investigated and considered, namely labour costs, tools and machinery costs, transportation costs, disposal costs and management costs. In the following, a detailed discussion will be held for each of these parameters.

CRP1 – Labour Costs:

Upon analysis of the interview data, it becomes evident that the foremost factor within the cost-related category of parameters, which significantly influences the decision-making process between demolition and deconstruction, is labour costs. Labour cost was introduced as an essential component because it determines the amount of time, effort, and resources that will be required to complete the process. The more labour-intensive a process is, the higher the cost involved (Llorente-González & Vence, 2020).

According to the interviewees, high labour costs associated with deconstruction make it less economically viable than demolition, particularly in New Zealand's current economy. This was attributed to the substantial workload required during and after the deconstruction procedure. When it comes to deconstruction, the process of dismantling a building requires a considerable amount of manual labour (Marzouk et al., 2019). It is a time-consuming process that requires careful disassembly of the building components to ensure that they can be salvaged and reused (Marzouk & Elmaraghy, 2021). This requires more time, effort, and resources, which ultimately results in higher labour costs. Additionally, the salvaged materials must be further processed before they can be marketed, which further adds to the cost (Shami, 2006).

On the other hand, demolition is characterised as a process with lower labour intensity that can be accomplished with the aid of heavy machinery (Coelho, 2013). Its efficiency lies in its rapidity, allowing for the complete dismantlement of a building in a matter of hours. In contrast, deconstruction, if performed manually, can take days, if not weeks, to complete (Shami, 2006). Consequently, the labour costs linked to demolition are notably lower in comparison to those associated with deconstruction. Moreover, the absence of a careful disassembly process means that there is no need to separate salvageable materials from those that cannot be preserved, which further contributes to the reduction in labour costs (Mayer, 2020).

The results from interview phase further validate the high influence of labour cost, emphasising its significance as a crucial factor to consider when choosing between demolition and deconstruction. As noted by the interviewees, the cost of labour is considerably higher when it comes to deconstruction, and this can make it less economically viable. The high cost of labour involved in deconstruction can also impact the project's overall budget and timeline, argued by interviewee #9. "For example, if the cost of labour increases considerably, it may result in project delays or cancellation due to budget constraints", continued interviewee #9.

The findings of this study regarding the impacts of labour costs on the decision-making process correspond to the outcomes seen in previous research. A study conducted by Balogun et al. (Balogun et al., 2022) explains that, deconstruction involves selectively dismantling a building, which requires skilled labour and more time than a straightforward demolition process, and this increased labour requirement can result in higher costs for deconstruction compared to demolition. Additionally, Dantata et al. (Dantata et al., 2005) concluded that the higher labour costs associated with deconstruction are due to several factors. First, deconstruction requires more manual labour than demolition, which means more workers are needed for a longer period of time. Second, deconstruction requires more specialised skills than demolition, which means that workers with these skills are in higher demand and can command higher wages. Finally, the process of carefully removing and sorting building materials in

deconstruction is more time-consuming and requires more attention to detail than demolition, which can add to labour costs.

According to the findings from TOPSIS method, the calculated ranking value has determined that BRP1, which represents labour costs, holds the top position in the category of cost-related parameters. This indicates that the experts consider it to be the most significant factor when deciding between demolition and deconstruction.

CRP2 – Tools and Machinery Costs: The data from the interviews suggests that cost of tools and machinery represents a fundamental factor to consider when determining the most suitable method of building removal. In this regard, interviewees confirmed that deconstruction, which requires hand tools and portable equipment to dismantle a building piece by piece, is more labour-intensive than demolition, which utilises heavy machinery to bring down the building. Consequently, it may appear that the cost of tools and machinery for deconstruction would be lower than that of demolition. Nevertheless, time emerges as a significant factor to take into account as stated by the majority of the interviewees.

Moreover, based on the perspectives shared by the interviewees, it was emphasised that securing heavy machinery for demolition work may be more expensive than securing hand tools for deconstruction. Besides, the interviewees noted that the demolition process tends to be quicker than deconstruction. As a result, it is essential to carefully consider the trade-off between machinery expenses and the time required to complete the task when selecting between the two methods.

It is also essential to acknowledge that the increased prevalence of deconstruction demands the use of specialised tools and equipment, added by the interview participants. Some deconstruction services have already adopted articulating forklifts, conveyor belts, and bobcats for efficient material handling, confirmed by interviewee #12. Although these specialised tools and equipment may sustain higher costs than traditional hand tools, they are expected to expedite the deconstruction process and enhance its cost-effectiveness in the long term, as suggested by interviewees #6 and #12.

Literature also emphasised the importance of equipment costs in determining an appropriate EOL approach. According to Carvalho Machado et al. (Carvalho Machado et al., 2018), the cost of tools and equipment is a critical consideration when deciding whether to deconstruct a building, particularly when compared to the cost of demolition. They note that the cost of tools and machinery can be a significant barrier to deconstruction, particularly for smaller buildings or those in less-developed regions. The authors also note that the availability of tools and machinery can be a limiting factor in the deconstruction process. It is also argued by the authors

that if the necessary tools and machinery are not available, or if they are too expensive to rent or purchase, then deconstruction may not be a viable option.

Based on the TOPSIS results, however, the aforementioned parameter was found to be the least significant factor in the decision-making process between demolition and deconstruction. This outcome is likely due to the higher level of importance assigned to the other parameters within the cost-related category of parameters.

CRP3 – Transportation Costs: Transportation costs are subject to significant fluctuations based on the intended destination of materials. According to the interview data, several variables, including the project location, proximity to designated landfills or storage facilities, and the volume of waste generated, all contribute to the transportation expenses.

In the case of demolition projects, explained interviewee #3, a substantial amount of waste is typically produced, leading to a notable increase in transportation costs. The transportation of such sizable quantities of debris to a landfill or recycling facility can incur substantial expenses, rendering it a pivotal factor in the decision-making process between demolition and deconstruction. Conversely, as discussed by other interviewees, deconstruction projects may also encounter higher transportation costs. This is because materials salvaged during the deconstruction process may require transportation to various destinations, such as warehouses, materials recycling facilities, or landfills, depending on their condition and intended use.

Furthermore, interviewees stated it is important to recognise that both demolition and deconstruction necessitate the movement of materials in equal quantities. Whether it is the debris produced during demolition or the materials salvaged in the deconstruction process, transportation costs will inevitably be incurred. Nevertheless, it is crucial to bear in mind that transportation expenses do not constitute the sole cost component of these processes. As per the consensus among the interviewees, labour costs represent another substantial expenditure factor that demands careful consideration.

The study conducted by Balogun et al. (Balogun et al., 2022), emphasises that deconstruction requires careful planning and coordination to maximise the value of materials and minimise transportation costs. This involves identifying and separating materials for reuse or recycling, as well as ensuring that the transport of these materials is efficient and cost-effective, stated by Dantata et al. (Dantata et al., 2005). Therefore, transportation costs should be considered as a crucial factor in the decision-making process between demolition and deconstruction. Balogun et al, (Balogun et al., 2022) also suggests that by incorporating these costs into decision-making frameworks, stakeholders can make informed decisions that consider the economic, environmental, and social benefits of deconstruction.

Transportation costs (BRP3) ranked fourth out of five parameters in TOPSIS calculations. This ranking could potentially have been affected by the critical role that transportation costs play in both demolition and deconstruction, rendering it a less influential parameter in the decision-making process as compared to other items in the cost-related category of parameters.

CRP4 – Disposal Costs: The role of disposal costs in the decision-making process cannot be overstated. According to the data collected during the interview phase, disposal costs are the expenses associated with the elimination of the waste generated during the deconstruction or demolition process. It was indicated that these costs are noteworthy and, in some instances, may even surpass the labour costs entailed in the undertaking. Consequently, it is essential to consider the disposal costs as a pivotal factor when making the choice between demolition and deconstruction.

The interviewees also pointed out that, deconstruction represents an environmentally friendly and economical approach to dismantling buildings and focuses on achieving the highest possible levels of resale and recycling. As a result, deconstruction facilitates a reduction in project waste disposal expenses. As such, it can be derived that the approach further enables demolition firms to reduce their disposal costs by redirecting debris from landfills, hence eliminating tipping fees, and maximising the value of recovered materials. In contrast, it was asserted that demolition represents a direct and immediate means of deconstructing a building. Nevertheless, it generates significant waste that necessitates disposal. The interviewees confirmed that in New Zealand this waste usually ends up into landfills, resulting in the imposition of tipping fees, which could prove considerably substantial. Furthermore, the materials arising from demolition are commonly mix and unsorted, complicating efforts to retrieve their value, hence escalating the costs associated with their disposal.

The above findings are further supported by the existing literature. A study conducted by Dantata et al. (Dantata et al., 2005) found that disposal costs for demolition waste are typically higher than for deconstruction waste. The process of demolishing a building generates a mixture of materials, including but not limited to concrete, wood, metal, and insulation, which requires the sorting and transportation of different materials to different facilities for disposal. This undertaking can be both time-consuming and expensive. In contrast, Ge et al. (Ge et al., 2017) conducted research on the topic of deconstruction waste management and highlighted that deconstruction, involving the meticulous disassembly of a building and the reclamation of materials, offers the potential for material reuse and recycling; this will then lead to waste reduction and consequently lowers disposal costs.

Moreover, the results obtained through the TOPSIS emphasise the significance of disposal costs in the process of decision-making. As illustrated in Table 4.4, the parameter denoted by

BRP4, which represents the disposal costs, was ranked as the second most crucial factor by the experts, preceded only by labour costs, in determining whether to opt for demolition or deconstruction.

CRP5 – Management Costs: According to the feedback received from the interviewees, in the process of selecting between demolition and deconstruction as a viable EOL approaches, management costs emerge as a critical factor to take into consideration. Management costs were described as the expenses generated from the coordination and supervision of a project, including hiring consultants, obtaining requisite permits and consents, and liaising with local authorities. Significantly, the cost of managing a deconstruction project may be substantially higher than that of a demolition project, as affirmed by the majority of the interviewees. This was explained to be attributed to the fact that deconstruction projects require more comprehensive coordination and the participation of multiple stakeholders in contrast to demolition projects. The disassembly of a building, salvage of recyclable materials, and reduction of waste characterise deconstruction, and demand specialised knowledge, skills, and equipment, involving additional stages compared to conventional demolition. Consequently, deconstruction projects tend to be more complex and time-intensive than the demolition counterparts, elucidated by the interviewees.

The interviewees further explained that the complexity of deconstruction projects requires a higher level of managerial expertise and time, leading to higher management costs. Based on their statements, this is particularly true when the project manager is a consultant or a specialist in deconstruction. The higher management costs associated with deconstruction projects can make them more expensive than traditional demolition. In addition to the cost of managing the project, there may be other expenses associated with deconstruction that fall under the umbrella of management costs, as per the assertation of interviewee #7. He further elaborated by providing specific instances, such as obtaining necessary permits and consents for deconstruction can be a time-consuming and expensive process. Similarly, dealing with local authorities and ensuring compliance with building codes and regulations can add to the overall cost of the project.

The parameter of management costs was not included in Table 2.9, indicating that it was not among the parameters gathered from the existing literature. Upon reviewing the literature, the author found no available information regarding the correlation between management costs and the decision-making procedure concerning the demolition and deconstruction options during the EOL phase of a building's lifecycle, to the best of their knowledge. Therefore, the identification of the management cost as a noteworthy factor represents a valuable contribution to the existing body of knowledge.

The TOPSIS calculations, on the other hand, place significant emphasis on management costs, illustrated by its third-ranking position, following only labour and disposal costs, according to Table 4.4.

Overall Discussion on CRP: Based on the preceding discussion, it becomes apparent that the category of cost-related parameters not only has a significant impact on the decision-making process at EOL phase of building lifecycle, but also is influenced by all other categories, including building, material, geographical, and structural-related categories of parameters. Therefore, this observation provides justification for hypotheses H6, H9, H10, and H12.

In addition, as per the TOPSIS results illustrated in Table 4.4, labour costs emerged as the most crucial parameter within the category of cost-related parameters, whereas disposal and management costs secured the second and third positions, respectively. On the other hand, transportation and equipment costs were identified as comparatively less significant parameters among the five.

5.3.3 Material-related Parameters

This category comprises of four evaluated parameters, including material reusability potentials, material recyclability potentials, secondary Market, and recycling market. A thorough discussion of each parameter is be presented in the following sections.

MRP1 and MRP2 – Material Reusability and Recyclability Potentials: During the interview sessions, the evaluation of the potential for material reuse and recycling was introduced as a fundamental factor in determining the optimal approach for a building demolition project. All the interviewees had the belief that deconstruction may be the preferable option if the building contains materials which can be salvaged, recycled, or repurposed; and, if the materials are not suitable for repurposing or recycling, then conventional demolition may be the more appropriate approach. Consequently, they were of the opinion that before making a decision on an appropriate EOL approach, a comprehensive assessment of the potential for material reuse and recycling should be conducted. This entails creating an inventory of salvageable resources that can be repurposed or recycled, which would enable decision-makers to make proper choices about whether deconstruction or demolition is the most viable option for the project, as explained by the participants.

As such, from the conducted data analysis it could be understood that buildings with high-quality materials that are capable of being repurposed or recycled are considered the most appropriate candidates for deconstruction. In particular, one interviewee referred to timber-framed buildings that include unique or heavy timber, as well as buildings featuring hardwood or native flooring, architectural mouldings, and unique electrical or plumbing fixtures, as the

prime examples of structures that are well-suited for deconstruction. Commercial buildings that own high-quality fixtures also worth considering for deconstruction due to the value of their materials, claimed by another interviewee. He also shared the view that, repurposing or recycling of such materials makes deconstruction a more sustainable alternative to conventional demolition, from both an environmental and economic perspective.

In summary, all the interviewees held the view that, the potential for material reusability and recyclability is deemed a critical factor in the decision-making process when determining the appropriate approach for removing a building. To make a proper decision between demolition and deconstruction, it is essential to undertake a comprehensive inventory of the materials and components that can be salvaged. According to the participants, this will enable stakeholders to make an appropriate choice about the most appropriate course of action for the project.

The discussion above aligns with previous studies. Carvalho et al. (Carvalho Machado et al., 2018) suggested that deconstruction is a justifiable process when there are building materials that can be reused. Moreover, according to Konth et al. (Knoth et al., 2022) reusing building materials for their original purpose, with minor repairs, is the end-of-life scenario that contributes the most to reducing the environmental impacts caused during a building's lifecycle This statement emphasises the importance of material reusability potentials in the deconstruction process.

Furthermore, the outcomes derived from the TOPSIS method highlight the crucial role of material reusability and recyclability potentials in the decision-making process between demolition and deconstruction. According to the TOPSIS ranking, the reusability and recyclability potentials are prioritised as the first and second factors, respectively, in the decision-making process for selecting an EOL approach.

MRP3 and MRP4 – Secondary and Recycling Market: Without exception, every interviewee expressed the conviction that, the secondary and recycling markets play a pivotal role in determining the economic feasibility of salvaging building materials. They held the belief that, in the absence of a market for salvaged materials, it may not be feasible to undertake deconstruction as it would not yield any substantial benefits. The profitability of salvaged materials was said to be dependent upon their availability and demand for, as these factors influences the market value that can be derived from them. Therefore, it can be concluded that the cost of recovering and transporting the materials must be less than the actual value of the materials to ensure a net economic gain.

Based on the discussions with the interviewees, it was noted that in New Zealand, the secondary and recycling markets are in the early stages of development, and there may be instances where a well-established market for salvaged building materials is not available in

certain areas. Consequently, buildings that have a substantial amount of reusable or recyclable materials may not be profitable to salvage due to the lack of demand or low prices offered for the materials. Hence, while making the decision between demolition and deconstruction, it is imperative to not only consider the potential for the reuse and recyclability of materials but also the market for these materials. Three of the interviewees referenced to the point that, by establishing an interdependent relationship between the supply and demand of salvaged building materials through partnerships between deconstruction services and reuse retailers, the potential of the market can be increased considerably. Ultimately, the choice between deconstruction and demolition should be made after a comprehensive evaluation of the economic viability and benefits of each alternative.

The above findings are consistent with the existing body of knowledge. Grothe and Neun (Grothe & Neun, 2002), highlight the significance of considering the type of deconstruction activity and the market for recovered materials. Additionally, Hradil et al. (Hradil et al., 2019) emphasises that the secondary and recycling market is prone to variability based on several factors including the geographical location, material type, and market demand for the materials. The authors further discuss that, in cases where there is high demand for specific materials like wood, metal, or glass, deconstruction can provide economic benefits through the retrieval and sale of these materials. Conversely, deconstruction may not be financially feasible if the market for recycled materials is oversaturated or there is a low demand for them, as noted by (Rios & Grau, 2020).

Overall Discussion on MRP: Drawing upon the above discussion, it becomes evident that the material-related parameters are dependent upon the building-related and geographical-related parameters, while concurrently impacting the cost-related parameters. The abovesaid provides support to hypotheses H7, H11, and H9, respectively.

Furthermore, the results obtained through TOPSIS analysis revealed that, among the material-related parameters considered by the professionals, recycling and secondary markets were ranked third and fourth in terms of their level of importance. This highlights the significance of these factors in the decision-making process after considering the potential for reusing and recycling salvaged materials.

5.3.4 Geographical-related Parameters

This category is comprised of three parameters that were explored, including project location, topography of site, and access to site. The following sections provide a comprehensive discussion of each parameter.

GRP1 – Project Location: As per the interviewees, the location of a project plays a vital role in the decision-making process, given its potential impact on the surrounding community, resource accessibility, and safety precautions that may be necessary. They argued, among the critical considerations in selecting between demolition and deconstruction is the project's neighbourhood, particularly if it is located in a densely populated residential area or near retirement homes. The interviewees were of the opinion that, in such locations, opting for deconstruction may be the more favourable alternative as demolition activities are likely to generate excessive noise, dust, and debris, which could severely disrupt the neighbourhood. Another point raised in this regard was that by selecting deconstruction, the degree of noise and mess could be reduced, and residents could be notified in advance to make necessary preparations if required.

The accessibility of resources represents another critical factor to be considered, as described by the interviewees. It was noted that the availability of different alternatives could vary depending on the project's location. For instance, it was mentioned that the absence of concrete crushing facilities in certain areas may hinder recycling or repurposing materials. In these instances, demolition could result in the debris being transported to a landfill, an outcome that is unsatisfactory from an environmental standpoint.

Moreover, throughout the interviews it was also highlighted that the location of a project has a notable influence on the materials utilised in the building. The climate of a specific region can impose a considerable effect on the materials. Extreme temperature, humidity, and rainfall can cause a range of issues, such as expansion, contraction, rusting, corrosion, or deterioration over time. For instance, in a humid tropical environment, a building may be at a higher risk of mould, rot, and insect damage than in a dry, arid climate.

Finally, it was remarked that the location of a project concerning public areas can significantly influence the selection between demolition and deconstruction. According to the interviewees, in situations where the project is close to a public place and involves potential risks of falling debris or hazardous noise, it becomes necessary to adopt special precautions to protect the public. In the event that such precautions are impractical, deconstruction may be the only feasible option.

Previous studies have also reflected the importance of project location in the decision-making between demolition and deconstruction. For instance, Akbarnezhad et al. (Akbarnezhad et al., 2014) explain having an up-to-date library of prices and energy consumption of each material and activity is crucial. This information can be derived from the project location, as it helps to identify nearby component production plants, recycling plants, component storages, etc. With the help of accurate GPS coordinates of the project, the location of the nearest

manufacturers, recyclers, and other processing facilities needed through the lifecycle of the building can be assigned. In addition, the study conducted by Tatiya et al. (Tatiya et al., 2018) also support the above findings by indicating that the project location can serve as a reliable indicator of lower labour, equipment, and dumping costs, while the opposite may be true as well.

The significance of project location in the decision-making process is further proved by the TOPSIS calculations. As evident from Table 4.4, the first item (GRP1), representing the project location, has received the highest ranking in comparison to the other two parameters.

GRP2 – Topography of Site: After analysing the results from the interview phase, it became clear that the topography of a site plays a crucial role when determining the appropriate approach for building removal, that is, either demolition or deconstruction. One of the interviewees further explained that the term topography, in this context, refers to the natural configuration of the land, such as slopes, hills, valleys, and other elevations. In instances where a site contains a steep slope, the demolition process can introduce significant challenges and result in destructive vibrations that may compromise the stability of surrounding lands or structures, as confirmed the participants. Consequently, it can be concluded that deconstruction by dismantling the building gradually and systematically rather than utilising heavy machinery may represent a more viable alternative in such circumstances.

The interviewees were of the view that, in New Zealand, landslip and destabilisation are major concerns when demolishing a building on a steep slope, and they may result in issues which demand significant expenses to remedy. It was also noted that, the access of heavy vehicles to the site can be difficult, which is a significant concern when it comes to demolishing a building on a steep slope. These factors, thus, must be carefully evaluated in the process of determining whether to opt for demolition or deconstruction.

While previous studies have explored the importance of project location and the accessibility of sites and buildings in the context of demolition and deconstruction decision, the specific examination of site topography in this decision-making process has been lacking. Therefore, this study serves as a novel contribution to the existing body of knowledge by highlighting the importance of considering this parameter.

Despite having been included into the table of parameters as per the recommendations provided by the interviewees, GRP2 is ranked third among the parameters categorised under this section. The rationale behind this ranking is due to the considerable importance attributed to GRP1 and GRP3, which respectively refer to project location and site access.

GRP3 – Access to Site: Access to the site is a crucial factor to consider when deciding between demolition and deconstruction, as confirmed by all the participants. During the interviews, it was brought up that limited accessibility, particularly for large vehicles, could make deconstruction the preferable alternative. If access to a site is limited, it may be difficult to transport large equipment and materials to and from the site, thereby making deconstruction unfeasible. Additionally, it was stated that, in situation of limited access , demolition may not be feasible, or may result in adverse effects on surrounding structures or the environment. Furthermore, access to the site was remarked as a crucial consideration that significantly affects the feasibility, cost, and environmental impact of both demolition and deconstruction options. The presence of nearby buildings or infrastructure may limit accessibility, particularly if they require special permits or approvals for access.

As previously mentioned in this chapter, the literature has identified site and building accessibility together as a significant factor that influences the decision-making process between demolition and deconstruction, while the current study has proved that the two parameters impact the decision-making process in distinct ways. In their study, Tatiya et al. (Tatiya et al., 2018) briefly discuss the importance of thoroughly evaluating site accessibility, as well as identifying constraints and limitations, when making a decision between demolition and deconstruction.

The results obtained from TOPSIS calculations also explains, in assessing the geographical-related parameters of a site, access to the site should be the next primary considerations after geographical location as it ranked second among the three available parameters within this group. In conclusion, access to a site plays a critical role in determining whether demolition or deconstruction is the more suitable option. It is, therefore, vital to thoroughly assess a site's accessibility when evaluating the feasibility of either method. This assessment should consider not only the physical characteristics of the site but also any regulatory or logistical constraints that may impact accessibility.

Overall Discussion on GRP: Considering the above discussion, it is evident that the geographical-related category of parameters has an impact on the cost and material-related categories of parameters, from which hypotheses H10 and H11 were formulated.

In addition, the outcomes derived from the application of TOPSIS analysis demonstrated that, project location, access to site, and topography of site were ranked first, second and third respectively. These observations provide additional support for the discussion around the importance of project location in the experts' judgment during the process of choosing an EOL strategy for a given project.

5.3.5 Structural-related Parameters

Two parameters were analysed and classified into this category, including type of structure, and complexity of structure. The two parameters are discussed in depth in the following sections.

SRP1 and SRP2 – Type and Complexity of Structure: The decision around demolition or deconstruction selection must account for various aspects concerning the structure, including the type of structure and its condition, from the interviewees' points of view. They were convinced that, when considering a steel-framed building that is in an acceptable condition, choosing deconstruction over demolition could present greater economic viability and environmental feasibility. This was mentioned to be attributed to the potential for recovering valuable components for reuse, thereby enhancing sustainability and cost-effectiveness. In contrast, it was suggested that in the case of a building constructed with substandard materials and subjected to inadequate maintenance, demolition may be deemed as the more appropriate course of action.

The interview participants also suggested that conducting a thorough survey of the structure is a critical step towards determining the appropriate EOL approach. According to their experience in New Zealand construction industry, this enables contractors to evaluate the structural system, identify any potential hazards such as structural instability, and determine the extent to which materials can be recovered for reuse. In particular, high-quality timber, an adaptable construction material, may be given priority during careful deconstruction, give that its quality meets the required standards.

Moreover, complexity was noted as another crucial factor concerning the structure of building at this decision-making process. The interviewees were of the view that, in circumstances where the structure is complex and access to its components is limited, deconstruction may not be a technically viable option. It was outlined that in situations where there are numerous connections of the same or different types, the separation process may become excessively slow, resulting in a considerable increase in the time required for deconstruction. Consequently, demolition becomes the only feasible option in such instances.

The importance of examining the type and complexity of structure before making a decision at EOL stage was reported by previous studies. For instance, Carvalho et al. (Carvalho Machado et al., 2018) discussed that the ease of disassembly and the possibility of reutilisation are closely related to the structure's characteristics, hence affecting the decision-making between demolition and deconstruction. Finish et al. (Finch et al., 2021) argue that, the type of fixing used in a structure can greatly affect the speed and cost of the deconstruction process. The

authors further discuss, if the fixings are easily removable, such as bolts or screws, the deconstruction process can be faster and less expensive. On the other hand, if the fixing is more complex, such as welding or adhesives, it can be more difficult and time-consuming to disassemble the structure, which can increase the cost of deconstruction.

Furthermore, the possibility of reutilisation is reported to be dependent upon the structure's characteristics, according to the study conducted by Webster and Costello (Webster & Costello, 2005). The researchers explain the expected durability of connections and the damage to connections during the disassembly process are important factors to consider. Chemical connections such as welding tend to lose their durability once they are broken during the disassembly process (Crowther, 2000). Therefore, if the structure involves a lot of welded connections, it may not be suitable for deconstruction as the connections may need to be remade if the elements are reused.

Overall Discussion on SRP: The discussion presented above provides a sound basis for formulating hypotheses H8 and H12, as it underscores the plausible links between structural-related parameters and building- and cost-related parameters.

In addition, the TOPSIS analysis results have revealed that in the structural-related category of parameters, SRP1 is ranked first, followed by SRP2 in second place. This suggests that both the type and complexity of the structure have significant influences on the decision-making process concerning the selection of demolition or deconstruction approaches.

5.3.6 Framework Outline

In the entropy-based TOPSIS approach, not only is the level of importance of each parameter within its respective category determined, but also the level of importance of each category with respect to one another was defined. According to the findings presented in Table 4.4, the cost-related category of parameters (CRP) ranked first in terms of importance when deciding between demolition and deconstruction. Several reasons could explain why CRP may have gained the highest rank in the decision-making process.

Firstly, CRP is a broad and extensive category that encompasses various aspects of the project's financial implications influencing the cost of demolition or deconstruction, including the cost of waste disposal, the potential revenue from salvaged materials, and the potential cost savings from recycling. As such, CRP is a fundamental consideration that directly impacts the project's financial viability. Secondly, financial gain is the primary objective of every project, including End-of-Life (EOL) projects. Therefore, the parameters within the CRP category are essential to the project's success. This further emphasises the critical role of CRP in the decision-making process.

Thirdly, the cost-related parameters are subject to influence from other category of parameters. This is evidenced by the impact that the complexity of the structure or the availability of labour and equipment can have on the cost of deconstruction or demolition. The CRP category thus serves as a primary component that integrates the various factors that impact the project's financial viability. Furthermore, it is worth noting that CRP is a category of parameters that can be measured and quantified relatively easy, in contrast to other categories that may possess more qualitative or subjective characteristics. This makes it easier to compare and evaluate different options and make an informed decision.

According to the findings presented in Table 4.4, the building-related parameters (BRP) and geographic-related parameters (GRP) were ranked second in importance in the decision-making process between demolition and deconstruction, and they mutually gained the second rank. This could be attributed to multiple of factors. Firstly, BRP is a crucial consideration because it directly impacts the DvDD and the cost, material, and structural-related categories. The type of building, its age, and the construction materials used can significantly affect the deconstruction or demolition process and the potential for salvaging materials. Hence, BRP category is a fundamental group in the decision-making process.

Secondly, the significance of GRP, ranked second mutually with BRP, could be attributed to New Zealand's specific geographic context. As previously mentioned, the distribution of resources, including labour and equipment, is uneven across New Zealand, and location can substantially influence other factors. Therefore, GRP plays a critical role in the decision-making process, as it can impact the availability of resources, transportation costs, and potential waste disposal. Moreover, BRP and GRP are closely linked because the geographic context can directly affect the building-related parameters. For example, the availability of skilled labour and specialised equipment may vary depending on the location, thereby impacting the feasibility and cost-effectiveness of the deconstruction or demolition process.

After the cost-related category, the building-related parameters (BRP) and geographic-related parameters (GRP) have mutually obtained the second rank as the most critical factors from the perspectives of the interview participants and entropy-based TOPSIS calculations. It is anticipated that BRP must be taken into consideration, as it affects not only the DvDD but also the cost-, material-, and structure-related categories. Based on the discussion and hypothesised relationship, BRP is the sole category of parameters that majority of other categories are affected by. Additionally, the significance of GRP as the second-ranked group alongside BRP could be explained by New Zealand's particular geographical context. For instance, the availability of resources such as labour and equipment is not uniformly distributed in New Zealand, which can significantly impact other factors, most likely costs.

The third category of parameters that gained the third rank in terms of importance is MRP. This category of parameters includes the material-related factors such as material recovery, reusability, and recyclability. These factors are significant because they not only impact the cost but also have an impact on the environment. Demolition activities can generate a significant amount of waste, and the proper handling and disposal of this waste can be costly. Therefore, considering the MRP category in the decision-making process can help to minimise the environmental impact and the associated costs.

Based on the findings presented in Table 4.4, material-related parameters (MRP) and structural-related parameters (SRP) were ranked third and fourth, respectively, in terms of their level of importance in the decision-making process between demolition and deconstruction. One possible reason for the relatively lower rankings of material-related parameters (MRP) and structural-related parameters (SRP), in comparison with CRP and BRP, could be their more specialised nature and limited relevance to certain aspects of the project. MRP includes factors such as the condition of materials and their potentials for being recycled or reused, which are undoubtedly important considerations. However, they may not have as direct and significant impacts on the decision as cost-related parameters, which are more general and prevalent.

Similarly, SRP includes factors such as the structural integrity and complexity of the building and the difficulty of dismantling it. These are crucial factors that must be considered, but they may not be directly related to financial gain, which is the primary objective of the project. Furthermore, the lower rankings of MRP and SRP may also be due to their dependence on other factors. For instance, the importance of MRP depends on the availability of recycling facilities or the environmental regulations in New Zealand. Similarly, the significance of SRP may depend on the availability of skilled labour or specialised equipment. Therefore, the relative importance of these parameters may vary depending on the specific context of the project. In summary, while MRP and SRP are crucial considerations in deciding between demolition and deconstruction, their lower rankings compared to cost-related parameters, building-related parameters, and geographic-related parameters may reflect their specialised and context-dependent nature.

It worth noting that, in this research study, it has been determined, to the best of the author's knowledge, that there is a significant lack of relevant research in scholarly sources concerning the decision-making process at the end-of-life (EOL) phase of a building’s lifecycle. As a result, the findings presented in this research are considered novel and contribute notably to the existing knowledge in the construction field.

5.4 Validation of Decision Support Framework

To validate the developed framework, a comprehensive quantitative study was designed and conducted. The data collected from this study underwent thorough analysis, utilising both descriptive and inferential statistical methods. The results of this analysis have been comprehensively documented and presented in Chapter 4 of this thesis. In the subsequent sections of this chapter, the results of the descriptive analysis will be discussed first, followed by an in-depth discussion of the results achieved through the implementation of partial least squares structural equation modelling (PLS-SEM).

5.4.1 Interpreting Results of Descriptive Analysis

Based on the demographic analysis presented in Chapter 4, several potential relationships can be identified between the number of conducted demolition or deconstruction projects, familiarity with deconstruction's benefits, perceived profitability of deconstruction compared to demolition, and the possibility of choosing deconstruction over demolition.

Firstly, there seems to be a correlation between the number of demolition or deconstruction projects that respondents have been involved in and their familiarity with the benefits of deconstruction. Respondents with more experience in the industry, as indicated by their involvement in a higher number of projects, may have more exposure to deconstruction and its benefits, leading to a higher level of familiarity. Conversely, those with less experience in the industry may have less exposure to deconstruction and, therefore, may be less familiar with its benefits. Being exposed to different demolition or deconstruction projects may have given professionals the opportunity to witness the positive outcomes of deconstruction, such as salvaging materials for reuse or repurpose, reducing waste sent to landfills, and potentially saving on disposal costs. Moreover, as professionals gained experience in the industry through working on different projects, they may have become more knowledgeable about the various techniques and tools used in the deconstruction process. This could lead to an increased understanding of how deconstruction can be more profitable compared to demolition, and how to identify which projects would be good candidates for deconstruction. Furthermore, exposure to more projects may have led to networking opportunities with other professionals in the industry who are familiar with deconstruction's benefits. This could have provided professionals with access to additional resources, such as best practices or case studies, that could help them better understand and communicate the advantages of deconstruction.

Secondly, there appears to be a strong relationship between familiarity with deconstruction's benefits and the perceived profitability of deconstruction compared to demolition. Professionals

who are more familiar with deconstruction's benefits may have a better understanding of how it can be more profitable than conventional demolition, leading to a higher likelihood of perceiving deconstruction as profitable. On the other hand, those with less familiarity with deconstruction's benefits may be less likely to perceive it as profitable, potentially due to a lack of understanding of its potential benefits. The better familiarity with deconstruction's benefit could help professionals to better evaluate the potential costs and benefits of each option and to determine which one is more profitable. For instance, professionals who are familiar with the benefits of deconstruction may understand that it can generate revenue through the salvage and resale of materials, while also reducing disposal costs. In contrast, those who are less familiar with deconstruction's benefits may not be aware of these potential cost savings and revenue streams, leading them to perceive demolition as more profitable. Therefore, increased familiarity with deconstruction's benefits can lead to a better understanding of how it can be more profitable than conventional demolition, which in turn can lead to a higher likelihood of perceiving deconstruction as a profitable option.

Thirdly, the perceived profitability of deconstruction compared to demolition seems to be strongly related to the likelihood of choosing deconstruction over demolition. Professionals who perceive deconstruction as more profitable may be more likely to choose it over conventional demolition. This could be due to several reasons:

1. Greater financial returns: By understanding the potential financial benefits of deconstruction, professionals may be more likely to choose it over demolition. For example, by salvaging materials for resale or reuse, deconstruction can generate additional revenue streams that are not available with traditional demolition.
2. Lower disposal costs: Deconstruction can be less expensive than demolition in some cases, particularly if there are local landfill tipping fees or other waste disposal costs associated with demolition. Deconstruction can reduce the amount of waste generated, and therefore reduce the disposal costs.
3. Meeting sustainability goals: Deconstruction can help professionals meet sustainability goals by reducing waste, preserving natural resources, and reducing greenhouse gas emissions associated with manufacturing new materials. By choosing deconstruction, professionals can demonstrate their commitment to sustainability and environmental stewardship.

In summary, the demographic analysis discussed above provides insights into potential relationships between the number of conducted demolition or deconstruction projects, familiarity with deconstruction's benefits, perceived profitability of deconstruction compared to demolition, and the possibility of choosing deconstruction over demolition. Understanding these

relationships can be useful for industry professionals who are interested in promoting the use of deconstruction as a more sustainable and profitable alternative to conventional demolition.

5.4.2 Interpreting Results of Inferential Analysis

The process of developing the conceptual framework gave rise to several inquiries regarding the interdependence of the categories of parameters and the existence of any potential correlations between them. These inquiries were subsequently formulated as hypotheses, as outlined in Chapter 4, Table 4.5, for further investigation. To analyse the collected data from the designed quantitative study, PLS-SEM was chosen as the appropriate analytical tool. The outcomes of this analysis were extensively presented in Chapter 4, section 4.3.4, will be discussed in the subsequent sections.

As illustrated in Table 4.5, hypotheses **H1** to **H5** elucidate the effects of the five predetermined categories of parameters on the experts' decision-making (DvDD) when selecting between demolition and deconstruction. As revealed in Table 4.23, the *t*-statistic values for H1 to H5 are exceeding 1.96, ranging from 17.76 to 24.81. This indicates that the argument that BRP, CRP, MRP, GRP and SRP notably influence the DvDD is statistically significant and supported by the findings. This result was expected as the affecting parameters within each category were sourced from relevant literature, affirming their impact on decision-makers' final choices.

Additionally, the calculated *p*-values establish the significance level of each category. Based on the results presented in Table 4.23, among the four categories, CRP stands out as the most influential category on DvDD, as indicated by the highest *p*-value of 0.744 in Table 4.23. Following closely behind is BRP, which demonstrates significant influence as the second most impactful category of parameters with a p-value of 0.725. GRP and MRP ranked third and fourth, respectively, with p-values of 0.713 and 0.689. Finally, SRP is identified as the least influential category among the four groups of parameters.

The obtained results are consistent with the findings derived from the entropy-based TOPSIS calculations. As depicted in Table 4.4, CRP, with a weight of 0.67, achieves the highest rank among the four categories, supporting the outcomes obtained through PLS-SEM analysis. While BRP and GRP share a similar weight and hold a joint second rank in entropy-based TOPSIS ranking, this outcome remains consistent with the PLS-SEM results, despite a slight discrepancy that can be attributed to the utilisation of two distinct methods, each involving different populations in terms of number and diversity. The entropy-based TOPSIS method employed data collection through 12 semi-structured interviews, reflecting the qualitative nature of the gathered data. In contrast, the PLS-SEM findings were derived from the analysis of 205

questionnaires, which inherently possess a quantitative essence. Subsequently, in the entropy-based TOPSIS calculations, MRP and SRP obtain the third and fourth rankings, respectively, confirming the observed sequence of ranking in PLS-SEM. Furthermore, as listed in Table 4.5, the hypotheses **H6** to **H8** represent the potential impacts of BRP on three other categories, including CRP, MRP, and SRP, respectively. The PLS-SEM results presented in Table 4.23 reveal that the *t*-statistic values for these hypotheses considerably exceed 1.96, indicating that the predicted relationships are statistically significant and proved by the findings. Conclusively, based on the above argument, the building-related category of parameters has a significant impact on cost-, material-, and structural-related parameters. This conclusion is in agreement with the earlier discussion in section 5.3.1, as the possible impacts of parameters within the building-related category on cost-related factors, as well as on material and structural factors, were thoroughly explained and discussed. For instance, the parameters of Building Age (BRP1) and Building Height (BRP2) can influence labour costs and machinery expenses associated with the demolition or deconstruction process. Older or larger buildings may require more time, resources, and specialised equipment for deconstruction, potentially leading to increased costs. Similarly, the parameters of Building Area (BRP3) and Material & Component Condition (BRP5) can affect disposal costs. Buildings constructed with materials that are difficult to recycle or dispose of may result in higher disposal costs for demolition, whereas buildings with salvageable or recyclable materials may reduce disposal costs through deconstruction.

Moreover, it was also discussed that the building-related parameters have implications for the material-related parameters. Material & Component Condition (BRP5) play a crucial role in determining the potential for material reuse, recyclability, and market demand – the parameters within MRP. Buildings with high-quality materials that can be salvaged and repurposed are more suitable candidates for deconstruction, as it enhances sustainability and cost-effectiveness. Additionally, it was suggested that Layout Design Complexity (BRP6) can influence the ease of disassembly and the potential for reutilisation. Buildings with easily removable fixtures and connections enable faster and more cost-effective deconstruction processes, while complex structures may pose challenges, making demolition a more viable option.

In section 5.3, a further discussion revealed that, the building-related parameters interact with the structural-related parameters. Layout Design Complexity (BRP6) again influence the type and complexity of the structure, which in turn impacts the decision between demolition and deconstruction. Buildings constructed with high-quality materials (BRP5), such as steel-framed structures, may present greater opportunities for deconstruction, while buildings with substandard materials and poor maintenance may lean towards demolition.

Hypothesis **H9**, as evidenced by Table 4.5, proposes that MRP potentially influences CRP. The results of the PLS-SEM, as displayed in Table 4.23, demonstrate a *t*-statistic value of 21.785 for H9, surpassing the accepted threshold significantly. This finding indicates a statistically significant relationship between MRP and CRP. Based on the discussion provided in section 5.3, the reusability and recyclability potential of materials directly impacts cost-related parameters. For instance, it was stated that by recovering valuable components in case of deconstruction, the disposal cost and tipping fees are reduced, conversely, if the materials are not suitable for repurposing or recycling, demolition may be more appropriate, leading to higher disposal costs.

According to the findings presented in Table 4.5, Hypotheses **H10** and **H11** propose the potential effects of GRP on both CRP and MRP. The findings from PLS-SEM analysis, as shown in Table 4.23, demonstrates that the *t*-statistic values for both H10 and H11 significantly surpass the accepted threshold. These results provide strong evidence that the relationships between GRP and both CRP and MRP are statistically significant. Likewise, hypothesis **H12,** which examines the effects of SRP on CRP, received support from the PLS-SEM results, displaying a substantial *t*-statistic value of 13.711. The resulted value indicates the statistical significance of the relationship between SRP and CRP.

Additionally, the *p*-values assigned to each parameter in Table 4.23 demonstrate the contribution of that parameter to the importance level assigned to its respective group. As such, it can be concluded that parameters with higher *p*-values hold greater importance within their associated category. Drawing from this interpretation, and the aforementioned discussion, Table 5.1 can be derived from the results, as presented below:

Table 5.1 Consequential Parameters and Their Level of Significance

Category	Parameter	Weight of Parameter	Significance of Parameter	Weight of Category	Significance of Category
BRP	BRP 1	0.781	2	0.725	2
	BRP 2	0.654	4		
	BRP 3	0.472	7		
	BRP 4	0.728	3		
	BRP 5	0.834	1		
	BRP 6	0.537	6		
	BRP 7	0.594	5		
CRP	CRP 1	0.893	1	0.744	1
	CRP 2	0.315	5		
	CRP 3	0.684	2		
	CRP 4	0.363	4		

	CRP 5	0.472	3		
MRP	MRP 1	0.939	1	0.689	4
	MRP 2	0.875	2		
	MRP 3	0.641	4		
	MRP 4	0.756	3		
GRP	GRP 1	0.833	1	0.713	3
	GRP 2	0.727	3		
	GRP 3	0.801	2		
SRP	SRP 1	0.765	1	0.561	5
	SRP 2	0.486	2		

The table above highlights that, labour costs (CRP1), material and component condition (MRP5), project location (GRP1), material reusability potentials (MRP1), and type of structure (SRP1), are the most important parameters in their respective group, affecting the decision-making process of EOL approach selection, choosing between demolition and deconstruction.

The results obtained from the PLS-SEM model are consistent with the discussion around the outcomes of the literature review, semi-structured interviews, and entropy-based TOPSIS analysis, upon which the conceptual framework was constructed. These findings collectively support the validity of the developed framework, and the statistical results substantiate this assertion. Therefore, it can be inferred that the developed framework is valid and empirically supported.

5.5 Summary

This chapter presented a discussion of the results of the four main research stages undertaken to fulfill the aim of the study: developing a decision support model to facilitate the decision-making process during the end-of-life (EOL) phase of the building lifecycle. These stages include a literature review, semi-structured interviews, entropy-based TOPSIS, and a survey study.

The chapter began by discussing the formation of the decision support framework. The factors that influence experts' decision-making (DvDD) are explained, based on the synthesis of the findings from the literature review, semi-structured interviews, and entropy-based TOPSIS. These factors are categorised into five groups: Building-related parameters (BRP), Cost-related parameters (CRP), Material-related parameters (MRP), Geographical-related parameters (GRP), and Structural-related parameters (SRP), which include a total of 21 parameters. This section also highlights the justifications behind each constructed hypothesis.

The next section was devoted to validating the developed conceptual decision support framework. The hypothesised relationships and the significance of the parameters on the DvDD and on other categories are discussed using the results obtained from Partial Least Squares Structural Equation Modelling (PLS-SEM). These results were utilised and discussed to validate and confirm the decision support model. Finally, the chapter concluded with a summary of the topics discussed.

Chapter 6 Conclusion

6.1 Chapter Introduction

This chapter aims to present the conclusions that have been derived from the current research study. To do so, the chapter commences with a comprehensive review of the research aim and objectives, which explains how the research questions have been addressed, and the objectives have been accomplished. Additionally, the research contribution to the existing body of knowledge is explicated, followed by a discussion of the research limitations. Subsequently, the chapter concludes by proposing recommendations for future studies. Figure 6.1 provides an outline of the chapter.

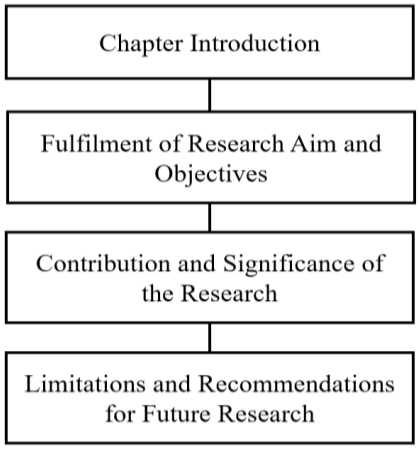

Figure 6.1 Content Outline of Chapter Six

6.2 Fulfilment of Research Aim and Objectives

The primary aim of this study entailed the development of a decision support framework to aid the decision-making process regarding the end-of-life (EOL) stage within the building lifecycle within the specific context of New Zealand. The study revealed that while deconstruction has emerged as a promising alternative to conventional demolition due to its

potential to unlock various benefits for a more sustainable industry, its utilisation has been limited, not only in New Zealand but also on a global scale. Furthermore, the research revealed that this limited implementation could be primarily attributed to the lack of familiarity with this approach, as well as the complex nature of the deconstruction process, which may make it impractical or unfeasible as a dismantling scenario.

With consideration of the aforementioned factors, the study formulated five distinct research objectives, which subsequently led to the development of five corresponding research questions, as outlined in Chapter 1. To effectively carry out the investigation, a sequential exploratory mixed method design was employed, with comprehensive details provided in Chapter 3. Following a systematic review of the existing literature to identify the research problem, the primary phase of the study involved the collection of extensive experiential data through in-depth interviews conducted with experts from the New Zealand construction industry. Subsequently, the application of entropy-based TOPSI, a mathematical data analysis method, was employed. Furthermore, an industry-wide questionnaire survey was administered to construction practitioners, encompassing consultants, contractors, subcontractors, and others. The gathered data was validated through the utilisation of partial least squares structural equation modelling (PLS-SEM). The subsequent sections elaborate on the successful achievement of the five research objectives.

6.2.1 Objective 1: Identifying the Critical Parameters Influencing the Selection of an Appropriate Approach for the EOL Phase of Building lifecycle

The first objective of the study was to identify the critical parameters influencing the selection of an appropriate approach for the EOL phase of the building lifecycle. The identification of affecting parameters was considered an initial and crucial step in the development of the decision support framework. Firstly, this process ensures that the framework encompasses all relevant factors that influence the decision-making process, thereby augmenting the precision and dependability of the decisions derived from the framework. Additionally, the identification of affecting parameters facilitates the comprehensive analysis of the decision challenge, enabling the framework to deliver a thorough evaluation.

Therefore, in order to fulfil this objective, a comprehensive and systematic literature review was carried out, and the findings were presented in Chapter 2. Despite the limited availability of studies on this topic, the literature review revealed several factors that have the potential to affect the deconstructability of a building, thereby influencing the decision-making process of professionals when choosing between demolition and deconstruction.

Based on the data collected from the literature, it was observed that certain parameters primarily relate to the physical characteristics of the building, such as its age, height, condition, design complexity, and presence of hazardous materials. These parameters were categorised as building-related parameters. Another set of parameters, which predominantly focused on expenditures and costs, included labour costs, equipment costs, transportation costs, and disposal costs. These were classified as cost-related parameters.

Furthermore, the literature review identified parameters related to the potential for material and component recycling or reuse, as well as the existence of markets for recycling and secondary materials. These parameters were grouped under reusability and recyclability parameters. Additionally, parameters such as geographical location, building area, and site/building accessibility were recognised as geographical-related parameters. Lastly, the type of structure and the recoverability of its materials were identified as two parameters falling under the category of structural-related parameters.

To summarise, the data collected from the literature review identified a total of 18 parameters, which were classified into six groups, as presented in Table 2.9 of Chapter 2. By obtaining these parameters, the initial research objective was successfully accomplished.

6.2.2 Objective 2: Verifying the Collected Parameters from the Literature in the Context of New Zealand's Construction Industry

The second objective of the study was to assess the applicability of the parameters gathered from the existing literature to the construction industry of New Zealand. It was crucial to evaluate the parameters' applicability to New Zealand due to potential influences from local factors such as cultural norms or economic conditions, as parameters derived from research conducted in other regions or countries could not be directly transferable to the construction industry in New Zealand.

In addition, the assessment of parameters' applicability within the local context holds significant importance in ensuring the customisation of the research findings and recommendations to address the unique requirements and potential complexities of the construction industry in New Zealand. Neglecting this crucial step could result in ineffective strategies, inefficient allocation of resources, and hindered advancements in enhancing the industry's overall performance.

Moreover, the evaluation of parameter relevance within the specific context of New Zealand serves as a valuable tool for determining any deficiencies in the current body of literature and shedding light on areas that require further investigation. This approach offers the possibility to contribute to future research endeavours and enhance the understanding and knowledge

surrounding the unique challenges and opportunities faced by the construction industry in New Zealand. To accomplish this, a series of semi-structured interviews were meticulously designed and conducted, involving 12 industry experts who possess over a decade of experience in the New Zealand construction sector. Subsequently, a comprehensive analysis was performed, resulting in the revision and update of the table of parameters originally derived from the literature review. The updated table, referred to as Table 4.2 in Chapter 4, is presented herein.

According to the revised table of parameters, the selection process between demolition and deconstruction was impacted by five distinct categories of parameters. These categories encompass building-related, cost-related, material-related, geographical-related, and structural-related parameters. Specifically, the categories include seven, five, four, three, and two parameters, respectively. The presentation of these categories and their corresponding parameters is provided below:

- Building-related parameters: building age, building height, building area/ volume, building accessibility, material and component condition, layout design complexity, and hazardous materials.
- Cost-related parameters: labour costs, tools and machinery costs, transportation costs, disposal costs, and management costs.
- Material-related parameters: material reusability potentials, material recyclability potentials, secondary market, and recycling market.
- Geographical-related parameters: project location (city, suburb, etc.), the topography of the site, and access to the site.
- Structural-related parameters: type of structure (steel, timber, etc.), complexity (framing, junctions, etc.)

Upon completion of this stage and thorough verification of the parameters, the second research objective of the study was achieved.

6.2.3 Objective 3: Developing a Decision Support Framework to Facilitate the Decision-Making Process on EOL Approach Selection

Following the successful identification and verification of the relevant parameters, the third research objective of the study was to establish a decision support framework to aid the decision-makers at the EOL phase of the building's lifecycle. The primary aim of this framework was twofold: first, to determine the crucial parameters influencing the decision-making process, and second, to prioritise these parameters based on their comparative importance. The identification and ranking of the influential parameters played a pivotal role in

establishing a decision support framework capable of providing valuable insights and facilitating effective decision-making.

Therefore, the entropy-based TOPSIS method was employed to ascertain the rank of parameters based on their relative importance. The outcomes, as depicted in Table 4.4, revealed that parameters associated with cost (CRP) were accorded the highest rank, followed by those related to the building (BRP) and geographic-related parameters (GRP), which obtained a shared second rank. Material-related parameters (MRP) and structural-related parameters (SRP) received the third and fourth rankings, respectively. It was discussed that the importance of CRP, BRP, and GRP could be attributed to their direct and substantial impact on financial viability and the overall success of the project. In contrast, MRP and SRP were positioned at the lower end of the ranking due to their specialised nature and dependence on other factors. The implications of these findings imply that incorporating CRP, BRP, and GRP into the decision-making process can facilitate informed decision-making between demolition and deconstruction, considering their substantial impact on the outcome.

Upon thorough examination of each category, it was determined that certain parameters held particular significance within their respective category. Specifically, the condition of building materials and components, labour costs, the potential for material reusability, project location, and the type of structure emerged as the most pivotal parameters within the building-related, cost-related, material-related, geographical-related, and structural-related categories, respectively.

Following the computation of parameter rankings through the entropy-based TOPSIS method, the decision support framework was developed as depicted in Figure 4.2. With the completion of this step, the research objective pertaining to the third objective was successfully addressed.

6.2.4 Objective 4: Examining the Impact of Consequential Parameters Influencing the Decision-Making Process Between Conventional Demolition and Deconstruction

After the establishment of the decision-support framework, the subsequent phase of the study aimed to further examine the significance of the identified influencing parameters and their corresponding category on the decisions made by experts. To accomplish this objective, a comprehensive questionnaire survey was developed and distributed among professionals within the New Zealand construction industry. A total of 205 responses were gathered and subsequently subjected to both descriptive and inferential analyses.

The analysis of the demographic findings highlights the relationships between the number of demolition or deconstruction projects, familiarity with deconstruction's benefits, perceived profitability, and the likelihood of choosing deconstruction over demolition. It was concluded that professionals with more experience in the industry tend to be more familiar with deconstruction's benefits, such as salvaging materials and reducing waste, and this familiarity is associated with a higher perception of deconstruction's profitability. Professionals who perceive deconstruction as profitable are more likely to choose it over demolition due to potential financial returns, lower disposal costs, and alignment with sustainability goals.

In addition, the statistical analysis performed on the gathered data revealed that the cost-related group of parameters is the most critical group of parameters, influencing the experts' decisions on selecting an EOL approach and choosing between demolition and deconstruction. Subsequently, the building-related and geographical-related categories of parameters emerged as the second and third most influential categories, respectively, in determining the choice between demolition and deconstruction. Following that, the material-related parameters and structural-related parameters constituted the final two categories, exhibiting comparatively lower importance than the aforementioned three categories in the decision-making process of selecting an EOL approach.

The findings further underscore the relative importance of each parameter within its respective category in relation to the other parameters within the same group. Within the building-related category, it was found that the material and component condition is the most significant factor, followed by building age, building accessibility, building height, hazardous materials, layout design and complexity, and building area/ volume.

The parameters within the cost-related group indicated a clear hierarchy of importance, with labour costs occupying the highest position, followed by transportation costs, management costs, disposal costs, and, finally, tool and machinery costs. Within the material-related category, the potentials for reusability and recyclability, respectively, took precedence as the highest-ranking factors, while recycling and the secondary market followed in the second and third order.

Moreover, the findings substantiate that among the geographical-related parameters, project location displayed the highest degree of significance, whereas access to the site and topography of the site ranked second and third, respectively. Lastly, among the structural-related parameters, the type of structure was identified as the most critical, with structural complexity ranking second in terms of importance.

By attaining the aforementioned findings, the study successfully accomplished its fourth research objective.

6.2.5 Objective 5: Validating the Developed Decision Support Framework using Structural Equation Modelling (SEM)

The final objective of the study involved the validation of the developed decision-support framework through the application of structural equation modelling (SEM). In order to achieve this objective, the study examined the potential interrelationships between different categories of parameters in accordance with the hypotheses outlined in Table 4.5, as well as the importance of each category and its corresponding parameters.

The assessment of the potential relationships among the categories of parameters was considered essential for several reasons. First, it would enable decision-makers to comprehend the interconnectedness and interdependence of different parameters from various categories. By evaluating these relationships, decision-makers could uncover dependencies that may exist between categories, which can significantly influence the decision-making process.

Furthermore, the analysis of inter-category relationships allows decision-makers to adopt a more holistic perspective when addressing the decision-making scenario. Instead of considering each parameter or category in isolation, professionals can deepen an understanding of how these factors interact and mutually influence one another. This broader perspective facilitates making well-informed decisions that take into account the interdependencies between various factors. Additionally, by examining the inter-category relationships, experts can identify potential unintended consequences or side effects of decisions, as changes made in one category have the potential to have unforeseen effects on other categories. Evaluating the inter-category relationships can assist in anticipating such effects and making necessary adjustments to mitigate any adverse consequences.

The analysis of the collected data using Partial Least Squares Structural Equation Modeling (PLS-SEM) supported the hypotheses formulated in Chapter 4 regarding the interdependence of the categories of parameters and their impact on the decision-making process in selecting between demolition and deconstruction. The statistical analysis revealed that the building-related parameters (BRP) significantly influenced cost-related parameters (CRP), material-related parameters (MRP), and structural-related parameters (SRP).

Furthermore, the examination of the data provided empirical support for the hypotheses positing that geographical-related parameters (GRP) exert influence on both cost-related and material-related categories. Additionally, the hypotheses proposing the impact of material-related, as well as structural-related parameters on the cost-related category of parameters were supported.

In conclusion, the analysis of the collected data confirms the hypotheses formulated in Chapter 4 concerning the interconnectedness and interdependence of the categories of parameters, as well as their influence on the decision-making process when choosing between demolition and deconstruction. Therefore, the developed framework has been validated, and the research has successfully achieved its final objective.

6.3 Contribution and Significance of the Research

The present study makes significant contributions to the existing body of knowledge, both theoretically and practically. As previously noted, the adoption of deconstruction as an alternative to the traditional demolition method is still in its early stages, lacking widespread recognition not only within the New Zealand construction industry but also globally. In this context, this research serves as a pioneering endeavour by examining the influential parameters affecting the decision-making process when selecting between demolition and deconstruction. Furthermore, it not only identifies various parameters of influence but also emphasises the potential interrelationships that exist among different categories of parameters.

Prior to this study, there were limited studies pertaining to the End-of-Life (EOL) phase within the building lifecycle. Furthermore, to the author's knowledge, no previous study has specifically investigated the decision-making process between traditional demolition and deconstruction, while taking into account the influential parameters that impact experts' decision-making (DvDD).

Given the scarcity of data regarding the subject matter of EOL and the decision-making process between demolition and deconstruction, this research enriches the existing knowledge by achieving the following contributions:

1. The study has successfully established scientific facts that contribute to a deeper comprehension of the two primary approaches, conventional demolition and deconstruction, within the EOL phase of buildings. The investigation sheds light on their distinctions, advantages, and challenges, providing valuable insights for both academic scholars and industry professionals by offering them an opportunity to enhance their knowledge and familiarity with this subject matter.
2. The investigation effectively identified the influential parameters that shape experts' decision-making (DvDD) when faced with the choice between demolition and deconstruction. Familiarity with these parameters empowers professionals in the field to make informed and strategic decisions, enhancing their ability to assess the precise factors that exert substantial influence on the selection process. Equipped with this knowledge, industry practitioners can navigate the decision-making process with more

confidence and precision, leading to the adoption of a more sustainable and efficient approach.

3. The developed framework provides valuable assistance to professionals by not only introducing the influential parameters and their respective levels of significance but also highlighting the interdependencies and impacts that exist among different categories of parameters. By gaining a comprehensive understanding of these parameters, their relative importance, and the interdependencies between categories, professionals are equipped with valuable knowledge to make informed decisions and effectively navigate the decision-making process. This enables them to optimise their approaches, enhance project outcomes, and address the complexities inherent in the selection of appropriate EOL strategies.

6.4 Limitations and Recommendations for Future Research

The present study, while effectively achieving its intended aim and corresponding objectives, is not without its limitations.

Firstly, the scope of the research was confined solely to the New Zealand construction industry. Although this focus allowed for an in-depth exploration of EOL practice and its two main approaches within a specific context, it restricts the generalisability of the findings to other geographic locations or cultural settings. The uniqueness of the New Zealand construction industry and its distinct regulations, policies, and practices may limit the applicability of the research outcomes to broader contexts.

Secondly, the research was limited to the examination of the two main approaches of EOL, namely demolition and deconstruction. The exclusion of alternative approaches, such as a combination of these two approaches or other emerging methodologies, may hinder a comprehensive understanding of the entire spectrum of EOL practices. By not considering these potential avenues, the study may overlook valuable insights into the potential innovations present in the field, consequently restricting its practical implications and relevance.

Lastly, an unanticipated challenge was encountered during the research period due to the onset of the COVID-19 pandemic. The ensuing lockdown measures imposed by authorities disrupted the original schedule of the study, resulting in time constraints and difficulties in adhering to the planned research activities. Additionally, the data collection process, involving interviews and questionnaires, was adversely affected by the limitations posed by social distancing measures and travel restrictions. These constraints may have impacted the sample size, data quality, and the ability to gather diverse perspectives, potentially influencing the validity and reliability of the findings.

In conclusion, while this research has shed light on the EOL phase of buildings' lifecycle within the New Zealand construction industry, it is important to recognise the limitations that emerged due to the restricted scope and the unforeseen circumstances surrounding the COVID-19 pandemic. These limitations, encompassing the geographic and methodological boundaries as well as the impact of the pandemic on data collection and scheduling, should be taken into account when interpreting and applying the findings.

Future studies may advance the research endeavour by either pursuing the subsequent stages or expanding upon the aforementioned limitations. This could entail broadening the scope to encompass additional regions and undertaking an extensive examination of diverse EOL approaches. By doing so, the comprehensiveness and robustness of research in this domain would be fortified, thereby contributing to a more comprehensive understanding of the subject matter. Having considered the findings of the research and aforementioned conclusions, the following recommendations are suggested:

- Integration of key stakeholders: Further research should be conducted to delve into the perspectives of various crucial stakeholders, including clients and regulatory agencies. This endeavour could acquire a more comprehensive grasp of the factors guiding the decision-making process between demolition and deconstruction at the conclusion of a building's life cycle. The overarching ambition is to align these decisions more effectively with the principles of circularity and sustainability within the construction industry, thereby paving the way for a significant contribution to the field.
- Expansion of geographical scope: Future research could aim to expand the geographical scope beyond New Zealand to include a broader range of regions and contexts. This would enable a comparative analysis of EOL practices, taking into account variations in industry dynamics, cultural factors, and regulations. By including diverse locations, a more comprehensive understanding of the research topic can be achieved. Allowing for the identification of best practices and potential areas for improvement across a wide range of regions.
- Exploration of alternative EOL approaches: In order to gain a holistic understanding of EOL practices, future studies could explore a wider range of approaches beyond the traditional demolition and deconstruction methods. The investigation of emerging methodologies, such as partial deconstruction, can provide valuable insights into innovative approaches that promote sustainability and minimise waste generation. By considering a broader spectrum of EOL approaches, researchers could identify novel strategies that may have significant environmental, social, and economic benefits for the construction industry.

- Collaboration between Academia and Industry: To bridge the gap between research and industry, future efforts could focus on promoting closer collaboration between academia and industry stakeholders. This can be achieved through knowledge-sharing platforms, industry-academia partnerships, and collaborative research projects. By involving industry professionals, experts and researchers in a collaborative dialogue, the findings of research studies can be effectively translated into practical applications, leading to the adoption of sustainable and efficient EOL practices within the construction industry.
- Integration of technological innovation: Future studies could explore the integration of technological advancements in EOL practices. This includes the utilisation of digital tools, such as building information modelling (BIM) and augmented reality, to enhance the efficiency and accuracy of the EOL phase of the building lifecycle. Investigating the potential of these technologies can lead to more sustainable and streamlined EOL practices, thereby addressing the changing demands and aspirations within the industry.

In conclusion, these recommendations serve as a guide for future research endeavours and provide insights into potential areas for improvement within the construction industry's End-of-Life practices.

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APPENDICES

Appendix A: Ethics Approval – Phase One: Interview

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

26 August 2020

Ali GhaffarianHoseini
Faculty of Design and Creative Technologies

Dear Ali

Re Ethics Application: 20/239 Optimisation of the End-of-Life Phase in Building Projects in the Context of Auckland, NZ

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 25 August 2023.

This approval is for the initial stage of the research only, and full information about each further stage needs to be provided to and approved by AUTEC before participants are recruited and data collected for that stage.

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 in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research 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.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

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

The AUTEC Secretariat

Auckland University of Technology Ethics Committee

Cc: atefeh.zeinalian.bafandeh@aut.ac.nz; Nicola Naismith; Amiirhosein Ghaffarianhoseini

Appendix B: Ethics Approval – Phase Two: Survey

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

9 December 2021

Ali GhaffarianHoseini
Faculty of Design and Creative Technologies

Dear Ali

Re Ethics Application: 20/239 Optimisation of the End-of-Life Phase in Building Projects, in the Context of Auckland, NZ

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

The second phase of the research has been approved for three years until 9 December 2024.

Standard Conditions of Approval

8. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
9. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
10. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
11. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
12. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
13. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
14. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
15. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research 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.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

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

The AUTEC Secretariat

Auckland University of Technology Ethics Committee

Cc: atefeh.zeinalian.bafandeh@aut.ac.nz; nicola.naismith@aut.ac.nz; amirhosein.ghaffarianhoseini@aut.ac.nz

Appendix C: Consent Form

For use when interviews are involved.

Project title: Optimisation of the End-of-Life Phase in Building Projects, in the Context of Auckland, NZ

Project Supervisor: *Dr. Ali Ghaffarianhoseini*

Researcher: *Atefeh Zeinalian-Bafandeh*

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 20 April 2020.
- ○ 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○

- ○ I consent to being contacted later in the research to see if I would like to be part of a group that reviews the outcomes of the research.

Participant's signature:

.....

Participant's name:

.....

Participant's Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

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

Appendix D: Participant Information Sheet – Phase One: Interview

This participant information sheet will be used for the interview stage.

Date Information Sheet Produced: 20 April 2020

Project Title: Optimisation of the End-of-Life Phase in Building Projects, in the Context of Auckland, NZ.

An Invitation

Our research team at the School of Future Environment at Auckland University of Technology (AUT) are pleased to invite you to participate in our study, to optimize the End-of-Life phase of building lifecycle in the context of Auckland, New Zealand. This study is supervised by Dr Ali GhaffarianHoseini, Dr Nicola Naismith and Dr Amirhosein GhaffarianHoseini. Moreover, this research contributes to the Doctor of Philosophy degree of the primary researcher: PhD candidate Atefeh Zeinalian Bafandeh.

What is the purpose of this research?

This research aims to optimize the End-of-Life Phase (EOL) in Building lifecycle, in the Context of Auckland, NZ; with the following main objectives:

1. To identify critical parameters affecting the selection of an appropriate approach for the end-of-life phase of the building lifecycle,

2. To examine the impact of consequences parameters, influencing the decision-making process between using deconstruction and demolition, and

3. To develop a BIM-based Digital Model, proposing the most optimized end-of-life approach for complex projects in the context of New Zealand.

The findings of this research will contribute to a part of the primary researcher's thesis for her PhD degree; and also will be used for academic publications.

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

You have been invited to participate in this research study as professionals who have deconstruction and demolition experiences (at least five years of work experience in the context of New Zealand, Auckland). Search engines have been used to identify the contractors in Deconstruction & Demolition field. Aside from Google, which is a general search engine, LinkedIn as a strong professional networking tool, has been used for selecting you as the interviewee. We depend on publicly shared emails on the official websites of the targeted organisation and any direct contact by the research team that have relevant experience to the research subject. Accordingly, a consent from and Participant Information Sheet has been sent to you by email.

How do I agree to participate in this research?

By signing and returning the accompanied consent form to the researcher, you will inform us that you would like to take part in the research. 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 are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is 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.

What will happen in this research?

We are conducting interviews to identify the influential parameters, localized in the context of New Zealand. We'd like to interview you over Zoom or Skype due to the Cvid-19 restriction. This interview would be recorded and transcribed, and a copy of the transcription will be made available to you.

From these interviews, we hope to build a digital model for supporting the decision-making processes around EOL approach (Demolition or Deconstruction) for building lifecycle.

As we near the end of the research, we may wish to contact you to see if you would be interested in being part of a group that reviews the outcomes of this research. You can agree to these interviews but do not have to participate in any subsequent review if do not wish to.

What are the discomforts and risks?

We do not expect any discomfort or risk from the proposed interviews. However, you can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. Once the findings have been produced, removal of your data may not be possible.

How will these discomforts and risks be alleviated?

We do not expect there to be any risk to the participants.

What are the benefits?

For the participants: The results from this research could assist you to find about critical factors in deciding between two different approaches in End-of-Life phase of a construction project (deconstruction and demolition). Using the end result, you will be able to choose the appropriate fit of their project. This could avoid choosing a wrong option, which will cost you time and budget. Besides, any publication as the result of this research will be shared with you for your consideration.

For the researcher: The end result of this research will be presented in the researcher's thesis, which results in a qualification for her PhD degree.

For the wider community: The results will provide future researchers with the information which will be a fundamental resource to design for deconstruction, following a sustainable construction/deconstruction process. Besides, it will benefit humanity, in the long run, by its positive environmental impacts.

How will my privacy be protected?

Only the research team will know who you, as the participants, are. Confidentiality will be maintained by changing the identity (such as the name of the participant, name of the organisation or employer) and any other potential identifiers of the participant in any publications, thesis writing or report resulting from the research.

All information which is not hereby known to others and is sensitive either commercially or technically is considered confidential and will only be used for academic purposes. Besides, given the small number of people, some readers may be able to infer some participants identity, and therefore only limited confidentiality can be offered. The AUT and the research team will keep this information and identities of participants confidential. The participants may withdraw themselves or any information/ documentation that they have provided for this research project at any given time before the completion of the data collection without being a disadvantage in any way. Additionally, it is absolutely unlikely that your identity be revealed by the provided information since no real excerpts from the interviews will be used in any research outputs and only the interviews garner general ideas for the subsequent stages.

In the final report, there will not be any identification of name, company, and their roles. The participants will not be identified individually but they will be acknowledged, if they wish to, as a social group of experts.

What are the costs of participating in this research?

Since it is going to be a Virtual/Online interview using Skype or Zoom application, you are need to dedicate your time, only. Each interview will not take longer than one hour, and you are free to leave at any time.

What opportunity do I have to consider this invitation?

One month.

Will I receive feedback on the results of this research?

A report of the research which is highlighting the results will be sent to the all the participants via email.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Ali GhaffarianHoseini, ali.ghaffarianhoseini@aut.ac.nz , +64 9 921 9999 ext. 7968.

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 your future reference. You are also able to contact the research team as follows:

Primary Researcher	**Research supervisor**
Atefeh Zeinalian-Bafandeh	Dr Ali GhaffarianHoseini
atefeh.zeinalian.bafandeh@aut.ac.nz	ali.ghaffarianhoseini@aut.ac.nz

Researcher Contact Details:

Atefeh Zeinalian-Bafandeh

Email Address: atefeh.zeinalian.bafandeh@aut.ac.nz

Physical Address: WZ816, Level 6, WZ Building, 6 St. Paul Street, Auckland University of Technology (AUT)

Project Supervisor Contact Details

Dr Ali GhaffarianHoseini

Email Address: ali.ghaffarianhoseini@aut.ac.nz

Physical Address: WS310, Level 3, WS Building, 34 St. Paul Street, Auckland University of Technology (AUT)

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix E: Participant Information Sheet – Phase Two: Survey

This participant information sheet will be used for the survey stage.

Date Information Sheet Produced: 06 December 2021

Project Title: Optimisation of the End-of-Life Phase in Building Projects, in the Context of Auckland, NZ.

An Invitation

Our research team at the School of Future Environment at Auckland University of Technology (AUT) are pleased to invite you to participate in our study, to optimize the End-of-Life phase of building lifecycle in the context of New Zealand. This study is supervised by Dr Ali GhaffarianHoseini, Dr Nicola Naismith and Dr Amirhosein GhaffarianHoseini. Moreover, this research contributes to the Doctor of Philosophy degree of the primary researcher: PhD candidate Atefeh Zeinalian Bafandeh.

What is the purpose of this research?

This research aims to optimize the End-of-Life Phase (EOL) in Building lifecycle, in the Context of New Zealand; with the following main objectives:

1. To identify critical parameters affecting the selection of an appropriate approach for the end-of-life phase of the building lifecycle,

2. To examine the impact of consequences parameters, influencing the decision-making process between using deconstruction and demolition, and

3. To develop a BIM-based Model, proposing the most optimized end-of-life approach for building lifecycle in the context of New Zealand.

The findings of this sruvey will contribute to a part of the primary researcher's thesis for her PhD degree; and also, will be used for academic publications.

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

The participants of this stage are professionals who have construction, deconstruction and demolition experiences (at least five years of work experiences). Search engines are used to identify the experts in these fields. Aside from Google, which is a general search engine, LinkedIn as a strong professional networking tool, is used for selecting you as the participant. We depend on publicly shared emails on the official websites of the targeted organisation, accordingly, an email with the survey link will be sent to the experts.

How do I agree to participate in this research?

By completing the survey, you will be giving consent to participate in the research. The participation in this research is voluntary and anonymous. You are also able to withdraw from the survey at any time; however, once the survey is submitted the data will not be able to be withdrawn.

What will happen in this research?

We have conducted interviews to identify the critical parameters, localized in the context of New Zealand that would affect experts' decision-making (DvDD) process at the End-of-Life phase of a building lifecycle, deciding to choose between conventional

demolition and deconstruction. Now, with this survey, we would like to ask you to rate and rank these parameters. This will allow us to understand how important each parameter is on making the decision, choosing between demolition and deconstruction.

After collecting and analysing the data, we hope to build a model for supporting the decision-making processes around EOL approaches (Conventional Demolition or Deconstruction) for building lifecycle.

What are the discomforts and risks?

We do not expect any discomfort or risk from the proposed research.

How will these discomforts and risks be alleviated?

We do not expect there to be any risk to the participants.

What are the benefits?

For the participants: The results from this research could assist you to find about critical factors in deciding between two different approaches in End-of-Life phase of a construction project (deconstruction and demolition). Using the end result, you will be able to choose the appropriate fit for any given project. This could avoid choosing a wrong option, which will cost time and budget.

For the researcher: The end result of this research will be presented in the researcher's thesis, which results in a qualification for her PhD degree.

For the wider community: The results will provide future researchers with the information which will be a fundamental resource to design for deconstruction, following a sustainable construction/deconstruction process. Besides, it will benefit humanity, in the long run, by its positive environmental impacts.

How will my privacy be protected?

The survey is anonymous, there is no information required that could reveal your identity.

What are the costs of participating in this research?

There is no physical effort involved in this research. You are only, and voluntarily, giving us your time. For this survey the questions are designed to be answered in less than 15 minutes

What opportunity do I have to consider this invitation?

One month.

Will I receive feedback on the results of this research?

Since the survey is anonymous, there won't be any feedback. However, you will be having the opportunity to follow-up on the survey findings by using the link below:

https://autuni-my.sharepoint.com/:w:/g/personal/em12925_aut_ac_nz/EVD8jA9EQGtBrFXvr81KGaMBYlmVHwgetEsVSPFaYpdKHg?e=v2U4Cn

This shared document will be updated once the survey is completed.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Ali GhaffarianHoseini, ali.ghaffarianhoseini@aut.ac.nz , +64 9 921 9999 ext. 7968.

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 for your future reference. You are also able to contact the research team using the following contact information:

Primary Researcher	**Research supervisor**
Atefeh Zeinalian-Bafandeh	Dr Ali GhaffarianHoseini
atefeh.zeinalian.bafandeh@aut.ac.nz	ali.ghaffarianhoseini@aut.ac.nz

Researcher Contact Details:

Atefeh Zeinalian-Bafandeh

Email Address: atefeh.zeinalian.bafandeh@aut.ac.nz

Physical Address: WZ816, Level 6, WZ Building, 6 St. Paul Street, Auckland University of Technology (AUT)

Project Supervisor Contact Details:

Dr Ali GhaffarianHoseini

Email Address: ali.ghaffarianhoseini@aut.ac.nz

Physical Address: WS310, Level 3, WS Building, 34 St. Paul Street, Auckland University of Technology (AUT)

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix F: Interview Schedule

The main purpose of this interview session is to:

1. Discuss the parameters that affect the selection of either ***demolition*** or ***deconstruction*** as the approach of ending a building project.
2. Identify the localized parameters that influence the decision of choosing between Deconstruction and Demolition as an appropriate of approach for ending a building project in Auckland, NZ.

The interviews will be conducted to achieve the abovementioned objectives by following the below instructions.

By reviewing the literature and the past studies, we have found different categories of effective parameters on the decision-making process when choosing between the main two approaches of EOL – Deconstruction and Demolition. The table below highlights a summary of the potential parameters:

Category	**Parameter**	**Data Type**	**Unit**
Building-related attributes	Building age	Continuous	Year
	Building story	Continuous	Number
	Building conditions	Continuous	Percentage
	Design complexity	Ordinal	Low/Medium/High
	Hazardous materials	Ordinal	Low/Medium/High
Cost attributes	Labour	Continuous	Dollar
	Equipment	Continuous	Dollar
	Transportation	Continuous	Dollar
	Disposal	Continuous	Dollar
Recyclability attributes	Material/Components Potentials	Ordinal	Low/Medium/High
	Recycling market	Ordinal	Fair/Moderate/Good
Reusability attributes	Material/Components Potentials	Ordinal	Low/Medium/High
	Secondary Market	Ordinal	Fair/Moderate/Good
Geographic coordinates attributes	Geographical location	Ordinal	Fair/Moderate/Good
	Site/building accessibility	Ordinal	Fair/Moderate/Good
	Building area	Continuous	Square foot
Structural attributes	Recoverability of structure type	Continuous	Low/Medium/High
	Recoverable materials	Ordinal	Low/Medium/High

Considering the above table, could you please let us know:

- Do you think all the above-mentioned parameters are applicable/feasible in the context of Auckland, NZ construction industry? Is there any item you wish to remove from the list?

- Based on your experience, are there any other items you would like to add to the list of parameters?
- In your opinion, have all the parameters been placed in the appropriate category?
- Do you think all the 5 above-mentioned categories are applicable/feasible in the context of Auckland, NZ construction industry? Is there any item you wish to remove from the list?
- Based on your experience, are there any other items you would like to add to the list of categories?

Appendix G: Questionnaire Survey

Part A – Background Information

1. How many years have you worked in the construction industry?

☐ 0-5 years ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ +20 years

2. What position(s) have you held during all these years? *(If applicable, you may choose more than one)*

☐ Project manager ☐ Site manager ☐ Project director ☐ Quantity surveyor

☐ Lead manager ☐ Company owner ☐ Project engineer ☐ Builder ☐ Other

3. How many Conventional Demolition projects have you been involved in approximately?

☐ 0-10 projects ☐ 11-20 projects ☐ 21-30 projects ☐ 31-40 projects ☐ +40 projects

4. How many Deconstruction projects have you been involved in approximately?

☐ 0-10 projects ☐ 11-20 projects ☐ 21-30 projects ☐ 31-40 projects ☐ +40 projects

5. How familiar you are with Deconstruction's benefits?

☐ Not at all familiar ☐ Slightly familiar ☐ Moderately familiar ☐ Very familiar ☐ Extremely familiar

6. Comparing with Conventional Demolition, how would you rate the level of overall profitability of Deconstruction?

☐ Very Low ☐ Low ☐ Average ☐ High ☐ Very High

7. Comparing with Conventional Demolition, how challenging would you find Deconstruction?

☐ Very Low ☐ Low ☐ Average ☐ High ☐ Very High

8. How likely it is for you to choose Deconstruction over Conventional Demolition?

☐ Not at all likely ☐ Not very likely ☐ Somewhat likely ☐ Very likely ☐ Extremely likely

Part B – Rating the Parameters

When choosing between conventional demolition and deconstruction to bring down a building, couple of factors may seem important in this decision-making process. Look at the table below and let us know, in your

opinion, how effective is each parameter on your decision to choose either demolition or deconstruction for the end of life phase of the building lifecycle.

The 5-point Likert scale highlights the level of effectiveness from {1=not at all effective} to {5=extremely effective}

Building -related Parameters	**1** *(Not at all)*	**2** *(Slightly)*	**3** *(Moderately)*	**4** *(Very)*	**5** *(Extremely)*
Building Age					
Building Height					
Building Area/ Volume					
Building Accessibility					
Material & Component Condition					
Layout Design Complexity					
Hazardous Materials					
Any other parameter? *(please also specify their level of effectiveness)*					
Cost -related Parameters	**1** *(Not at all)*	**2** *(Slightly)*	**3** *(Moderately)*	**4** *(Very)*	**5** *(Extremely)*
Labour costs					
Tools and Machinery costs					
Transportation costs					
Disposal costs					
Management costs					
Any other parameter? *(please also specify their level of effectiveness)*					
Material -related Parameters	**1** *(Not at all)*	**2** *(Slightly)*	**3** *(Moderately)*	**4** *(Very)*	**5** *(Extremely)*
Material Reusability Potential					
Material Recyclability Potential					
Secondary Market					
Recycling Market					
Any other parameter? *(please also specify their level of effectiveness)*					
Geographic -related Parameters	**1** *(Not at all)*	**2** *(Slightly)*	**3** *(Moderately)*	**4** *(Very)*	**5** *(Extremely)*
Project Location (city, suburb, etc)					
Topography of Site					
Access to Site					
Any other parameter? *(please also specify their level of effectiveness)*					
Structural -related Parameters	**1** *(Not at all)*	**2** *(Slightly)*	**3** *(Moderately)*	**4** *(Very)*	**5** *(Extremely)*
Type of Structure (steel, timber, …)					
Complexity (framing, junctions, …)					
Any other parameter? *(please also specify their level of effectiveness)*					

Part C – Ranking the Parameters

After rating the parameters, now we want you to rank them within their owns clusters. In this case, you would let us know about your opinion about which one has higher priority than the other one.

Building -related Parameters [give each parameter a score from 1=lowest priority to 7=highest priority]

	Building Age
	Building Height
	Building Area/ Volume
	Building Accessibility
	Material & Component Condition
	Layout Design Complexity
	Hazardous Materials

Cost -related Parameters [give each parameter a score from 1=lowest priority to 5=highest priority]

	Labour costs
	Tools and Machinery costs
	Transportation costs
	Disposal costs
	Management costs

Material -related Parameters [give each parameter a score from 1=lowest priority to 4=highest priority]

	Material Reusability Potential
	Material Recyclability Potential
	Secondary Market
	Recycling Market

Geographic-related Parameters [give each parameter a score from 1=lowest priority to 3=highest priority]

	Project Location (city, suburb, etc)
	Topography of Site
	Access to Site

Structural -related Parameters [give each parameter a score from 1=lowest priority to 2=highest priority]

	Type of Structure (steel, timber, etc)
	Complexity (framing, junctions, etc)