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Framework Development for Life Cycle Environmental Management of Demolition Wastes for Road Projects

by

Sajjad Shuker Ullah

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Framework Development for Life Cycle Environmental Management of Demolition Wastes for Road Projects

By

Engr. Sajjad Shuker Ullah

(DCE 183001)

Dr. Nasir Shafiq, Professor

Universiti Teknologi Petronas, Malaysia

(Foreign Evaluator 1)

Dr. Salman Azhar, J.E., Wilborn Professor

Auburn University, Auburn, USA

(Foreign Evaluator 2)

Dr. Ishtiaq Hassan

(Research Supervisor)

Dr. Majid Ali

(Head, Department of Civil Engineering)

Dr. Imtiaz Ahmad Taj

(Dean, Faculty of Engineering)

DEPARTMENT OF CIVIL ENGINEERING

CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

ISLAMABAD

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This PhD degree is dedicated to My Father, as this is his aspiration and motivation which make me able to complete it; Last but not the least, I dedicate this work to My Wife and Mother for their emotional and moral support and never-ending prayers.

CAPITAL UNIVERSITY OF SCIENCE & TECHNOLOGY ISLAMABAD

Expressway, Kahuta Road, Zone-V, Islamabad
Phone:+92-51-111-555-666 Fax: +92-51-4486705
Email: info@cust.edu.pk Website: https://www.cust.edu.pk

CERTIFICATE OF APPROVAL

This is to certify that the research work presented in the dissertation, entitled "**Framework Development for Life Cycle Environmental Management of Demolition Wastes for Road Projects**" was conducted under the supervision of **Dr. Ishtiaq Hassan**. No part of this dissertation has been submitted anywhere else for any other degree. This dissertation is submitted to the **Department of Civil Engineering, Capital University of Science and Technology** in partial fulfillment of the requirements for the degree of Doctor in Philosophy in the field of **Civil Engineering.** The open defence of the dissertation was conducted on **April 25, 2025**.

Student Name : Sajjad Shuker Ullah (DCE183001)

The Examination Committee unanimously agrees to award PhD degree in the mentioned field.

Examination Committee :

(a) External Examiner 1: Dr. Hafiz Zahoor Ahmad Khan
Associate Professor
MCE, NUST, Risalpur

(b) External Examiner 2: Dr. Khurram Iqbal Ahmad Khan
Associate Professor
NICE, NUST, Islamabad

(c) Internal Examiner : Dr. Muhammad Usman Farooqi
Assistant Professor
CUST, Islamabad

Supervisor Name : Dr. Ishtiaq Hassan
Professor
CUST, Islamabad

Name of HoD : Dr. Majid Ali
Professor
CUST, Islamabad

Name of Dean : Dr. Imtiaz Ahmed Taj
Professor
CUST, Islamabad

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(**Sajjad Shuker Ullah**)

Registration No: DCE183001

Dated: 25, April, 2025

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Registration No : DCE183001

List of Publications

It is certified that following publication(s) have been made out of the research work that has been carried out for this dissertation:-

1. **Shuker Ullah, S., I. Hassan, and S.S.S. Gardezi, Environmental Management Framework for Road Network Demolition Wastes for Construction Industry of Pakistan. Sustainability, 2024. 16(10): p. 4302.**

(Sajjad Shuker Ullah)

Registration No: DCE 183001

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Abstract

Demolition waste, particularly from road infrastructure projects, constitutes a substantial portion of global demolition waste, posing significant environmental challenges. With the growing emphasis on sustainability across environmental, social and economic domains, effective management of road demolition waste has become increasingly crucial. This study aims to develop a comprehensive and sustainable framework for Demolition Waste Management (DWM) specific to road projects. The primary objective is to identify and model the interrelationships among causes, impacts, challenges and solutions associated with DWM, thereby providing actionable strategies to enhance waste management practices.

The scope of research covers demolition activities related to road infrastructure, with a focus on the lifecycle and environmental impacts of waste generation and management. A literature review was conducted to identify prevailing issues in the sector. Subsequently, a focus group discussion and a pilot survey-based questionnaire—developed with input from industry experts—were employed to collect data on key DWM variables. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS, validating four models that explore different combinations of causal and relational factors influencing DWM outcomes.

The findings reveal strong statistical relationships, particularly between the causes of demolition waste and both its challenges (path coefficient: 0.727) and impacts (0.843), while challenges also exhibited a strong link to solutions (0.760). These results underscore the importance of addressing root causes to effectively mitigate broader issues. The relatively weaker direct associations between causes and solutions suggest that impacts act as key mediating factors. The proposed framework offers a strategic, systems-based approach to DWM, supporting industry professionals and policymakers with evidence-based pathways for sustainable implementation, capacity building, and policy development in the context of road project waste.

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Abbreviations

AVE	Average Variance Extracted
BIM	Building Information Modeling
CDA	Capital Development Authority
CDWM	Construction and Demolition Waste Management
CSR	Corporate Social Responsibility
DWM	Demolition Waste Management
DW	Demolition Waste
EWC	European Waste Catalog
EU	European Union
EMS	Environmental Management System
EMPs	Environmental Management Plans
FGD	Focus Group Discussion
GIS	Geographic Information System
IoT	Internet of Things
IT	Information Technology
ICT	Islamabad Capital Territory
IGP	Inspector General of Police
KPI	Key Performance Indicators
MCI	Metropolitan Corporation Islamabad
PLC	Project Life Cycle
PLS-SEM	Partial Least Squares Structural Equation Modeling
RAS	Reclaimed Asphalt Shingles
VIF	Variance Inflation Factor

VOCs	Volatile Organic Compounds
WRAP	Waste and Resources Action Programme
3R	Reduce, Reuse, Recycle
4R	Reduction, Reduce, Reuse, Recycle

Symbols

$f2$	Effect Size
$r2$	Coefficient of Determination
$rho - a$	Composite Reliability
$rho - c$	Composite Reliability

Chapter 1

Introduction

1.1 Background of Study

The construction industry significantly influences the global economy and national development, employing about 7% of the global workforce and contributing around 10% of the global GDP[1]. It consists of three main sectors: building, infrastructure and industrial, each with various sub-sectors. The infrastructure sector includes highways, railways, wastewater management and utilities, all essential for societal advancement.

However, the industry's rapid growth has led to a substantial increase in construction waste, accounting for 30-40% of total solid waste. Infrastructure projects, which comprise about 35% of the construction sector, generate a significant portion of this waste, necessitating proper management due to their complexity. Infrastructure projects, which represent roughly 35% of the construction sector,generate a large portion of this waste and require proper management due to their complexity and implementation challenges[2].

Demolition activities in road projects generate a significant volume of waste materials, including concrete, asphalt and metals, which, when improperly disposed of, pose environmental risks like soil and water contamination, air pollution and habitat degradation[3]. In urban areas, where these activities often occur, dust, noise and increased traffic congestion disrupt communities, impacting residents' health and well-being. Inadequate waste management may lead to illegal dumping, exacerbating social disparities and undermining community cohesion[4].

Life cycle environmental management of demolition wastes in road projects involves a holistic approach to minimize environmental impacts at each stage of the construction process. This framework seeks to address the significant challenges associated with demolition waste by promoting sustainable practices and optimizing resource use. The aim is to revolutionize waste management in the construction industry, focusing on the reduction, reuse and recycling of materials to support sustainability.

Moreover, inefficient waste management increases project costs due to waste transportation, landfill fees and regulatory compliance, while missed recycling opportunities further inflate expenses[5]. Inadequate management also intensifies the ecological footprint through resource extraction and processing, stressing the need for sustainable practices in demolition waste management[6].

Demolition activities also intensify the ecological footprint associated with resource extraction and processing. These embracing sustainable practices for managing demolition wastes is essential to conserve resources, reduce reliance on finite materials and promote circular economy principles[7].By addressing the challenges associated with demolition waste management, particularly in the context of road construction, this framework aims to promote sustainability and efficiency in infrastructure development. Through collaboration between stakeholders and the integration of innovative strategies, it seeks to optimize resource utilization, reduce environmental footprint and enhance the overall sustainability of road projects.

This study focuses on the increase in demolition waste during construction and its environmental impact. It aims to examine road demolition waste, identify causes and impacts, address management challenges and propose effective solutions for Demolition Waste Management (DWM). Improved DWM practices are essential for the industry's understanding and awareness. Advanced Industrialized Countries (AICs) like Australia, Germany, Denmark, the Netherlands, the UK and the USA have adopted DWM strategies to eliminate, minimize and reuse waste. These strategies aim to reduce waste during demolition, benefiting the economy, environment, climate and resource consumption..

1.1.1 Demolition Wastes

Rapid urbanization and population growth have led to an increase in demolition waste, particularly in developing countries where illegal dumping is a significant issue [8]. Demolition waste often contains hazardous materials, such as asbestos, heavy metals and bitumen, which can cause serious environmental contamination if not managed properly[9]. According to the European Waste Catalog (EWC), demolition waste is categorized into 38 subcategories, 16 of which are classified as hazardous [10]. Globally, demolition waste accounts for 40% of all waste, with countries like China and the USA generating significant amounts [11]. Waste is defined in various ways across industry and academia. Based on modern production concepts, waste refers to anything that, including during the demolition of a structure, causes excessive use of equipment, materials, labor, or money beyond what is necessary for construction. Waste includes both material losses and unnecessary work that adds cost and fine without adding value [12]. The construction sector has severe environmental impacts, so there have been efforts to reduce construction waste. Construction waste is defined as materials from activities like digging, building, demolition, renovation and road work. This waste often includes both inert (harmless) and non-inert (potentially harmful) materials.

The growing problem of demolition waste has caught researchers' attention. The European Union produces 800 million tons of this waste, while China produces about 2300 million tons[11, 13]. Globally, more than 10 billion tons of demolition waste are generated [14]. Both the United States and China, being major economies, struggle with managing this waste. Due to rapid growth in the building industry and urbanization, the United States contributes about 30% of the world's annual demolition waste and China accounts for approximately 30-40%[15].

The world generates approximately 2.01 billion tons of municipal solid waste

(MSW) annually, with about 33% of it managed in an environmentally safe manner [16]. The global per capita waste generation rate is around 0.74 kg per person per day, with significant regional variation[16]. High-income countries generate over 2.5 kg per person per day, while low-income countries generate less than 0.5 kg per person per day. By 2050, global waste generation is projected to increase to 3.4 billion tons annually, driven by population growth and urbanization [17]. Asia, particularly countries like China and India, is the largest contributor to global waste generation due to rapid urban growth, while Europe generates approximately 25% of the world's total waste but has a higher rate of recycling and waste management [16].

Focusing on waste generated from roads and highways, over the 50-year service life of an urban road, waste largely results from resurfacing, minor repairs and significant repairs. Resurfacing typically occurs every 10-15 years, leading to around 3-5 resurfacing events over the road's service life[18]. This process generates substantial waste, mainly in the form of asphalt milling and removed surface layers. Minor repairs, such as pothole patching, are performed every 2-5 years, contributing to waste such as crushed concrete and patching materials. Significant repairs, such as roadbed reconstruction, occur every 20-30 years and generate waste from excavated soil and damaged concrete [19].

In total, the waste generated during the 50-year service life of an urban road consists of materials like asphalt millings, removed surface layers, crushed concrete, patching materials and waste from excavated soil and damaged concrete[18]. The total waste generated over the service life of the road is estimated to be around 10,000-20,000 tons, depending on the size and maintenance requirements of the road[20]. Recycling and reusing many of these materials is important for reducing waste and promoting sustainability in road maintenance practices. The growing amount of demolition waste from roads and highways reflects the increasing trend of urbanization and infrastructure redevelopment, further underscoring the importance of recycling to minimize waste. Many materials generated from road repairs can be recycled or reused, contributing to a more sustainable approach to infrastructure maintenance [21].

In Pakistan, waste generation from roads and highways is a significant issue, particularly as urbanization and infrastructure development continue to grow. The country generates approximately 3.9 million tons of municipal solid waste annually [16] and road construction and maintenance activities contribute a substantial portion of this total waste. With a road network of over 260,000 kilometers[22] , Pakistan faces challenges in maintaining and resurfacing roads regularly, leading to the generation of asphalt millings, debris from roadbed reconstruction and materials from frequent pothole repairs. Although recycling and reuse practices for road repair materials are still limited in Pakistan, efforts are underway to improve waste management in the construction sector and promote sustainable practices [23]

Demolition waste generation in Pakistan, particularly from road projects, constitutes a significant portion of the country's annual solid waste production, with estimates reaching approximately 30% or 14 million tonnes per year[24]. This issue is exacerbated by rapid urbanization, population growth and the expansion of infrastructure projects. Despite the increasing volume of demolition waste, the current waste management practices are inadequate, largely due to limited awareness, insufficient regulatory frameworks and inadequate infrastructure for waste segregation, recycling and reuse.

The environmental management life cycle framework for demolition waste management faces several critical challenges, including the absence of standardized guidelines for waste handling, a limited understanding of the environmental impacts of demolition waste and ineffective regulatory enforcement. These gaps have led to informal handling practices, resulting in environmental degradation and public health risks. Projections indicate that if current practices persist, Pakistan's annual generation of demolition waste could reach 25 million tonnes by 2050[25].

Demolition waste comes from various sources during the demolition process. Some waste is due to design flaws before the project starts, while other waste comes from ongoing changes or market trends affecting the supply chain. To address the increasing problem of demolition waste, many waste management strategies have been implemented to reduce waste and increase recycling [26]. It's now essential to adopt sustainable Demolition Waste Management (DWM) principles to lessen the negative impacts of this waste on the economy, environment and public health [27]. In the construction industry, road engineering does create some waste, but it's not usually the main source. Most construction waste comes from building, demolition and excavation activities. Managing demolition waste in road projects is important because it impacts the environment, society and economy. Firstly, environmental challenges are significant. Demolition produces large amounts of waste like concrete, asphalt, metals and debris. If not properly managed, this waste can contaminate soil and water, pollute the air and destroy natural habitats[28]. Also, disposing of these materials in landfills uses valuable land and releases greenhouse gases, which contribute to climate change[29].

Social issues arising from demolition waste are also considerable. In urban and densely populated areas, demolition activities can cause significant disruptions. Noise, dust and increased traffic from waste transport can negatively impact the health and quality of life of local residents. Poor waste management practices, such as illegal dumping, often affect marginalized communities the most, leading to social inequities[30]. These disruptions can strain community relations and diminish public trust in construction projects, highlighting the need for better planning and communication with affected populations.

Economically, the mismanagement of demolition waste can lead to substantial costs. The expenses associated with transporting waste to disposal sites, paying landfill fees and meeting regulatory compliance requirements can significantly increase project budgets. Furthermore, the failure to recycle and reuse demolition materials results in the loss of potentially valuable resources and increases the demand for new, virgin materials, thereby driving up costs. Environmental remediation to address contamination and pollution from poorly managed demolition waste adds another layer of financial burden. Adopting efficient waste management practices and integrating circular economy principles can mitigate these costs, making demolition waste management both economically viable and environmentally sustainable. This research component explores the sources, impacts, challenges and solutions associated with demolition waste, which lacks a distinct or fixed definition. Demolition waste can originate from various sources and reasons during the demolition process. Design faults [31] existing before project execution, ongoing modifications and market trends affecting the supply chain can all contribute to the generation of demolition waste generated from rigid and flexible pavements as shown in figure 1.1 and 1.2.

FIGURE 1.1: Demolition Waste Generation from Rigid Pavement[32]

1.1.2 Impacts of demolition Waste

The impacts of demolition waste from road projects are multifaceted, affecting the environment, society and the economy in significant ways. Demolition activities generate large quantities of waste materials such as concrete, asphalt, metals and other debris. Improper disposal and management of these wastes can lead to severe environmental consequences, including soil and water contamination through leachate, air pollution from dust and particulate matter and the destruction of natural habitats [33]. Land-filling these materials occupies valuable land space and emits greenhouse gases, contributing to climate change. Additionally, the extraction of raw materials to replace wasted resources further exacerbates environmental degradation through deforestation, mining and energy consumption.

The social repercussions of demolition waste are particularly pronounced in urban and densely populated areas where road projects often occur. Dust, noise and increased traffic congestion from demolition and waste transportation disrupt the daily lives of local communities, adversely affecting residents' health and well-being. Inadequate waste management practices may lead to illegal dumping, disproportionately impacting marginalized communities and eroding social cohesion. The negative social impacts highlight the need for effective community engagement and transparent communication to mitigate disruptions and address public concerns. Economically, the mismanagement of demolition waste imposes substantial costs on road projects. Expenses associated with waste transportation, landfill fees and regulatory compliance significantly escalate project budgets. Moreover, missed opportunities for recycling and reuse result in lost revenue and increased demand for virgin materials, driving up costs further. Environmental remediation efforts to address pollution from poorly managed demolition wastes entail additional financial burdens. Efficient waste management strategies and the adoption of circular economy principles can mitigate these costs, enhancing project economics and promoting long-term sustainability. By prioritizing resource efficiency and waste minimization, road projects can reduce financial outlays and contribute to a more sustainable construction industry.

Figure 1.2: Demolition Waste Generation from Flexible Pavement[32]

1.2 Research Motivation and Problem Statement

1.2.1 Research Motivation

In developing countries like Pakistan, the generation of demolition waste, particularly from road projects, has become a growing concern. This is largely due to rapid urbanization, population growth and an increasing demand for infrastructure development. These factors contribute to a significant portion of the country's annual solid waste production, with demolition and construction waste accounting for approximately 30% of the total waste—around 14 million tonnes per year[32]. As the country continues to expand its road networks and urban areas, the volume of demolition waste is expected to rise dramatically, with projections indicating a potential increase to 25 million tonnes annually by 2050 if current practices remain unchanged[32]. This upward trend poses a substantial challenge for sustainable development and underscores the need for effective waste management strategies.These challenges include the absence of standardized guidelines for waste handling and disposal, insufficient infrastructure for waste segregation and recycling, inadequate awareness and understanding of the environmental impacts of demolition waste and the lack of robust regulatory frameworks to enforce effective waste management practices[34].

The motivation for this research arises from the urgent need to address the growing volume of demolition waste generated by road projects in Pakistan. With the environmental, social and economic implications of poorly managed waste, there is a pressing demand to develop a systematic approach that integrates sustainable waste management practices across all phases of road projects—from planning to decommissioning. This research aims to provide actionable solutions to the challenges of demolition waste management, supporting the country's broader sustainable development goals. By filling the gap in current research with a comprehensive framework, this study seeks to create a unified strategy that tackles the root causes, impacts and management challenges of demolition waste in road projects.

1.2.2 Problem Statement

Rapid urbanization in Pakistan leads to massive waste generation from road projects. Currently, the country produces around 14 million tons of demolition waste annually, which is expected to increase 25 million tons by 2050. Poor waste disposal causes serious pollution, health hazards and environmental damage due to the absence of a proper waste management framework.

- Weak laws and poor enforcement make waste management ineffective.
- Lack of awareness results in unsustainable practices.
- Limited recycling options force most waste into landfills, leading to resource wastage and higher greenhouse gas (GHG) emissions.

Existing research only addresses specific problems without offering a comprehensive solution. This study aims to develop a comprehensive framework that improves waste handling, promotes recycling and strengthens policies for sustainable infrastructure development in Pakistan.

1.2.3 Research Questions

This study explores the environmental management framework of demolition waste for infrastructure projects in Pakistan. It aims to address the lack of an integrated environmental management framework for demolition waste of the road projects. The study seeks to answer the following questions:

- Q.1: What are the causes road waste generation in Pakistan at different stages of the life cycle?
- Q.2: What are the impacts of demolition waste of road projects in Pakistan?
- Q.3: What are the main challenges in managing road demolition waste in the study area?

- Q.4: What solutions and management strategies can be proposed at the local/national level for better waste management in road projects?
- Q.5: Is there any connection between the causes of waste, its impact, the challenges and solutions?

These research questions delve deep into the complex issues surrounding demolition waste management in road projects, aiming to provide comprehensive insights into its causes, impacts, assessment methods, challenges and potential solutions.

1.3 Research Aims and Objectives

The primary aim of this research is to develop a comprehensive environmental management framework for demolition waste in road projects, focusing on reducing environmental impacts and promoting sustainability in developing countries like Pakistan.

The specific objectives are to:

- Investigate the Causes of Demolition Waste Generation at various stages of Road Projects.
- Assess the Environmental, Social and Economic impacts of Demolition Waste.
- Analyze the Challenges associated with Demolition Waste Management for Road Projects.
- Explore Solutions for Demolition Waste Management for Road Projects.
- Develop Environmental Management Framework (EMF) for Road Projects, providing actionable Recommendations for Policymakers and Stakeholders.

This focused scope ensures the development of a practical and effective framework that address the pressing challenges of demolition waste management in road projects.

1.4 Significance and Novelty of the Research

The growing environmental challenges associated with demolition waste from road construction projects in developing countries, particularly Pakistan, have highlighted the need for effective and sustainable waste management strategies. As urbanization accelerates and infrastructure demands rise, the volume of demolition waste generated from road projects continues to increase, posing significant risks to the environment, public health and resource sustainability. This research seeks to address these challenges by developing a comprehensive framework for managing demolition waste in road construction projects, with a focus on integrating environmental, social and economic considerations.

1.4.1 Significance of the Research

Demolition waste management is a crucial aspect of road projects, particularly in developing countries like Pakistan, where rapid urbanization and the expansion of infrastructure lead to significant waste generation. This waste, including materials like asphalt, concrete and excavated soil, can have adverse environmental impacts if not managed properly. Effective waste management not only reduces the environmental footprint of road projects by minimizing landfill use but also promotes resource conservation by recycling waste for construction. This reduces the need for virgin materials, cuts transportation distances and lowers project costs. Furthermore, proper waste management can mitigate emissions and conserve natural resources, contributing to a more sustainable road construction industry.

The significance of this study lies in its potential to address the regional and global challenges associated with demolition waste management in road projects. In the context of Pakistan, this research is highly relevant due to the country's rapid urbanization, limited resources and inadequate waste management infrastructure. These challenges exacerbate environmental degradation, pose public health risks and hinder sustainable development. By offering a comprehensive framework for managing demolition waste, the study aims to enhance environmental sustainability, improve resource efficiency and align Pakistan's construction practices with global sustainability standards. This will not only support the country's national development goals but also contribute to improved public health and a cleaner environment.

Globally, the research's significance extends to advancing sustainable construction practices, particularly in the Global South. By minimizing landfill dependency, promoting resource conservation and reducing carbon emissions, the findings of this study offer a model that can be adapted by other developing countries facing similar challenges. Moreover, the study directly contributes to the United Nations Sustainable Development Goals (SDGs), fostering sustainable growth and improving environmental health on a broader scale. The research's practical solutions are designed to support the transition to a more sustainable construction industry, ensuring that developing nations are not left behind in global sustainability efforts.

1.4.2 Novelty of the Research

This research is novel in several important ways. First, it addresses a significant gap in the existing literature by proposing a comprehensive environmental management framework specifically for road demolition waste—an area largely overlooked, especially in the context of developing countries like Pakistan. Unlike earlier studies that treat waste management in a fragmented or generalized manner, this work provides an integrated and context-specific approach tailored to the region's unique infrastructural, social and environmental conditions.

The research systematically examines the causes, impacts and challenges of road demolition waste, moving beyond basic analysis to offer structured and practical solutions. A central contribution is its emphasis on resource sustainability through the promotion of reusable materials, reducing reliance on landfilling and aligning with international environmental objectives. This approach not only conserves resources but also minimizes the ecological footprint of construction activities.

A particularly underexplored area that this study brings into focus is the impact of demolition waste on the living environment and natural ecosystems. By investigating this relationship, the research adds depth to the understanding of how poorly managed waste can harm both public health and biodiversity—dimensions often neglected in previous work.

Finally, the study stands out for its applied relevance. It offers actionable strategies for a wide range of stakeholders, including policymakers, construction professionals and environmental agencies. These practical recommendations aim to foster the adoption of sustainable practices in demolition waste management, making the study both academically significant and practically useful.

1.4.3 Research Scope

The scope of this research is centered on improving demolition waste management in road infrastructure projects, with a focus on developing countries such as Pakistan. The study includes the following key components:

- Identifying the causes, impacts, challenges and potential solutions related to demolition waste generated during the lifecycle of road projects, including planning, construction, maintenance and decommissioning stages.
- Developing a conceptual model or framework for effective demolition waste management specifically tailored to road infrastructure projects.
- Collecting and analyzing primary and secondary data to support the development and refinement of the proposed model/framework.
- Validating and modifying the model/framework through expert input, stakeholder feedback and statistical analysis to ensure practical relevance.
- Providing actionable recommendations for industry and policymakers to improve current demolition waste management practices, enhance regulatory frameworks and promote sustainable road construction and deconstruction.

This focused scope ensures a systematic and context-relevant approach to tackling the pressing issue of demolition waste in the road sector, with the ultimate aim of supporting environmental sustainability and infrastructure resilience.

1.4.4 Limitation of study

Developing a framework for life cycle environmental management of demolition wastes for road projects involves several key limitations:

1. Limited Stakeholder Scope: : Data collection was restricted to key stakeholders—clients, contractors and consultants—within Pakistan's road construction sector. As a result, the perspectives of other relevant actors, such as waste management authorities and community groups, were not included.

2. Sectoral Focus: The research exclusively focuses on demolition waste generated from road infrastructure projects. It does not account for demolition waste originating from residential, commercial, or industrial construction, limiting the broader applicability of the findings.

3. Geographical and Contextual Constraints: The study is based on conditions specific to Pakistan. While the findings may offer insights for other developing countries, policy recommendations and management strategies may need to be adapted to suit different regional, regulatory and socio-economic contexts.

4. Life Cycle Assessment & Analysis: The Life Cycle Assessment & Life Cycle Analysis are not part of scope.

These limitations emphasize the need for contextual sensitivity when applying the proposed framework to different regions or sectors. Demolition waste management strategies may not be equally effective across varying regulatory, cultural, and economic settings. As such, generalizing the findings should be approached with caution. Future studies should expand to include a wider range of stakeholders, industries, and geographic areas. This would strengthen the framework's applicability and support the development of more adaptable and sustainable practices.

1.5 Brief Methodology

The research employs a structured, four-stage methodology to examine demolition waste management and develop a comprehensive framework, as outlined in the Methodological Framework for Demolition Waste (Figure 1.3). Each stage is designed to build upon the previous one, ensuring thorough data collection and analysis.

Stage 1: Baseline Data Collection

This initial stage establishes the foundation for the study through a comprehensive literature review. The review explores existing research, identifies gaps, formulates research questions and defines study objectives. Primary document analysis is conducted to select relevant participants, respondents and infrastructure projects for further investigation.

Stage 2: Data Collection for Research Questions

The second stage focuses on gathering detailed data to address the research questions. Data triangulation ensures reliability through multiple methods, including surveys to identify key factors contributing to demolition waste generation, discussions with stakeholders and field observations. The focus group discussion involving expert discussions across multiple rounds to identify causes, impacts, challenges and potential solutions for effective demolition waste management.

Stage 3: Framework Design

In the design stage, the framework's core components are identified based on collected data. These components are contextualized, aligning them with real-world perspectives to ensure the framework's relevance and practicality in addressing identified issues.

Stage 4: Framework Development

The final stage involves refining and validating the framework. The variables, elements and constructs are finalized and validated, leading to the development of a comprehensive framework for demolition waste management. This framework synthesizes insights from the research to address challenges and opportunities in the field.

The research process culminates in data analysis and model assessment using advanced statistical techniques such as Partial Least Squares Structural Equation Modeling (PLS-SEM). Measurement model assessment ensures construct reliability and validity, while structural model assessment evaluates relationships between variables and overall model fit through metrics like Variance Inflation Factor (VIF), R^2, f^2 and Q^2. The results are discussed to highlight theoretical implications for academic research and practical applications for industry practitioners and policymakers, translating findings into actionable insights for future policies and practices in demolition waste management.

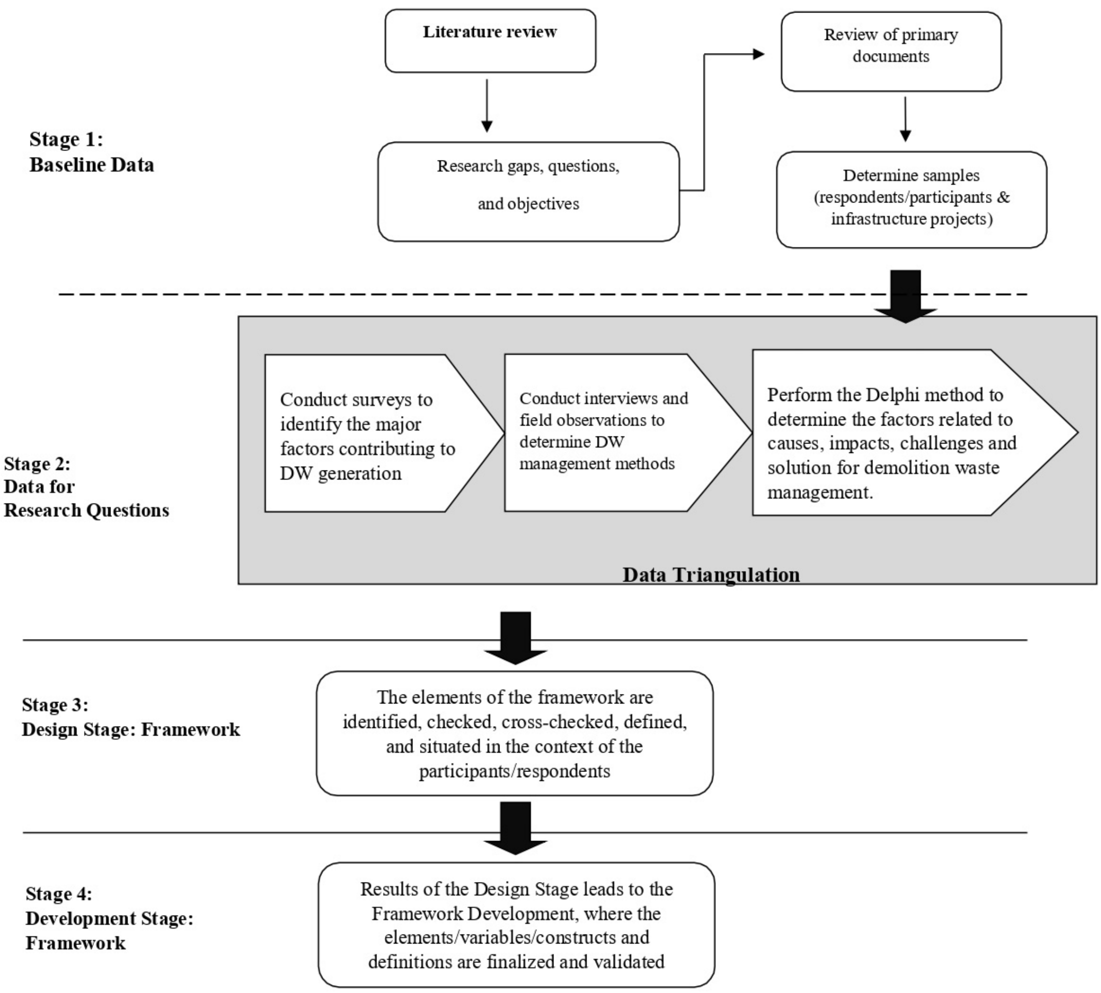

FIGURE 1.3: Methodological Framework for Demolition Waste Management

1.6 Organization of the Thesis

Below is the outline of this research, with a brief description of the content of each chapter:

Chapter 1: Introduction

This chapter sets the stage by introducing the importance of the construction industry in national development and the significant impact of demolition waste. It outlines the causes, impacts, challenges and potential solutions related to demolition waste management (DWM). The introduction should establish the research gap or problem statement, define the research objectives and articulate the expected outcomes of the study. It serves to orient the reader to the broader context and relevance of the research topic.

Chapter 2: Literature Review

The literature review chapter provides a comprehensive synthesis of existing research and scholarly work related to demolition waste. It covers the types of demolition waste, existing management systems and various factors influencing DWM in infrastructure projects. This chapter not only summarizes key findings from previous studies but also identifies gaps or contradictions in the literature that the current research aims to address. It helps justify the significance of the study and provides a theoretical framework for interpreting the empirical findings.

Chapter 3: Research Design and Methodology

In this chapter, detail the methodology used to collect data for study. It explains how factors contributing to demolition waste were identified and selected for investigation. The research design, sampling strategy, data collection methods (such as questionnaires) and the process of questionnaire design and validation. This chapter also outlines ethical considerations, reliability and validity checks and any statistical or analytical techniques employed in data analysis.

Chapter 4: Data Analysis and Critical Discussion

Chapter 4 focuses on analyzing the collected data and interpreting the results. It begins with presenting descriptive statistics of respondents, such as demographic profiles and characteristics related to demolition waste management roles. The chapter then delves into the importance and impact of identified factors (indicators) on demolition waste management practices. It discusses how the Structural Equation Model (SEM) was developed or utilized to represent relationships among variables. Finally, it includes a critical discussion of the findings in relation to existing literature and theoretical frameworks.

Chapter 5: Conclusions & Recommendations

Chapter 5 provides a synthesis of the study's findings, offering actionable recommendations to enhance demolition waste management in road projects in Pakistan. It stresses the need for early integration of waste management practices in the planning phase, the adoption of advanced recycling technologies and the implementation of stronger policies and regulations. Moreover, it highlights the importance of increasing stakeholder awareness, building capacity and providing financial and logistical support to overcome the challenges in waste management. The chapter concludes by summarizing the research's main findings, reaffirming the objectives and answering the research questions, while offering a comprehensive roadmap for improving sustainability in road project management. Additionally, future research directions are proposed, including expanding the Environmental Management Framework (EMF) to other infrastructure sectors, exploring technological innovations, evaluating policy impacts and fostering a circular economy approach to demolition waste management.

Chapter 2

Literature Review

2.1 Background

This section includes a detailed review of numerous studies conducted by various researchers related to the current research topic. According to [33], a literature review involves surveying scholarly sources to provide a comprehensive overview of a specific topic. In this context, a literature review serves both as a process and a product, offering a descriptive and analytical summary of existing research. Accordingly, this chapter has been designed to incorporate various studies related to the underlying research topic: the development of a framework for life cycle environmental management of demolition wastes in road projects. The construction industry plays a significant role in generating waste in large quantities globally. The study highlights that while the construction industry is vital for enhancing economic activities, it also significantly contributes to waste generation[2]. Specifically, it has been identified that infrastructure projects are major sources of demolition waste, even though they are crucial for boosting economic activities. This section reviews the perspectives of past researchers by analyzing various journal articles, published research papers and surveys related to demolition waste management in infrastructure projects. The literature review chapter of the study initiates a comprehensive exploration of demolition waste and its management. It distinguishes between physical and non-physical waste categories and elucidates the diverse construction activities contributing to waste generation. Factors like inaccurate handling and a lack of expertise among contractors lead to significant waste production. Subsequently, the chapter defines demolition waste and delineates common types found on construction sites, establishing a foundational understanding. It delves into the dimensions of demolition waste management, identifying causes, examining impacts and addressing associated challenges such as regulatory constraints. Additionally, it reviews existing strategies and technologies, including recycling and waste reduction techniques, while exploring relationships between variables and formulating hypotheses. This structured approach furnishes a thorough analysis of demolition waste, laying the groundwork for subsequent research endeavors.

2.2 Sustainability and the Built Environment

Sustainability is all about meeting the needs of the present without compromising the ability of future generations to meet their own needs. It's about finding a balance between economic, social and environmental factors to ensure that continue to thrive without depleting natural resources or harming the planet [35]. This concept applies to various aspects of life, including energy, agriculture, transportation and consumption patterns. Embracing sustainability involves making choices that minimize negative impacts on the environment, promote social equity and support economic prosperity in the long term. Environmental sustainability in demolition waste management focuses on reducing the ecological footprint of demolition activities while effectively handling the waste generated[36]. This approach emphasizes waste prevention, material reuse and recycling to minimize the amount of waste sent to landfills. By prioritizing strategies such as salvaging materials for reuse, properly managing hazardous materials and exploring energy recovery options, stakeholders can mitigate environmental impacts, conserve resources and promote a circular economy[37]. Compliance with regulations, thorough environmental assessments and public awareness initiatives are also essential

components of sustainable demolition waste management, ensuring that demolition activities are conducted in a manner that protects both the environment and human health. Through these efforts, the construction industry can play a significant role in advancing environmental sustainability and reducing its carbon footprint [38]. EEnvironmental sustainability in demolition waste management, when considered within the framework of the life cycle approach, involves evaluating the environmental impacts associated with demolition activities across their entire duration. This includes assessing the environmental burdens linked to raw material extraction, transportation, construction, operation, maintenance, and end-of-life disposal or recycling [39]. In the context of demolition waste management, the life cycle perspective helps identify opportunities to reduce environmental impacts by optimizing processes such as waste prevention, material reuse, recycling, and energy recovery. By quantifying the environmental footprint of different waste management strategies, stakeholders can make informed decisions to minimize overall environmental harm and promote sustainable practices throughout the demolition process. Incorporating the life cycle approach into demolition waste management enables a holistic understanding of environmental impacts and supports the development of more effective and environmentally sustainable solutions.
The life cycle of demolition waste management for road projects begins with the extraction of raw materials from quarries. These materials, including aggregates and other construction resources, are transported to the construction site where they are used for road building. Following construction, the road enters the operational phase, serving its intended purpose for traffic and transport over many years. This early phase of the cycle—covering quarrying, transport, construction, and operation—is essential in understanding the origin of materials that eventually contribute to demolition waste.

At the end of a road's service life, the demolition and rehabilitation phase is initiated. During this stage, the existing road infrastructure is dismantled, generating significant quantities of construction and demolition (C&D) waste. This waste is first transported to designated storage facilities where it is temporarily held. Storage serves as an interim stage before the waste undergoes segregation. Segregation involves sorting the waste materials based on their types and potential for further management processes.

Following segregation, the waste enters a management stage where different options are considered, guided by a waste management hierarchy from most to least preferable. Reuse is the most preferred option, where sorted materials are directly delivered for use in new projects without the need for extensive reprocessing. If reuse is not feasible, recycling becomes the next preferred strategy. In this case, waste materials are sent to processing plants where they are treated and transformed into new construction inputs. However, materials that cannot be reused or recycled are classified as rejects and are ultimately sent to landfills, representing the least desirable outcome due to environmental concerns.
The system boundary of flow of material includes all activities from demolition to final waste management, emphasizing sustainable practices. Flow arrows in the diagram illustrate the movement of materials through various stages, while a preference hierarchy highlights the goal of minimizing landfill disposal and maximizing material recovery through reuse and recycling efforts. This structured flow not only promotes environmental sustainability but also supports resource efficiency in road project demolition and reconstruction activities. The stage wise flow of material is shown in below figure-2.1

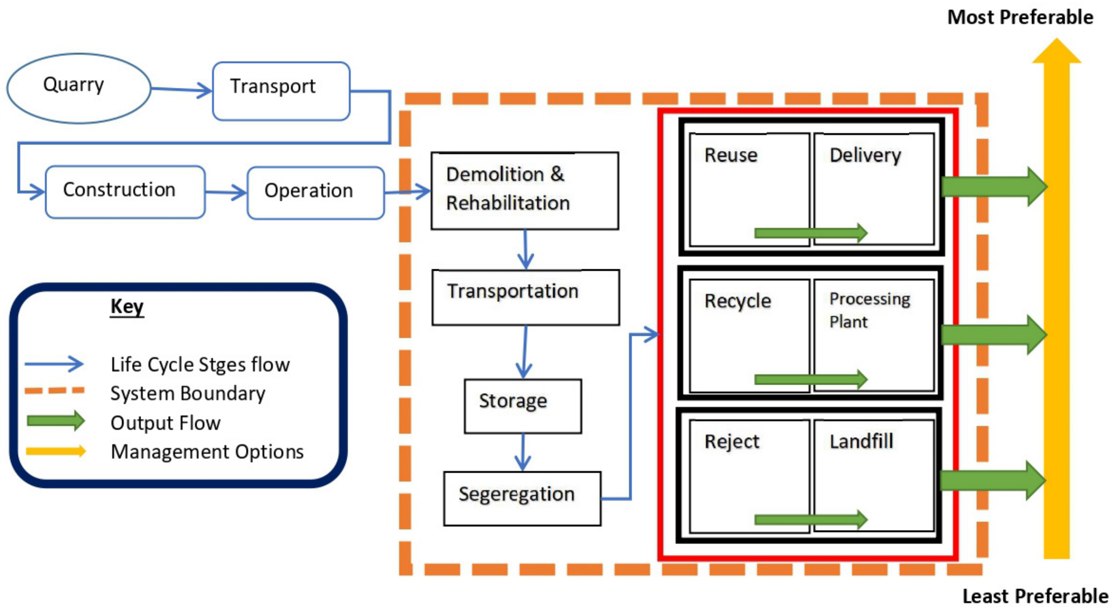

FIGURE 2.1: Stage wise flow of Material

2.2.1 Theory of Sustainability

The theory of sustainability represents a comprehensive approach to navigating the intricate relationships between environmental, social and economic elements, with the aim of securing the enduring welfare of both current and forthcoming generations.
Fundamentally, it endeavors to harmonize the demands of society, the environment and the economy, striving for a state of equilibrium where human endeavors can flourish without compromising the integrity of natural systems or the rights of future generations [40]. Embedded within the theory of sustainability are key principles and concepts that provide a guiding framework for action. These include recognizing the inter-connectedness of environmental, social and economic systems, advocating for long-term thinking to assess impacts over extended horizons, adhering to the precautionary principle in the face of uncertainty, prioritizing resilience and adaptation to cope with change, ensuring equity and justice in sustainable development, acknowledging the finite nature of resources through limits to growth, fostering participation and collaboration in decision-making processes and promoting transformative change at various levels [41]. Ultimately, the theory of sustainability offers a holistic lens through which to comprehend the complex dynamics of human-environment interactions. It serves as a compass for efforts aimed at constructing a future characterized by resilience, equity and sustainability. Encouraging a departure from unsustainable patterns of consumption and production, it advocates for regenerative and inclusive approaches that prioritize the well-being of both people and the planet.

The theory of sustainability is a multidisciplinary framework that addresses the complex interplay between environmental, social and economic factors to ensure the long-term well-being of both present and future generations[42]. At its core, sustainability theory seeks to balance the needs of society, the environment and the economy to achieve a state of equilibrium where human activities can thrive without compromising the integrity of natural systems or the rights of future generations [43, 44],Figure 2.2.

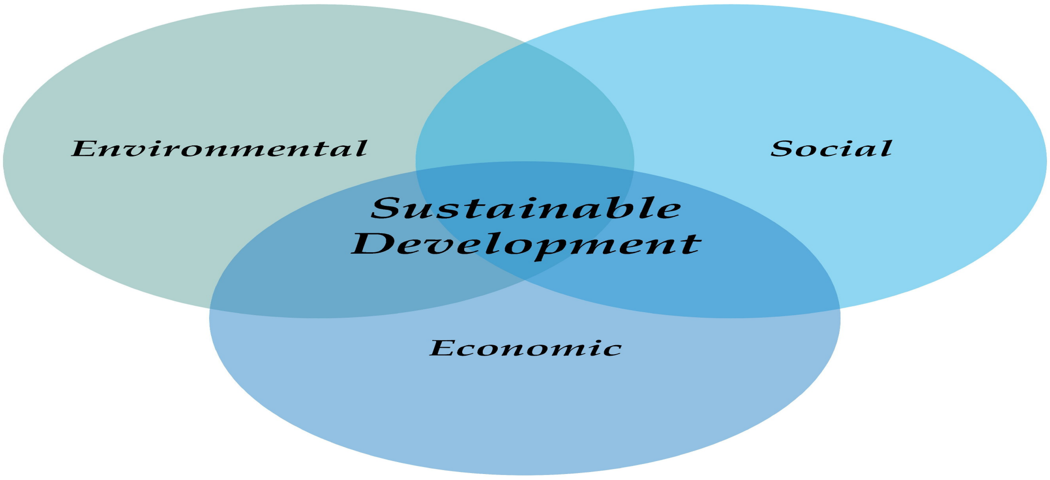

FIGURE 2.2: Dimensions of Sustainability[45]

Key principles and concepts within the theory of sustainability include:

2.2.2 Concept of life cycle

The concept of the life cycle provides a comprehensive framework for understanding and addressing the environmental impacts associated with demolition activities. From the extraction of raw materials to the final disposal of waste, the life cycle approach evaluates the environmental consequences at each phase of a road project [46]. The ISO-based Life Cycle Assessment (LCA) basic approach framework, as standardized in 2006, is illustrated in Figure 2.3 [47, 48]

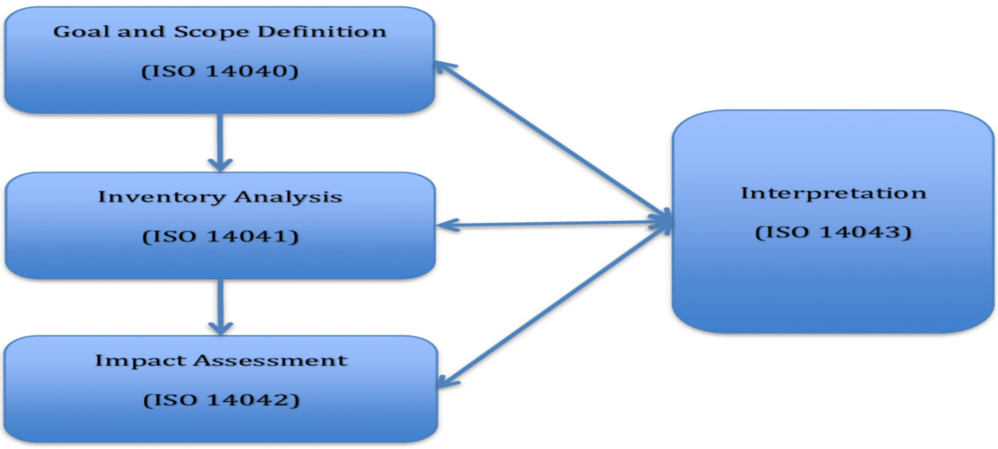

FIGURE 2.3: ISO-based (Standardization 2006) LCA (basic) Approach Framework, (LCA) Standard Diagram

At the end of a road's life cycle, demolition or deconstruction generates waste that requires careful management. Environmental impacts of various waste management options, including land-filling, recycling and reuse. By comparing the environmental impacts of disposal and recycling options, stakeholders can identify the most sustainable solution, considering factors like material conservation and energy intensity of processing [49]. Overall, Life cycle informs decision-making to optimize waste management strategies by uncovering trade-offs between different environmental impacts. Continuous monitoring and assessment enable stakeholders to identify opportunities for improvement, such as waste reduction measures, technological advancements in recycling and efficiency enhancements in transportation and processing. By adopting a life cycle approach, the construction industry can minimize resource consumption, pollution and ecosystem degradation, promoting sustainable demolition waste management practice. The life cycle of the project (PLC) [50]is elaborated in figure 2.4.

FIGURE 2.4: ISO-based (Project Life Cycle (PLC)[50]

2.2.3 Role and Challenges for Construction Industry

Construction industry indeed serves as a vital catalyst for advancing sustainable development on multiple fronts. Infrastructure projects, such as roads and utilities, are integral components of economic development, facilitating commerce, mobility and connectivity. However, their construction and operation can have significant environmental implications. By embracing sustainable planning and design principles, the construction industry can mitigate these impacts and contribute to environmental resilience [51].

Efforts to prioritize sustainability in infrastructure development involve various strategies. These include incorporating green building practices, utilizing eco-friendly materials, optimizing energy efficiency and implementing effective waste management systems. For instance, road and highway construction projects may integrate features such as permeable pavements, green spaces and renewable energy sources to minimize environmental footprint and enhance user experience. Moreover, sustainable infrastructure initiatives not only address environmental concerns but also prioritize social equity and economic viability. They can improve accessibility, enhance public health and create job opportunities while promoting long-term environmental sustainability. By integrating sustainability into infrastructure development, the construction industry plays a crucial role in building resilient communities and fostering a more sustainable future for all.

The construction industry undeniably faces a complex array of challenges, with sustainability and environmental concerns at the forefront. Balancing development needs with environmental preservation requires a holistic approach that integrates sustainable practices throughout the construction life-cycle [52]. This entails adopting eco-friendly materials, implementing energy-efficient technologies and minimizing waste generation. Embracing sustainability not only reduces ecological impact but also enhances operational efficiency and long-term viability. In addition to environmental challenges, navigating regulatory requirements poses significant obstacles to construction projects.

Compliance with building codes, zoning regulations and environmental mandates demands meticulous planning and coordination, often leading to delays and increased costs. Proactive engagement with regulatory authorities, coupled with streamlined processes and innovative solutions, is essential for overcoming these hurdles and ensuring project success. Moreover, the construction industry grapples with a critical shortage of skilled labor, further complicating project time-lines and budgets. Addressing this workforce gap requires concerted efforts to attract and retain talent through training programs, apprenticeships and career development initiatives. By investing in workforce development and embracing technological advancements, construction firms can mitigate labor shortages and position themselves for sustainable growth and innovation in the years ahead.

Construction industry's role in the global sustainability agenda is multifaceted, extending beyond environmental considerations to encompass social responsibility, innovation and collaboration. By prioritizing fair labor practices, diversity and community engagement, construction companies can contribute to building a more equitable and socially responsible society[53]. Furthermore, fostering partnerships with stakeholders, including governments, non-governmental organizations and local communities, is essential for addressing complex sustainability challenges. By collaborating on sustainable development initiatives and sharing best practices, the construction industry can amplify its impact and drive meaningful change. Innovation also plays a crucial role in advancing sustainability within the construction sector. Embracing technological advancements, such as Building Information Modeling (BIM), prefabrication and renewable energy integration, enables construction firms to enhance efficiency, reduce waste and minimize environmental impact[54]. Ultimately, by integrating environmental stewardship, social responsibility, innovation and collaboration into their operations, the construction industry can lead the way toward a more resilient, equitable and sustainable future for generations to come [55].

2.3 Demolition Waste and Environmental Issues

The definition of demolition waste encompasses a broad spectrum of materials and debris resulting from various construction-related activities, spanning from the alteration to the destruction of man-made structures. Unlike general construction waste, demolition waste specifically pertains to materials rendered unusable or unnecessary due to demolition processes, encompassing a diverse array of substances

from buildings, roads, houses and industrial facilities to roadways[56].
Environmental issues encompass a wide array of challenges that threaten the health of our planet, from local pollution to global climate change. Climate change stands out as one of the most urgent issues, driven by human activities such as burning fossil fuels and deforestation, leading to rising temperatures, sea level rise and extreme weather events. Air pollution also poses significant risks, with pollutants from vehicle emissions and industrial activities causing respiratory and cardiovascular diseases[57].
Water pollution is another critical concern, affecting both freshwater and marine environments due to contamination from industrial discharges, agricultural runoff and improper waste disposal. Deforestation exacerbates environmental degradation, leading to habitat loss, biodiversity decline and increased carbon emissions. Loss of biodiversity further threatens ecosystems and compromises their ability to provide essential services. Waste management presents its own set of challenges, with inadequate practices contributing to pollution of land, water and air. Ocean pollution, particularly plastic pollution and marine debris, poses significant threats to marine life and ecosystems. Additionally, natural resource depletion, driven by unsustainable exploitation of minerals, fossil fuels and freshwater, exacerbates habitat destruction and soil degradation[58].
Addressing these environmental issues requires concerted efforts at all levels, involving governments, businesses, communities and individuals. Transitioning to renewable energy sources, adopting sustainable land and resource management practices, promoting conservation and restoration of ecosystems and implementing policies to reduce pollution and mitigate climate change are crucial steps towards a more sustainable future.

2.3.1 Effects of Roads Demolition Waste Material

During execution, alteration and demolition activities, certain materials can pose significant risks to both human health and the environment. These include asbestos, lead-based paints, mercury-containing devices, Polychlorinated Biphenyls

(PCBs), volatile organic compounds (VOCs), formaldehyde and silica dust[56]. Asbestos, for instance, when disturbed, releases fibers that can cause severe respiratory issues like lung cancer. Lead-based paints and mercury-containing devices pose risks of lead poisoning and mercury vapor exposure, respectively. PCBs, VOCs, formaldehyde and silica dust contribute to air and soil contamination, leading to various health problems. To mitigate these risks, thorough inspections, proper handling, engineering controls and adherence to safety regulations are crucial, along with promoting sustainable practices like recycling and responsible waste management[59, 60]. The effects of materials used in execution, alteration and demolition activities pose high-priority concerns regarding land degradation, air pollution, water pollution and the creation of hazardous buildings. Given these risks, there's an urgent need to minimize wastage and reduce environmental impact. This imperative underscores the importance of implementing sustainable practices throughout the construction and demolition process, including the adoption of eco-friendly materials, efficient waste management strategies and the promotion of recycling initiatives. By prioritizing environmental stewardship, that mitigate the adverse effects on both human health and the ecosystem while fostering sustainable development for future generations[61].

In certain countries within the United States and Europe, where concrete resources are limited, recycling demolition waste (DW) has emerged as the preferred strategy[62]. Recognizing the scarcity of concrete resources, several concrete waste recycling and sorting plants have been established to address this need. By recycling DW, these regions can mitigate the demand for new concrete production, conserve natural resources and reduce the environmental footprint associated with construction and demolition activities. This shift towards recycling demonstrates a proactive approach to sustainable resource management and highlights the importance of adopting innovative solutions to address resource scarcity challenges [63]. The negative impacts of demolition waste (DW) on the environment have indeed escalated into a global concern. As urbanization and development accelerate worldwide, the volume of DW generated continues to rise, leading to significant environmental challenges. Improper disposal of DW can result in land degradation, air and water pollution, habitat destruction and ecosystem disruption. Additionally, the presence of hazardous materials within DW, such as asbestos, lead and chemicals, poses health risks to both humans and wildlife. Addressing these issues requires concerted efforts at local, national and international levels to promote responsible waste management practices, prioritize recycling and reuse initiatives, enforce regulations and raise public awareness about the environmental consequences of DW. By tackling the negative impacts of DW on a global scale, that can strive towards a more sustainable and resilient built environment for future generations [64].

2.3.2 Magnitude of Demolition Waste

The magnitude of demolition waste in road construction and maintenance projects is substantial, influenced by several factors. Larger projects, such as highway expansions or urban redevelopment, generate more waste due to extensive demolition. The type of infrastructure impacts waste volume, with different road features like pavements, bridges and intersections producing varying amounts based on materials and structures. Older infrastructure yields higher waste due to deterioration, affecting recycling feasibility. Demolition methods play a crucial role; selective deconstruction can reduce waste by salvaging materials, while traditional methods may lead to mixed, less recyclable debris. Effective waste management practices, including on-site sorting, recycling partnerships and waste diversion plans, are essential for sustainability. Regulatory requirements and public engagement further shape waste management, emphasizing compliance and awareness to promote sustainable practices. Through thorough assessments and proactive strategies, road projects can reduce waste, enhance resource utilization and support environmentally responsible development.

In Pakistan, the issue of demolition waste is particularly pronounced in urban areas, where rapid urbanization and infrastructure development have driven significant waste generation. Urban road projects in cities such as Karachi and Lahore account for approximately 40-50% of the country's total construction and demolition (C&D) waste, generating between 500,000 to 1 million tons of waste annually[65]. This waste primarily consists of materials such as asphalt, concrete and mixed debris. For instance, asphalt waste alone contributes up to 30% of the total C&D waste produced in urban road projects. Furthermore, large-scale highway projects, such as the Lahore-Islamabad Motorway, are estimated to generate 1.5 to 2 million tons of waste annually, with 30-40% of this waste comprising asphalt due to extensive resurfacing and upgrading activities [66].

In Pakistan, building construction activities contribute significantly to the overall construction and demolition (C&D) waste. According to [67], material wastage rates in building projects can range from 20% to 30% of the total materials used, depending on project type and management practices. Similarly, [68] reported that major building materials such as bricks, tiles and mortar contribute heavily to construction waste, with waste percentages varying between 15% and 25% across different types of buildings. These studies highlight the pressing need for improved waste management systems and efficient material handling practices within Pakistan's construction sector, especially in rapidly urbanizing regions.

Another critical factor contributing to the magnitude of demolition waste in Pakistan is the use of low-quality materials in road construction. Cheaper materials, often used in budget-constrained projects, lead to rapid deterioration and frequent repairs, which, in turn, generate significant amounts of waste. For example, the resurfacing and maintenance of poorly constructed roads generate approximately 200,000 tons of waste every few years[67].This highlights the need for improved construction practices and materials to minimize waste generation and enhance the longevity of road infrastructure.

Globally, construction and demolition waste constitutes about 30% of total waste, amounting to over 3 billion tons annually. Road construction projects account for a significant share of this figure, contributing 15-20%, which translates to 450 to 600 million tons of waste per year [69]. Developed countries like the United States and nations within the European Union exhibit considerable contributions to this figure due to their expansive road networks and frequent infrastructure upgrades.

In the United States, road construction and maintenance activities generate approximately 100 million tons of waste annually, representing 40-50% of total C&D waste [70]. Similarly, in the European Union, road projects produce an estimated 150-200 million tons of waste annually, with about 50% of this waste being recycled, showcasing the region's relatively robust recycling infrastructure [66]. On the other hand, developing nations like China face challenges due to rapid urbanization. The country generates around 50-60 million tons of C&D waste annually, with 25-30% of this waste attributed to road construction projects [69].This demonstrates the varying capacities and approaches of countries in managing demolition waste, which is often influenced by economic and regulatory factors.

The type and quality of road construction significantly influence the quantity and composition of demolition waste. Asphalt roads, for instance, contribute between 30-40% of total C&D waste in road construction projects. A typical example is the demolition of a 10-kilometer urban highway, which can generate between 10,000 to 20,000 tons of asphalt waste[70]. Concrete roads, on the other hand, produce larger quantities of waste. For instance, a 10-kilometer concrete highway can result in the generation of 15,000 to 25,000 tons of waste, primarily from broken slabs and subgrade materials [65]. Mixed materials from road demolition projects, which include asphalt, concrete, metals, wood and plastics, further add to the waste volume. A typical urban road project can produce 5,000 to 10,000 tons of mixed material debris, with asphalt and concrete constituting the predominant components [66]. Low-quality road construction exacerbates the problem. Poorly built roads using substandard materials deteriorate faster, requiring frequent repairs and generating recurring waste. For example, resurfacing and maintenance activities on such roads often yield significant amounts of asphalt and concrete waste, highlighting the importance of high-quality materials and sustainable design practices to reduce the lifecycle waste burden [67].The historical context of demolition waste generation reveals a steady increase in waste volumes, primarily driven by urbanization and the expansion of road networks. In Pakistan, the absence of robust data tracking systems and weak regulatory enforcement has hindered the accurate assessment of historical waste generation trends. However, recent studies focusing on urban centers and major infrastructure projects have provided valuable insights into the scale of the issue [67].

Globally, countries with well-developed road networks, such as the United States and European nations, have more comprehensive data on C&D waste, enabling them to implement better waste management and recycling strategies. Developing nations, including Pakistan and China, face challenges related to data collection, infrastructure limitations and a lack of enforcement mechanisms, further complicating waste management efforts [69].

2.3.3 Global Perspective of Demolition Waste Management

Managing demolition waste is a pressing global concern due to the substantial volumes generated by the construction sector, fueled by rapid urbanization and infrastructure development[71]. Challenges include rising waste generation, particularly in developing countries with limited waste management infrastructure, leading to environmental degradation and resource scarcity. Inconsistent regulatory frameworks hinder effective waste management, emphasizing the need for stronger policies. Strategies like waste reduction, reuse, advanced demolition techniques and circular economy approaches are vital for sustainable waste management [72]. Global initiatives, including UN Sustainable Development Goals and collaborations among international organizations and nations, support capacity building and knowledge sharing to address this issue comprehensively. Overall, a multifaceted strategy integrating sustainable practices, technological advancements and regulatory improvements is essential for effective demolition waste management and the advancement of a resource-efficient and environmentally conscious construction sector on a global scale. This approach entails implementing measures such as recycling and reuse of demolition waste, adopting innovative technologies for waste sorting and processing, enhancing regulations to promote responsible waste disposal and fostering collaboration among stakeholders to drive sustainable practices throughout the construction life-cycle. By embracing these initiatives, the construction industry can minimize environmental impact, conserve resources and move towards a more sustainable and resilient built environment for current and future generations[73].

In the United States, the demolition waste generation rate is approximately 20-25 tons per kilometer of road constructed or maintained over the service life of the road. This high figure reflects the extensive infrastructure network, including highways and urban roads and the frequent maintenance and upgrades required to sustain them throughout their lifecycle. The use of durable materials such as asphalt and concrete also contributes to this high waste volume. However, the US has made considerable progress in managing this waste through advanced recycling programs and sustainable construction practices, which have helped stabilize waste generation rates in recent years [74, 75].

In Pakistan, the demolition waste generation rate is estimated at 10-15 tons per kilometer of road constructed or maintained over the service life of the road. This lower figure is primarily due to less frequent maintenance activities, the use of lower-grade materials driven by economic constraints and the limited infrastructure for waste management. However, Pakistan's rapid urbanization and large-scale infrastructure projects, such as those under the China-Pakistan Economic Corridor (CPEC), are expected to increase these waste generation rates in the coming years [34, 76].

The United States has historically generated significant volumes of demolition waste due to the rapid expansion of its road infrastructure. However, the adoption of advanced technologies and strict environmental regulations has resulted in a positive trend over time. Waste generation rates have stabilized or slightly declined per kilometer of road due to widespread implementation of recycling initiatives such as cold-in-place recycling, which enables the reuse of materials on-site and the promotion of circular economy principles [75].

The United States is expected to maintain its positive trend, with further reductions in waste generation due to continued advancements in recycling technologies and sustainable practices. These efforts align with long-term sustainability goals aimed at reducing environmental impacts while conserving natural resources [74].

In Pakistan, the evolution of demolition waste generation follows a negative trend, with volumes steadily increasing over time. Current estimates suggest that construction and demolition (C&D) waste accounts for approximately 30% of the country's total solid waste, equating to around 14 million tonnes annually. If existing practices remain unchanged, this figure could rise dramatically to 25 million tonnes per year by 2050 [34].

This increase is driven by rapid urbanization, population growth and large-scale infrastructure development projects. The lack of standardized guidelines, insufficient recycling infrastructure and inadequate public awareness exacerbate the problem. However, Pakistan has significant potential to reverse this trend by adopting efficient waste management strategies, enhancing recycling infrastructure and introducing regulatory frameworks to enforce sustainable practices [34, 76].

The United States is on a positive trajectory, with waste generation per kilometer decreasing over time due to advancements in recycling and sustainable construction practices. Pakistan, on the other hand, faces a negative trend, with waste generation expected to rise significantly unless immediate action is taken to improve waste management and recycling efforts. While the US serves as a model of effective waste management through technological and regulatory interventions, Pakistan must address its unique challenges by developing tailored solutions that prioritize recycling, waste reduction and public awareness.

2.4 Causes of Demolition Waste Generation

Demolition waste arises at different stages of a project life-cycle (PLC) assessment, encompassing planning, execution and monitoring/control stages, each presenting distinct challenges and opportunities for effective waste management and mitigation. In the planning stage, improper design, inadequate assessment of existing structures and lack of consideration for waste management strategies can contribute to unnecessary demolition waste generation. During the execution stage, inefficient demolition techniques, excessive material removal and inadequate sorting practices can exacerbate waste generation. Additionally, unforeseen challenges such as encountering hazardous materials or structural complexities may further contribute to waste generation.

In the monitoring and control stage, ineffective monitoring systems, poor project oversight and inadequate enforcement of waste management protocols can hinder efforts to minimize and mitigate demolition waste. Addressing these challenges requires comprehensive planning, proactive waste management strategies, stakeholder engagement and robust monitoring mechanisms to ensure that demolition activities are conducted efficiently, with minimal waste generation and environmental impact. An overview of the causes of demolition waste at each stage:

2.4.1 Planning Stage

Efficient data collection is indeed paramount for effective demolition waste management in road projects. Gathering comprehensive information about the causes of demolition waste enables informed decision making and supports research through out the project life cycle (PLC), spanning planning, execution and monitoring & control stages. During the planning stage, data on existing road conditions, materials and structures inform decisions regarding demolition methods, material reuse potential and waste management strategies. In the execution stage, real-time data on waste generation rates, material composition and sorting practices facilitate efficient demolition operations and resource recovery efforts. Furthermore, data collected during the monitoring & control stage provide insights into the effectiveness of waste management measures, allowing for adjustments and improvements to be made as needed. By leveraging data across the PLC, road projects can optimize demolition waste management practices, minimize environmental impact and promote sustainable construction practices[77].

According to the Waste and Resources Action Programme (WRAP), stakeholders such as the owner or client, consultants and contractors play pivotal roles in either enhancing or hindering the effectiveness of demolition waste management.Owners or clients set the tone by establishing project goals, priorities and expectations regarding waste reduction and resource recovery. Consultants contribute by providing expertise in waste management strategies, conducting assessments and integrating sustainable practices into project planning and design. Contractors, on the other hand, are responsible for implementing waste management plans, executing demolition activities and ensuring compliance with waste reduction targets and regulations. Effective communication, collaboration and accountability among these stakeholders are essential for achieving successful demolition waste management outcomes, optimizing resource utilization and minimizing environmental impacts throughout the project life cycle[78].

In completing a project, the responsibilities of stakeholders are as follows: the owner or client provides the necessary funds and conceptual idea for the project, setting project goals and expectations. Consultants are tasked with estimating, designing and overseeing the project, translating the client's vision into detailed plans and specifications while ensuring compliance with regulations and industry standards. Contractors, on the other hand, are responsible for executing the construction work based on the provided drawings, designs and specifications, managing labor, materials and equipment to deliver the project according to agreed-upon schedules and quality standards. Effective collaboration and communication among these stakeholders are essential for achieving project success, meeting objectives and delivering value to all parties involved [79, 80].

The stages of the Product Life Cycle (PLC) are indeed crucial as they offer valuable insights into the factors influencing demolition waste generation, aiding stakeholders in comprehending and addressing this issue in their daily practices. Initially, shortcomings in the bidding process or bidding documents can indeed contribute to waste generation during the planning stage. Incomplete or inaccurate project specifications, insufficient consideration of waste management strategies and lack of emphasis on sustainable practices in bidding documents can lead to sub-optimal decision-making and inefficient resource utilization. By recognizing and addressing these challenges early in the planning process, stakeholders can mitigate waste generation, optimize resource recovery and promote sustainable demolition practices throughout the project life cycle [81, 82].

Estimating the demolition quantity accurately at the initial stage is crucial as it can substantially enhance project efficiency and outcomes. Accurate estimation allows stakeholders to plan effectively, allocate resources efficiently and minimize potential disruptions during the demolition process. With precise quantity estimates, project time-lines can be optimized, material procurement can be streamlined and waste management strategies can be tailored to specific project requirements. Additionally, accurate estimation helps in identifying potential challenges and risks early on, enabling stakeholders to develop proactive mitigation plans and ensure project success. By prioritizing accurate estimation at the initial stage, stakeholders can improve project efficiency, reduce costs and enhance overall project outcomes[83, 84].

Not having a demolition waste management plan in the bidding documents for a road project makes it hard to manage waste properly during the project. Without clear guidelines, contractors and project managers might not handle waste efficiently, leading to environmental impacts, higher costs and problems with waste disposal laws. Including detailed waste management instructions in the bidding documents is crucial for ensuring proper waste handling throughout the project. While it may not legally force contractors to follow a waste management plan, it's essential for promoting sustainable practices and reducing negative impacts on the environment and project results[85]. Furthermore, inadequate or incomplete waste management plans during the planning stage can indeed lead to inefficient handling and disposal of demolition waste during project execution. Incomplete or inaccurate estimates, drawings and bidding documents can cause waste throughout a project. When these key documents lack detail, misunderstandings and mistakes can occur during construction or demolition. Contractors might encounter unexpected issues, leading to wasted materials from incorrect or excessive orders and necessary adjustments for missing information. Therefore, it's crucial to ensure that estimates, drawings and bidding documents are thorough and detailed to minimize waste and enhance project efficiency. Comprehensive documentation aids in better planning, resource allocation and decision-making, ultimately resulting in more sustainable and cost-effective project outcomes[86]. A significant drawback in project administration often stems from the lack of proper documentation throughout the project life-cycle, spanning from the initial steps to project delivery. This deficiency in documentation can lead to confusion, miscommunication and inefficiencies, hindering project progress and outcomes. To address this issue, it's crucial to emphasize guidance for upcoming projects to ensure thorough and comprehensive documentation at every stage of the project. This includes documenting key decisions, milestones, project requirements, communication channels and any changes or updates that occur throughout the project life-cycle. By prioritizing robust documentation practices, project teams can enhance transparency, accountability and knowledge sharing, ultimately improving project management effectiveness and ensuring successful project delivery. This emphasis on comprehensive documentation serves as a foundational aspect of efficient project administration, facilitating better decision-making, risk management and stakeholder engagement throughout the project life-cycle [87, 88].

2.4.1.1 Causes of Waste Generation During the Design Stage

Inadequate consideration of demolition and waste management during the design phase can lead to inefficiencies in material usage. Designing structures with complex configurations or materials that are difficult to dismantle and recycle contributes to increased demolition waste. The selection of non-recyclable or non-reusable materials in construction designs also leads to higher volumes of waste during demolition. Furthermore, failing to account for salvageable materials and recycling potential in initial material specifications increases waste generation. By involving stakeholders from various disciplines early in the planning process, efforts can focus on selecting appropriate sustainable materials to minimize waste generation and maximize resource recovery. Integrating considerations for material recyclability and re-usability into project designs helps mitigate environmental impacts and optimize project outcomes. Comprehensive planning and integration of waste management strategies during the design phase ensure project success while promoting sustainability.

Research indicates that decisions made during the design stage significantly impact waste generation during construction. For instance, a study found that architects often lack awareness of the implications their design choices have on waste generation, leading to increased construction waste [89]. Additionally, intricate detailing and the use of non-standard components can complicate construction processes, resulting in material wastage [90]. Therefore, adopting a Design Out Waste (DOW) strategy, which involves early collaboration among stakeholders and careful material selection, is crucial for minimizing waste and enhancing sustainability in construction projects[89].

2.4.1.2 Minimizing Waste Generation through Thoughtful Design

A significant step toward sustainable construction is reducing waste generation at its source. By integrating careful planning and well-thought-out design practices, it is possible to optimize resource utilization, reduce material wastage and improve overall project efficiency. Thoughtful design not only minimizes waste but also contributes to cost savings and environmental sustainability in construction projects.

The design of a project is indeed critical for achieving optimal outcomes and involving all project stakeholders during the planning stage of a road project is essential. Selection of non-recyclable or non-reusable materials in construction designs can lead to higher volumes of waste during demolition. Lack of consideration for salvageable materials and recycling potential in the initial material specifications can also contribute to increased waste generation. By involving stakeholders from various disciplines early in the planning process, efforts can be concentrated on selecting appropriate sustainable materials that minimize waste generation and maximize resource recovery. This collaborative approach facilitates informed decision-making, promotes sustainable practices and ensures that project designs align with waste reduction goals and environmental objectives. Ultimately, integrating considerations for material recyclability and re-usability into project designs can help minimize waste, reduce environmental impact and optimize project outcomes[91, 92].

Inadequate consideration of demolition and waste management during the design phase can indeed lead to inefficiencies in material usage. Designing structures with complex configurations or materials that are difficult to dismantle and recycle contributes to increased demolition waste. Many researchers emphasize that the success of a project depends significantly on its design and execution. If there are changes observed in the design or scope of the project, the project can suffer. Similarly, changes in these aspects can also impact the waste produced during the project. Therefore, comprehensive planning and consideration of demolition and waste management strategies during the design phase are essential to minimize waste generation, optimize material usage and ensure project success. This underscores the importance of integrating sustainability principles into the design process to mitigate environmental impacts and promote resource efficiency throughout the project life cycle[93, 94].

2.4.2 Execution Stage

During the execution stage of a road project, effective demolition waste management entails coordinated efforts to carry out demolition activities while implementing waste reduction and recycling strategies established during the planning phase. This involves executing demolition operations according to project specifications, sorting and segregating materials to maximize resource recovery, salvaging reusable materials, responsibly disposing of non-recyclable waste, monitoring compliance with safety and environmental regulations and maintaining detailed documentation to track progress and ensure accountability. By prioritizing efficient waste management practices during the execution stage, stakeholders can minimize environmental impact, optimize resource utilization and achieve project objectives effectively.

Many researchers have highlighted the significant impact of stakeholder collaboration on demolition waste management, underscoring its dependency on the alignment between stakeholders to mitigate risks of schedule delays, cost overruns and scope creep. When stakeholders are not adequately aligned in their objectives, communication, or decision-making processes, it can lead to inefficiencies and challenges in waste management. For instance, conflicting priorities among stakeholders may result in delays in obtaining necessary permits or approvals, which can prolong project time-lines and increase waste generation. Similarly, disagreements over project scope or specifications may lead to changes in demolition plans, resulting in additional waste generation and disposal requirements. Therefore, fostering strong collaboration and communication among stakeholders is crucial to address these issues effectively. By promoting a shared understanding of project goals, priorities and expectations, stakeholders can work together to implement proactive waste management strategies, optimize resource utilization and achieve successful project outcomes[82, 93].

Waste generation is significantly influenced by frequent changes in project scope or last-minute alterations, which can lead to inefficiencies and increased waste during project execution. When project scope changes occur unexpectedly, it can disrupt established demolition plans, resulting in the need to revise schedules, procure additional materials, or adjust demolition methods. These changes often lead to inefficiencies in resource utilization, as materials that were previously allocated for specific tasks may no longer be suitable or required, contributing to increased waste generation. Additionally, last-minute alterations may necessitate the removal of newly installed materials or structures, further exacerbating waste generation. Therefore, it is essential for project stakeholders to carefully consider and communicate any proposed changes to project scope to minimize their impact on waste generation and ensure efficient project execution. Proactive planning, regular communication and effective change management processes are key to mitigating the adverse effects of scope changes on demolition waste management and optimizing project outcomes [86]. Frequent changes in project scope can indeed disrupt or even lead to the neglect of the waste management plan, significantly contributing to increased waste generation. When project scope changes occur, resources and attention may be diverted away from waste management activities, leading to inadequate planning, oversight and implementation of waste reduction strategies. As a result, materials may be handled inefficiently, recyclable materials may be overlooked and waste may be disposed of improperly. Additionally, the lack of alignment between the revised project scope and the waste management plan can lead to mismatches in resource allocation and waste handling practices, further exacerbating waste generation. Therefore, it is essential for project stakeholders to prioritize the integration of waste management considerations into all stages of the project, including during scope changes, to minimize the impact on waste generation and promote sustainable project outcomes. This underscores the importance of proactive planning, effective communication and robust change management processes in addressing the challenges posed by frequent changes in project scope on waste management[86, 92].

A significant amount of waste is indeed generated due to a lack of properly trained staff and labor, as well as inadequate provision of necessary equipment. Insufficient training may result in inefficient work practices, improper handling of materials and increased likelihood of accidents or errors leading to waste generation. Additionally, the absence of essential equipment or tools may hinder the ability to execute tasks efficiently, potentially resulting in material damage, overuse, or unnecessary waste production. Research sources indicate that strict supervision can play a crucial role in mitigating waste generation by ensuring that workers are adequately trained, equipped and supervised to perform their tasks effectively and efficiently. Through regular monitoring, guidance and enforcement of best practices, supervisors can identify and address issues promptly, optimize resource utilization and minimize waste generation on construction sites. Therefore, investing in training programs, providing necessary equipment and implementing stringent supervision practices are essential strategies for reducing waste and improving overall project performance [85, 94].

Proper storage, salvaging, or returning of waste or remaining materials can significantly contribute to reducing waste generation, as supported by findings from research sources. Implementing effective waste management practices, such as segregating and storing reusable or recyclable materials, facilitates their salvage and reuse in future projects or alternative applications, minimizing the need for new materials and reducing waste generation. Additionally, returning excess materials to suppliers or recycling facilities helps prevent unnecessary waste disposal and promotes resource recovery. By prioritizing these strategies, construction projects can optimize material utilization, reduce environmental impact and achieve cost savings. Therefore, integrating storage, salvaging and return mechanisms into waste management plans is essential for promoting sustainability and minimizing waste generation in construction activities [10, 84].

2.4.3 Monitoring & Control Stage

To establish monitoring and evaluation mechanisms for assessing demolition waste performance and identifying opportunities for continuous improvement throughout the project life cycle, it's essential to define key performance indicators (KPI's), develop a comprehensive monitoring plan, implement data collection processes, analyze performance data, identify improvement opportunities, implement action plans, monitor progress and communicate results to stakeholders. By systematically assessing demolition waste performance and identifying areas for enhancement, project teams can optimize resource utilization, minimize environmental impact and foster continuous improvement in waste management practices. By addressing the causes of demolition waste at each stage of the project life-cycle assessment and implementing targeted mitigation strategies, project stakeholders can optimize resource utilization, reduce environmental impact and enhance overall project sustainability.

According to many researchers, demolition waste is largely influenced by the alignment of stakeholders, as discrepancies can lead to time, cost and scope overruns. Therefore, fostering collaboration and communication among stakeholders is crucial to minimize waste generation and achieve project objectives efficiently. Through proactive planning, effective coordination and stakeholder engagement, construction projects can mitigate the adverse effects of demolition waste and promote sustainable practices throughout the project life cycle[82, 93]. Waste generation is also influenced by frequent changes in project scope or last-minute alterations, which can indeed contribute to inefficiencies and increased waste during project execution. When project scope changes occur unexpectedly, it can disrupt established plans and lead to adjustments in materials, resources and schedules. These alterations often result in inefficiencies in resource utilization, as materials may become redundant or misaligned with the revised project scope. Moreover, last-minute changes can necessitate rushed or improvised demolition methods, increasing the likelihood of material damage or waste generation. Therefore, minimizing changes to project scope and ensuring thorough planning and coordination are essential to mitigate the impact of scope changes on waste generation and promote efficient project execution[86].

The cause of demolition waste primarily hinges on the timely identification and quantification of waste, as noted by research. Efficient waste management relies on accurately assessing the types and quantities of materials generated during demolition activities. Failure to promptly identify and quantify waste can lead to inadequate planning and implementation of waste management strategies, resulting in inefficient resource utilization and increased waste generation. Therefore, prioritizing comprehensive waste characterization and quantification processes is essential for effective demolition waste management, enabling stakeholders to develop targeted mitigation measures and optimize resource recovery efforts throughout the project life-cycle [10, 86], This waste can indeed be reduced by leveraging Information Technology (IT) for waste identification and quantification, as supported by studies.

IT tools and technologies, such as Building Information Modeling (BIM), Geographic Information Systems (GIS) and waste tracking software, offer powerful capabilities for accurately capturing, analyzing and managing data related to demolition waste. BIM, for instance, enables stakeholders to create digital representations of structures, facilitating the visualization and assessment of materials throughout the project life-cycle. GIS allows for spatial analysis and mapping of waste generation patterns, aiding in the identification of hot-spots and optimization of waste collection and disposal routes. Additionally, waste tracking software provides real-time monitoring and tracking of waste streams, enhancing transparency and accountability in waste management practices. By harnessing IT solutions for waste identification and quantification, project stakeholders can improve decision-making, optimize resource utilization and minimize waste generation, ultimately leading to more sustainable and efficient demolition practices [88, 95, 96].

Subsequently, sorting the waste based on type using suitable methods or techniques aligned with site capabilities can indeed further aid in waste reduction, as highlighted by research. Implementing effective waste sorting practices allows for the segregation of materials into categories such as recyclable, reusable and non-recyclable, enabling targeted waste management strategies. Various sorting methods, including manual sorting by workers, automated sorting systems and mechanical separation processes, can be employed based on the scale and complexity of the project and the available resources. By segregating waste at the source and utilizing appropriate sorting techniques, project stakeholders can optimize resource recovery, minimize landfill disposal and reduce overall waste generation. This approach not only promotes environmental sustainability but also enhances cost-effectiveness and regulatory compliance in demolition waste management. Therefore, integrating waste sorting practices into demolition projects is essential for maximizing diversion rates and achieving sustainable waste management outcomes[10, 97].

After sorting the waste, the next critical step involves proper storage and handling of the waste. Adequate storage facilities and procedures are essential to ensure that sorted materials are protected from contamination, weather damage and unauthorized access. Additionally, proper handling practices, including the use of appropriate equipment and personal protective gear, are necessary to prevent accidents, injuries and environmental hazards during transportation and storage. By implementing robust storage and handling protocols, project stakeholders can maintain the quality and integrity of sorted materials, facilitate efficient waste management operations and minimize the risk of adverse impacts on human health and the environment. This emphasis on proper storage and handling of waste underscores the importance of comprehensive waste management planning and execution in demolition projects [10, 93, 98].

Another significant factor contributing to waste generation is the practice of subcontract awarding or subletting, which can result in quality compromises and the need for redoing work due to the use of substandard materials, ultimately leading to waste and time consumption. When subcontractors are involved in project tasks, there may be variations in work standards, material specifications and quality control measures, increasing the likelihood of errors, rework and waste generation. Additionally, subcontractors may prioritize cost savings over quality, opting for cheaper or inferior materials that are more prone to defects or failures, further exacerbating waste generation and inefficiencies. Therefore, effective oversight, quality assurance measures and clear communication between primary contractors and subcontractors are essential to minimize the risk of waste associated with subcontracting practices. By fostering collaboration and accountability among all project stakeholders, construction projects can mitigate the adverse effects of subcontracting on waste generation and promote sustainable project outcomes [91, 98].

Implementing the principles of 3R (Reduce, Reuse, Recycle) is indeed an effective strategy for demolition waste minimization, as recommended by many researchers in their work. The 3R approach focuses on reducing the generation of waste at the source, promoting the reuse of materials whenever possible and maximizing the recycling of materials to divert them from landfills. By prioritizing waste reduction, reuse and recycling throughout the project life-cycle, stakeholders can minimize the environmental impact of construction and demolition activities, conserve natural resources and reduce overall waste generation. This holistic approach aligns with sustainable development goals and promotes responsible resource management practices. Therefore, integrating the principles of 3R into demolition waste management strategies is essential for achieving long-term environmental sustainability and improving the efficiency and effectiveness of construction projects[99, 100].

2.4.4 Variables Related to causes of Demolition Waste Generation

In relation to above sub-section. Table 2.1 shows the details various Variables related to cause of demolition waste generation and table 2.2 shows the reasons why it is an impact and its severity level.

TABLE 2.1: Causes of Demolition Waste Generation

Causes / Variable	Country	References
Pre-Demolition audit at planning stage.	Not Specified	[83, 92, 101]
Role of supervision Skills	Central Asia	[84, 85, 93, 94, 102]
Errors and omissions in contract documents, need to be Revised contractual clauses	Not Specified	[82, 93]
Promoting sustainable material while designing	Dev. countries	[91, 103]
Implementation of lesson learnt.	Dev. countries	[87, 88]
Role of 3R (Reduce, Reuse, Recycle) strategy.	Iran	[99, 100]
Waste generation due to poor workmanship.	Hong Kong	[86, 94]
Discrepancies in Bidding document	Not Specified	[82, 93]
Incorporation of Demolition Waste Management in bidding process.	Central Asia	[85]
Incomplete Bidding documents before tendering	Hong Kong	[86]
Scope/design Changes	Hong Kong	[86, 93, 94]
Identification and quantification of Demolition waste.	Hong Kong	[9, 86, 93, 98]
Coordination and Communication Among Stakeholders.	Hong Kong	[86, 92]
Utilization of sub-standard materials resulting in wastage.	Not Specified	[91, 103]
Inadequacy of implementation in waste management plan.	Hong Kong	[82, 84, 86]

Inappropriate storage for unused construction materials.	Canada	[9, 86]
Impact of eleventh-hour change of scope.	Hong Kong	[86]
Coordination and Communication gap among stakeholders.	Not Specified	[82, 85]
Role of I. T in Demolition Waste Management mechanism.	Not Specified	[88, 96]
Consideration of site storage and space availability.	Portugal	[9, 84, 98]
Impact of on-Site Sorting Techniques.	Philippines	[9, 104]
Impact of sub-letting / subcontracting.	Not Specified	[9, 86, 93]
Contract modification due to discrepancies.	Philippines	[86, 105]

Table 2.2 shows the reasons why it is an impact and its severity level.

TABLE 2.2: Causes of Demolition Waste Generation-Impact Reasons and Severity Levels

Causes / Variable	**Reason(s) Why It Is an Impact**	**Severity Level**
Pre-Demolition Audit at Planning Stage	Identify potential waste, enabling proper planning for reduction and management.	High
Role of Supervision Skills	Ensures monitoring and compliance with best practices to reduce waste during construction and demolition.	High
Errors and Omissions in Contract Documents	Leads to discrepancies, unclear expectations and inefficiencies, causing significant waste.	High
Promoting Sustainable Material in Design	Reduces reliance on resource-intensive materials, supporting environmental sustainability.	High
Implementation of Lessons Learned	Prevents repeated mistakes and improves waste management practices over time.	High

Waste Generation Due to Poor Workmanship	Results in unnecessary material waste due to low-quality work and lack of skill.	High
Discrepancies in Bidding Documents	Creates confusion during project execution, leading to mismanagement of resources and waste.	Medium
Incomplete Bidding Documents Before Tendering	Causes delays and errors in planning, increasing the risk of waste during project execution.	Medium
Scope/Design Changes	Introduces unexpected waste due to redesign or rework requirements.	Medium
Identification and Quantification of Demolition Waste	Allows for better planning, segregation and recycling of materials.	Medium
Coordination and Communication Among Stakeholders	Miscommunication leads to inefficiencies in waste management practices.	Medium
Utilization of Sub-Standard Materials	Increases waste due to poor durability and material quality.	Medium
Inadequacy of Waste Management Plan Implementation	Reduces the effectiveness of waste reduction efforts.	Medium
Inappropriate Storage for Unused Materials	Damages materials, reducing the chance for reuse or recycling.	Medium
Impact of Eleventh-Hour Scope Changes	Introduces unforeseen waste due to last-minute alterations in project requirements.	Medium
Coordination and Communication Gaps	Limits stakeholder alignment, leading to inefficiencies and waste in demolition projects.	Medium
Role of I.T in Demolition Waste Management	Enhances monitoring, reporting and optimization of waste management practices.	Medium

Consideration of Site Storage and Space Availability	Poor planning leads to material damage or loss, increasing waste.	Medium
Impact of On-Site Sorting Techniques	Inefficient sorting increases the likelihood of contamination and limits recycling opportunities.	Medium
Impact of Sub-Letting/Subcontracting	Lack of direct oversight often results in suboptimal waste management practices.	Medium
Contract Modification Due to Discrepancies	Changes in contracts lead to rework and increased waste.	Medium

2.5 Impacts of Demolition Waste

The impacts of demolition waste can be significant and wide-ranging, affecting the environment, society and economy. Understanding these impacts is crucial for implementing effective waste management practices and promoting sustainable development. Here's a breakdown of the environmental, social and economic impacts of demolition waste:

2.5.1 Environmental Impacts of Demolition wastes

Roads undoubtedly play a critical role in transportation networks, especially as more consumers rely on automobiles for daily travel. However, the extensive road network also has significant detrimental environmental effects, including contributing to global warming through emissions of greenhouse gases such as carbon dioxide. Moreover, roads increase energy use, both directly through vehicle fuel consumption and indirectly through the construction and maintenance processes.

Land transformation associated with road construction can lead to habitat loss and fragmentation, threatening biodiversity and ecological balance. Additionally, the use of certain construction materials and runoff from roads can contribute to soil and water acidification, further impacting ecosystems and aquatic life. Addressing these environmental impacts requires sustainable transportation planning and infrastructure development, integrating measures to mitigate emissions, minimize habitat disruption and promote eco-friendly construction practices. By prioritizing environmental considerations in road development, that can work towards more sustainable transportation systems that meet societal needs while minimizing environmental harm [106].

Landfills for waste disposal poses its own environmental challenges, including the risk of soil and groundwater contamination from leachate produced by decomposing waste. Landfills must be carefully engineered and managed to minimize these risks through measures such as liners, leachate collection systems and monitoring programs. Additionally, the consumption of resources such as green land for landfill development can lead to habitat loss and fragmentation, disrupting ecosystems and biodiversity. To address these issues, it's essential to prioritize sustainable waste management practices that prioritize waste reduction, reuse and recycling to minimize the volume of waste sent to landfills. Additionally, alternative disposal methods such as incineration or resource recovery should be considered to further reduce environmental impacts. Overall, a holistic approach to waste management that considers environmental, social and economic factors is essential to mitigate soil contamination and promote sustainable development [26, 107].

Water pollution due to demolition wastes of roads can occur through various mechanisms. When roads are demolished, construction debris and sediment containing pollutants such as heavy metals, hydrocarbons and chemicals can be washed into nearby water bodies during rainfall events. This runoff can carry contaminants into rivers, streams and groundwater, leading to water pollution. Additionally, if demolition waste is improperly disposed of in landfills or dumped illegally, leachate containing pollutants can seep into the surrounding soil and groundwater, further contributing to water pollution. To mitigate water pollution from demolition wastes of roads, proper waste management practices should be implemented, including containment measures to prevent runoff, sediment control techniques such as silt fences and erosion blankets and proper disposal or recycling of demolition materials. Additionally, regular monitoring and enforcement of regulations are essential to ensure compliance with environmental standards and protect water quality. Collaboration among stakeholders, including government agencies, contractors and communities, is crucial to effectively address water pollution issues associated with road demolition activities[106, 108] and also creating dust generation and air contamination [105, 109].

Demolition waste can pose a significant risk to groundwater quality by leaching harmful chemicals and minerals into underground water sources. When demolition waste, which may contain various contaminants such as heavy metals, asbestos, petroleum products and construction chemicals, is improperly managed or disposed of, rainwater or groundwater can percolate through the waste, picking up these pollutants. As a result, contaminated leachate can infiltrate the soil and eventually reach groundwater reservoirs, leading to groundwater pollution. This contamination poses serious risks to human health and the environment, as groundwater serves as a vital source of drinking water for many communities and supports ecosystems. To mitigate this risk, it's crucial to implement proper waste management practices, including containment measures, waterproof liners and leachate collection systems at disposal sites. Additionally, regular monitoring of groundwater quality and enforcement of regulations are essential to detect and address contamination issues promptly.

By prioritizing responsible waste management practices, that can safeguard groundwater resources and protect public health and the environment from the adverse impacts of demolition waste[104, 107]. Thirdly, Waste generation not only involves leftover building materials but also contributes to the wastage of natural resources, increasing energy consumption and the use of construction materials [83, 110]. Fourthly, Improper waste disposal and deposition instead of utilization contribute to energy consumption and greenhouse gas emissions through transportation [64, 111].

Greenhouse gas emissions, particularly methane, indirectly contribute to global warming by trapping heat in the Earth's atmosphere and causing the greenhouse effect. Methane is a potent greenhouse gas with a much higher heat-trapping potential than carbon dioxide over a shorter time frame, although it persists in the atmosphere for a shorter duration. While methane is emitted from various natural sources such as wetlands and livestock, human activities, including the decomposition of organic waste in landfills, agricultural practices and the production and transport of fossil fuels, are significant contributors to methane emissions.

In the context of demolition waste, methane emissions can occur during the decomposition of organic materials such as wood, paper and food waste disposed of in landfills. These emissions contribute to the greenhouse effect, leading to global warming and climate change. Therefore, reducing methane emissions from demolition waste through waste diversion, recycling and organic waste management practices is essential for mitigating its indirect contribution to global warming and promoting environmental sustainability [91].

Marine life, including fish, marine mammals and coral reefs, is also vulnerable to the impacts of climate change, with rising sea temperatures, ocean acidification and habitat degradation affecting biodiversity, reproductive cycles and the health of marine ecosystems. Additionally, extreme weather events and sea-level rise associated with climate change can further exacerbate the challenges faced by animals and marine life, leading to population declines, species extinctions and ecosystem collapse. Therefore, mitigating greenhouse gas emissions and addressing climate change through sustainable practices and conservation efforts are essential for protecting animals and marine life and promoting global biodiversity and ecosystem health [112].

The deposition of demolition waste on green land can indeed obstruct precipitation, which is crucial for recharging the water table and sustaining ecosystems. When demolition waste is improperly disposed of on green land, it can alter the natural hydro-logical processes and reduce the infiltration of rainwater into the soil. Instead of percolating into the ground and replenishing groundwater reservoirs, precipitation may run off the surface of the waste, leading to increased surface runoff and soil erosion. This obstruction of precipitation can disrupt the water cycle, diminish soil moisture levels and hinder the replenishment of aquifers and water tables, ultimately affecting water availability for plants, animals and human communities. Additionally, the accumulation of demolition waste on green land can degrade soil quality, reduce biodiversity and fragment habitats, further exacerbating the impacts on ecosystems and ecological balance. Therefore, proper waste management practices that prioritize waste reduction, recycling and responsible disposal are essential for safeguarding green land, preserving natural hydrological processes and ensuring the sustainability of water resources and ecosystems [99, 104].

2.5.2 Social Impacts of Demolition Wastes

The social impact of demolition waste management is indeed a key aspect of sustainability, with significant concerns raised about human health risks for residents living near dumping sites or areas where demolition waste is illegally disposed. Improper management of demolition waste can lead to the release of hazardous substances into the environment, contaminating air, soil and water sources. Residents living in close proximity to waste disposal sites may be exposed to pollutants through inhalation of airborne particles, ingestion of contaminated water or food and direct contact with contaminated soil. These exposures can pose serious risks to human health, leading to respiratory illnesses, skin conditions, neurological disorders and other adverse health effects. Furthermore, communities located near waste sites often experience social and economic disparities, with reduced property values, limited access to amenities and increased stigma associated with living in areas perceived as unhealthy or environmentally degraded.

Addressing the social impacts of demolition waste management requires equitable access to information, resources and decision-making processes for affected communities, as well as transparent and accountable governance structures. By prioritizing community engagement, public health protection and environmental justice principles, that can mitigate the social risks associated with demolition waste management and promote inclusive and sustainable development for all [92, 103].

Moreover, ensuring the health and safety of individuals is paramount and this can be compromised by the effects of demolition waste. The improper handling, disposal, or exposure to demolition waste can pose significant risks to human health, including respiratory issues, skin irritation and long-term health complications due to exposure to hazardous substances. Additionally, accidents or structural failures during demolition activities can result in injuries or fatalities for workers and nearby residents. Furthermore, the presence of demolition waste in communities can create environmental hazards, attract pests and contribute to the spread of diseases. Therefore, prioritizing comprehensive risk assessment, proper waste management practices and stringent safety protocols are essential to safeguarding the health and well-being of individuals and communities affected by demolition activities. By implementing proactive measures to mitigate health and safety risks associated with demolition waste, that can create safer environments and promote the overall well-being of society [113, 114].

Sustainable development definitely relies on addressing the social, environmental and economic impacts caused by demolition waste. By adopting holistic approaches to demolition waste management, stakeholders can mitigate adverse effects on communities, ecosystems and economies while promoting long-term sustainability. Socially, sustainable demolition practices prioritize public health and safety, community engagement and equitable access to resources and decision-making processes, ensuring that the needs and concerns of all stakeholders are addressed. Environmentally, sustainable demolition waste management minimizes habitat destruction, reduces pollution, conserves natural resources and protects biodiversity, fostering resilient ecosystems and mitigating climate change impacts. Economically, sustainable practices optimize resource utilization, minimize waste generation and create opportunities for job creation, innovation and cost savings, contributing to economic growth and resilience.

By integrating social, environmental and economic considerations into demolition waste management strategies, stakeholders can achieve sustainable development goals and create healthier, more equitable and more prosperous communities for present and future generations[91, 103].

Effective coordination and communication among stakeholders are indeed vital for the success of any project, particularly in demolition waste management, where stakeholder attitudes play a crucial role. By fostering collaboration, transparency and mutual understanding among stakeholders, project teams can align their objectives, address concerns and develop consensus-driven solutions that promote sustainability and meet the needs of all parties involved. Clear communication channels, regular meetings and inclusive decision-making processes facilitate the exchange of information, feedback and ideas, enabling stakeholders to contribute their expertise, perspectives and resources to the project. Additionally, cultivating positive stakeholder attitudes towards demolition waste management requires proactive engagement, education and awareness-building initiatives that highlight the benefits of sustainable practices, address misconceptions and address potential conflicts of interest. By prioritizing effective coordination and communication among stakeholders, project teams can overcome challenges, build trust and achieve shared goals, ultimately enhancing the success and impact of demolition waste management initiatives [85, 115].

Managing demolition waste is indeed a complex task that necessitates additional human resources to uphold social viability. Beyond the technical aspects of waste sorting, recycling and disposal, addressing the social dimensions of demolition waste management requires a dedicated workforce. This entails personnel responsible for community engagement, ensuring transparent communication and addressing concerns from affected stakeholders. Moreover, promoting awareness and education about sustainable waste management practices demands human resources dedicated to outreach and advocacy efforts. By allocating sufficient human resources to manage demolition waste comprehensively, organizations can ensure that social considerations are integrated into waste management strategies, thereby fostering community acceptance and support for sustainable practices [91, 108, 116], So, managing demolition waste comprehensively can lead to increased energy consumption. Transporting waste materials to recycling facilities, operating sorting and processing machinery and implementing advanced waste management technologies all require energy inputs. Additionally, recycling and re-purposing materials often involve energy-intensive processes such as shredding, melting and re-manufacturing. However, it's important to note that while the initial stages of waste management may require additional energy, the long-term environmental benefits of recycling and reusing materials can outweigh these costs. By reducing the demand for virgin resources and minimizing the need for landfill disposal, sustainable waste management practices contribute to energy conservation and mitigate the environmental impacts of resource extraction and waste generation. Therefore, while increased energy consumption may be a short-term consideration, the overall sustainability benefits of comprehensive demolition waste management are significant in the long run [115, 116].

Demolition waste generation can indeed contribute to noise pollution and vibrations, which can be disruptive to nearby communities. However, these impacts can be effectively mitigated through the implementation of proper mechanisms and the adoption of specifications designed to minimize negative effects in nearby areas. This may include employing noise barriers, using quieter equipment, scheduling demolition activities during off-peak hours and providing advance notice to affected residents. Additionally, adopting best practices and adhering to regulatory guidelines can help minimize noise and vibration levels during demolition operations.

One of the challenges in addressing these issues is often a lack of awareness regarding the social impacts of demolition waste management. By raising awareness among stakeholders, including project developers, contractors, local authorities and residents, about the potential impacts of demolition activities on nearby communities, it becomes possible to foster greater understanding and cooperation in implementing mitigation measures. Through proactive communication, engagement and education efforts, stakeholders can work collaboratively to minimize the social impacts of demolition waste management and ensure that demolition activities are conducted in a manner that is considerate of local communities and their well-being[96, 117].

Raising awareness and motivating the general public and stakeholders to implement waste sorting, recycling and reuse practices can significantly contribute to the reduction of demolition waste and the conservation of natural resources. By educating individuals about the environmental benefits of sustainable waste management practices and providing accessible recycling infrastructure and incentives, that can inspire behavior change and foster a culture of waste reduction. Through collaborative efforts and proactive engagement, that can empower communities to embrace responsible waste disposal habits, ultimately mitigating the environmental impact of demolition activities and promoting a more sustainable future [10, 108], Additionally, By prioritizing the use of reclaimed or re-purposed materials in architectural and construction projects, designers can honor cultural heritage, promote sustainable practices and reduce the environmental impact of new developments.

This approach not only conserves valuable resources but also preserves the historical significance and character of existing structures, contributing to the cultural identity and sense of place within communities. Additionally, integrating recycled materials into innovative design solutions can inspire creativity and foster a deeper appreciation for sustainability, ultimately enhancing the overall aesthetic and functionality of built environments. By embracing the principles of circular design and adaptive reuse, designers can strike a balance between honoring tradition and embracing innovation, creating spaces that are both environmentally responsible and culturally meaningful[79].

2.5.3 Economics Impacts of Demolition waste

The economic impact of waste management also includes the costs associated with the management and operation of waste management systems. These costs encompass various activities, such as waste collection, transportation, sorting, recycling, treatment and disposal. Factors influencing these costs include the size and complexity of the waste management infrastructure, the efficiency of collection and sorting processes, the availability of recycling and treatment facilities and labor and operational expenses. Additionally, investments in technology, equipment and infrastructure upgrades can impact operational costs. While these costs represent financial expenditures, they are essential for ensuring the effective and sustainable management of waste and the protection of public health and the environment. By optimizing waste management systems, streamlining operations and investing in innovative technologies, communities can minimize costs while maximizing the efficiency and effectiveness of waste management practices, ultimately achieving long-term economic and environmental benefits [116].

The financial impact associated with creating awareness about waste management practices can vary depending on the scale and scope of awareness campaigns, as well as the methods and channels used to disseminate information. Costs may include expenses related to designing and producing educational materials, organizing events and workshops, conducting outreach activities and running advertising or media campaigns. Additionally, personnel costs for staff involved in planning, implementing and evaluating awareness initiatives should be considered.

While creating awareness may entail upfront financial investments, the long-term benefits can outweigh these costs. By educating individuals and stakeholders about the importance of waste management, promoting behavior change and fostering a culture of sustainability, awareness campaigns can lead to reduced waste generation, increased participation in recycling programs and improved compliance with waste management regulations. These outcomes can result in cost savings associated with waste disposal, resource conservation and environmental protection. Furthermore, the social and economic benefits of a more informed and engaged community, including improved public health, enhanced environmental quality and increased social cohesion, contribute to the overall value of investing in awareness initiatives. Therefore, while there are financial implications, the investment in creating awareness about waste management practices can yield significant returns in terms of environmental, social and economic sustainability [91, 103].

The financial impact of recycling plants and material stockpiled is influenced by operational costs, market demand for recycled materials and revenue generated from the sale of recycled products. While recycling plants incur expenses related to equipment, labor and compliance, they also generate income from selling recycled materials. However, fluctuations in market conditions and changes in recycling markets can pose challenges, impacting profitability. Material stockpiled at recycling plants may provide flexibility but also entails costs for storage and management. Balancing operational efficiency, market dynamics and strategic management of material inventories is crucial for ensuring the economic sustainability of recycling operations and maximizing financial benefits [91, 116].

Promoting awareness and disseminating knowledge about the economic impact of waste management through recycling or reuse is essential for encouraging sustainable practices and maximizing economic benefits. By educating individuals, businesses and communities about the financial advantages of recycling and reuse, such as cost savings, revenue generation and job creation, that can motivate behavior change and foster a culture of resource conservation.
Additionally, raising awareness about the potential economic consequences of improper waste disposal, such as landfill costs, environmental cleanup expenses and lost opportunities for resource recovery, highlights the financial incentives for adopting sustainable waste management practices. Through targeted awareness campaigns, educational initiatives and outreach efforts, that can empower stakeholders to make informed decisions that not only benefit the environment but also contribute to economic prosperity and resilience [91, 118].

Providing designated landfill sites for construction waste management is a crucial aspect of sustainable waste management practices. These sites offer a controlled environment for the disposal of construction and demolition debris, ensuring that hazardous materials are properly contained and managed to prevent environmental contamination. By designating specific areas for construction waste disposal, regulatory authorities can enforce waste management regulations more effectively and monitor compliance with environmental standards. Additionally, having dedicated landfill sites for construction waste streamlines waste collection and disposal processes, reducing the risk of illegal dumping and unauthorized disposal activities. Furthermore, these sites can serve as hubs for recycling and resource recovery efforts, allowing for the separation and recovery of valuable materials from construction waste streams. Overall, providing designated landfill sites for construction waste plays a crucial role in promoting responsible waste management practices, protecting public health and the environment and supporting sustainable development initiatives [114].

Providing designated landfill sites for construction waste management can also lead to job creation. The establishment and operation of these sites require various personnel, including site managers, waste handlers, equipment operators, maintenance staff and administrative personnel. Additionally, the development of recycling and resource recovery facilities within or adjacent to landfill sites can create additional employment opportunities in industries such as material sorting, processing and transportation. Moreover, as construction waste management practices evolve to prioritize recycling, reuse and recovery, there is a growing demand for skilled workers in areas such as sustainable construction, waste diversion and environmental remediation.By investing in designated landfill sites and associated waste management infrastructure, communities can not only address environmental challenges but also stimulate economic growth, support local businesses and create job opportunities in the green economy [96, 117].

2.5.4 Variables Related to Impacts of Demolition Waste Management

In relation to the above sub-section, Table 2.3 presents a comprehensive overview of the various variables associated with the impacts of demolition waste management. These variables encompass environmental, economic, and social dimensions, highlighting the multifaceted nature of demolition waste and its influence on sustainable development.

Furthermore, Table 2.4 provides an in-depth analysis of the underlying reasons each variable is considered impactful, along with an assessment of the severity level of these impacts. This classification aids in understanding the relative importance of each variable and supports the prioritization of mitigation strategies in sustainable demolition waste practices.

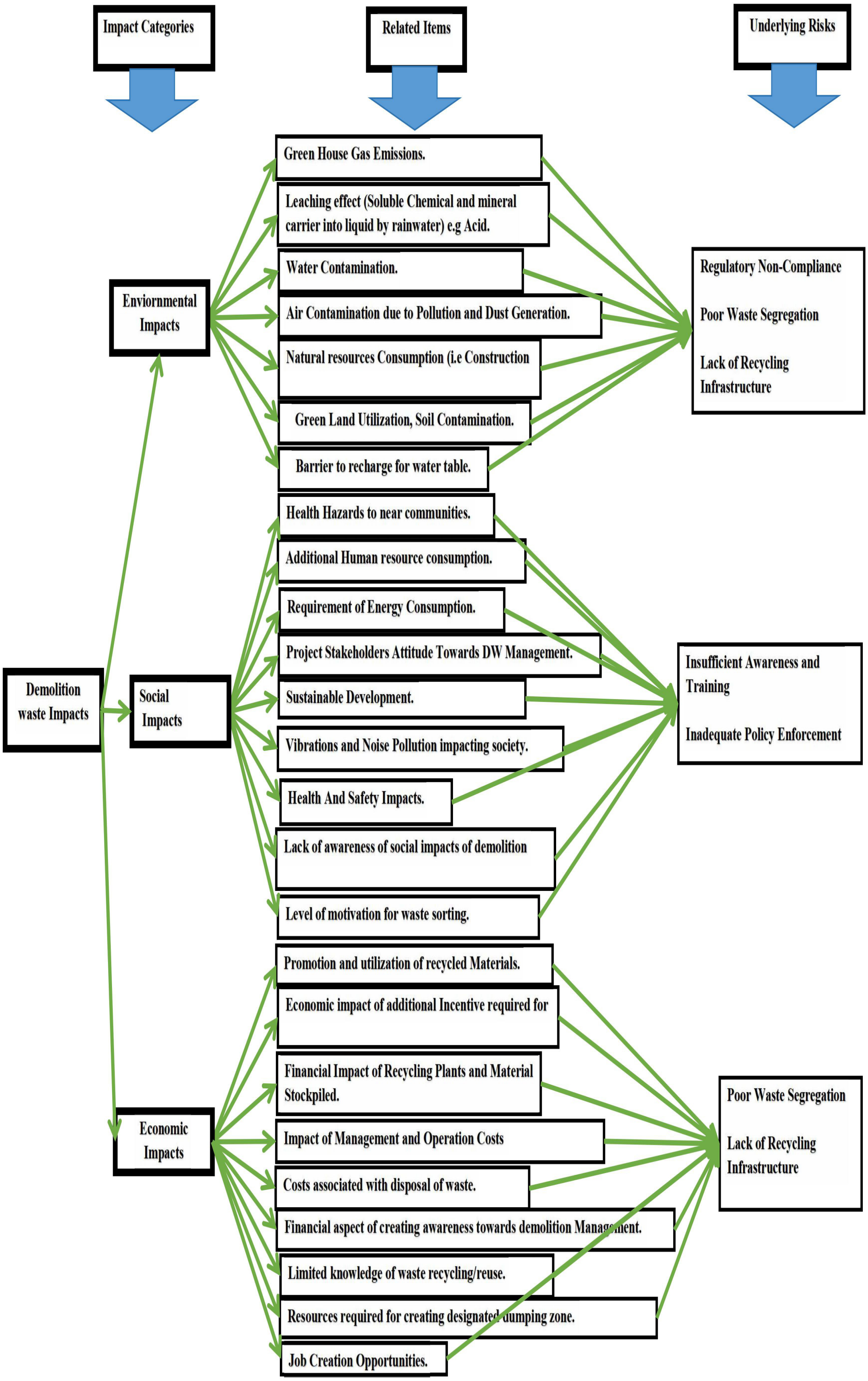

Figure 2.5: Impact Categories and their underlying Risks

TABLE 2.3: Impacts of Demolition Waste Management

Impacts / Variables	Country	References
Barrier to recharge for water table.	Iran, Brazil	[99, 103, 104, 112, 118]
Air Contamination due to Pollution and Dust Generation.	Malaysia	[64, 105, 109, 119]
Indirect Impact on creation Climate Change (e.g., Methane Gas etc.)	Malaysia, Australia	[64, 87, 91, 111, 117]
Requirement of Energy Consumption	China	[64, 91, 108, 115, 116]
Vibrations and Noise Pollution impacting society.	Pakistan	[91, 118]
Financial Impact of Recycling Plants and Material Stockpiled.	Not specified	[91, 117]
Impact of Management and Operation Costs	China	[64, 91, 103, 115, 116]
Limited knowledge of waste recycling/reuse	Pakistan	[91, 118]
Level of motivation for waste sorting / reusing.	China	[9, 108]
Consideration of conservative cultural aspects during construction design.	Sri Lanka	[79]
Green House Gas Emissions.	Philippines, Peru	[64, 91, 105, 111, 117]
Leaching effect (extraction of soluble Chemical and mineral carrier into liquid by rainwater) e.g., Acid.	Saudi Arabia, Kuwait	[94, 96, 103, 107, 117, 120]
Water Contamination	China, Pakistan	[64, 91, 108, 118]
Job Creation Opportunities	Saudi Arabia, Kuwait	[96, 103, 117, 119, 120]
Natural resources Consumption (i.e., Construction material)	Finland, Europe, Australia, China	[83, 103, 110, 121–124]

Green Land Utilization, Soil Contamination	Philippines,Finland	[64, 103, 104, 108, 110, 125]
Sustainable Development	Not specified	[91, 103]
Impact of biodiversity (e.g., Harm Towards Animal and Marine Life).	Philippines, Malaysia, Peru, Australia	[64, 91, 105, 111, 117]
Additional Human resource consumption	China	[91, 108, 116]
Health Hazards to near communities.	China,Vietnam	[92, 103, 113, 114, 126]
Health And Safety Impacts	China,Vietnam	[9, 92, 103, 113, 114]
Lack of awareness of social impacts of demolition wastes.	Saudi Arabia,Kuwait	[96, 103, 117, 119, 120]
Project Stakeholders Attitude Towards DW Management	China,Portugal	[9, 85, 87, 98, 115]
Costs associated with disposal of waste	China,Portugal	[9, 85, 87, 98, 115]
Resources required for creating designated dumping zone.	China,Vietnam	[9, 92, 103, 113, 114]
Economic impact of additional Incentive required for proper Waste Management.	China,Vietnam	[9, 92, 103, 113, 114]
Financial aspect of creating awareness towards demolition Management.	Not specified	[91, 103]
Promotion and utilization of recycled Materials.	Australia	[127]

Table 2.4 provides a detailed explanation of the reasons behind the classification of each variable as an impact in the context of demolition waste management for the road projects.

Table 2.4: Impacts of Demolition Waste-Reasons and Severity Levels

Variables	Reason(s) Why It Is an Impact	Severity Level
Barrier to recharge for water table	Demolition waste can block or disrupt natural water filtration and absorption, affecting groundwater recharge.	High
Air Contamination due to Pollution and Dust Generation	Dust and pollutants from demolition activities contribute to poor air quality and respiratory health issues.	High
Indirect Impact on Climate Change (e.g., Methane Gas, etc.)	Demolition waste releases greenhouse gases like methane, contributing to global warming.	High
Requirement of Energy Consumption	The processing and transportation of demolition waste consume significant energy resources.	Medium
Vibrations and Noise Pollution impacting society	Demolition activities cause vibrations and noise, leading to disturbances for surrounding communities.	Medium
Financial Impact of Recycling Plants and Material Stockpiled	Recycling plants require investment and stockpiling materials adds storage costs, affecting the economy.	Medium
Impact of Management and Operation Costs	Poor management and inefficient operation increase the overall costs of demolition waste handling.	High
Limited knowledge of waste recycling/reuse	Lack of knowledge on recycling practices leads to more waste ending up in landfills instead of being reused.	High
Level of motivation for waste sorting/reusing	Low motivation for sorting/reusing materials results in increased waste generation and inefficiency.	Medium
Consideration of conservative cultural aspects during construction	Cultural factors can influence the design choices that generate more waste, but this impact is often limited.	Low

Greenhouse Gas Emissions	Demolition waste contributes to the emission of greenhouse gases, exacerbating climate change.	High
Leaching effect (extraction of soluble chemicals and minerals by rain)	Toxic chemicals leach into the soil and water, causing contamination and long-term environmental damage.	High
Water Contamination	Runoff from demolition sites can contaminate local water bodies, harming ecosystems and human health.	High
Job Creation Opportunities	Recycling and waste management practices can create employment, though the impact depends on industry adoption.	Medium
Natural Resources Consumption (i.e., construction materials)	Demolition waste involves the depletion of natural resources like stone and sand, affecting sustainability.	High
Green Land Utilization, Soil Contamination	Improper waste disposal can degrade land quality and lead to soil contamination, reducing usable land area.	High
Sustainable Development	Mismanagement of demolition waste undermines sustainability by increasing landfill use and resource depletion.	Medium
Impact on biodiversity (e.g., harm to animals and marine life)	Waste disposal in landfills or water bodies harms wildlife and marine life, disrupting ecosystems.	High
Additional Human Resource Consumption	Demolition waste management requires additional labor, adding to the overall human resource consumption.	Medium
Health Hazards to Nearby Communities	Hazardous materials in waste can pose health risks to nearby communities through exposure and contamination.	High

Health and Safety Impacts	Improper handling of demolition waste can lead to accidents and safety concerns for workers and nearby populations.	High
Lack of Awareness of Social Impacts of Demolition Wastes	Without awareness, demolition waste causes significant social harm, including health risks and reduced quality of life.	High
Project Stakeholders' Attitude Towards DW Management	Negative attitudes toward demolition waste management hinder progress in sustainable waste practices.	Medium
Costs Associated with Disposal of Waste	The cost of proper disposal of demolition waste is significant, contributing to financial burdens for projects.	High
Resources Required for Creating Designated Dumping Zones	Setting up appropriate disposal areas requires investment in infrastructure and land, increasing project costs.	High
Economic Impact of Additional Incentives for Proper Waste Management	Incentives are necessary to encourage proper waste management, but they increase the economic burden.	Medium
Financial Aspect of Creating Awareness Towards Demolition Management	Raising awareness incurs costs but is essential for improving waste management practices.	Medium
Promotion and Utilization of Recycled Materials	Increased use of recycled materials reduces waste but requires financial investment in technology and processes.	Medium

2.6 Challenges of Demolition Waste Management

Demolition waste management faces significant challenges that can be categorized into three main types: illegal dumping and disposal, awareness and training and policy & legislation.

2.6.1 Demolition Waste Handling

Illegal dumping of demolition waste is a pervasive issue that contributes to environmental degradation and public health risks. Addressing illegal dumping requires a multifaceted approach involving enhanced enforcement, increased penalties for violations, public awareness campaigns and accessible disposal options to discourage improper waste disposal practices. The disposal of demolished materials poses significant challenges and negative effects on human beings and the environment. These challenges are prioritized through waste management strategies, awareness campaigns, waste handling training and the implementation of policies and legislation. One of the primary issues contributing to demolition waste challenges is the illegal dumping of waste in nearby ditches or depressions. By implementing measures to prevent illegal dumping, such as installing surveillance cameras, increasing fines and providing convenient disposal options, communities can mitigate the adverse impacts of demolition waste and promote responsible waste management practices [120, 127]. Adequate planning and preparation, including the identification and reservation of appropriate landfill areas, ensure that construction and demolition waste can be managed effectively and responsibly throughout the project life-cycle. By establishing designated landfill sites in advance, regulatory authorities can enforce waste management regulations, monitor compliance and prevent illegal dumping and unauthorized disposal activities. Furthermore, allocating suitable landfill sites before the start of construction work facilitates efficient waste collection, transportation and disposal, minimizing disruptions to project time-lines and reducing the risk of environmental contamination. Therefore, proactive measures to supervise and designate landfill sites are critical for promoting sustainable construction practices, protecting public health and the environment and ensuring the success of construction projects [108].

Government agencies must prioritize law enforcement and take strict actions against violators to ensure compliance with environmental regulations, particularly in waste management. Simultaneously, promoting awareness about environmental protection laws is crucial to foster voluntary compliance among individuals and businesses. Supporting government legal enforcement with adequate resources and collaborating with stakeholders are essential for effective implementation. By combining enforcement efforts, awareness campaigns and supportive measures, government agencies can control waste management practices, protect the environment and promote sustainable development [86, 128]. The responsibility for promoting the effective utilization of recycled materials extends beyond government agencies to include construction industry companies. These stakeholders play a vital role in driving sustainable practices within the construction sector by actively supporting and promoting the use of recycled materials in their projects. By incorporating recycled materials into construction processes, companies can reduce their environmental footprint, conserve natural resources and mitigate the impacts of waste generation. Moreover, construction industry companions can collaborate with suppliers, contractors and clients to prioritize the procurement and utilization of recycled materials, thereby creating demand and stimulating market growth for sustainable construction products. Through collective efforts and industry-wide initiatives, construction companies can contribute significantly to the advancement of circular economy principles, fostering a culture of sustainability and responsible resource management within the construction sector [85, 87, 103]. Effective waste management depend upon budget allocation and adopt Strategic plans for effective Demolition Waste Management [123, 129].

Preparation and implementation of a strategic plan indeed hinge upon close coordination and communication among stakeholders. Effective collaboration ensures that all parties involved share a common understanding of the objectives, priorities and action steps outlined in the strategic plan. By fostering open communication channels, stakeholders can exchange ideas, address concerns and align their efforts towards achieving shared goals. Additionally, close coordination allows for the allocation of resources, assignment of responsibilities and monitoring of progress, ensuring that the strategic plan is executed efficiently and effectively. Moreover, regular feedback mechanisms and evaluation processes enable stakeholders to adapt and adjust the strategic plan as needed, based on changing circumstances or emerging priorities. Ultimately, by working together in a spirit of cooperation and mutual support, stakeholders can maximize the impact of their strategic planning efforts and drive positive outcomes for the organization or project [122, 129], To foster acceptance, stakeholders need to be informed about the benefits of using recycled materials, including reduced environmental impact, conservation of natural resources and cost savings. Additionally, stakeholders may need reassurance regarding the quality, durability and performance of recycled materials compared to new materials. Providing evidence-based data, case studies and demonstrations of successful projects using recycled materials can help build confidence and trust among stakeholders. Moreover, involving stakeholders in the decision-making process, seeking their input and addressing any concerns or objections can facilitate buy-in and support for incorporating recycled materials into construction projects. Ultimately, by promoting awareness, demonstrating the viability and engaging stakeholders in the transition to using demolition waste as recycled material, the construction industry can accelerate the adoption of sustainable practices and contribute to a more circular economy [119, 128].

Effectively managing demolition waste requires the identification and engagement of specialized companies for waste handling, each assigned specific tasks within the waste management process. By partnering with companies specializing in waste collection, sorting, recycling and disposal, construction projects can streamline the supply chain and minimize associated issues. Specialized companies bring expertise, experience and resources to efficiently manage demolition waste, ensuring that materials are handled safely, responsibly and in compliance with regulations. Moreover, assigning specific tasks to specialized companies allows for greater accountability, transparency and optimization of waste management practices. For example, waste collection companies can focus on efficient transportation and logistics, while recycling facilities can concentrate on processing and recovering valuable materials. This coordinated approach maximizes resource recovery, minimizes land-filling and reduces the environmental impact of demolition activities. By leveraging the capabilities of specialized companies, construction projects can achieve better outcomes in managing demolition waste and contribute to sustainable waste management practices [130, 131].

2.6.2 Awareness & Training

Promoting awareness and providing adequate training to stakeholders involved in demolition waste management is crucial for improving waste handling practices. Effective awareness campaigns and training initiatives are crucial for changing behavior and promoting sustainable waste management practices in construction projects. Often, waste management practices outlined in contract documents are overlooked, leading to improper disposal of waste in environmentally sensitive areas such as jungles, ditches, or depressions, in violation of contractual agreements. By conducting targeted awareness campaigns and providing comprehensive training to all project stakeholders, including contractors, subcontractors and laborers, construction projects can ensure that waste management requirements are understood and followed throughout the project life-cycle. These initiatives can emphasize the importance of proper waste handling, segregation and disposal methods, as well as the consequences of non-compliance with contractual agreements and environmental regulations. Additionally, providing practical guidance, resources and support to implement effective waste management practices can empower stakeholders to take ownership of their responsibilities and contribute to a culture of sustainability on construction sites. By integrating awareness and training into project planning and execution, construction projects can minimize the risk of improper waste disposal, protect natural habitats and uphold contractual obligations, ultimately promoting environmental stewardship and responsible waste management practices [82, 85, 86].

Training and courses in demolition waste management are indeed essential for raising awareness and reducing the environmental impact of waste disposal. These educational initiatives provide stakeholders, including project managers, contractors, engineers and workers, with the knowledge, skills and best practices necessary to effectively manage demolition waste throughout the project life-cycle.

By offering training and courses focused on topics such as waste identification, segregation, handling, transportation, recycling and disposal, construction industry professionals can gain a deeper understanding of the environmental, social and economic implications of waste management practices. Moreover, specialized training can familiarize participants with relevant regulations, standards and technologies for waste management, enabling them to comply with legal requirements and implement sustainable solutions. Additionally, practical training exercises, site visits and case studies can provide hands-on experience and demonstrate real-world applications of waste management principles. By investing in training and education, construction industry stakeholders can empower individuals and teams to make informed decisions, adopt responsible waste management practices and contribute to a more sustainable built environment [115].

By providing specialized training programs tailored to the needs and roles of employees involved in waste management, companies can ensure that staff members possess the necessary knowledge, skills and competencies to implement sustainable practices effectively. In-house training initiatives can cover a range of topics, including waste identification, segregation, handling techniques, regulatory compliance and the use of innovative technologies for waste minimization and recycling. Furthermore, by incorporating practical exercises, case studies and real-world examples into training sessions, companies can enhance engagement and facilitate the application of learning outcomes in day-to-day operations. Investing in continuous training and development not only strengthens the company's waste management capabilities but also fosters a culture of environmental responsibility, innovation and continuous improvement. Moreover, by equipping employees with the skills and expertise needed to address waste management challenges proactively, companies can enhance their competitiveness, reduce environmental impact and contribute to sustainable development goals [102, 115].

By providing targeted training programs focused on waste identification, segregation, handling techniques and regulatory compliance, companies can enhance the knowledge and skills of execution staff, enabling them to implement best practices and adopt innovative approaches to waste management. Through training, staff members gain a deeper understanding of the environmental, social and economic implications of waste management practices, as well as the importance of adhering to legal requirements and industry standards. Moreover, practical training exercises, simulations and case studies allow staff members to apply their learning in real-world scenarios, fostering confidence and competence in waste management tasks. Additionally, ongoing training initiatives enable companies to stay abreast of emerging trends, technologies and regulations in waste management, ensuring that execution staff are equipped to address evolving challenges and opportunities effectively. By investing in training initiatives, companies can improve the performance of execution staff, optimize waste management processes, minimize environmental impact and enhance overall project outcomes [85, 87].

Innovation and adaptation are key to overcoming waste management challenges and while changing existing practices may be daunting, experimenting with different methods and adopting the most successful approaches can lead to significant improvements. By fostering a culture of continuous improvement and encouraging experimentation, companies can identify innovative solutions, optimize waste management processes and minimize environmental impact. Involving employees at all levels, establishing clear goals and leveraging partnerships with external stakeholders can further enhance the effectiveness of experimentation efforts, ultimately driving sustainable outcomes in waste management practices [84].

Integrating waste management considerations into broader project planning and execution processes, companies can optimize resource utilization, reduce project time-lines and enhance overall efficiency. This may involve adopting innovative technologies, implementing sustainable construction practices and promoting circular economy principles to minimize waste generation and maximize resource recovery. Furthermore, incentivizing waste reduction and recycling initiatives, standardizing best practices and fostering collaboration among stakeholders can drive industry-wide improvements in demolition waste management while simultaneously delivering economic benefits. Ultimately, by revising industry norms to align with the triple bottom line of people, planet and profit, companies can achieve sustainable outcomes in demolition waste management while enhancing competitiveness and long-term viability [130, 132].

Improving supplier knowledge and cooperation towards using recycled materials is instrumental in conserving natural resources and mitigating environmental impacts associated with waste disposal. By educating suppliers about the benefits of recycled materials, including reduced energy consumption, lower greenhouse gas emissions and decreased landfill waste, companies can foster a culture of sustainability throughout the supply chain. Encouraging suppliers to prioritize recycled materials in their product offerings, sourcing practices and manufacturing processes not only promotes resource conservation but also stimulates market demand for recycled products. Additionally, fostering collaboration and communication with suppliers enables companies to identify opportunities for innovation, optimize material sourcing and address challenges related to quality, availability and pricing of recycled materials. By working together towards a common goal of sustainability, companies and their suppliers can contribute to a more circular economy, minimize environmental impact and create long-term value for both businesses and society [130].

Leveraging innovative technologies such as Building Information Modeling (BIM), Internet of Things (I.O.T) sensors and data analytics, companies can optimize waste management processes, enhance efficiency and minimize environmental impact. For example, BIM can facilitate accurate material quantity estimation, waste reduction through prefabrication and efficient project planning and coordination. IoT sensors can enable real-time monitoring of waste generation, improve logistics and transportation efficiency and support proactive maintenance of equipment and machinery. Data analytics tools can provide insights into waste generation patterns, identify optimization opportunities and inform decision-making for continuous improvement. Furthermore, emerging technologies such as 3D printing and robotics offer potential for on-site recycling and up-cycling of construction waste, further reducing reliance on virgin materials and minimizing waste generation. By embracing technological innovation, companies can transform waste management practices, achieve sustainability goals and contribute to the evolution of a smarter, greener construction industry [99].

2.6.3 Policy & Legislation

Establishing and enforcing robust policies and legislation is essential for improving demolition waste management. Addressing the challenges of demolition waste management necessitates a multifaceted approach that encompasses combating illegal dumping, enhancing awareness and training and fortifying policy and legislation frameworks. By tackling these critical areas, stakeholders can advance towards more sustainable and environmentally responsible demolition waste management practices. Promoting the utilization of recycled or waste products and materials, coupled with incentivizing an industrial culture that values sustainability, not only benefits society but also fosters a circular economy and reduces the strain on natural resources. Through collaborative efforts and concerted actions, that can create a future where demolition waste is managed responsibly, minimizing environmental impact and maximizing resource efficiency for generations to come [88, 112]. Utilizing social media platforms to disseminate information, raise awareness and showcase the benefits of recycled materials, companies and organizations can educate and engage a wide audience, including consumers, businesses and policymakers. Through compelling content, such as educational videos, info-graphics, case studies and success stories, social media can highlight the economic, environmental and social advantages of using recycled materials in construction projects. Moreover, interactive features like polls, Q&A sessions and virtual events can encourage dialogue, foster community engagement and address concerns or misconceptions surrounding recycled materials. By harnessing the power of social media as a communication tool, stakeholders can effectively communicate the value proposition of recycled materials, build trust and inspire action towards sustainable consumption and production practices [72].

Implementing stringent policies and regulations that mandate responsible waste management practices, including the reduction, reuse and recycling of materials, companies can incentivize compliance and deter environmentally harmful behavior. Penalties for non-compliance with waste management regulations can serve as a deterrent, while rewards or incentives for exceeding recycling targets can motivate positive action. Monitoring mechanisms and regular audits can ensure accountability and track progress towards sustainability goals. By embedding environmental considerations into project planning, execution and monitoring processes, companies can create a culture of environmental responsibility and drive continuous improvement in waste management practices. Ultimately, strict enforcement of rules and regulations fosters a commitment to sustainability, promotes resource conservation and minimizes environmental impact throughout the project life cycle [133, 134].

Legal frameworks Defining responsibilities and regulating activities that impact the environment, including waste management practices. By enacting and enforcing environmental laws, governments can establish guidelines for waste generation, disposal and recycling, as well as impose penalties for non-compliance with regulatory requirements. Moreover, legislation can incentivize sustainable practices by offering tax breaks, or other financial incentives to businesses that adopt environmentally friendly technologies and practices. Additionally, environmental regulations can provide a framework for monitoring and enforcement, ensuring that companies adhere to established standards and take responsibility for their environmental impact. Overall, legislation serves as a vital tool for safeguarding the environment, promoting sustainability and holding individuals and organizations accountable for their actions [128].

Contract documents serve as formal agreements between parties involved in a construction project, outlining specific responsibilities, requirements and expectations related to waste management. By adhering to the waste management plans outlined in the contract or bidding documents, contractors demonstrate their commitment to fulfilling their contractual obligations and upholding the terms agreed upon with clients, regulatory authorities and other stakeholders. Moreover, compliance with waste management plans reflects a commitment to environmental stewardship, sustainability and social responsibility, aligning with industry best practices and legal requirements aimed at minimizing the environmental impact of construction activities. Failure to comply with waste management plans not only exposes contractors to legal and financial risks but also undermines trust, reputation and credibility within the industry. Therefore, contractors must prioritize compliance with waste management plans, proactively implementing measures to minimize waste generation, promote recycling and reuse and ensure proper disposal of waste materials throughout the project life-cycle [121, 133, 134].

Enforcement of environmental protection laws and policies indeed plays a crucial role in addressing waste challenges and promoting sustainability. These laws and policies provide the legal framework for regulating waste management practices, setting standards for pollution control and safeguarding natural resources and ecosystems. By enforcing environmental laws, governments can hold individuals, businesses and organizations accountable for their actions, ensuring compliance with established regulations and promoting responsible environmental stewardship.

Enforcement actions may include inspections, monitoring, penalties for non compliance and legal proceedings against violators. Moreover, effective enforcement mechanisms deter environmentally harmful behavior, incentivize compliance with environmental regulations and create a level playing field for businesses committed to sustainability. Additionally, enforcement efforts can foster transparency, accountability and public trust in government institutions tasked with protecting the environment. Overall, robust enforcement of environmental protection laws and policies is essential for mitigating environmental degradation, conserving natural resources and advancing the transition to a more sustainable and resilient future [85, 102].

2.6.4 Variables Related to Challenges of Demolition Waste Management

In relation to above sub-section. Table 2.5 shows the details various Variables related to challenges of demolition waste Management and table 2.6 shows the reasons why it is an impact and its severity level.

TABLE 2.5: Challenges of Demolition Waste Management

Challenges / Variables	Country	References
Arrangement for Designated Landfill sites	China,Vietnam	[85, 108, 114]
Issues With Supply Chain Management	Portugal,Egypt	[98, 130, 132]
Limited Specialized Demolition Waste Handling Companies.	China,Tanzania	[87, 108, 124]
Knowledge of supplier's Co-Operation towards waste material utilization.	Not specified	[130]
Industry support for effective utilization of Demolition waste.	Not specified	[85, 87, 103]
Role of Awareness and Training for Environmental Protection	China	[85, 86, 92, 115]
Illegal dumping of Demolition Waste.	China,Australia	[83, 96, 103, 113, 120, 127]
Engaging all types of social media for promoting Demolition Waste Management	Not specified	[9, 72]
Strategic plans for effective Demolition Waste Management.	Turkey	[84, 129]
Role of regulatory control and Government Legal Enforcement	Hong Kong, Egypt	[86, 131, 132]
Support of Existing Practice and Policies	Not specified	[84]
Demolition Waste Management Budget allocation.	Central Asia, China	[85, 87, 123]
Acceptance of Stakeholders for demolition waste as recycling material.	China, Saudi Arabia, Australia	[83, 87, 113, 119, 122, 128]
Promotion of Collaboration among stakeholders	china, Turkey, Australia	[84, 98, 122, 123, 129]
Arrangement of In-House Training on Environmental Management	China	[102, 115]
Role of project executing staff towards Demolition Waste Management.	Not specified	[85, 87]

Role of Legislation for enforcing Policies to protect environment.	China	[86, 128]
Penalization mechanism for generating demolition waste and damaging environment.	Pakistan, China	[85, 103, 118, 135]
Demolition Waste Management consideration in Project Life Cycle.	China, Egypt, Dev.countries	[72, 113, 132, 133]
Level of Demolition Waste Management by Trained Staff and Expertise personals as per contract Document.	Not specified	[82, 85, 86]
Level of support by Government agencies for Environmental Protection Promotion	China	[128]
Enforcement of Legal Requirements on Environmental Protection.	China,Portugal	[9, 85, 98, 102]
Industry Culture of incentives policies to promote utilization of Demolition Waste Management.	Turkey	[88, 112, 129]
Inadequacy of Industry Norms	Not specified	[87]
Role of Technological Support for Smart Construction	Iran	[99]
Level of enforcement Waste Management Plan.	Europe,Dev. countries	[121, 133, 134]
Impact of industrial focus on cost and time rather than Demolition Waste Management.	Egypt	[98, 112, 130, 132]

Table 2.6: Challenges of Demolition Waste-Reasons and Severity Levels

Challenges / Variables	Reason(s) Why It Is an Impact	Severity Level
Arrangement for Designated Landfill Sites	Ensures proper disposal locations to prevent illegal dumping and promote organized waste management.	High

Issues With Supply Chain Management	Improves efficiency in managing waste materials from generation to disposal.	High
Limited Specialized Demolition Waste Handling Companies	Promotes the establishment of companies specializing in waste handling and recycling.	High
Knowledge of Supplier Cooperation Towards Waste Material Utilization	Strengthens supplier collaboration to maximize recycling and reuse opportunities.	Medium
Industry Support for Effective Utilization of Demolition Waste	Encourages industry-wide initiatives to reuse and repurpose waste materials.	Medium
Role of Awareness and Training for Environmental Protection	Enhances awareness and skills of stakeholders to manage waste sustainably.	Medium
Illegal Dumping of Demolition Waste	Implements strict penalties and monitoring to curb illegal waste disposal.	High
Engaging All Types of Social Media for Promoting Waste Management	Leverages social media platforms for advocacy and education on demolition waste management.	Medium
Strategic Plans for Effective Demolition Waste Management	Develops comprehensive plans to streamline waste management processes.	Medium
Role of Regulatory Control and Government Legal Enforcement	Strengthens laws and their enforcement to ensure compliance with environmental policies.	High
Support of Existing Practices and Policies	Updates and reinforces policies to improve waste management efficiency.	Medium
Demolition Waste Management Budget Allocation	Allocates sufficient funds to support effective waste management initiatives.	High

Acceptance of Stakeholders for Demolition Waste as Recycling Material	Promotes stakeholder buy-in for using recycled materials in construction projects.	Medium
Promotion of Collaboration Among Stakeholders	Encourages collective efforts for efficient demolition waste management.	Medium
Arrangement of In-House Training on Environmental Management	Builds organizational capacity for sustainable waste handling practices.	Medium
Role of Project Executing Staff Towards Demolition Waste Management	Enhances staff accountability and active participation in waste reduction.	High
Role of Legislation for Enforcing Policies to Protect the Environment	Implements strict legal frameworks to ensure compliance with waste management practices.	High
Penalization Mechanism for Generating Demolition Waste	Introduces fines or penalties to discourage wasteful practices and environmental damage.	High
Demolition Waste Management Consideration in Project Life Cycle	Integrates waste management strategies throughout all project phases.	High
Level of Demolition Waste Management by Trained Staff	Assigns trained and skilled personnel to manage waste efficiently as per contract requirements.	High
Level of Support by Government Agencies for Environmental Protection	Strengthens institutional support for promoting sustainable practices.	Medium
Enforcement of Legal Requirements on Environmental Protection	Ensures strict adherence to environmental protection laws.	High
Industry Culture of Incentives Policies to Promote Waste Management	Encourages businesses to adopt incentive-driven waste management practices.	Medium

Inadequacy of Industry Norms	Identifies gaps in industry practices and establishes better standards for waste management.	Medium
Role of Technological Support for Smart Construction	Integrates advanced technologies to optimize waste handling and recycling processes.	Medium
Level of Enforcement of Waste Management Plan	Monitors and ensures the effective implementation of waste management plans at all project stages.	High
Impact of Industrial Focus on Cost and Time Rather Than Waste Management	Balances economic priorities with environmental concerns by promoting sustainable practices.	High

2.7 Solution/Results of Demolition Waste Management

Demolition waste management solutions can be broadly categorized into administrative (or managerial) solutions and technical solutions. Each type plays a crucial role in addressing the challenges associated with demolition waste effectively. Explanation regarding solutions of waste management, these two types of solutions, Administrative and technical solutions.

2.7.1 Administrative Solution

Administrative solutions focus on policy, planning, coordination and oversight aspects of demolition waste management. They involve strategic decisions, regulations and initiatives aimed at improving overall waste management practices.
Enforcing environmental protection measures on managerial staff is crucial to ensure that construction and demolition projects adhere to environmental regulations

and best practices. By providing comprehensive training, establishing clear policies and implementing monitoring systems, organizations can empower managerial staff to prioritize environmental considerations in project planning and execution. Offering incentives for compliance and holding staff accountable for their environmental performance further reinforces a culture of environmental responsibility. Ultimately, by enforcing environmental protection on managerial staff, organizations can mitigate environmental risks, promote sustainability and uphold their commitment to environmental stewardship [72, 103].

Proper implementation of Demolition Waste Management can lead to significant improvements in health and safety levels across various aspects of construction and demolition projects. By effectively managing demolition waste, potential hazards associated with handling, storage and disposal of materials can be minimized, reducing the risk of accidents and injuries for workers and the surrounding community. Proper waste management practices also help prevent the release of harmful substances into the environment, mitigating health risks associated with air and water pollution. Additionally, by promoting recycling and reuse of materials, Demolition Waste Management can contribute to resource conservation and reduce the need for raw material extraction, further enhancing environmental sustainability and long-term health benefits. Overall, implementing proper Demolition Waste Management measures not only improves health and safety outcomes but also supports a more sustainable and responsible approach to construction and demolition activities [10, 92, 113, 114].

Improving corporate image and business competitiveness through environmental performance involves adopting strategies such as implementing Environmental Management Systems (EMS), innovating green products, ensuring supply chain sustainability, embracing energy efficiency and renewable energy, reducing waste, engaging stakeholders transparently, complying with regulations and promoting CSR initiatives. By integrating these practices into operations and communication efforts, companies can enhance their reputation, attract environmentally conscious customers and gain a competitive advantage in the market while contributing to sustainability goals [15, 130, 136].

Promoting incentive and penalty policies for demolition waste management involves offering financial rewards, grants and recognition for compliant practices, while enforcing fines, project delays, or permit revocations for non-compliance. By combining incentives with penalties and accompanying them with education and outreach efforts, authorities can create a regulatory framework that incentivizes sustainable practices, ensures accountability and fosters a culture of responsible waste management among contractors, developers and other stakeholders [10, 85, 98, 102].

Proper implementation of demolition waste management laws and regulations necessitates a multifaceted approach, including clear and enforceable regulations, effective enforcement mechanisms, public awareness campaigns, capacity building initiatives, stakeholder engagement, monitoring systems, incentives for compliance, continuous improvement efforts, transparency and international cooperation. By integrating these elements, authorities can ensure the responsible handling of demolition waste, mitigate environmental risks and promote sustainable practices in the construction industry [95, 132, 137]. Preserving natural resources, particularly raw materials, requires a multifaceted approach. This involves reducing consumption through efficient processes and product design, promoting reuse and recycling to extend material life-cycles, sourcing sustainably, conserving forests and habitats, enforcing regulations, raising awareness and fostering collaboration. By implementing these strategies collectively, stakeholders can mitigate resource depletion, minimize environmental impact and promote a sustainable future for generations to come [110, 121, 124].

Incorporating environmental management strategies into contract documents is crucial for ensuring project adherence to environmental standards and sustainability goals. These documents should outline environmental policies, legal requirements and expectations for contractors, including the development and implementation of Environmental Management Plans (EMPs), resource conservation measures, waste management protocols, monitoring and reporting procedures, stakeholder engagement and mechanisms for performance evaluation and improvement. By formalizing environmental considerations within contract terms, project owners can effectively mitigate environmental risks, promote responsible practices and uphold environmental integrity throughout project execution [86, 105].

By implementing effective recycling practices as part of the 3R (Reduce, Reuse, Recycle) strategy in construction, companies can generate additional revenue by selling recycled materials. This revenue stream arises from the sale of salvaged and processed materials such as concrete, asphalt, metals and wood, which are recovered from demolition waste or construction sites.
By sorting, processing and selling these materials to recycling facilities or other buyers, construction companies can turn what would otherwise be considered waste into valuable commodities. This not only generates additional income but also reduces disposal costs associated with traditional waste management methods. Moreover, selling recycled materials contributes to a circular economy by reintroducing valuable resources back into the market, promoting sustainability and resource conservation.

Proper documentation of demolition data is essential for ensuring regulatory compliance, managing project risks and optimizing resource utilization. This includes recording information on inventory, permitting, waste management, health and safety measures, financial records, community engagement efforts, monitoring and reporting. By maintaining accurate and comprehensive documentation, stakeholders can track progress, assess impacts and make informed decisions to achieve project objectives efficiently and transparently while adhering to legal requirements [87, 138].

Imposing responsibilities on all stakeholders throughout the project life-cycle to consider waste management plans is vital for fostering accountability and sustainability in construction projects. This entails integrating waste reduction targets, recycling initiatives and environmental considerations into project planning, design, construction and operations. Project owners, designers, contractors, suppliers, waste management providers, regulatory authorities, community stakeholders and educational institutions all play key roles in ensuring adherence to waste management regulations, promoting resource efficiency and minimizing environmental impact. By working collaboratively and prioritizing waste management throughout the project life-cycle, stakeholders can achieve cost savings, mitigate risks and contribute to a more sustainable built environment [83, 113, 119]. Training and education programs are essential in the construction industry for fostering awareness, imparting skills and cultivating a culture of sustainability. These programs cover topics such as environmental awareness, waste management, green building practices, energy efficiency, health and safety, innovation and technology, regulatory compliance, community engagement, sustainability leadership and continuous improvement. By equipping construction professionals with the knowledge and skills needed to incorporate sustainable practices into their work, these programs contribute to improved project outcomes, reduced environmental impact and a more resilient and socially responsible construction industry [92, 132, 133].

Enhancing the priority level of demolition waste management involves bolstering policy emphasis, strengthening regulatory frameworks, fostering public awareness, implementing incentive programs, investing in research and innovation, fostering collaborative partnerships, providing capacity building, stimulating market development, transitioning to a circular economy model and establishing robust monitoring and evaluation mechanisms. By prioritizing these efforts, stakeholders can accelerate progress towards sustainable demolition practices, waste reduction, resource recovery and environmental protection, contributing to a more resilient and circular construction industry [85].

Utilizing waste in various forms contributes significantly to environmental protection by reducing resource depletion, minimizing pollution and fostering a circular economy. Through strategies such as recycling, energy recovery and waste-to-energy technologies, waste can be diverted from landfills, reducing methane emissions and conserving landfill space while generating renewable energy. Additionally, re-purposing waste materials in manufacturing and construction processes reduces the demand for virgin resources, mitigating habitat destruction and ecosystem degradation. By promoting waste utilization, that not only mitigate environmental harm but also contribute to resource conservation and sustainability, aligning with global efforts to address climate change and promote a greener, more resilient future [72, 79, 103, 125].

2.7.2 Technical Solutions

Technical solutions involve innovative technologies, engineering practices and operational methods aimed at optimizing waste handling, recycling and disposal processes in demolition projects.
The application of advanced technologies revolutionizes demolition waste management by enhancing sorting and segregation processes with robotic systems and optical sensors, enabling on-site recycling through mobile units and advanced crushing equipment and facilitating real-time monitoring and optimization via IoT sensors and data analytics. Additionally, construction waste management software streamlines administrative tasks, while emerging technologies like chemical recycling and drones offer innovative solutions for recycling complex materials and site assessment. Augmented and virtual reality technologies further bolster safety training and simulation efforts. Together, these advancements drive efficiency, resource recovery and sustainability in demolition waste management practices [112, 114].

Establishing prefabricated design and construction technologies involves a comprehensive approach encompassing research and development, standardization, digitalization, advanced manufacturing, sustainability integration, collaborative partnerships, training, advocacy, demonstration and a culture of continuous improvement. By embracing these elements, stakeholders can revolutionize the construction industry, delivering projects faster, more sustainably and with higher quality and efficiency [98, 102, 135]. Promoting potential cost savings strategies due to the 3R (Reduce, Reuse, Recycle) elements involves minimizing material consumption through efficient design and processes, reusing materials and components to reduce procurement costs, recycling construction waste to generate revenue and avoid disposal fees, extending the lifespan of structures to lower maintenance expenses, leveraging tax incentives and rebates, improving efficiency and productivity and enhancing brand reputation and market differentiation. By embracing these strategies, construction companies can achieve significant cost savings while advancing environmental sustainability objectives [96, 122].

Promoting recycled products and integrating new technologies into demolition waste management involves raising awareness, establishing certifications, offering financial incentives, fostering supply chain collaboration, investing in technological innovation, implementing pilot projects, supporting regulatory measures, facilitating collaborative research, advocating for public procurement policies and continuously monitoring and evaluating performance. By implementing these strategies collectively, stakeholders can accelerate the adoption of recycled materials, optimize waste management practices and advance sustainability in the construction industry [102, 135].

Innovating existing practices and policies to elevate awareness regarding demolition waste involves integrating advanced technologies for efficient waste tracking, fostering comprehensive education and training programs, advocating for policy reforms, fostering collaborative partnerships, engaging local communities, promoting circular economy principles, introducing incentive mechanisms, encouraging green building certification, organizing innovation challenges and launching public awareness campaigns. These strategies collectively aim to drive positive change, reduce environmental impacts and transition towards a more sustainable and circular economy [84].

Continuous improvement in environmental management through the 3R (Reduce, Reuse, Recycle) strategy requires a holistic approach. "Reduce" focuses on minimizing waste generation by optimizing processes, product design and packaging. "Reuse" extends product lifespan through refurbishment, asset management and reusable packaging. "Recycle" converts waste into new products, necessitating investment in sorting technology, market development, education and collaboration. Ongoing assessment, innovation and stakeholder commitment are crucial for sustainable development and resource conservation [96, 122].

Continuous and effective supervision at the site level is imperative for ensuring project success, maintaining safety standards and achieving quality outcomes. Supervisors oversee construction activities, conduct regular inspections to monitor progress and compliance with regulations, coordinate resources, address issues promptly and facilitate communication among stakeholders. By prioritizing safety, quality and efficiency, supervisors play a crucial role in mitigating risks, optimizing productivity and delivering projects on time and within budget [82, 85, 86, 94].

By combining administrative and technical solutions, stakeholders can create a comprehensive and effective demolition waste management strategy that addresses regulatory compliance, operational efficiency, environmental sustainability and community engagement. Collaboration among policymakers, industry professionals, researchers and local communities is essential for implementing these solutions and achieving positive outcomes in demolition waste management.

2.7.3 Variables Related to Solution for Demolition Waste Management

In relation to above sub-section. Table 2.7 shows the details various Variables related to Solution for demolition waste Management and table 2.8 shows the reasons why it is an impact and its severity level.

Table 2.7: Solution for Demolition Waste Management

Solutions / Variables	Country	References
Enforcing Protecting Environment on Managerial Staff	Not specified	[72, 103]
Improvements in health and safety level due to proper Demolition Waste Management implementation.	China,Vietnam	[9, 92, 113, 114]
Continuous Improvement in Environmental Management through 3R (Reduce, Reuse, Recycle) Strategy.	Australia	[96, 122]

Improving Corporate Image and Business Competitiveness in Environmental Performance	Not specified	[15, 130, 136]
Promote incentive and Penalty Polices regarding Demolition Waste Management.	Portugal	[9, 85, 98, 139]
Proper implementation of Demolition Waste Management laws and regulations.	Egypt,China	[79, 102, 132, 137]
Application of advanced technologies.	Vietnam	[112, 114]
Preserve or save the natural resources-raw materials	Europe, Australia, China	[110, 121–124]
Consideration of Environmental Management Strategy as part of contract documents.	Philippines	[86, 105]
Promotion of recycled product and apply new technologies in Demolition Waste Management	China	[85, 98, 102, 135]
Establish prefabricated design and construction technologies	China	[85, 98, 102, 135]
Promoting Potential cost savings strategy due to 3R (Reduce, Reuse, Recycle) elements.	Australia	[96, 122]
Additional revenue by selling material.	Not specified	[132]
Continuous and effective supervision at site level.	Hong Kong	[82, 85, 86, 93, 94]
Innovating Existing Practice and policies elevating awareness regarding demolition waste.	Not specified	[84]
Proper documentation of Demolition data.	Not specified	[87, 88]
Imposing Responsibilities to All the stakeholders for considering waste management plan in the project life-cycle.	China, Saudi Arabia	[83, 113, 119]
Training and education programs	China	[115, 132, 134, 140]
Enhancing Priority level of Demolition Waste Management	Not specified	[85]
Utilization of waste in Contribution to environmental protection.	Sri Lanka	[63, 103, 125]

Table 2.8: Solution for Demolition Waste Management-Reasons and Severity Levels

Solutions /Variables	Reason(s) Why It Is an Impact	Severity Level
Enforcing Protecting Environment on Managerial Staff	Ensures adherence to environmental policies and encourages sustainable practices at the managerial level.	High
Improvements in Health and Safety Level	Enhances safety protocols and minimizes risks associated with demolition waste handling.	High
Continuous Improvement in Environmental Management	Promotes the 3R (Reduce, Reuse, Recycle) strategy to achieve long-term sustainability.	High
Improving Corporate Image and Competitiveness	Elevates business reputation and improves competitiveness through better environmental performance.	Medium
Promote Incentive and Penalty Policies	Encourages compliance with waste management practices through reward and penalty systems.	Medium
Proper Implementation of Waste Management Laws	Ensures effective enforcement of regulations to minimize environmental harm.	High
Application of Advanced Technologies	Integrates modern technologies to optimize waste management processes.	Medium
Preserving Natural Resources	Reduces the consumption of raw materials by promoting the use of recycled materials.	High
Consideration of Environmental Strategy in Contracts	Embeds environmental management as a critical element in project contracts.	Medium
Promotion of Recycled Products	Encourages the use of recycled materials and adoption of new technologies for waste management.	Medium
Establishment of Prefabricated Technologies	Promotes modular and prefabricated construction to minimize waste.	Medium

Promoting Cost Savings Through 3R	Demonstrates financial benefits of adopting reduce, reuse and recycle practices.	Medium
Generating Additional Revenue	Generates income by selling salvaged or recycled materials.	Low
Continuous and Effective Supervision	Ensures site-level monitoring to enhance waste management practices.	High
Innovating Practices and Policies	Elevates awareness and improves current demolition waste management strategies.	Medium
Proper Documentation of Demolition Data	Maintains accurate records for better planning and compliance.	Medium
Imposing Responsibilities on Stakeholders	Ensures collective accountability in integrating waste management throughout the project lifecycle.	High
Training and Education Programs	Improves awareness and builds the capacity of stakeholders to manage waste effectively.	Medium
Enhancing Priority Level of Waste Management	Elevates the importance of waste management as a critical component of project planning and execution.	High
Utilization of Waste for Environmental Protection	Highlights the environmental benefits of using waste materials in sustainable applications.	Medium

The tables 2.1, 2.2, 2.4 and 2.5 provide a clear and comprehensive overview of various research studies focusing on construction and demolition waste management across different countries and regions. This global perspective is crucial for understanding the diverse challenges and approaches to waste management, emphasizing the need for context-specific strategies to address these challenges effectively.

The literature reviewed highlights the multifaceted challenges of demolition waste management across diverse geographical and socio-economic contexts. Key themes emerge, such as the causes of waste generation, its environmental impacts, regulatory shortcomings and the exploration of innovative solutions, all of which underscore the global relevance of sustainable practices. These insights collectively pave the way for sustainable and context-sensitive practices in demolition waste management.

2.8 Demolition waste management practices in Pakistan

Demolition waste management practices in Pakistan are available but remain underdeveloped and are often informal. In general, demolition waste in Pakistan is managed inefficiently, leading to significant environmental, economic and social challenges. A major issue in demolition waste management is the widespread practice of open dumping. Demolition waste, including materials like concrete, asphalt, bricks and wood, is often disposed of in open landfills or along roadsides, contributing to environmental pollution, water contamination and urban aesthetic degradation [141].

Recycling of demolition waste in Pakistan is minimal due to the lack of infrastructure and technical expertise. Although materials such as concrete and asphalt can be recycled for use in road construction and other infrastructure projects, there are very few facilities capable of processing these materials. Additionally, the construction industry tends to favor using new, virgin materials over recycled ones, primarily due to cost concerns and limited awareness about the benefits of recycling [141].

Waste segregation practices are not widely followed at construction sites. Materials like metals, concrete and wood are not separated from non-recyclable waste, leading to valuable materials being mixed with waste that cannot be recycled, thus hindering the recycling process [142].

While the Pakistan Environmental Protection Act (PEPA) provides general guidelines for environmental protection, there are no specific laws governing the management of demolition waste. The lack of targeted regulations for demolition waste segregation, recycling and disposal results in inconsistent practices across different construction projects. The key challenges include the lack of formal waste management systems, limited recycling infrastructure, low public awareness and financial constraints that prevent construction companies from investing in sustainable waste management practices. However, opportunities exist to improve demolition waste management through the introduction of specific regulations, the development of recycling infrastructure and the promotion of public awareness and capacity-building initiatives [143]. Despite these challenges, there are growing efforts to improve waste management practices in Pakistan, particularly in the construction and demolition sectors. Several studies and reports have highlighted the need for formal systems and improved policies to handle demolition waste more effectively and sustainably.

2.9 Methodology Selection for data Analysis

Based on a literature review of 83 papers, Figure 2.6 has been established to illustrate the distribution of various data analysis techniques utilized in the context of construction and demolition waste management (CDWM). These techniques are employed to assess different aspects such as decision-making processes, efficiency and effectiveness of waste management practices. The following techniques have been observed:

AHP (Analytic Hierarchy Process) and FAHP (Fuzzy AHP)

AHP: A structured technique for organizing and analyzing complex decisions, grounded in mathematics and psychology. It helps break down a complex problem into a hierarchy of more manageable sub-problems.

FAHP: Incorporates fuzzy logic into AHP, allowing for the handling of uncertainty and vagueness in the decision-making process.

PLS-SEM (Partial Least Squares Structural Equation Modeling)

PLS-SEM: A statistical technique that models complex relationships between observed and latent variables. It is particularly useful in exploratory research where the primary objective is to predict key target constructs or identify key driver constructs.

Application in CDWM: PLS-SEM is the most appropriate technique for assessing correlations among variables due to its ability to handle complex models with many indicators and its flexibility in working with small to medium sample sizes. It is highly effective in understanding the structural relationships between different aspects of waste management practices and outcomes.

ANP (Analytic Network Process)

ANP: A more generalized form of AHP, incorporating interdependencies among criteria. It is used for decision-making with dependence and feedback.

ANP-SNA (ANP and Social Network Analysis)

ANP-SNA: Combines ANP with Social Network Analysis (SNA) to evaluate both the interdependencies among decision criteria and the relationships between actors involved in the decision-making process.

AHP and MAUT (Multi-Attribute Utility Theory)

AHP and MAUT: Leverages the decision hierarchy structure of AHP and the utility-based evaluation of MAUT to make more comprehensive decisions.

SMPI & AHP (Simplified Multi-Attribute Rating Technique and AHP)

SMPI & AHP: Combines SMPI, which simplifies the multi-attribute decision-making process, with AHP to benefit from both simplicity and structured decision analysis.

FAHP & TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)

FAHP & TOPSIS: Integrates FAHP with TOPSIS to rank alternatives based on their closeness to the ideal solution, considering both uncertainty and the relative importance of criteria.

VIKOR & AHP: VIKOR is a multi-criteria decision-making method that focuses on ranking and selecting from a set of alternatives. When combined with AHP, it helps prioritize alternatives based on a comprehensive analysis.

CE-CDW (Cost-Effectiveness and Construction and Demolition Waste) CE-CDW: Focuses on evaluating the cost-effectiveness of various CDWM practices, ensuring that the most economical and efficient methods are identified.following research Papers has been selected for selection of Methodology [36, 53, 54, 62, 144–147, 147, 148]

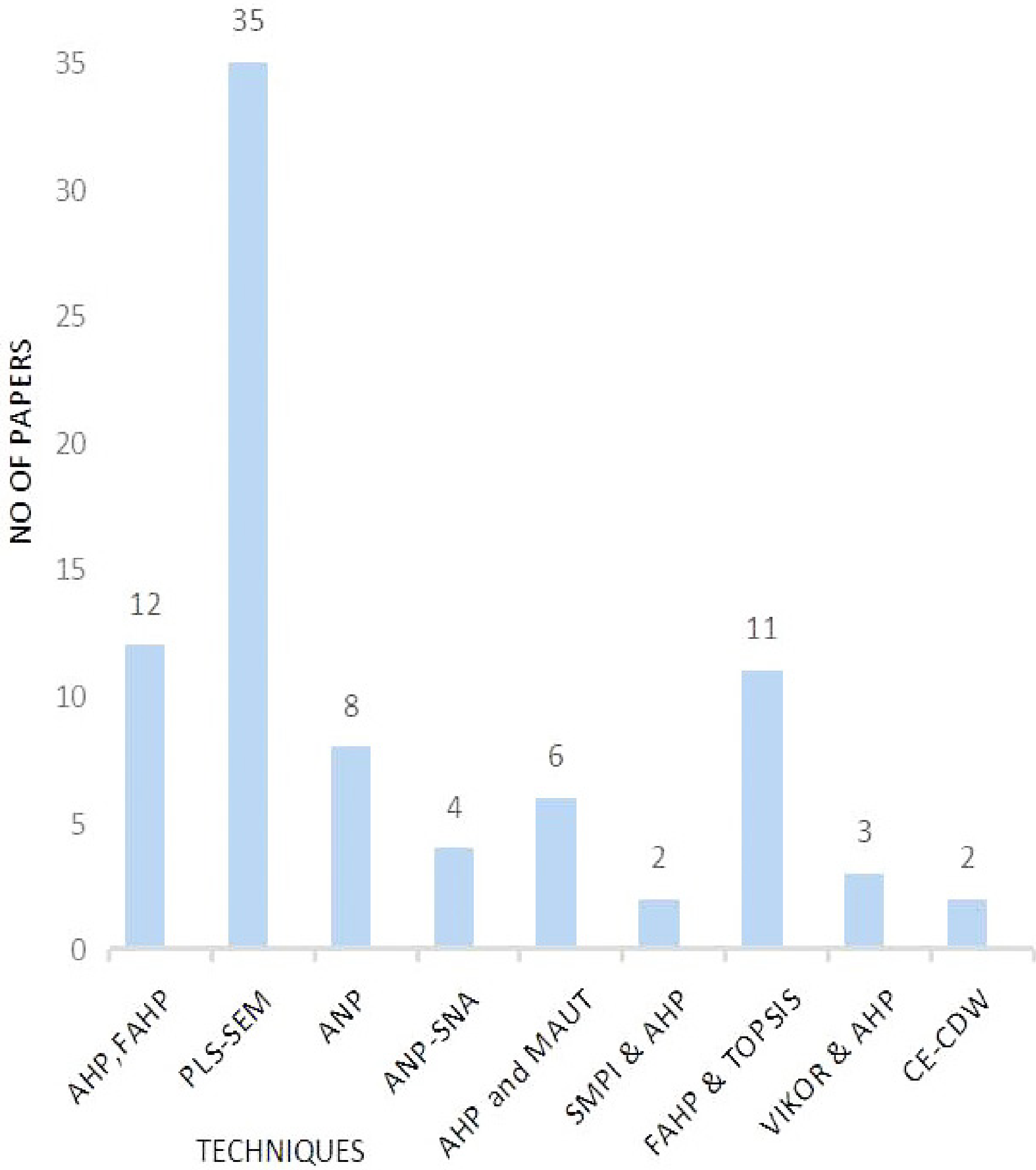

Figure 2.6: Methodology Selection for data Analysis

This distribution indicates that PLS-SEM is the most extensively used technique, highlighting its significance and suitability in the field of CDWM. Among these techniques, PLS-SEM stands out as the most appropriate for assessing correlations in CDWM due to its robust capability in modeling complex relationships and its flexibility with data requirements. It helps in identifying and understanding the underlying factors and their interconnections, which is crucial for effective waste management strategies.

Researchers have identified several reasons for using Partial Least Squares Structural Equation Modeling (PLS-SEM), especially when dealing with challenges like small sample sizes and complex models in predictive modeling [149]. PLS-SEM is particularly advantageous for handling complex models with multiple constructs and relationships, allowing researchers to effectively predict and validate outcomes despite limitations in sample size and model complexity.
A major strength of PLS-SEM is its ability to perform well with small sample sizes, which are common in business and marketing studies. It also demonstrates strong predictive capabilities, making it suitable for studies that need to address model complexity while ensuring accurate predictions. Moreover, researchers are increasingly adopting PLS-SEM because of its ability to estimate and validate theoretically grounded models using constructs, its applicability in complex modeling scenarios with limited data and its robust predictive performance [150, 151]. PLS-SEM is recognized as a valuable analytical tool for exploring and understanding constructs and variables in research, presenting new opportunities for scholars across various fields.

2.10 Previous Studies and Research Gap

The management of construction and demolition waste (CDW) has become an increasingly critical issue as urbanization and infrastructure development continue to grow globally. Construction and demolition activities generate significant amounts of waste, which, if not managed properly, can lead to severe environmental, economic and social impacts. Various researchers have developed frameworks to address these challenges, focusing on different aspects of CDW management across diverse contexts. The details of previous studies extracted from the literature review, along with references, are shown in Table 2.9 below.

TABLE 2.9: Framework Proposed based on Previous Studies

Description of Studies	References	Observations
A Sustainable Construction and Demolition Waste Management Assessment: The Case of Malaysia	[118]	Conceptual framework for sustainable construction and demolition wastes by using EAHP for questionnaire development and PLS SEM for data Analysis, framework for this study shown in below Figure 2.7.
Construction and demolition waste framework of circular economy: A mini review.	[26]	Framework developed based on Categorization of construction and demolition waste generation, As shown in below Figure 2.8.
The Effect Of Waste Behaviour On Waste Management In The UK	[79]	The waste management strategy involves 8 main components, framework for this study shown in below Figure 2.9.
A conceptual foundation for effective construction and demolition	[126]	Proposed conceptual framework for effective management of construction and demolition components,As shown in below Figure 2.10
Circular Economy on Construction and Demolition	[152]	Construction and demolition waste (CDW) flow in Beijing, framework for this study shown in below Figure 2.11

Proposing building information modeling-based theoretical framework for construction and demolition waste management: strategies and tools	[153]	Proposed theoretical framework for BIM-based CDW management, As shown in below Figure 2.12
Analysis of factors affecting construction and demolition waste safe disposal in Egypt	[154]	Theoretical framework of the study.
Investigate the dynamics influencing Sustainable Construction Waste Management (SCWM)	[151]	Considering Practice and Policies Improving Waste Management, , as shown in below Figure 2.13
Sustainable construction practices through effective Waste Management. .	[155]	Considering Impacts of Waste, as shown in below Figure 2.14.

The management of construction and demolition waste (CDW) has become an increasingly critical issue as urbanization and infrastructure development continue to grow globally. Construction and demolition activities generate significant amounts of waste, which, if not managed properly, can lead to severe environmental, economic and social impacts. Various researchers have developed frameworks to address these challenges, focusing on different aspects of CDW management across diverse contexts.

2.10.1 Sustainable Construction and Demolition Waste Management in Malaysia

In the study "A Sustainable Construction and Demolition Waste Management Assessment: The Case of Malaysia," researchers aimed to develop a sustainable framework for managing CDW in Malaysia. Malaysia, like many other developing countries, faces significant challenges in handling the increasing volume of CDW due to rapid urbanization and construction activities. This study utilized the Energy Analysis Hierarchy Process (EAHP) and Partial Least Squares Structural Equation Modeling (PLS SEM) to create a conceptual framework that could guide sustainable CDW management practices. The framework, depicted in Figure 2.6 of the study, addresses the need for structured approaches to CDW management, considering the local context and the sustainability goals of Malaysia.

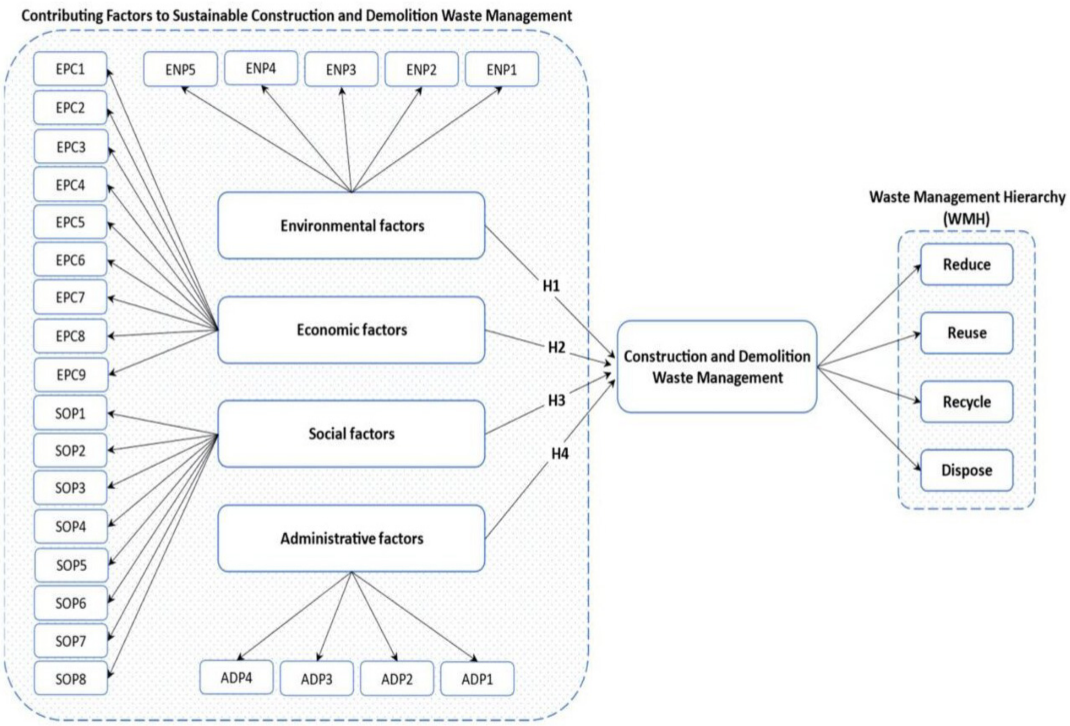

FIGURE 2.7: Conceptual framework for sustainable construction and demolition wastes [118].

2.10.2 Circular Economy in Construction and Demolition Waste

The mini-review "Construction and Demolition Waste Framework of Circular Economy: A Mini Review" focused on applying circular economy principles to CDW management. The circular economy model emphasizes reducing waste, reusing materials and recycling resources to minimize the environmental impact of construction activities. This study developed a framework based on the categorization of construction and demolition waste generation, aiming to promote resource efficiency and sustainability. The framework, illustrated in Figure 2.7, provides insights into how waste from construction and demolition activities can be managed within a circular economy context, highlighting best practices and strategies for waste reduction and resource recovery.

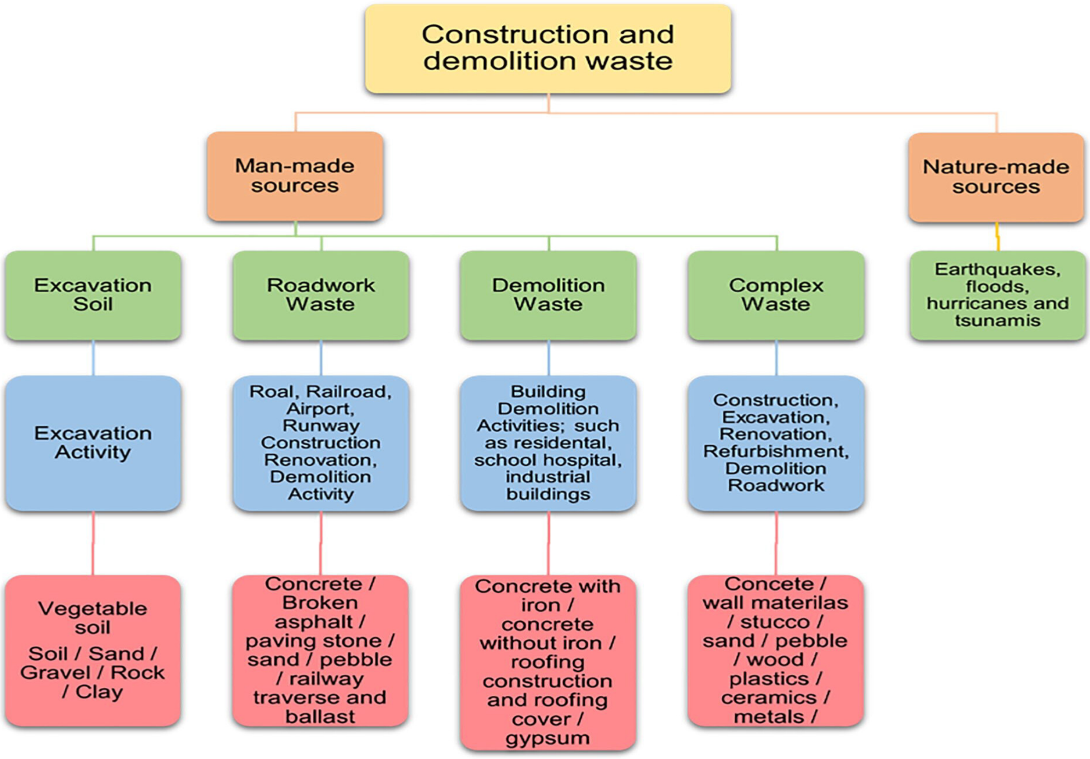

FIGURE 2.8: Framework for construction and demolition waste generation[26].

2.10.3 Waste Behavior and Management Strategies in the UK

In "The Effect of Waste Behavior on Waste Management in the UK," the researchers explored how waste behavior impacts CDW management strategies. The UK, with its stringent environmental regulations and commitment to sustainable development, presents a unique context for studying waste management behaviors. This study identified eight main components of an effective waste management strategy and proposed a framework to address these components, as shown in Figure 2.8. The framework underscores the importance of understanding behavioral factors in developing effective CDW management practices, emphasizing the need for behavioral change initiatives alongside technical and regulatory measures.

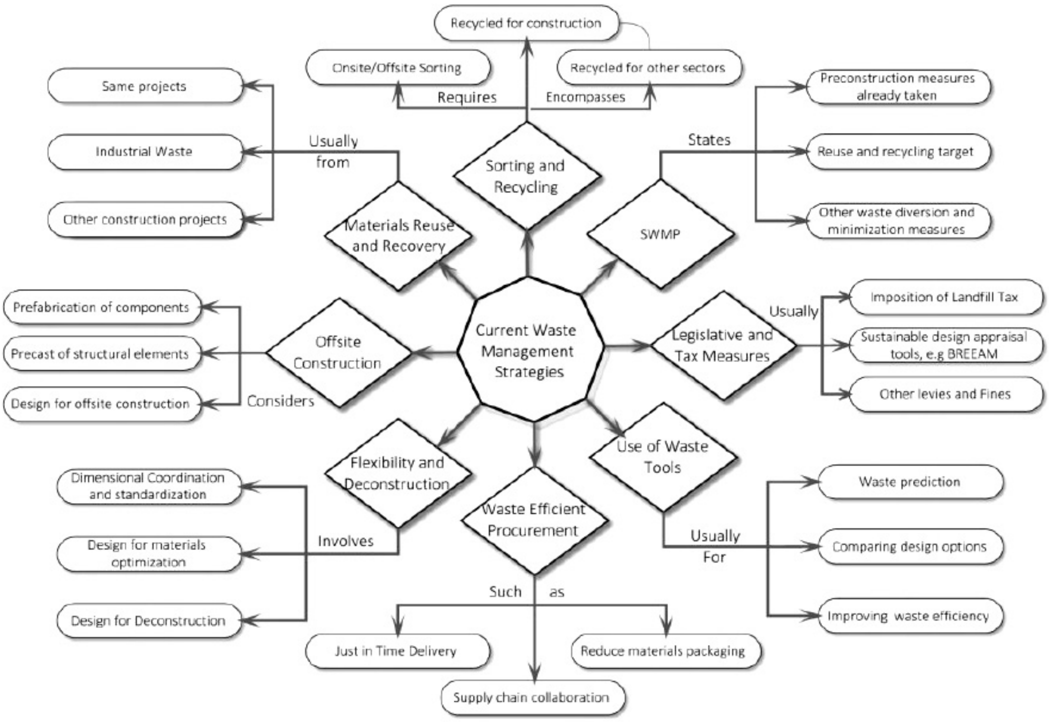

FIGURE 2.9: The waste management strategy involves 8 main components[79].

2.10.4 Effective Management of Construction and Demolition Components

The study "A Conceptual Foundation for Effective Construction and Demolition" proposed a conceptual framework for managing construction and demolition components effectively. This framework, depicted in Figure 2.9, aims to enhance the efficiency and sustainability of CDW management practices. By focusing on the specific components of CDW, the study provides a detailed approach to managing the various materials and waste products generated during construction and demolition activities, promoting best practices for waste reduction, reuse and recycling.

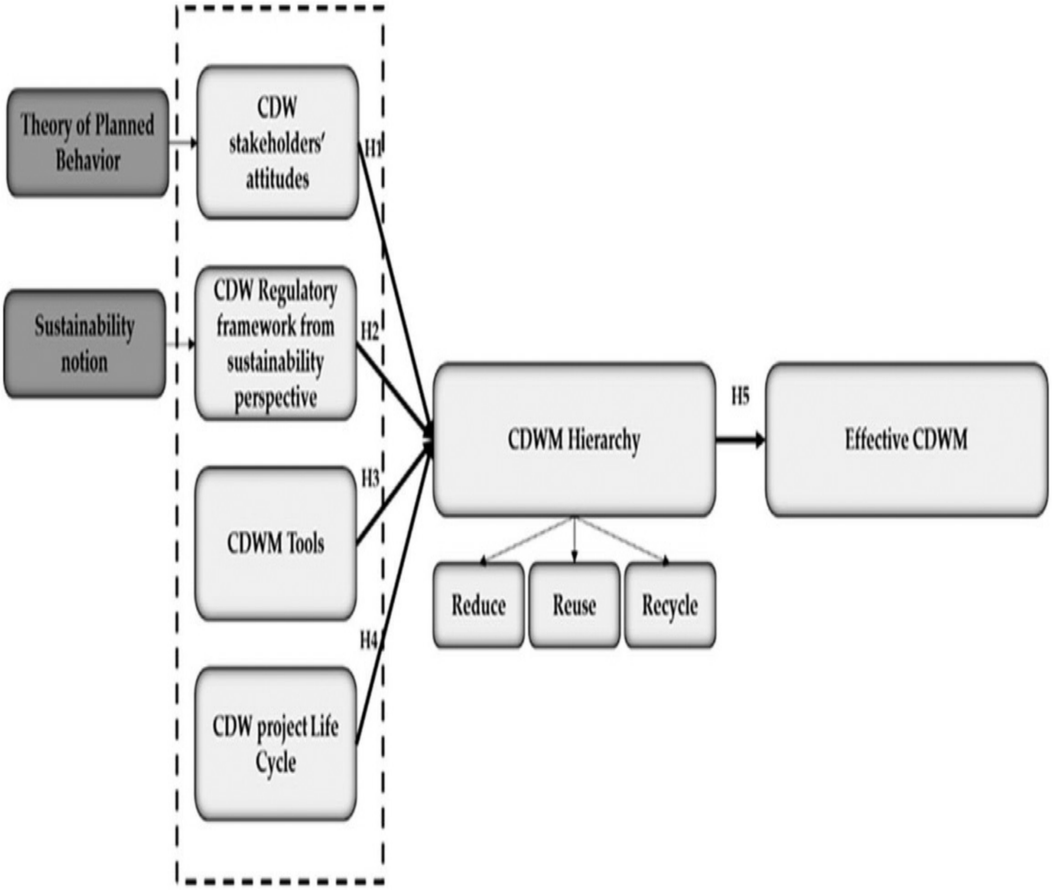

FIGURE 2.10: Conceptual framework for effective management of construction and demolition waste[126].

2.10.5 Circular Economy in Beijing's Construction and Demolition Waste

The research "Circular Economy on Construction and Demolition" examined the flow of CDW within the context of a circular economy in Beijing. Beijing, as a rapidly developing urban center, faces significant challenges in managing its CDW. The study presented a dynamic framework for managing urban CDW, as shown in Figure 2.10, highlighting the need for adaptable frameworks that can respond to the unique challenges of urban settings. The framework emphasizes the importance of integrating circular economy principles into urban waste management strategies to promote resource efficiency and sustainability.

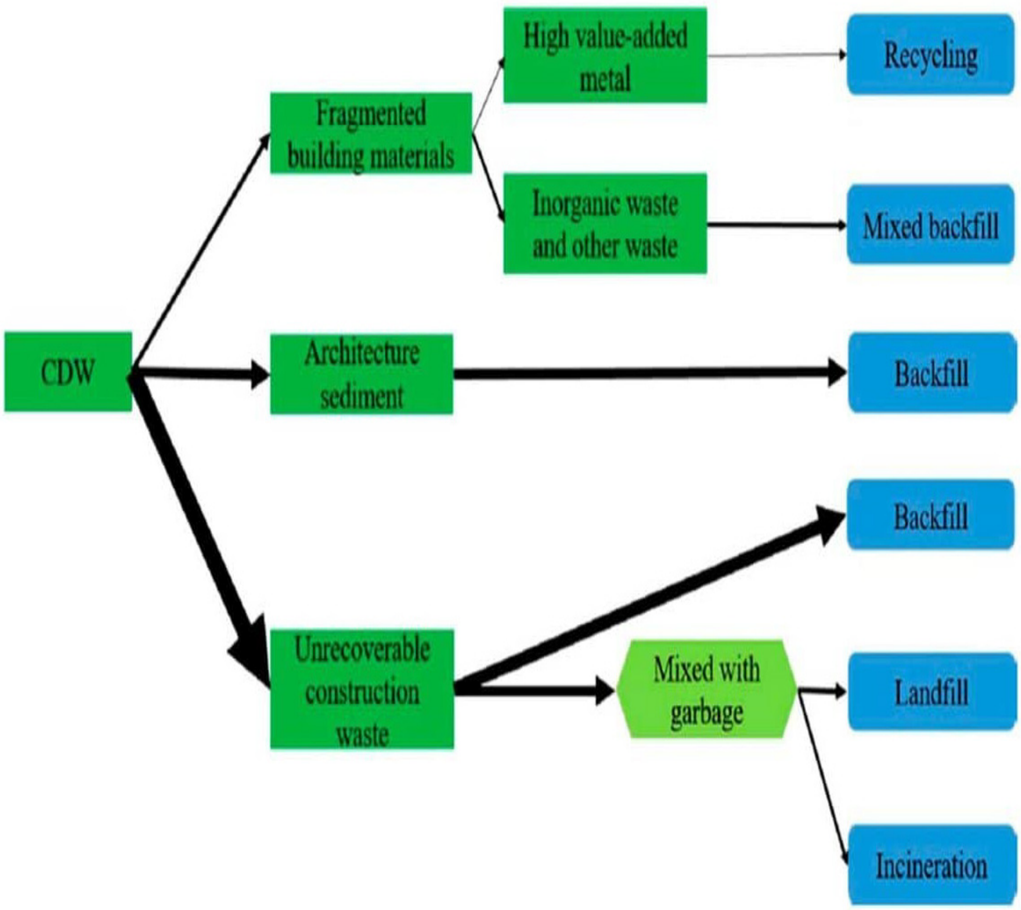

FIGURE 2.11: Construction and demolition waste flow in Beijing[152].

2.10.6 BIM-Based Theoretical Framework for CDW Management

In "Proposing Building Information Modeling-Based Theoretical Framework for Construction and Demolition Waste Management: Strategies and Tools," the researchers introduced a theoretical framework for integrating Building Information Modeling (BIM) into CDW management strategies. BIM technology offers significant potential for improving CDW management by providing detailed information on construction processes and materials. The proposed framework, illustrated in Figure 2.11, outlines various strategies and tools for enhancing CDW management through BIM, promoting more efficient and effective waste management practices.

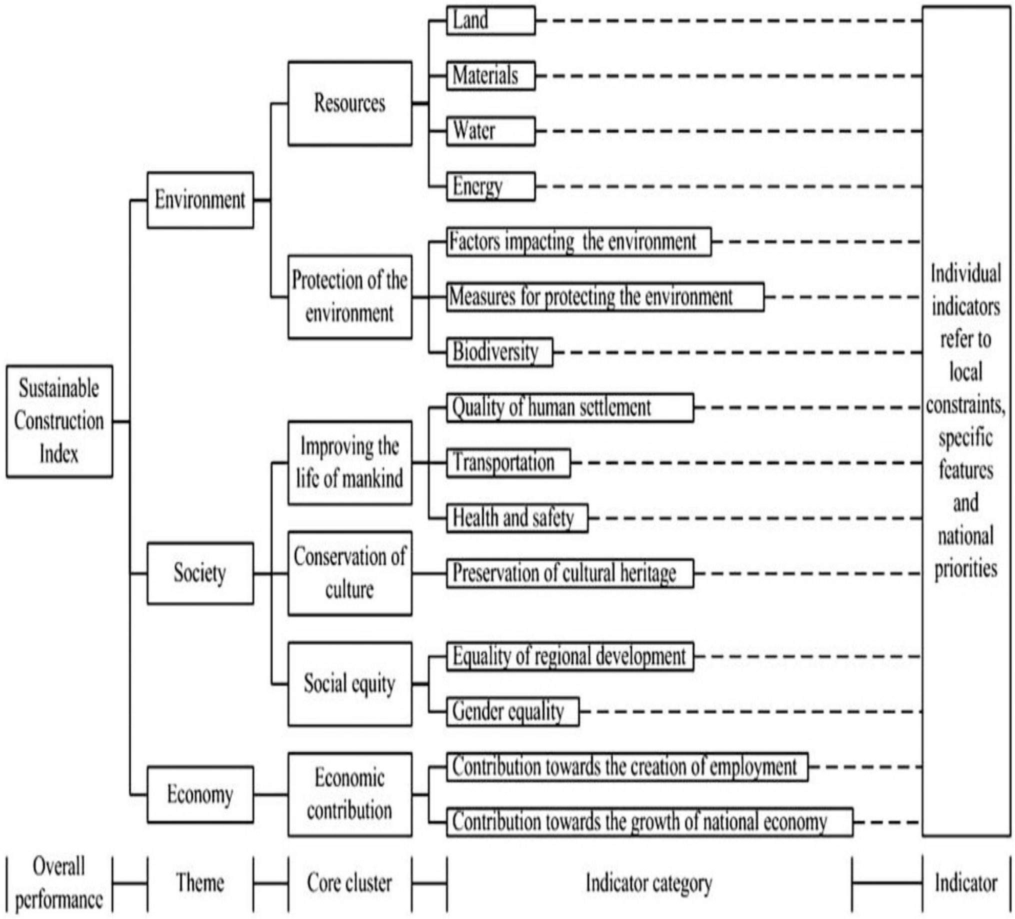

FIGURE 2.12: Theoretical framework for BIM-based C&DW Management[153].

2.10.7 Safe Disposal of Construction and Demolition Waste in Egypt

The study "Analysis of Factors Affecting Construction and Demolition Waste Safe Disposal in Egypt" analyzed the factors affecting the safe disposal of CDW in Egypt. Egypt, with its growing construction sector, faces challenges in ensuring the safe and sustainable disposal of CDW. The study provided a theoretical framework for addressing these challenges, considering various factors such as regulatory environments, technical limitations and economic constraints. The framework aims to improve safe disposal practices and promote sustainable CDW management in Egypt.

2.10.8 Policies playing a key role in improving Waste Management

This study identified and quantified the relationships between various factors, including construction waste generation drivers and improvement strategies, and how these elements directly influence the overall effectiveness of waste management systems. One of the key findings of the research was the pivotal role that policy and regulatory frameworks play in enhancing SCWM outcomes. Specifically, the study emphasized that well-formulated and strictly enforced policies not only help reduce waste at the source but also encourage the adoption of sustainable practices across the construction sector. Moreover, the framework provided empirical evidence that improvement measures—such as training, stakeholder engagement, and technological innovation—can significantly bolster the performance of SCWM initiatives. By applying a robust statistical model, the study offered valuable insights for decision-makers, highlighting the need for integrated approaches that combine technical, managerial, and regulatory components to achieve sustainable outcomes in construction waste management, particularly in developing countries.

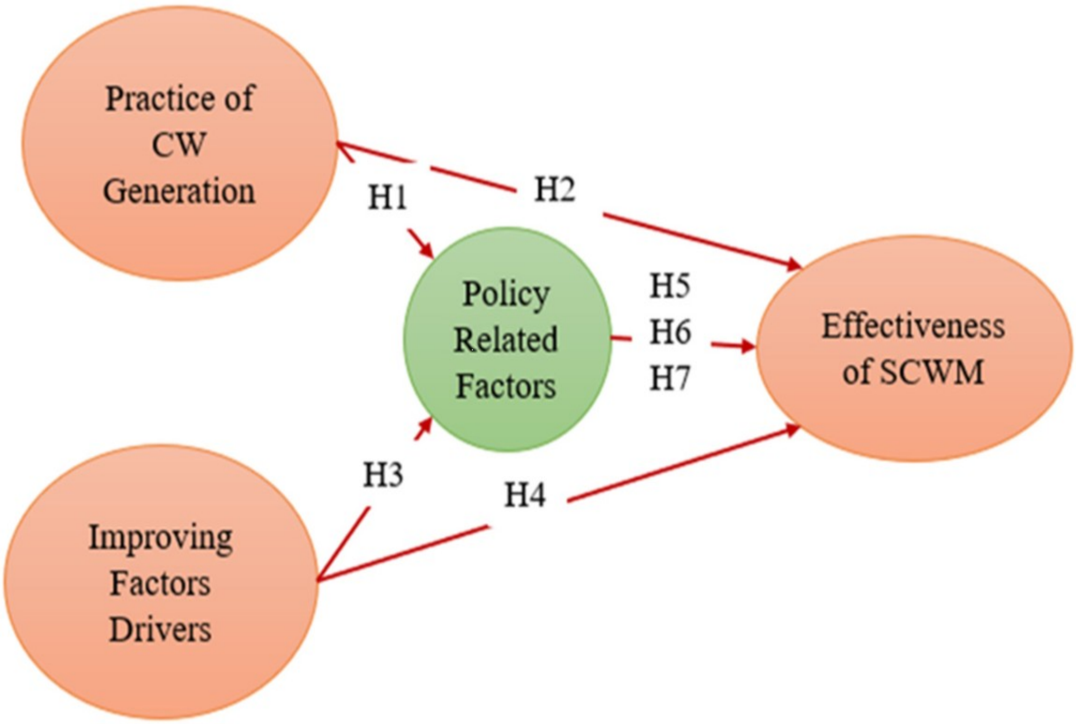

FIGURE 2.13: Practice and Policies Improving Waste Management[151]

2.10.9 Sustainable construction practices through effective Waste Management

A conceptual framework to examine how environmental, social, and economic sustainability dimensions contribute to enhancing sustainable construction practices through effective Construction Waste Management (CWM). Utilizing Partial Least Squares Structural Equation Modeling (PLS-SEM), the study empirically validated the relationships between these sustainability factors and their influence on construction outcomes. The findings revealed that CWM serves as a critical intermediary that bridges sustainability principles with practical construction processes, thereby reinforcing the integration of sustainable practices within the industry. Specifically, the research demonstrated that environmentally conscious waste management practices, socially responsible project execution, and economically efficient resource use collectively strengthen the foundation for sustainable construction. By positioning CWM as a pivotal mechanism, the study underscores its strategic importance in achieving long-term sustainability goals in construction projects.

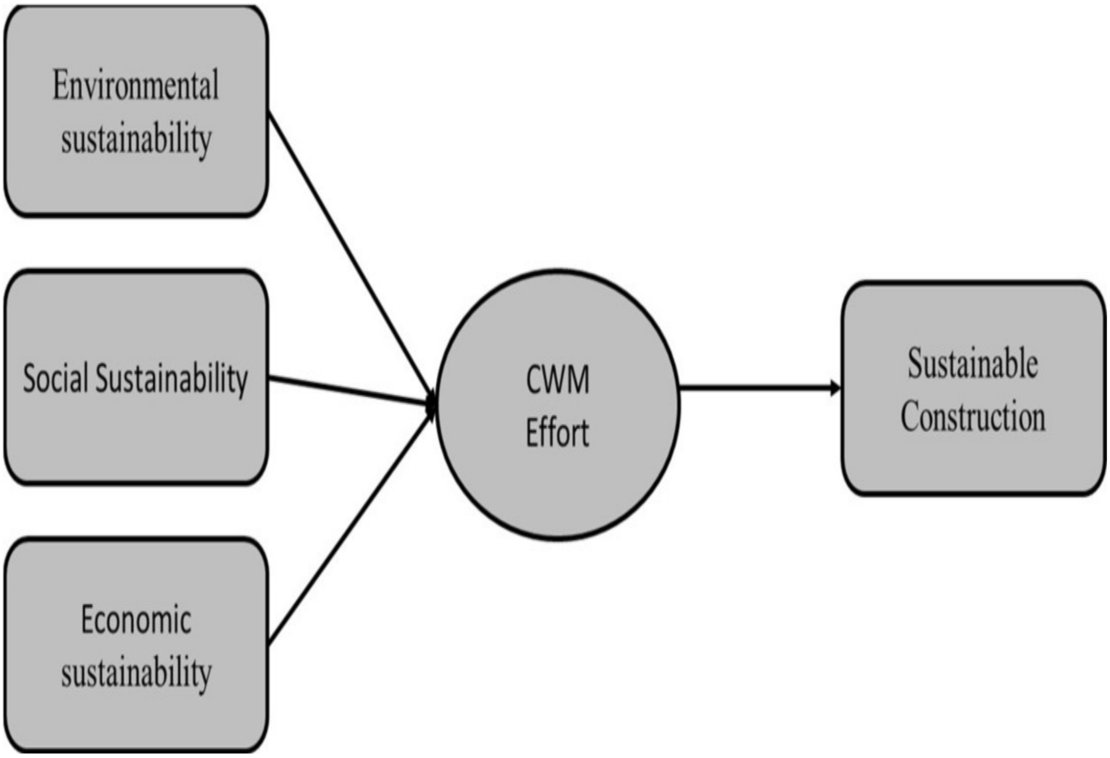

FIGURE 2.14: Sustainable construction Waste Management[155]

2.10.10 Research Gap

The research gap in road demolition waste management, particularly in developing countries like Pakistan, is marked by several key deficiencies. First, there is no integrated framework that addresses the entire life cycle of road demolition waste management. Existing studies focus on isolated issues like waste generation, environmental impacts and recycling, but fail to present a unified approach. A lack of detailed data on road-specific demolition waste also hinders the development of targeted management strategies. Moreover, limited research on recycling technologies for road materials such as asphalt and concrete in Pakistan restricts the adoption of sustainable practices. As noted by [156] understanding the composition and volume of road demolition waste is crucial for effective policy formulation and recycling strategies. Without this data, it is difficult to create reliable benchmarks or adopt best practices from more advanced systems.

Additionally, there is a lack of specific policies for managing road demolition waste, with weak enforcement of existing regulations further complicating waste management efforts. The environmental impacts of road demolition waste on soil, water and air quality have been insufficiently studied and the advantages of recycling versus disposal have not been fully explored. This gap has significant implications for policymakers and practitioners, as they lack clear, actionable guidelines. Localized case studies tailored to Pakistan's unique challenges, such as urban density and infrastructure limitations, are also scarce. These gaps in research, as highlighted by [143, 157]prevent the development of effective, context-specific solutions for sustainable waste management in road construction. Addressing these gaps is essential to improving waste management practices in Pakistan and aligning them with global sustainability standards.

To address this research gap, a new framework is necessary. This framework should integrate the causes, impacts, challenges and solutions specific to road demolition waste. It would provide a holistic approach to assessing and managing road demolition waste, ensuring that all contributing factors and potential interventions are thoroughly considered. This targeted framework would support policymakers and practitioners in developing more effective waste management strategies and promote the broader goals of sustainability in the construction industry.

2.11 Summary of the Chapter

Chapter 2 provides a comprehensive analysis of demolition waste in road projects, identifying its causes, impacts and challenges and reviewing existing frameworks for waste management. The chapter highlights the need for a holistic approach to managing demolition waste, revealing that previous studies have largely focused on isolated aspects, such as waste generation causes, environmental impacts and waste management challenges. While these studies offer valuable insights, they fail to integrate these elements into a unified, life-cycle-based strategy.

The main findings emphasize that demolition waste is generated across various stages of road projects and has significant environmental, social and economic impacts, such as pollution, resource depletion and public health issues. However, the existing research lacks a comprehensive framework that addresses these issues across the entire life cycle of road projects. The chapter also identifies key challenges in waste management, such as inadequate awareness, insufficient training and weak regulatory frameworks, which hinder effective waste management practices.

A critical research gap highlighted in the chapter is the absence of a tailored framework for managing road demolition waste. Most studies focus on building demolition waste, leaving road demolition waste underexplored. Additionally, existing frameworks are often narrow in scope, addressing individual components without considering the interconnected nature of the waste management process. This gap underscores the need for a comprehensive, life-cycle-oriented framework that can manage waste generation, recycling and disposal in road projects.

In conclusion, Chapter 2 underscores the need for a holistic, integrated framework for demolition waste management in road projects. It highlights the gaps in current research, particularly in relation to road demolition waste and stresses the importance of a comprehensive approach to address the challenges and impacts across the entire life cycle of road projects. These findings align with the study's objectives, which aim to propose a unified framework that addresses all aspects of demolition waste management.

Chapter 3

Research Design and Methodology

3.1 Background

The comprehensive literature review conducted in the previous chapter underscored the importance of adopting demolition waste management as an alternative to conventional demolition practices. It highlighted significant issues such as the causes and impacts of demolition waste, the challenges associated with its management and potential solutions. Despite these insights, the review identified a notable knowledge gap in developing structured methodologies and frameworks to guide stakeholders in the End-of-Life (EoL) decision-making process for road construction and demolition. This chapter aims to address this gap by introducing and elaborating on the methodological approach and methods employed in the study. The rationale for selecting specific strategies and designs for this study is provided, ensuring they align with the research objectives and questions. The chapter then delves into the methods and processes of data collection, detailing techniques such as focus group discussions for questionnaire development and pilot studies. For data analysis, PLS-SEM (Partial Least Squares Structural Equation Modeling) is employed. Ethical considerations are also addressed, emphasizing the importance of maintaining standards such as obtaining informed consent, ensuring confidentiality and anonymity, avoiding conflicts of interest. These ethical considerations are paramount to maintaining the integrity and credibility of the research process. In conclusion, this chapter provides a comprehensive overview of the methodological approach and methods used in the study, setting the foundation for the subsequent chapters that present and analyze the research findings.

3.2 Research Design Flow Chart

This research employed to develop a framework for the environmental management for the demolition of roads. The primary data collection was meticulously validated and further analyzed to ensure accuracy and quality. The process included a series of steps such as focused group discussions and pilot studies to create a robust database for the framework. Through these methods, any errors in the data were identified and corrected, ensuring the reliability and validity of the results. This comprehensive approach ensured that the developed framework was grounded in accurate and high-quality data, enhancing its applicability and effectiveness in real-world scenarios. The study utilized a questionnaire as the primary tool to measure its variables. The validation of this survey instrument was conducted in two distinct stages. In the first phase, the face and content validity of the survey were assessed by experts in the field. These experts reviewed the survey to ensure that it effectively captured the intended variables and content areas, ensuring that the questions were clear, relevant and comprehensive. In the second phase, a pilot study was conducted to evaluate the instrument's reliability before deploying it in the main study. Pilot study aimed to test the survey's effectiveness and consistency in measuring the variables of interest. This step was crucial for identifying any potential issues or areas for improvement in the survey instrument, ensuring its robustness and reliability before it was used in the larger study. This two-tier validation process ensured that the survey instrument was both reliable and valid, providing a strong foundation for the research findings. This step helped identify any potential issues or improvements needed in the survey instrument before proceeding with the main study [127, 155].Figure 3.1.

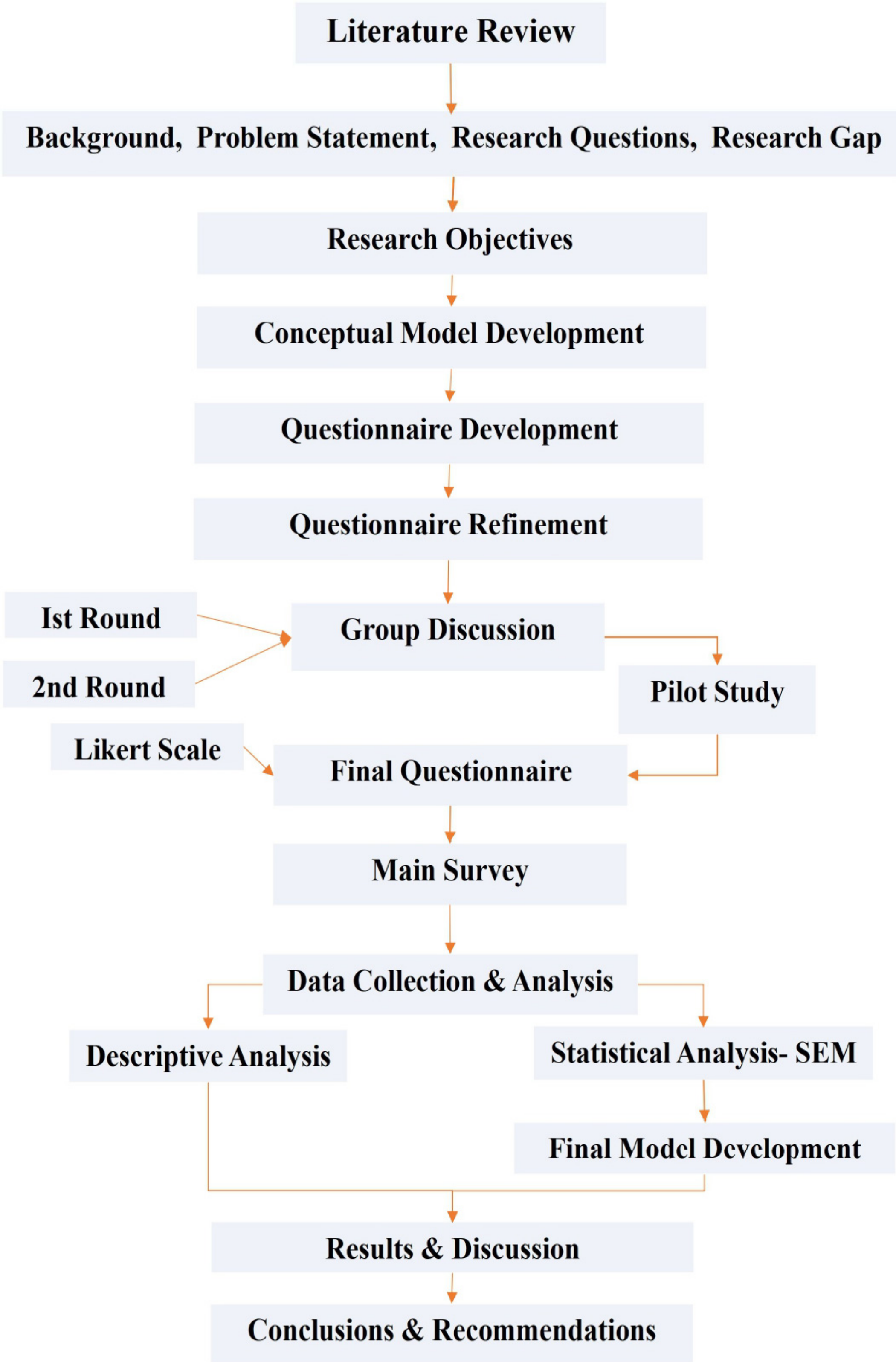

FIGURE 3.1: Research Flow chart

3.2.1 Source of Data

The source of data refers to the origin or location from which information is obtained for research, analysis, or study purposes. In the context of demolition waste management for road projects in Pakistan, sources of data can be categorized into two main types:

3.2.1.1 Primary Source of Data

Primary sources of data refer to information that is collected firsthand by the researcher or data collector for a specific purpose or study. In the context of demolition waste management related to the road projects in Pakistan, primary sources of data can include:

Administered to construction companies, contractors, government agencies and local communities to gather quantitative data on waste generation rates, management practices and challenges faced.

Direct observations made at demolition sites to gather data on types and quantities of waste generated, methods of handling and disposal, compliance with regulations and environmental impacts.

These primary sources are crucial for obtaining specific, firsthand information that can inform empirical studies, theoretical frameworks and practical interventions aimed at improving waste management practices in construction projects in Pakistan.

3.2.1.2 Secondary Source of Data

Secondary sources of data for demolition waste management related to road projects in Pakistan encompass existing information and research collected by others, which researchers can utilize for analysis and study purposes. These sources include, research articles etc.

Published by agencies such as the Ministry of Climate Change, Environmental Protection Agencies and municipal authorities, providing data on policies, regulations and statistics related to waste management in Pakistan.

Research articles, theses, dissertations and academic journals from Pakistani universities and research institutions offering theoretical insights, case studies and empirical data on construction and environmental management practices.

Reports from construction industry associations, consulting firms and non-governmental organizations (NGOs) detailing trends, technologies and best practices in demolition waste management specific to Pakistan.

Accessible repositories, environmental portals and international organizations' websites housing data sets, research papers and reports relevant to demolition waste management and sustainable construction practices in Pakistan.

3.3 Research Design

This study adopts a mixed methods research design, combining qualitative and quantitative approaches to comprehensively explore demolition waste (DW) management in road construction and maintenance projects. The research follows a structured Methodological Framework, which includes multiple stages such as a thorough literature review, primary document review and expert insights through the focus group discussion and pilot study. These stages help identify gaps, refine research questions and define the scope of the study. The data collection process involves various methods such as surveys, focus group discussions and field observations. These methods gather both qualitative and quantitative data from stakeholders in the road construction sector, including project managers, engineers and waste management professionals. A pilot study is conducted to validate the data, ensuring its reliability and consistency. The research also includes the development of a questionnaire that used to collect broader quantitative data to refine the Demolition Waste Management Framework. Data analysis is performed using

PLS-SEM (Partial Least Squares Structural Equation Modeling), which is ideal for testing complex relationships between variables. This approach allows for a detailed examination of the factors influencing DW generation and management practices. The combination of qualitative and quantitative data provides a robust understanding of the challenges and opportunities in DW management, offering actionable insights that can improve practices in road construction projects.

3.3.1 Focus Group Discussions

Designing a focus group requires meticulous planning and execution to ensure that the discussion meets its objectives effectively. Focus group discussions (FGDs) are a valuable method used by researchers to develop and refine questionnaires for their studies.

Firstly, FGDs provide researchers with an opportunity to engage participants in discussions about draft questionnaire items. This interaction helps researchers understand how potential respondents interpret and react to the questions. Through these discussions, researchers can identify any ambiguities, cultural sensitivities, or language nuances that might affect the clarity and validity of the survey instrument. By addressing these issues early on, researchers can refine the wording and structure of the questions to ensure they are easily understood and relevant to the intended audience.

Secondly, FGDs serve as a crucial step in testing the validity and comprehensiveness of the questionnaire. Participants' feedback during these discussions helps assess whether the questions adequately cover all relevant aspects of the research topic. It also ensures that the questions resonate with the experiences and perspectives of the target population. Through iterative discussions and revisions based on FGD insights, researchers can develop a robust questionnaire that enhances the quality and effectiveness of data collection in their study.

Selecting the right participants for an FGD is pivotal for extracting valuable insights that are aligned with the research objectives. Initially, researchers define the target audience by considering demographic characteristics such as age, gender and geographic location. This step ensures that the participants are relevant to the study's goals and can provide meaningful contributions based on their unique perspectives and experiences. Employing a suitable sampling strategy, whether purposive (selecting participants based on specific criteria) or convenience-based (choosing participants who are readily available), helps streamline the selection process. Factors such as accessibility to the target population and the diversity required to capture a range of perspectives are carefully considered in this process.

Table 3.1, which summarizes the participants of the focus group discussion, provides a clear overview of the demographic breakdown and selection criteria. This table highlights the efforts taken to ensure a representative and balanced group, reinforcing the credibility and comprehensiveness of the research findings. It serves as a reference for understanding the composition of the discussion group and the rationale behind participant selection, thereby enhancing the reliability of the insights gained from the study.

Table 3.1: Participants of Focus Group Discussions

Designation	**Qualification**	**Experience (Years)**	**Organization**
Director General	MS-Civil Eng.	25	Client
Director	BSc-Civil Eng.	23	Client
Director	BSc-Civil Eng.	22	Client
Deputy Director	BSc-Civil Eng.	20	Client
Deputy Director	MS-Civil Eng.	20	Client
Material Engineer	MS-Civil Eng.	23	Consultant
Project Manager	MS-Civil Eng.	25	Consultant
Construction Manager	MS-Civil Eng.	22	Consultant
Project Manager	BSc-Civil Eng.	22	Consultant
Owner/C.E.O	BSc-Civil Eng.	25	Contractor
Owner/C.E.O	BSc-Civil Eng.	23	Contractor
Owner/C.E.O	BSc-Civil Eng.	20	Contractor

The Focused Group Discussion (FGD) comprised participants representing a well-balanced distribution of organizational roles within the road construction sector, including clients (e.g., public infrastructure authorities), consultants (e.g., design and planning firms) and contractors (e.g., construction and execution entities). This classification ensured that insights were captured from all phases of the project lifecycle—ranging from initial planning and design to execution and post-construction operations. Each participant brought over 20 years of professional experience specifically related to road infrastructure projects.

Their areas of expertise encompassed project management, materials engineering and strategic leadership, contributing both technical knowledge and high-level decision-making perspectives. Notably, all participants had direct, hands-on experience with demolition waste management and roadwork implementation, which added practical depth to the discussions. The diversity in organizational backgrounds, combined with substantial field experience, enabled a comprehensive and contextually grounded exploration of the challenges, practices and potential improvements in demolition waste management within road construction projects.

3.4 Questionnaire development

Based on the literature review, 107 factors have been selected and a questionnaire has been developed following the initial meeting with Focus Group Discussion (FGD) participants, where their details and experience were elaborated in previous tables. The development of this questionnaire is now being presented to the group again for the FGD.

This iterative process ensures that the questionnaire aligns closely with the insights and expertise shared by the FGD participants. By incorporating their detailed experiences and perspectives into the questionnaire design, the research aims to gather comprehensive and relevant data on demolition waste management in road networks. The FGD participants, selected for their expertise and relevance to the research topic, further refine and validate the questionnaire through structured discussions and feedback sessions. This collaborative approach enhances the questionnaire's validity and ensures that it effectively captures the diverse viewpoints and practical insights essential for the study.

Following a comprehensive literature review, variables were identified for further exploration and discussion using the Focus Group Discussions (FGDs), aims to achieve consensus among experts through iterative feedback rounds. Initially selected based on their significant citation in literature from 2014 to 2024, these variables underwent detailed examination through FGDs process.

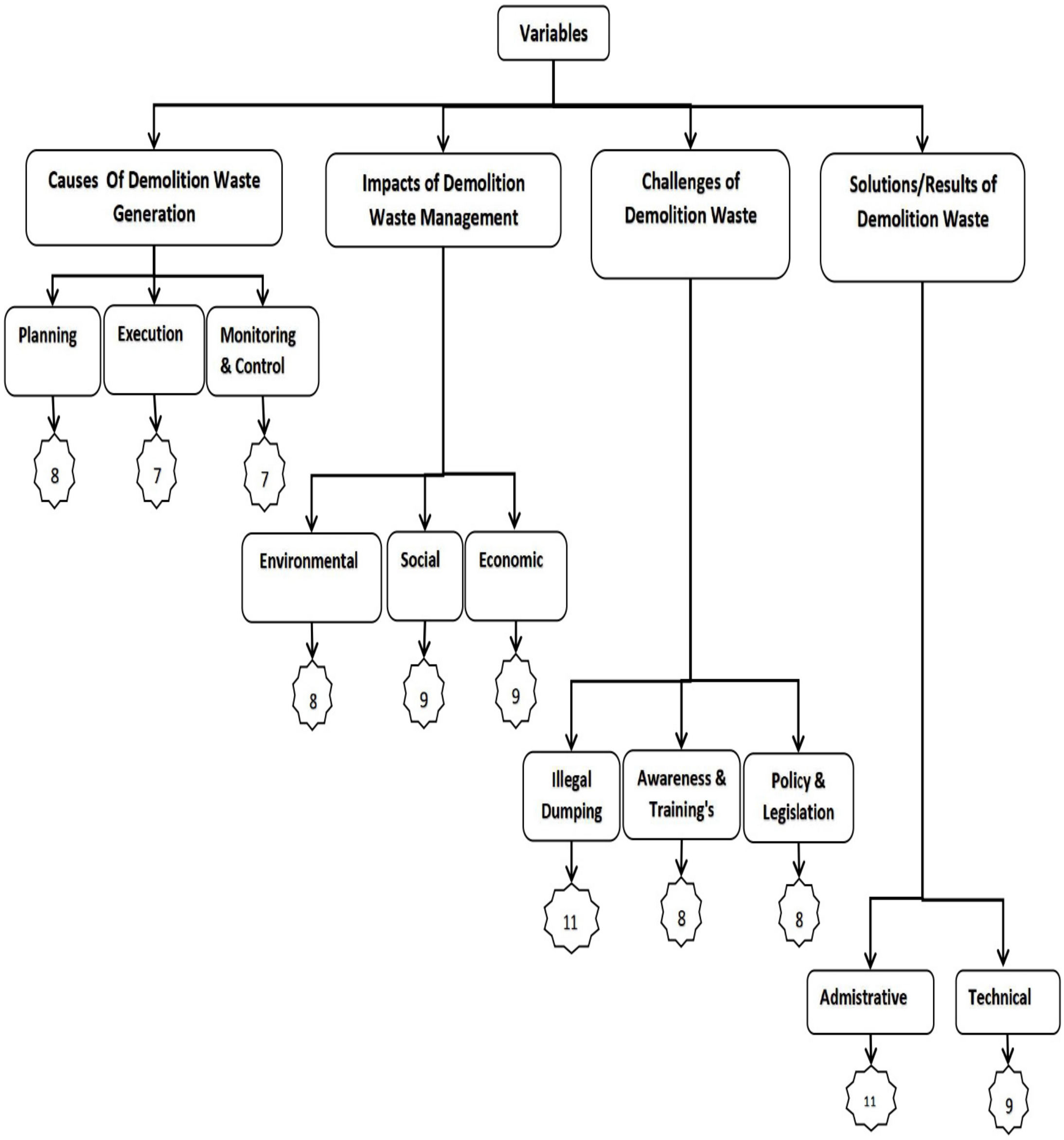

FIGURE 3.2: Categorization Mechanism for Demolition Waste Management (Accepted Frame work)

A detailed literature review identified 107 factors, which were then shared with field experts during the first round of group discussions. After thorough discussion six factors were removed because they overlapped or required similar actions so they were merged with other related factors. This reduced the total number of factors to 101. In the second round of discussions, the revised questionnaire was reviewed again by the same field experts and three more factors were again merged with other related factors. As a result 98 factors were finalized, these factors were selected for the pilot study to refine the questionnaire further and validate the relevant factors.

Based on the results of two rounds of focus group discussions, the Categorization Mechanism for Demolition Waste Management has been established, as shown in Figure 3.2. This accepted framework reflects the finalized categorization and the corresponding number of variables within each column of the framework.

3.4.1 Pilot Study

Before acquiring data from the field for the study on demolition waste management in road networks, conducting a pilot study is crucial. This pilot test involves gathering feedback from a small sample of respondents to identify any ambiguities, comprehension issues, or missing topics in the questionnaire. The primary goal is to refine research instruments, procedures and protocols to ensure their validity and reliability before scaling up to the main study.

Pilot studies serve several essential purposes. They provide an opportunity to assess the clarity and relevance of questions posed to respondents. Feedback from the pilot study helps researchers understand how well participants comprehend the questions and whether there are any misunderstandings or uncertainties that need clarification. This iterative process allows for adjustments to be made to the questionnaire, ensuring that it effectively captures the data necessary to inform sustainable waste management practices and policy decisions related to demolition waste in road networks.

Moreover, pilot studies help researchers optimize the study design. By testing the questionnaire with a smaller group, researchers can identify potential logistical challenges or methodological issues that may arise during data collection. Addressing these challenges early on improves the overall quality and effectiveness of the main study by refining data collection procedures and ensuring that all aspects of the research are well-planned and executed.

Conducting a pilot study before finalizing the questionnaire ensures that the research instruments are well-designed and suitable for the specific context of demolition waste management in road networks. This approach not only enhances the validity and reliability of the study but also maximizes the potential for collecting comprehensive and insightful data that can drive meaningful improvements in sustainable waste management practices and policy decisions.

The Pilot Study engaged a targeted group of 22 professionals, purposefully selected for their extensive experience and relevance to road construction and demolition waste management. Participants were drawn from key organizational categories within the sector, comprising 8 individuals from client organizations (such as government infrastructure departments), 7 from consultancy firms (involved in technical assessments and design) and 7 from contracting companies (responsible for on-site execution of roadworks). This distribution ensured a comprehensive representation of the project lifecycle—from planning and design to implementation and operational stages.

All participants had more than 20 years of experience in road-related civil engineering, with professional backgrounds spanning project supervision, materials selection and construction management. Their practical knowledge of demolition waste handling and roadwork implementation offered valuable, context-specific feedback during the pilot phase. The combination of diverse institutional affiliations and seasoned expertise enabled effective refinement of the data collection instruments, ensuring they were clear, contextually appropriate and aligned with the research objectives related to demolition waste management in road infrastructure projects. In pilot study, 3 factors were eliminated, 95 out of 98 has been selected for final survey. Table 3.2 shows the details of the participants involved in the Pilot Study.

TABLE 3.2: Participants of Pilot Study

Designation	**Qualification**	**Experience (Years)**	**Organization**
Deputy Director	PhD Civil Eng	26	Client
Director	BSc-Civil Eng.	21	Client
Director	BSc-Civil Eng.	20	Client
Executive Engineer	BSc-Civil Eng.	21	Client
Superintendent Engineer	MS-Civil Eng.	25	Client
Assistant Director	BSc-Civil Eng.	20	Client
Executive Engineer	PhD Civil Eng	24	Client
Chief Eng	PhD Civil Eng	27	Client
Material Engineer	MS-Civil Eng.	20	Consultant
Material Engineer	MS-Civil Eng.	20	Consultant
Construction Manager	BSc-Civil Eng.	25	Consultant
Project Manager	MS-Civil Eng.	25	Consultant
Material Engineer	MS-Civil Eng.	22	Consultant
Material Engineer	MS-Civil Eng.	23	Consultant
Construction Manager	BSc-Civil Eng.	22	Consultant
Owner/C.E.O	DAE	22	Contractor
Owner/C.E.O	BSc-Civil Eng.	25	Contractor
Owner/C.E.O	BSc-Civil Eng.	23	Contractor
Owner/C.E.O	BSc-Civil Eng.	25	Contractor
Owner/C.E.O	DAE	22	Contractor
Owner/C.E.O	BSc-Civil Eng.	25	Contractor
Owner/C.E.O	DAE	24	Contractor

This approach provides transparency and clarity regarding the factors under investigation and their categorization within the broader research context. The rigorous coding system and framework enable researchers to capture detailed insights into demolition waste management practices in road networks. This thorough methodology enhances the interpretation of collected data and supports evidence-based decision-making and policy formulation aimed at promoting sustainability in infrastructure development.

The structured design of the questionnaire and its systematic implementation provide a robust foundation for generating actionable insights and advancing knowledge in environmental management and sustainable development. The comprehensive data gathered through this approach is instrumental in informing effective strategies for managing demolition waste and improving environmental stewardship in road construction projects. Table 3.3 outlines the coding guidelines used for the questionnaire.

TABLE 3.3: Coding adopted

Factors	**Code**
Causes of demolition waste generation	**CW**
Causes of demolition waste generation at planning stage	**CW-PN**
Causes of demolition waste generation at execution stage	**CW-EX**
Causes of demolition waste generation at monitoring control stage	**CW-MC**
Demolition waste impacts	**WI**
Demolition waste impacts on Environment	**WI-EN**
Demolition waste impacts on Social	**WI-SO**
Demolition waste impacts on Economic	**WI-EC**
Demolition waste Management challenges	**WC**
Demolition waste Management challenges for Waste Handling	**WC-WH**
Demolition waste Management challenges for Awareness Training	**WC-AT**
Demolition waste Management challenges for Policy Legislation	**WC-PL**
Solutions of Demolition Waste Management- Administrative	**SD-AS**
Solutions of Demolition Waste Management- Technical	**SD-TS**

The survey questionnaire for the study on demolition waste management in road networks includes a detailed structure with four sections, as illustrated in Figure 3.2 and elaborated in the accompanying tables. Each variable is assigned a specific code within this framework.

A 5-point Likert scale was used to measure the perceived impact of various factors. This scale ranges from "1-Very Low Impact" to "5-Very High Impact," allowing respondents to assess and quantify the influence of each factor[158]. Here's how the scale works:

- **1 (Very Low Impact):** Indicates minimal influence.
- **2 (Low Impact):** Suggests a low level of impact.
- **3 (Moderate Impact):** Denotes a moderate level of impact.
- **4 (High Impact):** Signifies a high level of impact.
- **5 (Very High Impact):** Represents the highest level of impact.

This structured approach allows respondents to differentiate between levels of influence accurately, providing a clear understanding of the relative importance of each factor based on their perceptions. The use of this scale enables nuanced responses and supports a more detailed analysis of the data.

The variables, along with their codes, are detailed in the Appendix A, which offer a comprehensive overview of the factors under investigation and their categorization within the research framework. This organization facilitates consistency in data collection and aids in rigorous analysis, supporting the study's objectives in understanding and improving demolition waste management in road networks.

3.5 Final Questionnaire

Developing a final comprehensive questionnaire is a methodical process crucial for effectively achieving research objectives. This process begins by clearly defining the study's goals and objectives, guiding the selection of relevant variables and the drafting of unbiased questions. Each question must be clear, concise and logically organized to ensure it aligns with the research focus and is easily understood by respondents. Providing appropriate response options, such as Likert scales or multiple-choice formats, enhances the questionnaire's reliability and validity.

After drafting, the questionnaire undergoes pretesting and revisions based on feedback to ensure clarity and relevance. It's important that participants in previous research stages, such as FGDs Rounds 1 & 2 and the pilot study, are distinct from those who receive the final questionnaire. This approach minimizes bias and ensures diverse perspectives contribute to the study's findings.

Once finalized, the questionnaire is distributed to the target sample. Responses are collected and meticulously analyzed to derive meaningful insights. Data analysis techniques vary depending on the nature of the responses, ranging from qualitative thematic analysis to quantitative statistical methods. The findings are then interpreted in relation to the research goals, providing valuable insights that inform decision-making, policy development, or further research directions.

For this study on demolition waste management in road networks, the final questionnaire was developed through an integrated approach involving FGDs Rounds 1 & 2 and a pilot study. The questionnaire is divided into two sections: the first section contains 7 questions designed to profile the respondents, gathering demographic information and relevant experience. The second section includes 95 factors related to causes of demolition waste, impacts of demolition waste, challenges of demolition waste management and potential solutions. The final questionnaire is shown at Appendix A.This rigorous process ensures that the questionnaire is robust, relevant and capable of generating comprehensive data essential for advancing knowledge and addressing practical challenges in environmental management and sustainability.

Based on insights gained from the literature review, focus group discussions and the pilot study, Figure 3.3, a conceptual framework has been developed to illustrate the interrelationships among key latent variables in demolition waste management.

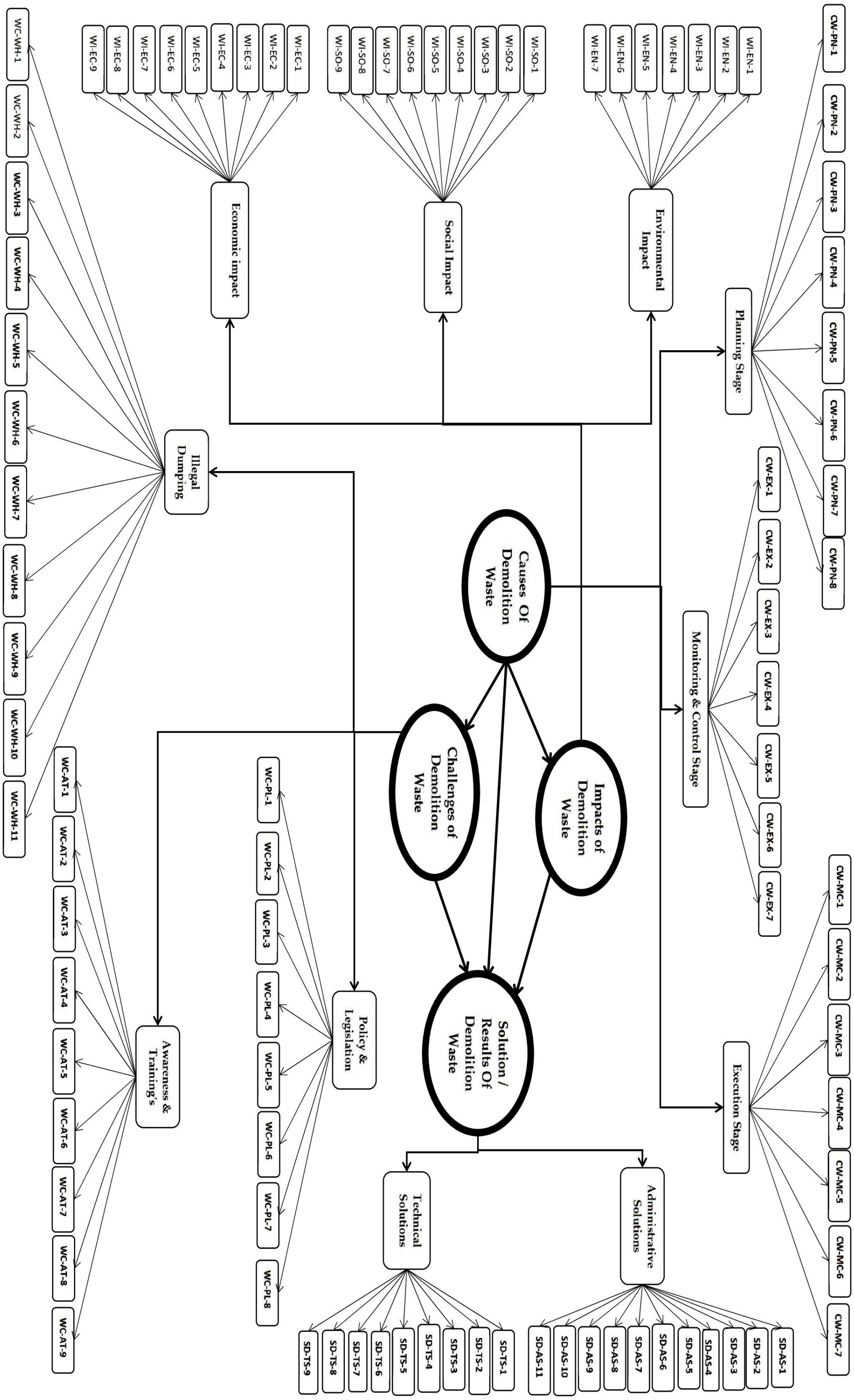

FIGURE 3.3: Conceptual Framework for Research Study

The framework visually presents how the causes of demolition waste generation influence the overall process, highlighting the resulting environmental and socio-economic impacts. It also identifies the major challenges encountered in managing demolition waste effectively, such as regulatory gaps, lack of awareness, and inadequate infrastructure, solutions related to demolition waste practices, including policy reforms, capacity building, technological integration and sustainable reuse strategies. This conceptual framework serves as a foundation for further analysis and supports the development of targeted interventions in the context of road construction projects.

3.6 Data Collection and Sampling Techniques

Data collection based on questionnaires is a fundamental aspect of research across various disciplines, including demolition waste management. The process begins with designing a questionnaire that aligns with the research objectives, ensuring clarity of questions and relevance to the study's focus. Researchers have the flexibility to choose between different administration methods, such as online surveys, paper-based questionnaires, depending on the target population and logistical considerations. Administering the questionnaire involves distributing it to a selected sample of participants who meet specific criteria, often identified through purposive sampling methods. Clear instructions accompany the questionnaire to ensure participants understand how to complete it accurately. This step is crucial for minimizing response errors and ensuring consistency in data collection. Whether responses are quantitative (e.g., Likert scales, multiple-choice) or qualitative (e.g., open-ended responses), researchers strive to capture comprehensive data that provides insights into participants' attitudes, behaviors, opinions and perceptions related to demolition waste management.

The insights derived from questionnaire-based data collection are invaluable for informing research outcomes and supporting evidence-based decision-making in demolition waste management and related fields. By systematically gathering and analyzing data, researchers can uncover actionable findings that contribute

to advancing sustainable practices, optimizing waste management strategies and addressing environmental challenges effectively. Ultimately, questionnaire-based data collection serves as a powerful tool for generating knowledge, shaping policies and driving positive change in infrastructure development and environmental management contexts.
Sampling techniques are methods used to select a subset of individuals or observations from a larger population to make inferences about that population. Here are the main types of sampling techniques:

3.6.1 Probability Sampling

In probability sampling, every member of the population has a known, non-zero chance of being selected. This type of sampling is often considered more reliable and objective.

3.6.1.1 Simple Random Sampling

Every member of the population has an equal chance of being selected. This can be done using random number tables or computer algorithms[159].

3.6.1.2 Systematic Sampling

A starting point is chosen at random and then every nth member of the population is selected. This method is simpler than simple random sampling but can introduce bias if there is a pattern in the population[160].

3.6.1.3 Stratified Sampling

The population is divided into subgroups (strata) based on a characteristic and random samples are taken from each stratum. This ensures representation from each subgroup[161].

3.6.1.4 Cluster Sampling

The population is divided into clusters (usually based on geography or other natural groupings) and a random sample of clusters is selected. All members of the chosen clusters are included in the sample. This is useful when the population is large and spread out[162].

3.6.1.5 Multistage Sampling

A combination of different sampling methods, often involving selecting clusters and then performing random or systematic sampling within those clusters[163].

3.6.2 Non-Probability Sampling

In non-probability sampling, not every member of the population has a chance of being selected. This can be useful in exploratory research or when probability sampling is not feasible, but it may introduce bias.

3.6.2.1 Convenience Sampling

Samples are taken from a group that is conveniently accessible. This method is quick and easy but may not represent the population well[164].

3.6.2.2 Judgmental or Purposive Sampling

The researcher uses their judgment to select participants who are believed to be representative of the population. This can introduce researcher bias[165].

3.6.2.3 Snowball Sampling

Existing study subjects recruit future subjects from among their acquaintances. This is often used in studies involving hard-to-reach populations[163].

3.6.2.4 Quota Sampling

The population is segmented into mutually exclusive subgroups and samples are taken from each subgroup to meet a predefined quota. This method ensures representation of certain characteristics but may not be random[166].

3.6.2.5 Self-Selection Sampling

Individuals volunteer to participate in the study. This is common in online surveys and can introduce volunteer bias.

3.6.2.6 Choosing the Right Sampling Technique

The choice of sampling technique depends on the research objectives, the nature of the population, available resources and the desired level of accuracy and reliability. Probability sampling methods are generally preferred for their ability to provide more generalizable and unbiased results, while non-probability methods can be useful in exploratory research or when constraints prevent the use of probability sampling.

3.6.3 Judgmental or Purposive Sampling

Purposive sampling is a deliberate and systematic approach used in qualitative and quantitative research to select participants who possess specific characteristics or qualities deemed essential for the study's objectives. Unlike random sampling methods that aim for representativeness across a population, purposive sampling focuses on identifying individuals or groups with particular expertise, experiences, or attributes that align closely with the research focus[167].
This method is particularly advantageous in fields like demolition waste management, where insights from knowledgeable stakeholders can provide deep understanding and practical solutions to complex issues.

In the context of demolition waste management research, researchers may employ purposive sampling to target participants such as demolition contractors, waste management experts, environmental consultants, policymakers and other key stakeholders directly involved in decision-making or operational aspects of demolition projects. These participants are selected based on criteria such as their professional roles, years of experience in the industry, specific expertise in waste reduction strategies, or their involvement in regulatory compliance related to environmental standards. By focusing on these criteria, researchers can ensure that the data collected is relevant, comprehensive and reflective of real-world practices and challenges. One sub-type of purposive sampling is expert sampling, which specifically targets individuals recognized for their authoritative knowledge and contributions within their field of expertise. For instance, in demolition waste management, experts could include researchers renowned for their publications on sustainable construction practices, engineers specializing in waste disposal technologies, or policymakers involved in shaping environmental policies.

Engaging these experts ensures that the study benefits from their profound insights, innovative approaches and informed perspectives, which can significantly enrich the research findings and contribute to advancing the field. When implementing purposive sampling, researchers must maintain transparency and rigor throughout the participant selection process. This involves clearly documenting the criteria used to identify and recruit participants, as well as justifying how these criteria align with the study's objectives. Additionally, researchers should strive to achieve diversity within the selected sample to capture a broad spectrum of viewpoints and experiences while maintaining focus on the specific expertise or attributes deemed critical to addressing the research questions effectively. By adhering to these practices, researchers can leverage purposive sampling to generate nuanced insights, inform evidence-based practices and drive meaningful advancements in demolition waste management and sustainability initiatives. Identify Criteria: Determine the criteria that are relevant to research objectives. These criteria could include factors such as the type of demolition project (e.g., residential, commercial, industrial), geographic location, size of the demolition site, or specific stakeholders involved in waste management (e.g., demolition contractors, waste management companies, policymakers). Select Participants: Use these criteria to purposively select participants who meet the criteria and are likely to provide valuable insights into the research topic. For example, select demolition contractors with extensive experience in handling demolition waste or waste management experts who specialize in demolition waste management and waste reduction strategies.

Purposive sampling was employed in this study to intentionally select participants who possess specific knowledge, experience, or involvement in demolition waste management within road construction projects. This sampling technique allowed the researcher to focus on individuals—such as contractors, engineers, waste management professionals, and government officials—who were most likely to provide relevant and insightful information aligned with the research objectives. The targeted nature of purposive sampling ensured the inclusion of diverse yet informed perspectives, contributing to a deeper understanding of the causes, challenges, impacts, and solutions related to demolition waste. This method was particularly suitable for addressing complex, real-world issues where generalization is less important than obtaining detailed, context-rich data.

3.7 Partial Least Squares Structural Equation Modeling (PLS-SEM)

Partial Least Squares Structural Equation Modeling (PLS-SEM) has been utilized in managing construction and demolition waste[118]. PLS-SEM is a statistical method used to analyze complex relationships in data with high collinearity and limited sample sizes. It combines Structural Equation Modeling (SEM) and Partial Least Squares (PLS) regression, making it advantageous for datasets with many variables and small sample sizes. PLS-SEM can analyze multiple dependent variables and evaluate both direct and indirect effects among latent (unobserved) variables.

Partial Least Squares Structural Equation Modeling (PLS-SEM) is widely used across disciplines like social sciences, business and economics to uncover relationships between latent variables, providing insights into complex data despite challenges like small sample sizes or collinearity among variables.

Researchers emphasize several reasons for choosing PLS-SEM, especially when dealing with limited sample sizes and complex predictive models [149]. PLS-SEM excels in managing intricate models with multiple constructs and relationships, allowing for effective prediction validation within constraints of sample size and model complexity.

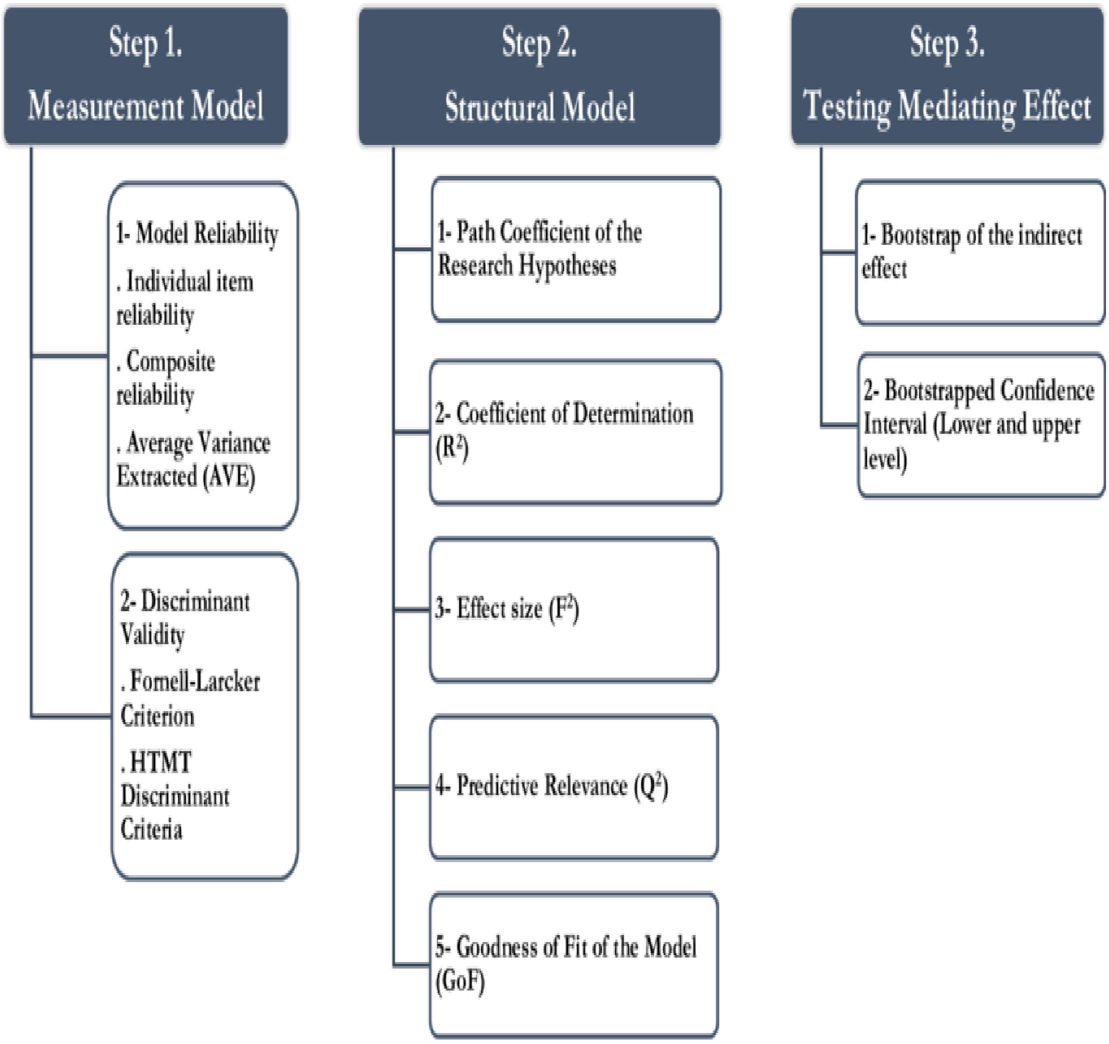

FIGURE 3.4: PLS-SEM Steps

One of PLS-SEM's strengths is its ability to perform well with small sample sizes, common in business and marketing studies. It also offers strong predictive capabilities, making it suitable for studies that demand accurate predictions amidst model complexity. Researchers are increasingly adopting PLS-SEM for its capacity to validate theoretically grounded models using constructs, its applicability in complex modeling scenarios with limited data and its robust predictive performance [150, 151]. PLS-SEM is highly valued for exploring and understanding variables and constructs in research, providing new opportunities for scholars across diverse fields,Figure 3.4. [168].

The development of four distinct models, aims to explore the various factors influencing demolition waste management. These models were constructed using comprehensive data collected from the literature, as well as insights gained from focus group discussions and a pilot study. The models incorporate variables that reflect critical elements essential for understanding the causes, impacts, challenges and solutions associated with demolition waste management. The primary objective of these models is to investigate the relationships between the causes of demolition waste generation, its impacts, the challenges waste management and solutions for improving waste management practices. Each model is designed to capture a specific aspect of demolition waste management, offering a detailed framework for addressing the underlying issues.

Table 3.4: Detail of Variables with respect to Models

Sr. No.	**Variables**
Model 1	Causes of demolition waste generation, Impact of demolition waste Challenges of demolition waste management.
Model 2	Causes of demolition waste generation, Challenges of demolition waste management Solutions of demolition waste management.
Model 3	Causes of demolition waste generation, Impact of demolition waste Solutions of demolition waste management.
Model 4	Causes of demolition waste generation, Impact of demolition waste, Challenges of demolition waste management Solutions of demolition waste management.

Based upon the collected data following four (4) Models has been developed and tested on Smart PLS-SEM, detail of each model along with variables has been shown in table 3.4.

3.7.1 Statistical Analysis (PLS-SEM)

Data analysis using SmartPLS for Structural Equation Modeling (SEM) involves a series of detailed steps that ensure comprehensive and reliable examination of both measurement and structural models. Initially, the process begins with importing the data-set and defining the latent variables and their indicators. Latent variables represent unobservable constructs such as attitudes or perceptions, while indicators are observable measures associated with these constructs. This step is crucial for setting the groundwork of the model, ensuring that each construct is accurately represented by its corresponding indicators. For instance, in a study on demolition waste management, latent variables might include factors like "Environmental Impact," "Economic Efficiency," and "Regulatory Compliance," with specific survey items serving as indicators for these constructs. Next, researchers specify the measurement and structural models within SmartPLS. The measurement model involves linking latent variables to their indicators, which can be reflective or formative. Reflective indicators are assumed to be manifestations of the latent construct, while formative indicators are viewed as defining characteristics of the construct. Meanwhile, the structural model outlines the hypothesized relationships between the latent variables, essentially mapping out the theoretical framework of the study. This step requires careful consideration of the theoretical underpinnings and the research questions to ensure that the model accurately captures the hypothesized relationships. Once the models are specified, the PLS algorithm is run to estimate path coefficients and outer loadings. This algorithm is particularly suitable for handling complex models with multiple constructs and indicators, especially when data does not meet the strict assumptions of co-variance-based SEM. The analysis then proceeds to evaluate the measurement model for reliability and validity. Reliability is assessed through metrics such as outer loadings, Cronbach's Alpha and Composite Reliability, ensuring that the constructs are measured consistently. Validity is evaluated using the Average Variance Extracted (AVE) for convergent validity and the Fornell-Larcker criterion or HTMT ratio for discriminant validity, confirming that the constructs are distinct from one another. Finally, the structural model is assessed by examining path coefficients, R^2 values, f^2 effect sizes and Q^2 for predictive relevance. Path coefficients indicate the strength and direction of relationships between constructs, while R^2 values reveal the proportion of variance explained by the model. f^2 effect sizes measure the impact of one construct on another and Q^2 values indicate the model's predictive relevance. Bootstrapping is then performed to test the statistical significance of the paths, involving multiple re-sampling iterations to generate a distribution of path coefficients. This helps in determining which paths are statistically significant. Additionally, model fit indices such as the SRMR are evaluated to ensure a good fit. The results are then compiled, including descriptive statistics, reliability and validity assessments and structural model outcomes, which provide a comprehensive understanding of the theoretical and practical implications of the study. Fig-3.5 shows the Flow Chart of PLS-SEM approach.

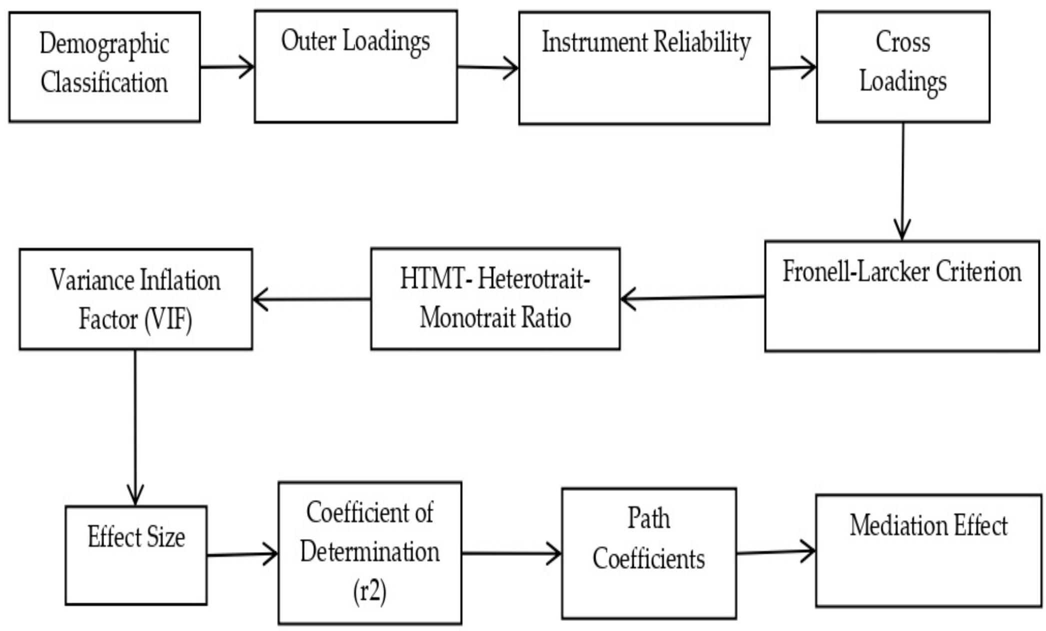

Figure 3.5: Flow Chart of PLS-SEM

3.7.2 Measurement Model Assessment

The assessment of the measurement model in SmartPLS is a crucial step in Partial Least Squares Structural Equation Modeling (PLS-SEM), as it ensures that the constructs used in the model are measured accurately and reliably. This evaluation focuses on several important criteria, including indicator reliability, internal consistency reliability, convergent validity, and discriminant validity.

Indicator reliability is examined through the outer loadings of the indicators on their respective constructs. Ideally, each indicator should exhibit an outer loading greater than 0.7, indicating that the indicator strongly reflects the underlying construct. However, loadings between 0.4 and 0.7 may be tolerated if other metrics such as the average variance extracted (AVE) and composite reliability (CR) remain within acceptable thresholds[169].

Internal consistency reliability is another essential component, typically assessed using Cronbach's Alpha and Composite Reliability (CR). Cronbach's Alpha provides a measure of the interrelatedness among items within a construct, with values above 0.7 considered acceptable for demonstrating internal consistency[170, 171].

Composite Reliability, which accounts for varying indicator loadings, is preferred in PLS-SEM because it provides a more accurate reliability estimate in models with heterogeneous indicators. A CR value above 0.7 similarly suggests that the indicators reliably measure the construct[170, 171].

Convergent validity assesses the extent to which indicators of a particular construct share a high proportion of variance. This is evaluated using the AVE, which should be above 0.5. An AVE value greater than 0.5 indicates that the construct explains more than half of the variance in its indicators, supporting the adequacy of the measurement model.

To establish discriminant validity, which ensures that constructs are truly distinct from one another, two primary techniques are employed: the Fornell-Larcker criterion and the Heterotrait-Monotrait Ratio (HTMT). The Fornell-Larcker criterion requires that the square root of the AVE of each construct exceed the construct's highest correlation with any other construct in the model [172].

This indicates that each construct shares more variance with its own indicators than with other constructs. The HTMT ratio is a more recent and stringent method, where values below 0.85 (or below 1.0 in more lenient cases) suggest that discriminant validity is established[171, 173, 174].

3.7.3 Structural Model Assessment

Once the measurement model is validated, attention shifts to the structural model, which examines the hypothesized relationships between constructs. The structural model evaluation in SmartPLS involves several critical steps, including the assessment of multicollinearity, the coefficient of determination (R^2), effect sizes (f^2), and hypothesis testing.

Multicollinearity among predictor constructs is evaluated using the Variance Inflation Factor (VIF). VIF values below 5 indicate that multicollinearity is not a concern and that the predictors do not exhibit high redundancy. If VIF values exceed this threshold, it suggests that certain predictor constructs may be highly correlated, which can distort the estimation of path coefficients and lead to unreliable results. In such cases, researchers might consider removing or combining predictors to address the issue[172].

The coefficient of determination, denoted as R^2, measures the proportion of variance in the endogenous (dependent) construct that is explained by the exogenous (independent) constructs in the model. Higher R^2 values signify greater explanatory power and a better-fitting model. In PLS-SEM, R^2 values range from 0 to 1, with values closer to 1 indicating a strong model. While there are no fixed thresholds, R^2 values of 0.25, 0.50, and 0.75 can be considered weak, moderate, and substantial, respectively, depending on the context and discipline[171, 173, 174].

Effect sizes (f^2) provide insight into the practical significance of each predictor construct by quantifying its impact on the R^2 value of the dependent construct.

An f^2 value of 0.02 is interpreted as a small effect, 0.15 as a medium effect, and 0.35 as a large effect. This metric is particularly useful in identifying which predictors meaningfully contribute to explaining the variance in the dependent variable, even when statistical significance is achieved[171, 173, 174].

Finally, hypothesis testing is conducted to assess the significance of the paths in the structural model. This process involves formulating a null hypothesis, which posits no relationship between the constructs, and an alternative hypothesis, which predicts the existence and direction of a relationship. Bootstrapping, typically performed with 5000 resamples, is used to generate standard errors and p-values for each path coefficient. Paths with p-values below the selected significance level (commonly 0.05) are considered statistically significant, leading to the rejection of the null hypothesis and confirming the hypothesized relationships between constructs[171, 173, 174].

3.8 Hypotheses Development

The hypotheses of this study for Model-1, 2 ,3 & 4 were tested using PLS-SEM, Model-1 shows in below Figure-3.6

3.8.1 Hypotheses Formulation for Model-1

Hypothesis 1 (Ho1-HAlt1):

Null Hypothesis (Ho1): Demolition waste causes do not have a significant impact on demolition waste challenges. Alternative Hypothesis (HAlt1): Demolition waste causes have a significant impact on demolition waste challenges. This hypothesis suggests that the factors or reasons contributing to demolition waste significantly affect the challenges encountered in managing demolition waste.

Hypothesis 2 (Ho2-HAlt2):

Null Hypothesis (Ho2): Demolition waste causes do not have a significant impact on demolition waste impacts. Alternative Hypothesis (HAlt2): Demolition waste causes have a significant impact on demolition waste impacts. This hypothesis proposes that the factors contributing to demolition waste significantly influence the environmental, economic, or social impacts associated with demolition waste.

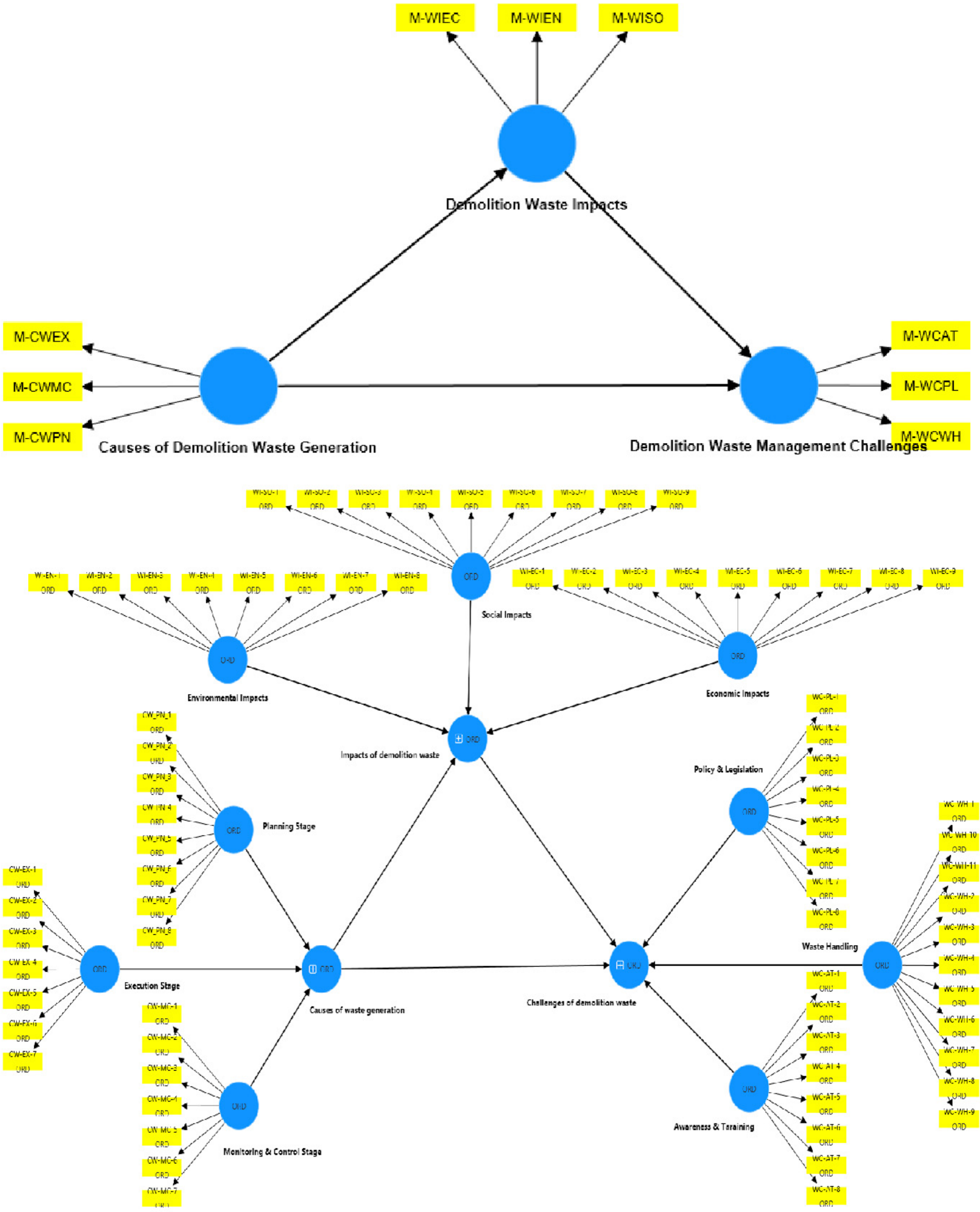

FIGURE 3.6: Research Detailed Model 1

Hypothesis 3 (Ho3-HAlt3):

Null Hypothesis (Ho3): Demolition waste impacts do not have a significant impact on demolition waste challenges. Alternative Hypothesis (HAlt3): Demolition waste impacts have a significant impact on demolition waste challenges. This hypothesis examines whether the consequences or impacts of demolition waste significantly influence the difficulties or challenges associated with managing demolition waste.

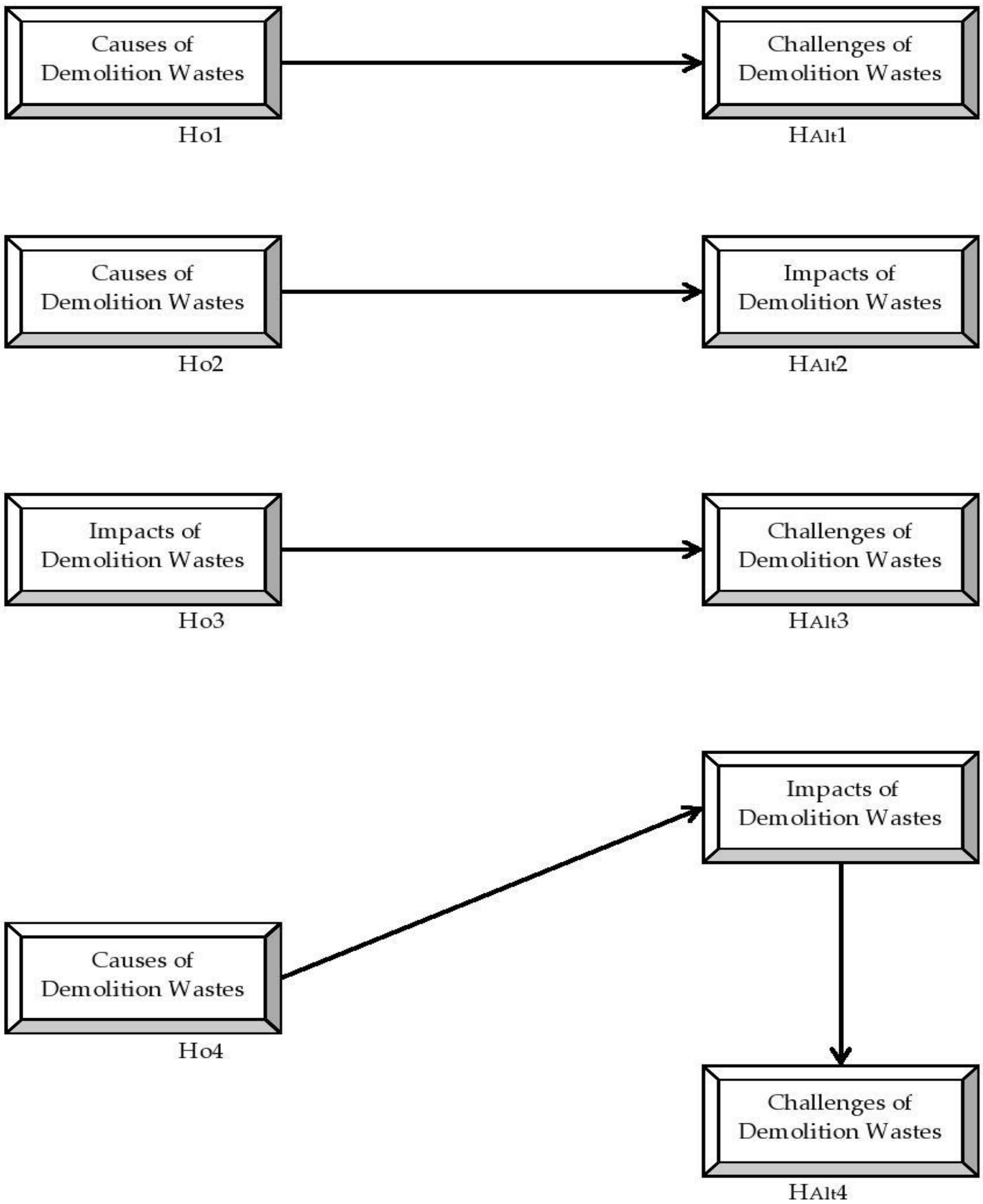

FIGURE 3.7: Hypothesis for Research Model 1

Hypothesis 4 (Ho4-HAlt4):

Null Hypothesis (Ho4): There is no mediating effect of demolition waste between causes of demolition waste generation, demolition waste impacts and demolition waste challenges. Alternative Hypothesis (HAlt4): There is a mediating effect of demolition waste between causes of demolition waste generation, demolition waste impacts and demolition waste challenges. This hypothesis investigates whether demolition waste acts as a mediator between the factors that cause demolition waste, the impacts resulting from demolition waste and the challenges faced in managing demolition waste. It explores whether demolition waste plays a significant role in connecting the causes to their impacts and subsequently influencing the difficulties or challenges associated with managing demolition waste.

These hypotheses collectively aim to explore different dimensions of how demolition waste causes, impacts and challenges interrelate and influence each other. They provide a structured framework for empirical research to investigate these relationships and understand their implications for effective management strategies for demolition waste, figure 3.7 shows the Hypothesis for Research Model 1.

3.8.2 Hypotheses Formulation for Model-2

Hypothesis 1 (Ho1-HAlt1):

Null Hypothesis (Ho1): Demolition waste causes do not have a significant impact on demolition waste challenges. Alternative Hypothesis (HAlt1): Demolition waste causes have a significant impact on demolition waste challenges. This hypothesis suggests that the factors contributing to demolition waste significantly affect the challenges associated with managing demolition waste.

Hypothesis 2 (Ho2-HAlt2):

Null Hypothesis (Ho2): Demolition waste causes do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt2): Demolition waste causes have a significant impact on demolition waste solutions. This hypothesis proposes that the factors contributing to demolition waste significantly influence the solutions that can be implemented to manage or reduce demolition waste.

Hypothesis 3 (Ho3-HAlt3):

Null Hypothesis (Ho3): Demolition waste challenges do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt3): Demolition waste challenges have a significant impact on demolition waste solutions. This hypothesis examines whether the difficulties or challenges related to demolition waste management significantly affect the effectiveness of the solutions proposed to manage or mitigate demolition waste.

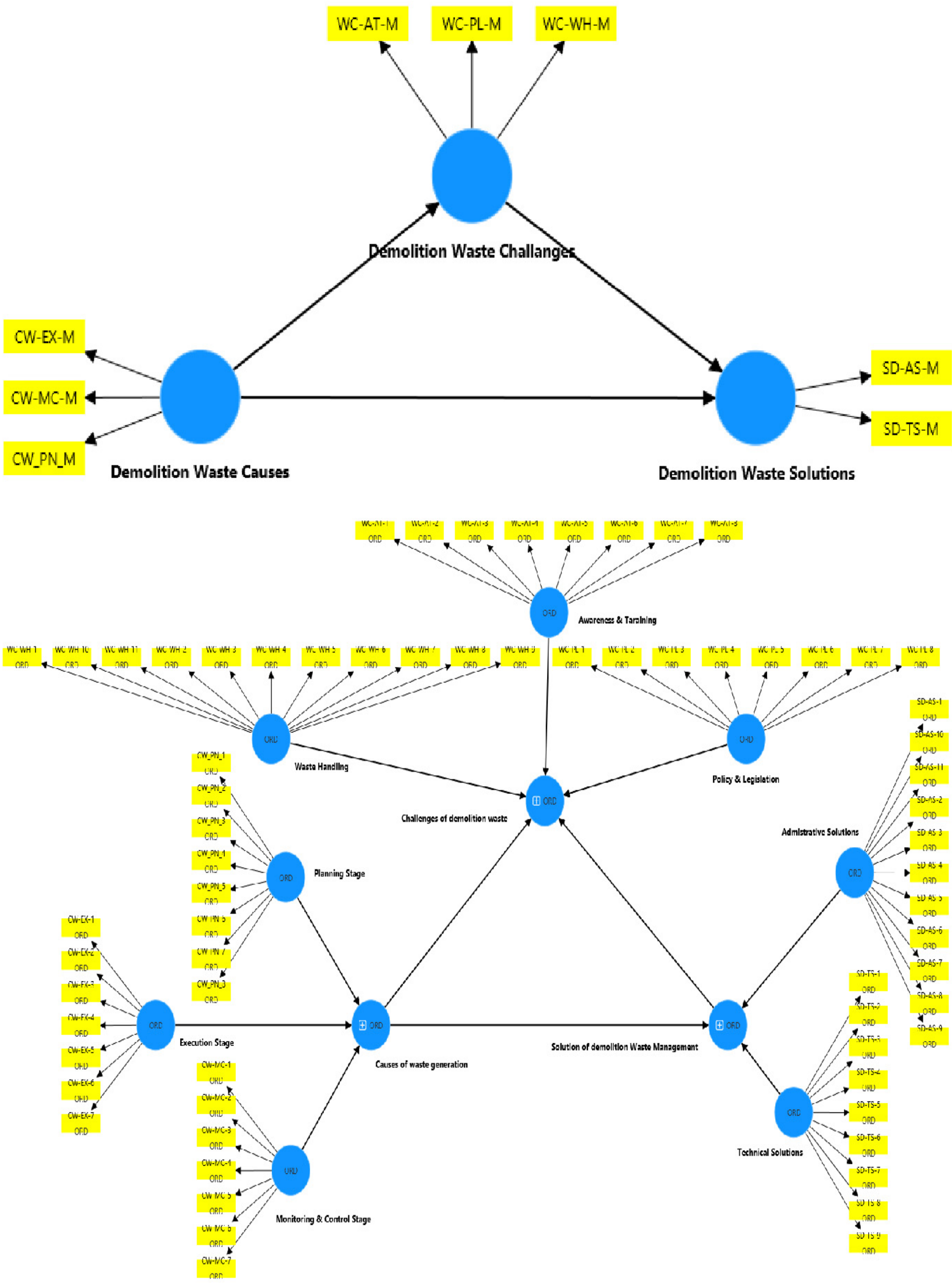

FIGURE 3.8: Research Detailed Model 2

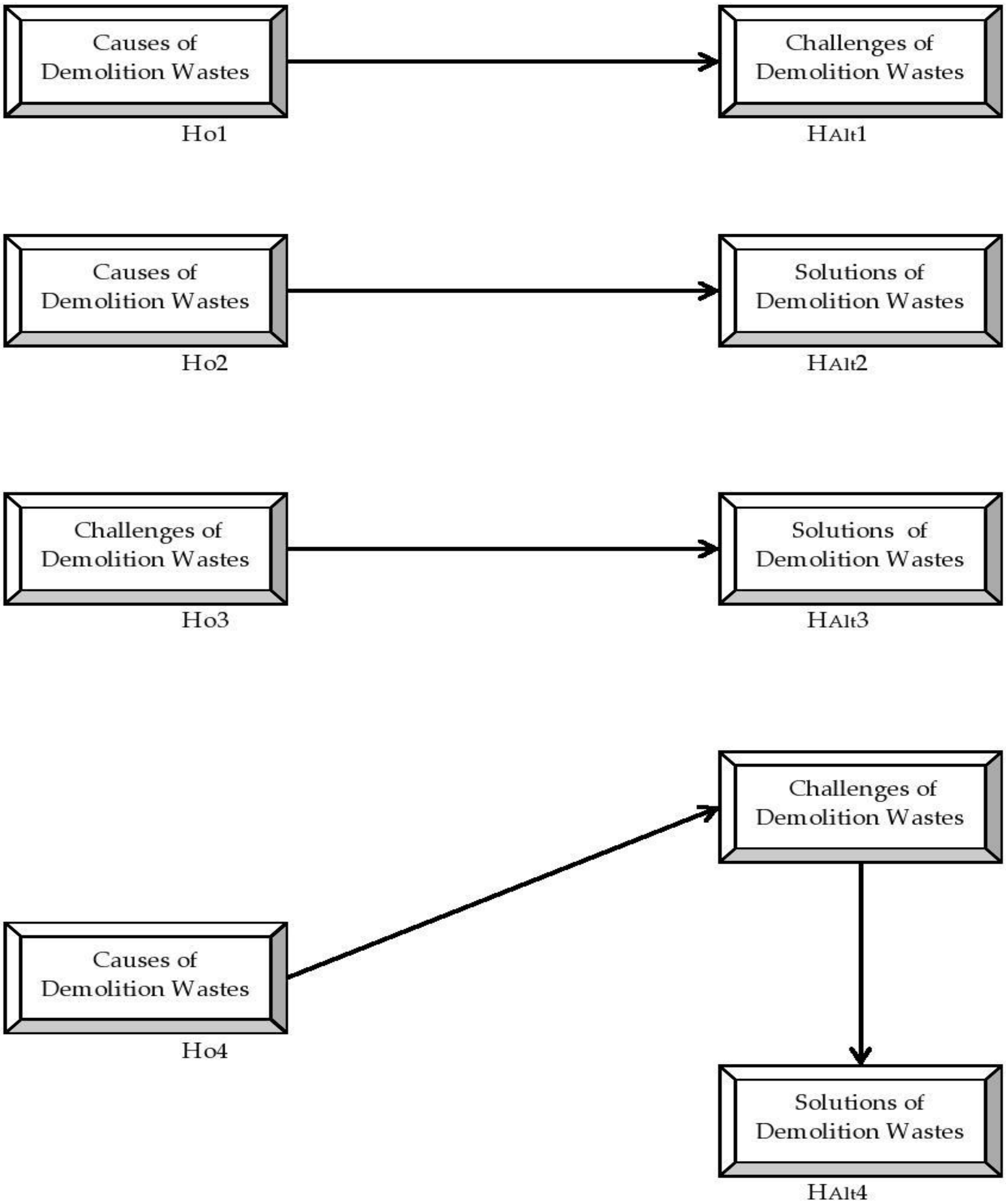

FIGURE 3.9: Hypothesis for Research Model 2

Hypothesis 4 (Ho4-HAlt4):

Null Hypothesis (Ho4): There is no mediating effect of demolition waste between the causes of demolition waste generation, demolition waste challenges and demolition waste management solutions. Alternative Hypothesis (HAlt4): There is a mediating effect of demolition waste between the causes of demolition waste generation, demolition waste challenges and demolition waste management solutions.

This hypothesis investigates whether demolition waste acts as a mediator between the factors that cause demolition waste, the challenges faced in managing it and the solutions implemented to address it. In other words, it explores whether demolition waste plays a significant role in linking causes to challenges and solutions in demolition waste management. These hypotheses collectively aim to understand the relationships and interactions between the causes, challenges and solutions related to demolition waste. They form the basis for empirical research or analysis to test these relationships statistically and draw conclusions about the impact of various factors on demolition waste management, figure 3.9 shows the Hypothesis for Research Model 2.

3.8.3 Hypotheses Formulation for Model-3

Hypothesis 1 (Ho1-HAlt1):

Null Hypothesis (Ho1): Demolition waste causes do not have a significant impact on demolition waste impacts. Alternative Hypothesis (HAlt1): Demolition waste causes have a significant impact on demolition waste impacts. This hypothesis suggests that the factors or causes contributing to demolition waste significantly affect the environmental, economic, or social impacts associated with demolition waste.

Hypothesis 2 (Ho2-HAlt2):

Null Hypothesis (Ho2): Demolition waste causes do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt2): Demolition waste causes have a significant impact on demolition waste solutions. This hypothesis proposes that the factors contributing to demolition waste significantly influence the solutions or strategies that can be implemented to manage or reduce demolition waste.

Hypothesis 3 (Ho3-HAlt3):

Null Hypothesis (Ho3): Demolition waste impacts do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt3): Demolition waste impacts have a significant impact on demolition waste solutions. This hypothesis examines whether the consequences or impacts of demolition waste significantly influence the effectiveness or nature of the solutions proposed to manage or mitigate demolition waste.

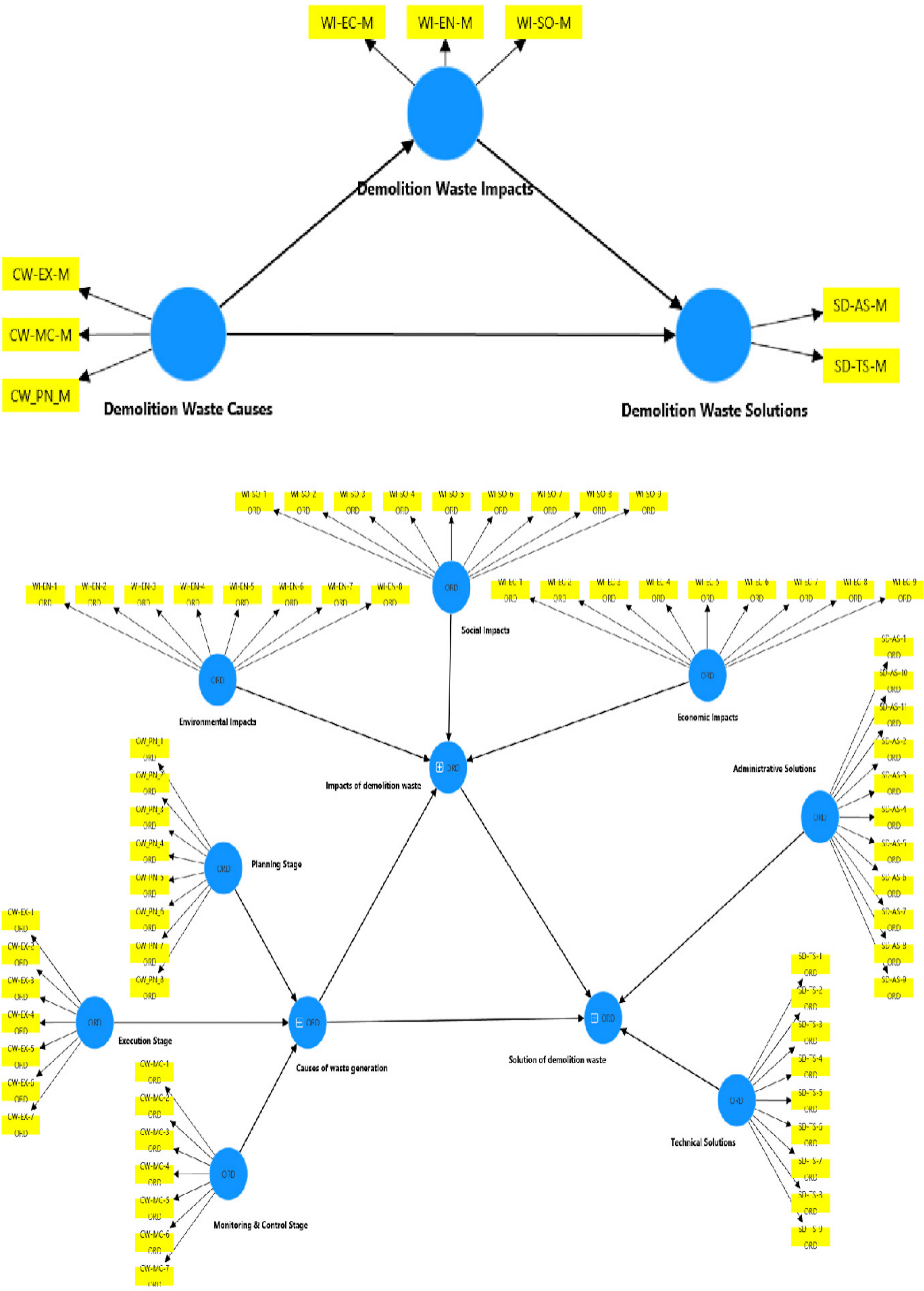

FIGURE 3.10: Research Detailed Model 3

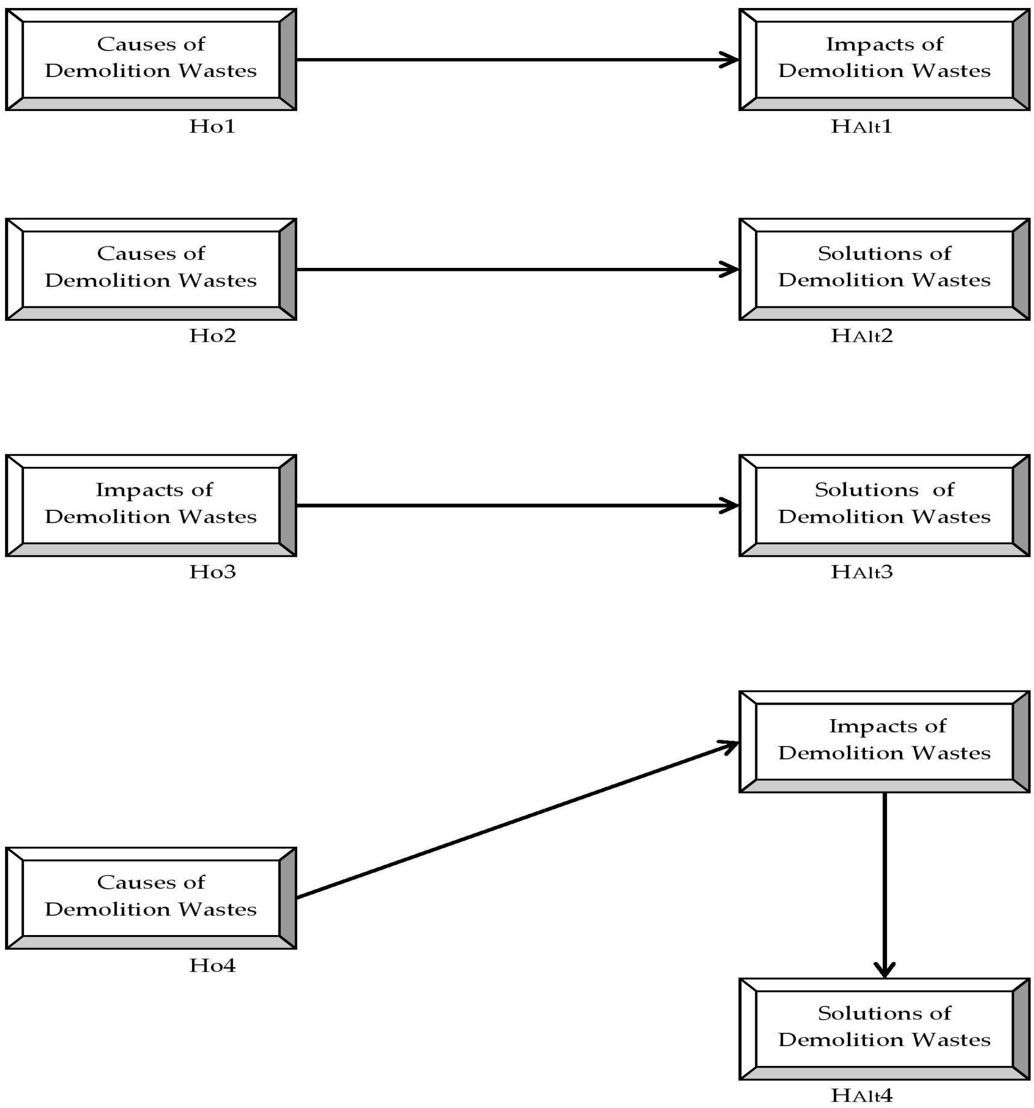

FIGURE 3.11: Hypothesis for Research Model 3

Hypothesis 4 (Ho4-HAlt4):

Null Hypothesis (Ho4): There is no mediating effect of demolition waste between the causes of demolition waste generation, demolition waste impacts and demolition waste management solutions. Alternative Hypothesis (HAlt4): There is a mediating effect of demolition waste between the causes of demolition waste generation, demolition waste impacts and demolition waste management solutions. This hypothesis investigates whether demolition waste acts as a mediator between the factors that cause demolition waste, the impacts resulting from demolition waste and the solutions implemented to address it. In essence, it explores whether demolition waste plays a significant role in connecting the causes to their impacts and subsequently influencing the effectiveness of solutions in managing demolition waste. These hypotheses collectively aim to explore the relationships and dependencies between the causes of demolition waste, its impacts and the solutions proposed to manage it. They provide a structured framework for empirical research or analysis to validate these relationships and draw meaningful conclusions about effective strategies for demolition waste management, figure 3.11 shows the Hypothesis for Research Model 3.

3.8.4 Hypotheses Formulation for Model-4

Hypothesis 1 (Ho1-HAlt1):
Null Hypothesis (Ho1): Demolition waste causes do not have a significant impact on demolition waste challenges. Alternative Hypothesis (HAlt1): Demolition waste causes have a significant impact on demolition waste challenges. This hypothesis suggests that the factors or reasons contributing to demolition waste significantly affect the challenges encountered in managing demolition waste.

Hypothesis 2 (Ho2-HAlt2):
Null Hypothesis (Ho2): Demolition waste causes do not have a significant impact on demolition waste impacts. Alternative Hypothesis (HAlt2): Demolition waste causes have a significant impact on demolition waste impacts. This hypothesis proposes that the factors contributing to demolition waste significantly influence the environmental, economic, or social impacts associated with demolition waste.

Hypothesis 3 (Ho3-HAlt3):
Null Hypothesis (Ho3): Causes of demolition waste do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt3): Causes of demolition waste have a significant impact on demolition waste solutions. This hypothesis examines whether the factors or causes contributing to demolition waste significantly influence the effectiveness or nature of the solutions proposed to manage or mitigate demolition waste.

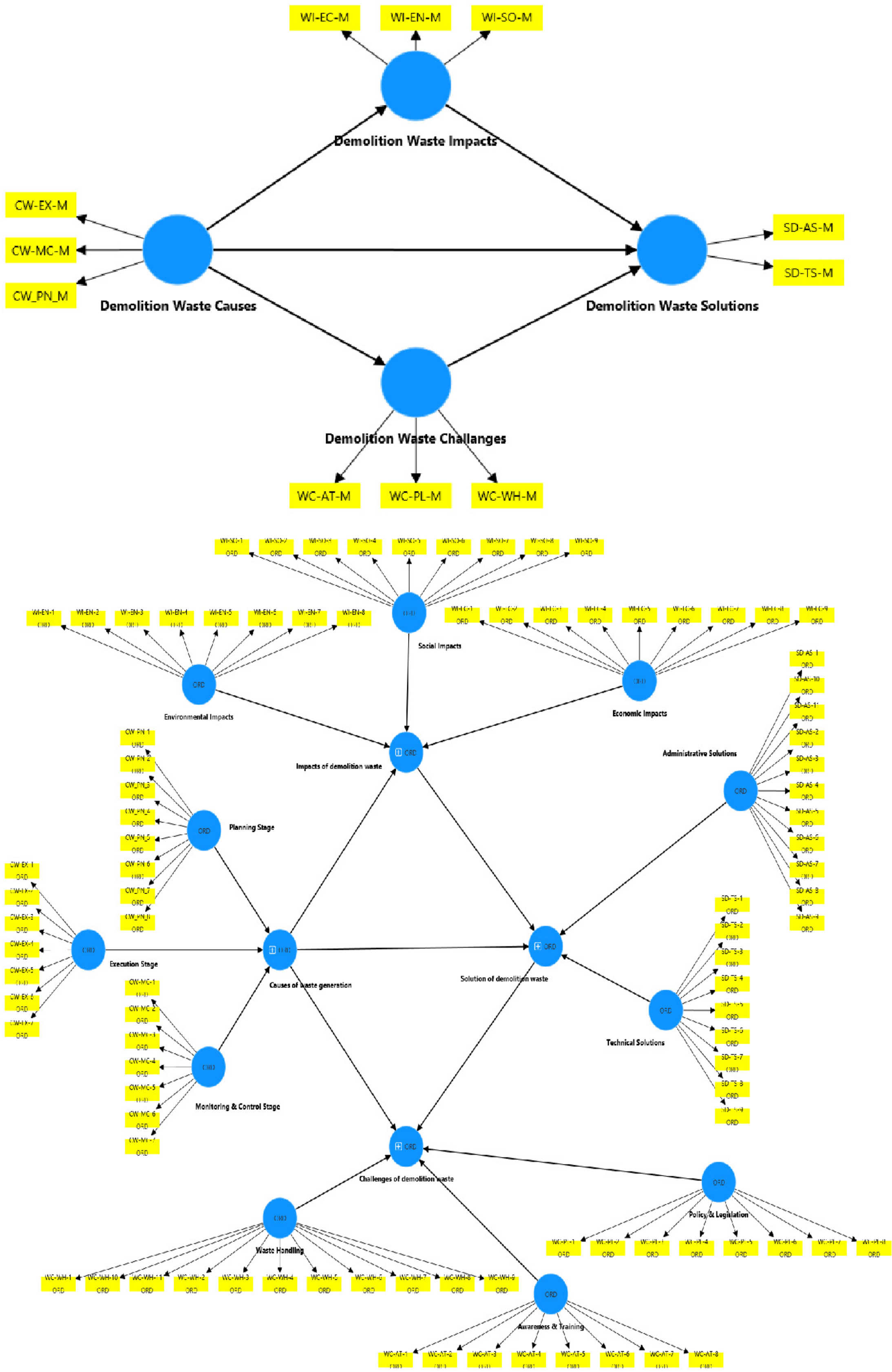

FIGURE 3.12: Research Detailed Model 4

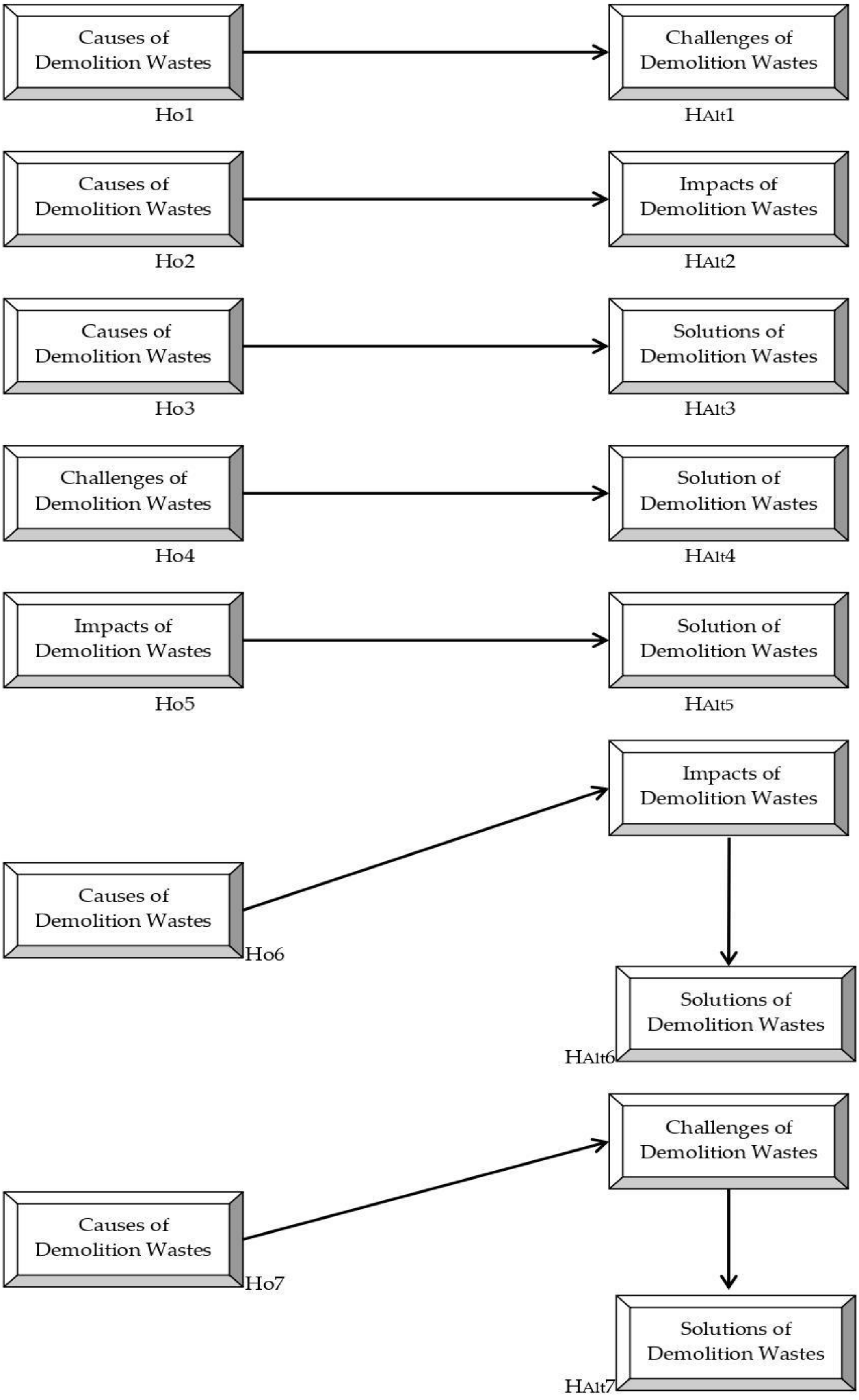

FIGURE 3.13: Hypothesis for Research Model 4

Hypothesis 4 (Ho4-HAlt4):

Null Hypothesis (Ho4): Challenges of demolition waste do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt4): Challenges of demolition waste have a significant impact on demolition waste solutions. This hypothesis investigates whether the difficulties or challenges associated with managing demolition waste significantly influence the effectiveness or nature of the solutions implemented to address it.

Hypothesis 5 (Ho5-HAlt5):

Null Hypothesis (Ho5): Demolition waste impacts do not have a significant impact on demolition waste solutions. Alternative Hypothesis (HAlt5): Demolition waste impacts have a significant impact on demolition waste solutions. This hypothesis examines whether the consequences or impacts of demolition waste significantly influence the effectiveness or nature of the solutions proposed to manage or mitigate demolition waste.

Hypothesis 6 (Ho6-HAlt6):

Null Hypothesis (Ho6): There is no mediating effect of demolition waste between the causes of demolition waste generation, demolition waste impacts and demolition waste management solutions. Alternative Hypothesis (HAlt6): There is a mediating effect of demolition waste between the causes of demolition waste generation, demolition waste impacts and demolition waste management solutions. This hypothesis investigates whether demolition waste acts as a mediator between the factors that cause demolition waste, the impacts resulting from demolition waste and the solutions implemented to address it. It examines whether demolition waste plays a significant role in connecting the causes to their impacts and subsequently influencing the effectiveness of solutions in managing demolition waste.

Hypothesis 7 (Ho7-HAlt7):

Null Hypothesis (Ho7): There is no mediating effect of demolition waste between the causes of demolition waste generation, demolition waste challenges and demolition waste management solutions. Alternative Hypothesis (HAlt7): There is a mediating effect of demolition waste between the causes of demolition waste generation, demolition waste challenges and demolition waste management solutions.

Similar to Hypothesis 6, this hypothesis examines whether demolition waste acts as a mediator between the factors that cause demolition waste, the challenges faced in managing it and the solutions implemented to address it. These hypotheses collectively aim to explore various aspects of the relationships between demolition waste causes, impacts, challenges and solutions. They provide a structured approach to empirically investigate and understand how these factors interact and influence effective management strategies for demolition waste, figure 3.13 shows the Hypothesis for Research Model 4.

3.9 Summary

Chapter 3 of the research methodology centers on the application of Partial Least Squares Structural Equation Modeling (PLS-SEM). It provides a comprehensive flow chart detailing the research methodology, which includes key components such as research design, focus group discussions and pilot studies, final questionnaire refinement, data collection procedures, sampling techniques and statistical analysis using PLS-SEM. The chapter underscores methodological rigor in defining latent variables, rigorously assessing the reliability and validity of the measurement model, estimating path coefficients and evaluating the structural model using techniques like bootstrapping. Overall, it presents a structured approach to conducting thorough and credible research using PLS-SEM methodology.

Chapter 4

Data Analysis and Validation of Framework

4.1 Background

In this chapter, present a detailed exploration of the results and analysis derived from this study using Partial Least Squares Structural Equation Modeling (PLS SEM) and based on data gathered through a meticulously designed questionnaire. this research focused on investigating various facets of demolition waste management, including the causes, impacts, challenges and solutions. By employing PLS SEM, that aimed to comprehensively assess the relationships among these key constructs across four distinct models, each addressing different aspects of demolition waste management dynamics.
The questionnaire development process was rigorous, involving methodologies such as focus group discussions and a pilot study. These steps were essential to ensure the robustness and validity of measurement instruments, which were tailored to capture nuanced insights into the factors influencing demolition waste practices. The application of PLS SEM enabled us to not only validate the measurement constructs in terms of reliability and validity but also explore both the direct and indirect relationships among these constructs within each of the four models.

This chapter is structured to provide a systematic and insightful analysis of findings. Begin by outlining the demographic characteristics and descriptive statistics of sample, providing a contextual backdrop for interpreting subsequent analyses. Following this, rigorously examine the measurement models, focusing on indicators such as factor loadings, Cronbach's alpha, Composite Reliability, Average Variance Extracted and Discriminant Validity. Subsequently, delve into the structural models to test hypotheses and explore the intricate relationships between causes, impacts, challenges and solutions of demolition waste management.
Ultimately, the findings presented in this chapter contribute significant insights to both academic knowledge and practical applications in the field of environmental sustainability and construction waste management. By elucidating the complexities of demolition waste dynamics, this study aims to inform strategic decision-making processes aimed at minimizing environmental impact, enhancing resource efficiency and promoting sustainable development practices in the construction industry and beyond.

4.2 Data Analysis

To determine the appropriate sample size for PLS-SEM in this study, a discussion of sampling techniques is provided in Section 3.7, where purposive sampling was selected. The complexity of the model, the number of constructs and their associated indicators were carefully assessed. The model comprises 11 constructs with indicators ranging from 7 to 11. These include: Planning Stage (8), Execution Stage (7), Monitoring and Control Stage (7), Environmental Impacts (8), Social Impacts (9), Economic Impacts (9), Waste Handling (11), Policy and Legislation (8), Awareness and Training (8), Administrative Solutions (11) and Technical Solutions (9). According to [175, 176] the widely used 10-times rule, the minimum sample size should be at least 10 times the highest number of indicators or structural paths directed at any latent variable. As the most complex constructs—Waste Handling and Administrative Solutions—each have 11 indicators, the minimum required sample size is therefore 110. This ensures sufficient statistical power and robustness in model estimation.

In this study, a total of 184 questionnaires were distributed to professionals in the construction sector, specifically targeting those involved in demolition waste management. This strategic selection aimed to gather relevant and expert insights to address the research objectives. At the conclusion of the survey period, 172 completed questionnaires were received. However, 10 of these were found to be incomplete or contained redundant data, thus were excluded from the final analysis. Consequently, the study achieved a usable response rate of 88.58%, with data from 163 participants being deemed valid. This high response rate indicates strong engagement and interest from the targeted professionals, enhancing the reliability of the findings. The demographic distribution of the respondents, as detailed in Figure 4.1 , provides a comprehensive overview of the sample's characteristics, which is crucial for contextualizing the survey results. The categorizes respondents based on their years of experience in the construction sector, type of organization, designation and the nature of projects they have handled. For instance, categorizing respondents by experience allows the study to gauge the depth of industry knowledge and practical insights contributed by each participant. Understanding the types of organizations represented—whether construction firms, waste management companies, government agencies, or consulting firms—sheds light on the diverse operational contexts from which the data is drawn. Further categorization by designation helps to identify the range of professional roles involved in the study, from senior managers and engineers to project coordinators and site supervisors. This diversity in roles ensures that the study captures insights from various levels of decision-making and operational implementation within the sector. Additionally, detailing the types of projects handled by the respondents, particularly those related to demolition activities, provides context to their expertise and the practical challenges they face. This information is critical for understanding the practical implications of the study's findings and for developing targeted recommendations. The demographic data enriches the study by allowing for a nuanced analysis of the responses. It ensures that the findings are not only statistically robust but also contextually relevant. The high response rate and the varied demographic profile of the respondents enhance the credibility and generalizability of the study's conclusions. This detailed breakdown allows the researchers to identify trends and patterns specific to different organizational contexts and professional experiences, thereby supporting the study's aim of improving sustainability and efficiency in demolition waste management practices. By providing a solid foundation for the analysis, the demographic insights help to ensure that the study's recommendations are both practical and impactful, addressing the real-world challenges faced by professionals in the construction sector.

4.2.1 Demographic Classification

To begin with, respondents were classified based on their current role profiling and expertise in demolition waste management. The first attribute considered was the type of organization they were associated with. Out of the total, 85 respondents were from firms operating on an ownership/client model, 37 were from consultancy-based firms, 41 represented contractor firms, while none belonged to other possible categories. This classification helps to understand the diversity of organizational contexts within which the respondents operate.

In terms of job roles, the respondents held various positions reflecting their involvement in demolition waste management. Specifically, 48 respondents were in senior leadership positions such as CEO or Managing Director, 27 were Project manager and a significant number, 70, were project engineers. However, 10 respondents were serving as project Quantity surveyor , 8 respondents were serving project architects, indicating a concentration of responses from certain roles within the industry. This distribution provides insight into the levels of decision-making and operational execution represented in the survey.

Experience in the construction sector was another critical profiling attribute. 15 of the respondents had 10-15 years of industry experience, highlighting a highly experienced participant pool. Specifically, 59 respondents had 16-20 years of experience, while the majority, 89, had over 20 years of experience in the construction industry. This substantial experience base ensures that the insights gathered are well-informed by extensive industry knowledge and practice.

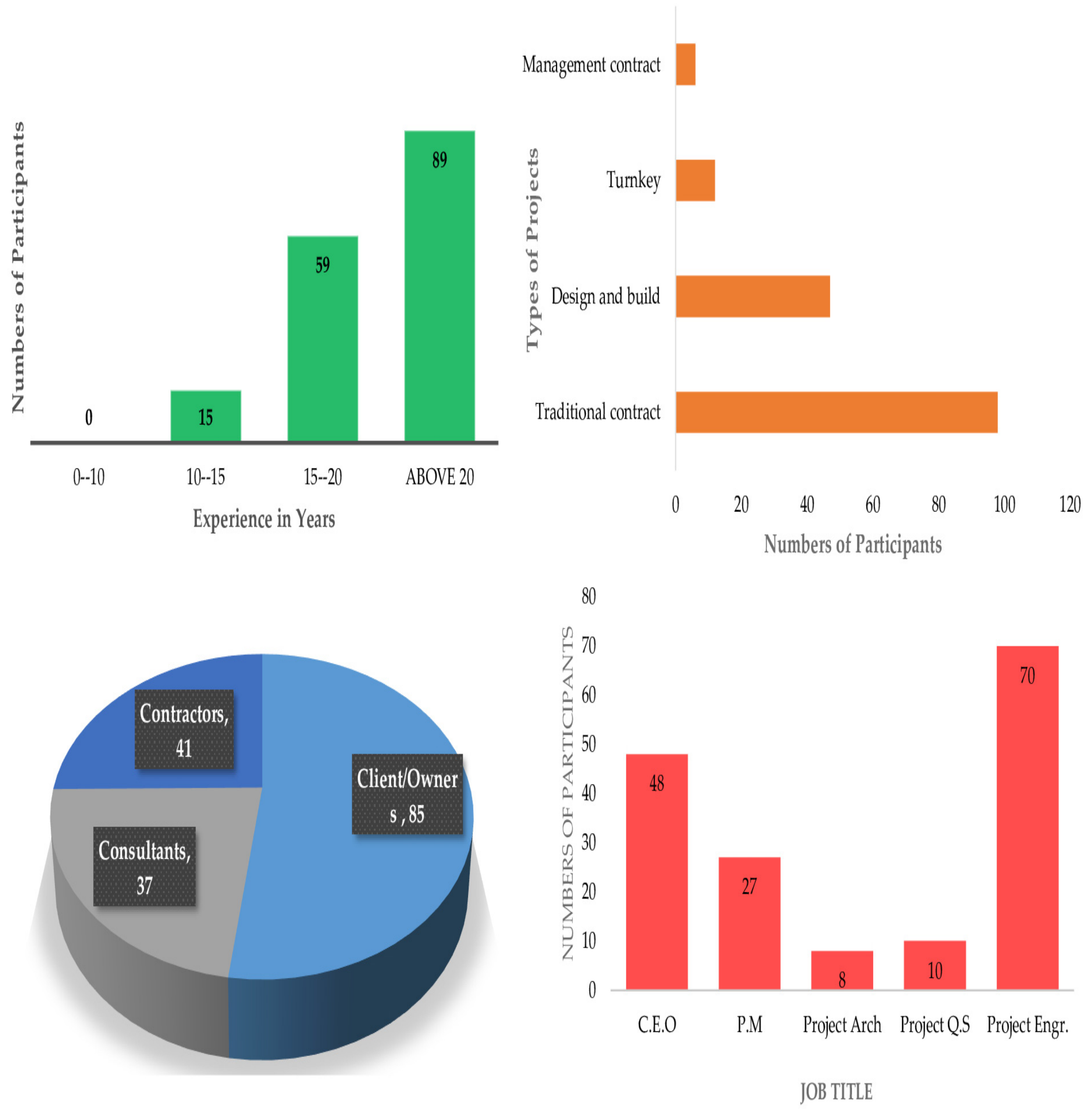

FIGURE 4.1: Demographic Classification.

The nature of projects respondents were involved in also varied. Traditional contracts were represented by 98 respondents, while 47 were engaged in design and build projects. There were 12 respondents involved in turnkey and 6 involved in management contracts. When asked about their familiarity with demolition waste management, all 163 respondents confirmed their firsthand experience in managing demolition waste. Moreover, all 163 respondents also confirmed the inclusion of reduce and reuse practices in their projects. Finally, when asked whether demolition waste management plans should be included in construction contracts, all 163 agreed, highlighting a unanimous consensus on its importance. This detailed classification and profiling of respondents underscore the relevance and expertise of the participant pool, providing a robust foundation for the study's findings. (See Figure 4.1)

4.3 Results For Model-1 (M-1)

Model 1 as shown in figure 4.2, is analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM), focusing on three critical dimensions of demolition waste management:

1.Causes of Demolition Waste Generation

2.Impact of Demolition Waste

3.Challenges of Demolition Waste

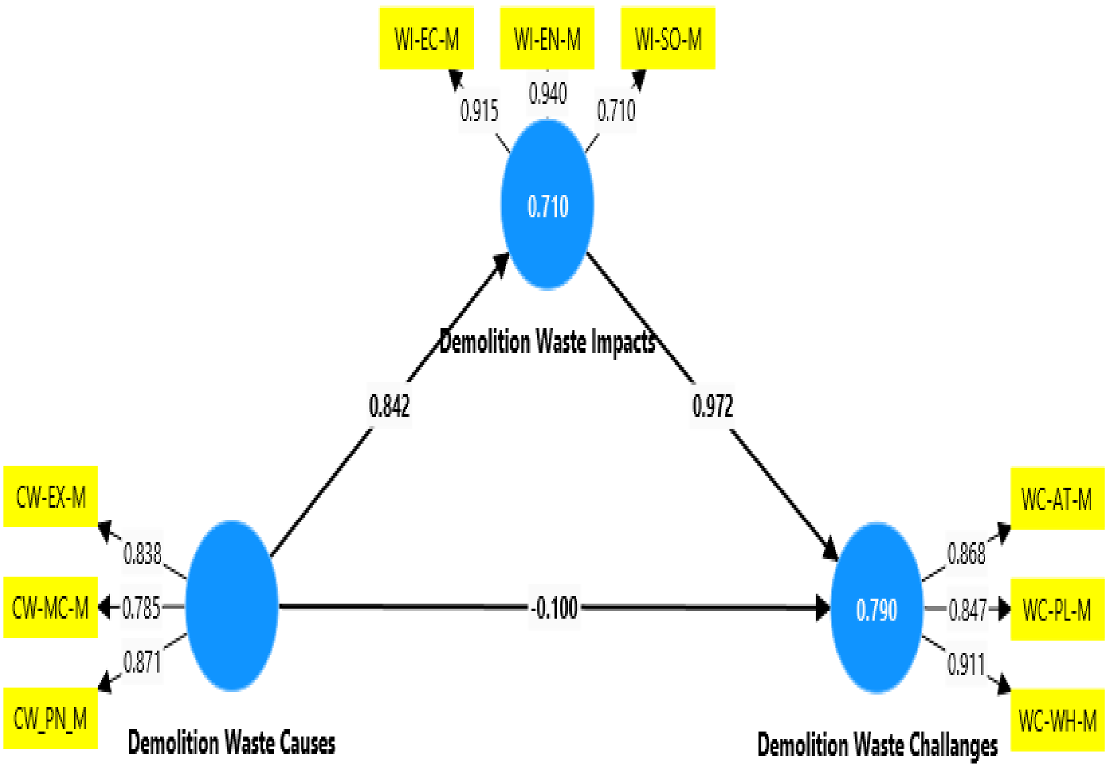

FIGURE 4.2: Research Model 1

Management PLS-SEM is employed as the primary analytical method due to its ability to model complex relationships among constructs and its suitability for data with small to medium sample sizes. The objective of this analysis is to identify the key drivers behind the generation of demolition waste, evaluate the range of its impacts and understand the challenges associated with managing demolition waste. By examining the relationships between these constructs, the analysis aims to uncover how the causes of waste generation influence its impacts and the challenges faced in its management. The PLS-SEM approach allows for the assessment of both the measurement model (the relationships between observed variables and their respective constructs) and the structural model (the relationships between the constructs themselves). This methodology provides insights into the strength and significance of the relationships, helping to pinpoint the most influential factors driving demolition waste generation and management challenges. By using PLS-SEM, this analysis contributes to a comprehensive understanding of the factors influencing demolition waste management, offering actionable insights for improving practices and addressing the challenges identified in the study.

4.3.1 Outer Loadings

In the next stage, the research items were tested to ensure they matched their related research variables and proposed hypotheses.

Table 4.1: Outer Loadings M-1

Items	**Demolition Waste Causes**	**Demolition Waste Challenges**	**Demolition Waste Impacts**
CW-EX-M	0,838		
CW-MC-M	0,785		
CW_PN_M	0,871		
WC-AT-M		0,868	
WC-PL-M		0,847	
WC-WH-M		0,911	

WI-EC-M	0,915
WI-EN-M	0,94
WI-SO-M	0,71

First, the chosen research variables were examined for their internal variance and correlation among the research items, using factor loadings. According to [169] each research item should have a factor loading of 0.6 or higher. It was found that each variable had a factor loading well above 0.6, indicating they were suitable for further testing without needing to remove any research items from the model (See Table 4.1).

4.3.2 Instrument Reliability

Secondly, the statistical testing involved checking the reliability of research instrument to ensure it accurately measures each variable. Cronbach's alpha is a widely accepted parameter for gauging the reliability of research instruments [170, 171].The minimum threshold for Cronbach's alpha is 0.7. The research variables performed well

For the construct Demolition Waste Causes, Cronbach's alpha is 0.777, which exceeds the commonly accepted threshold of 0.7, indicating acceptable internal consistency. The composite reliability values—rho-A (0.786) and rho-C (0.871)—are both well above the recommended minimum of 0.7, confirming strong reliability. The AVE value of 0.692 is greater than the 0.5 threshold[171, 177], indicating that the construct explains a substantial proportion of the variance in its indicators, thus confirming good convergent validity.

For Demolition Waste Challenges, even stronger reliability is observed. The Cronbach's alpha is 0.848 and both rho-A (0.854) and rho-C (0.908) are significantly higher than the minimum acceptable levels. The AVE of 0.767 further supports excellent convergent validity, suggesting that the measurement items are highly representative of the underlying construct.

Similarly, the Demolition Waste Impacts construct demonstrates robust reliability and validity. The Cronbach's alpha value of 0.825, rho-A of 0.894 and rho-C of 0.895 all surpass standard benchmarks, indicating very high internal consistency. The AVE of 0.742 confirms that the construct captures a strong portion of variance from its indicators.

In summary, all three constructs exhibit strong reliability and convergent validity, as all values meet or exceed the commonly accepted thresholds. These results validate the robustness of the measurement model and support the credibility of the subsequent structural analysis. Therefore, deeming all the adapted research items to be convergently valid (See table 4.2).

Table 4.2: Instrument Reliability M-1

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted(AVE)**
Demolition Waste Causes	0,777	0,786	0,871	0,692
Demolition Waste Challenges	0,848	0,854	0,908	0,767
Demolition Waste Impacts	0,825	0,894	0,895	0,742

4.3.3 Cross Loadings

Next , the discriminant validity conforms to the dissimilarity existent between the opted research items of each variable from the research items of other variables in the study. Table 4.3: Cross Loadings (Model M-1) provides evidence for the discriminant validity of the constructs—Demolition Waste Causes, Demolition Waste Challenges and Demolition Waste Impacts—by examining the degree to which each item loads more strongly on its associated construct than on others.

This is a key requirement in PLS-SEM to confirm that constructs are empirically distinct[172].

Table 4.3: Cross Loadings M-1

Items	**Demolition Waste Causes**	**Demolition Waste Challenges**	**Demolition Waste Impacts**
CW-EX-M	0,838	0,541	0,618
CW-MC-M	0,785	0,569	0,7
CW_PN_M	0,871	0,67	0,77
WC-AT-M	0,537	0,868	0,801
WC-PL-M	0,742	0,847	0,716
WC-WH-M	0,627	0,911	0,808
WI-EC-M	0,704	0,875	0,915
WI-EN-M	0,927	0,84	0,94
WI-SO-M	0,463	0,518	0,71

The results show that each item exhibits its highest loading on its intended construct, satisfying the cross-loading criterion for discriminant validity.

Items CW-EX-M (0.838), CW-MC-M (0.785) and CW-PN-M (0.871) load highest on Demolition Waste Causes, with lower loadings on the other constructs (e.g., 0.541–0.7), indicating that they are strongly associated with their designated latent variable.

Items related to Demolition Waste Challenges, including WC-AT-M (0.868), WC-PL-M (0.847) and WC-WH-M (0.911), also display the highest loadings on their intended construct. Although there is some moderate cross-loading with the "Impacts" construct (e.g., 0.801–0.808), the primary association remains clear and strongest with the "Challenges" factor.

For Demolition Waste Impacts, the items WI-EC-M (0.915), WI-EN-M (0.94) and WI-SO-M (0.71) load significantly higher on their target construct than on the others. Particularly, WI-EN-M shows very strong loading (0.94), reinforcing its validity as a key indicator of impacts.

While a few items, such as CW-PN-M (0.77 on Impacts) and WC-AT-M (0.801 on Impacts), exhibit some degree of cross-loading, their highest loadings remain on their intended constructs, which is acceptable in social science research as long as the primary loadings are substantially stronger (typically by 0.1 or more).

In summary, the cross-loading results confirm discriminant validity of the constructs in the measurement model. Each item loads most strongly on its respective latent variable, supporting the structural integrity of the model and justifying further interpretation of the structural relationships among causes, challenges and impacts of demolition waste.

4.3.4 Fornell-Larcker Criterion

Table 4.4 presents the Fornell–Larcker criterion results, a widely accepted method for assessing discriminant validity in PLS-SEM. According to this criterion, the square root of the Average Variance Extracted (AVE) for each construct—shown on the diagonal—should be greater than its correlations with any other constructs in the model, which are shown off-diagonal[172].

The square root of AVE for Demolition Waste Causes is 0.832, which is higher than its correlation with Demolition Waste Challenges (0.718), but slightly lower than its correlation with Demolition Waste Impacts (0.842). This suggests a strong correlation between Causes and Impacts, which may raise minor concerns regarding discriminant validity. For Demolition Waste Challenges, the square root of AVE is 0.876, which exceeds its correlation with Causes (0.718), but is slightly less than its correlation with Impacts (0.887). Similarly, Demolition Waste Impacts shows a square root of AVE of 0.861, which is slightly lower than its correlations with Causes (0.842) and Challenges (0.887).

In summary, while the constructs exhibit strong internal consistency, the Fornell–Larcker results indicate potential overlap between Demolition Waste Impacts and the other two constructs. This suggests that although the constructs are generally valid, further confirmation—such as through HTMT analysis—may be needed to fully establish discriminant validity.

Table 4.4: Fornell-Larcker Criterion M-1

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**
Demolition Waste Causes	0,832		
Demolition Waste Challenges	0,718	0,876	
Demolition Waste Impacts	0,842	0,887	0,861

4.3.5 HTMT- Heterotrait-Monotrait Ratio

Finally, Table 4.5 presents the HTMT values used to assess discriminant validity among the constructs in Model M-1. The HTMT criterion evaluates whether constructs are empirically distinct, with recommended threshold values typically set at 0.85 (conservative) or 0.90 (liberal).

According to the table, the HTMT value between Demolition Waste Causes and Demolition Waste Challenges is 0.887, which falls just under the 0.90 threshold, indicating acceptable but borderline discriminant validity. The HTMT values between Demolition Waste Causes and Demolition Waste Impacts (0.896) and between Demolition Waste Challenges and Demolition Waste Impacts (0.897) are also slightly below the 0.90 limit.

These results suggest that while the constructs are empirically distinguishable according to the HTMT criterion, they are closely related and conceptually interconnected. The proximity of the values to the threshold indicates a need for caution, but does not conclusively violate discriminant validity.

In summary, all HTMT values are within the acceptable range for discriminant validity, though the high correlations imply strong interrelationships among the constructs, which should be acknowledged in the interpretation of the structural model.

Table 4.5: HTMT- Heterotrait-Monotrait Ratio-M-1

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**
Demolition Waste Causes			
Demolition Waste Challenges	0,887		
Demolition Waste Impacts	0,896	0,897	

4.3.6 Variance Inflation Factor (VIF)

Once verifying the reliability and validity of the researches instrument, the next stage involves evaluating the research items for their internal consistency in terms of variance inflation factor (VIF). Table 4.6 presents the Variance Inflation Factor

(VIF) values for the indicators used in Model M-1, which are essential for evaluating the presence of multicollinearity among the predictor variables in the measurement model. Multicollinearity occurs when independent variables are highly correlated, potentially distorting the estimation of path coefficients and reducing the reliability of regression outcomes.

Table 4.6: Variance Inflation Factor (VIF)- M-1

Item	**VIF**
CW-EX-M	1,831
CW-MC-M	1,396
CW_PN_M	1,848
WC-AT-M	1,953
WC-PL-M	1,999
WC-WH-M	2,552
WI-EC-M	2,911
WI-EN-M	3,178
WI-SO-M	1,429

In general, VIF values below 5 are considered acceptable, with values below 3.3 preferred in PLS-SEM to ensure low collinearity among indicators[172].
As shown in the table, all items have VIF values ranging from 1.396 to 3.178, indicating that multicollinearity is not a concern in this model. For example, items such as CW-MC-M (1.396) and WI-SO-M (1.429) exhibit very low collinearity, which enhances the stability and interpretability of the results. Indicators like WI-EN-M (3.178) and WI-EC-M (2.911) have relatively higher VIF values but still remain well below the critical threshold of 5, indicating acceptable tolerance levels.

In summary, the VIF results confirm that multicollinearity is not a threat to the model's validity. The indicator items are sufficiently independent of each other, supporting the robustness of the measurement and structural model estimations in the PLS-SEM analysis.

4.3.7 Effect Size (F2)

Next, to determine the effect size of each variable (f^2), used an indicator that shows how much an external variable affects an internal variable. The effect size is categorized into three ranges: small (0.02-0.14), medium (0.15-0.35) and large (0.36 and above) [171, 173, 174]. Table 4.7 presents the effect size (f^2) values, which assess the individual contribution of exogenous variables to the explained variance (R^2) of endogenous constructs in Model M-1.

TABLE 4.7: Effect Size (f2)-M-1

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**
Demolition Waste Causes		0,016	2,445
Demolition Waste Challenges			
Demolition Waste Impacts		1,307	

The effect size of Demolition Waste Causes on Demolition Waste Challenges is 0.016, which is below the minimum threshold of 0.02, indicating a negligible direct effect. However, the effect of Demolition Waste Causes on Demolition Waste Impacts is 2.445, representing an extremely large effect, far exceeding the conventional standards. Similarly, Demolition Waste Challenges have a substantial impact on Demolition Waste Impacts, with an f^2 value of 1.307, which also falls into the very large effect category.

These findings suggest that while causes do not significantly influence challenges directly, both causes and challenges strongly determine the extent of demolition waste impacts. This emphasizes the importance of addressing both strategic-level issues (causes) and operational challenges in order to effectively mitigate the environmental and logistical impacts associated with demolition waste.

4.3.8 Coefficient of Determination (R^2)

In order to determine the overall predictability/impact percentage of endogenous variables to determine the endogenous variable the parameter of coefficient of determination (R^2) is utilized[171, 173, 174]. Table 4.8 presents the R-square (R^2) and adjusted R-square values, which measure the explanatory power of the independent variables in predicting the dependent constructs in Model M-1. In PLS-SEM, R^2 values of 0.75, 0.50 and 0.25 are generally interpreted as substantial, moderate and weak, respectively.

TABLE 4.8: Coefficient of Determination (R^2)-M-1

	R-square	**R-square adjusted**
Demolition Waste Challenges	0,79	0,788
Demolition Waste Impacts	0,71	0,708

The R^2 value for Demolition Waste Challenges is 0.79, with an adjusted R^2 of 0.788, indicating that approximately 79% of the variance in challenges is explained by the model. This reflects a substantial level of predictive accuracy, suggesting that the antecedent constructs included in the model—particularly demolition waste causes—are strong predictors of the challenges faced in managing demolition waste.

Similarly, the R^2 for Demolition Waste Impacts is 0.71, with an adjusted value of 0.708, which also indicates a substantial degree of explained variance. This demonstrates that the combination of causes and challenges in the model effectively predicts the impacts associated with demolition waste management in road projects.

Overall, the R^2 values confirm that the model possesses strong explanatory power, validating the robustness of the relationships defined among the latent constructs

4.3.9 Assessment of PLS-SEM Path Model Results

After confirming that the current research model met the fitness criteria of the measurement model, calculations for the structural model were done to determine how one variable impacts another. This helped identify the most impactful research variable. The path coefficient, ranging from -1 to +1, was used to evaluate impact magnitude. A p-value under 0.05 indicates the significance of each impact [171, 173, 174].

Table 4.9 summarizes the results of the structural model assessment in PLS-SEM, focusing on the strength and significance of the hypothesized paths among the constructs. The evaluation includes the original sample estimates (O), sample means (M), standard deviations (STDEV), t-statistics and p-values for each path relationship.

The path from Demolition Waste Causes to Demolition Waste Challenges shows a coefficient of -0.1 with a t-statistic of 1.191 and a p-value of 0.234, indicating that this relationship is statistically insignificant at the conventional 0.05 significance level. This suggests that, within the context of this model, the direct influence of causes on challenges is weak and not supported by the data.

In contrast, the path from Demolition Waste Causes to Demolition Waste Impacts has a strong positive coefficient of 0.842, with an extremely high t-value of 55.422 and a p-value of 0.000, demonstrating a highly significant and substantial effect. This implies that the root causes of demolition waste have a direct and major influence on the impacts observed in road project waste management.

Similarly, the path from Demolition Waste Challenges to Demolition Waste Impacts also shows a strong positive effect (0.972) with a t-value of 12.698 and a p-value of 0.000, further supporting its high statistical significance. This finding indicates that challenges encountered in managing demolition waste significantly contribute to the overall impacts, such as environmental degradation, cost escalation and health risks.

Table 4.9: Assessment of PLS-SEM Path Model Results-M-1

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Challenges	-0,1	-0,099	0,084	1,191	0,234
Demolition Waste Causes - Demolition Waste Impacts	0,842	0,844	0,015	55,422	0
Demolition Waste Impacts - Demolition Waste Challenges	0,972	0,971	0,077	12,698	0

In summary, while the direct link between causes of demolition waste generation and challenges regarding demolition waste management is not significant, both causes and challenges have strong, significant effects on the impacts of demolition waste, validating the structure and directional influence in the proposed PLS-SEM model.

4.3.10 Mediation Effect

Finally, the mediatory effect of Demolition Waste between Causes of Demolition Waste Generation and Demolition Waste Management Challenges was measured by calculating the specific indirect impact between the variables.

Table 4.10 presents the mediation analysis results in the PLS-SEM model (Model M-1), assessing whether Demolition Waste Challenges mediate the relationship between Demolition Waste Causes and Demolition Waste Impacts. The original sample value (O) for the indirect path is 0.819, with a sample mean (M) of 0.819, a standard deviation (STDEV) of 0.067, a t-statistic of 12.267 and a p-value of 0.000.

Table 4.10: Mediation Effect-M-1

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Impacts - Demolition Waste Challenges	0,819	0,819	0,067	12,267	0

These results indicate that the mediation effect is highly significant, as the p-value is well below the 0.05 threshold and the t-statistic exceeds the critical value of 1.96 for a 95% confidence level.
The strong path coefficient (0.819) suggests that a substantial portion of the effect of Demolition Waste Causes on Demolition Waste Impacts is transmitted through Demolition Waste Challenges [171, 173, 174].

4.4 Results For Model-2 (M-2)

Model 2 as shown in figure 4.3, delves into the complex dynamics of demolition waste management by examining three critical dimensions:

1.Causes of Demolition Waste Generation

2.Challenges of Demolition Waste Management

3.Solutions for Demolition Waste Management

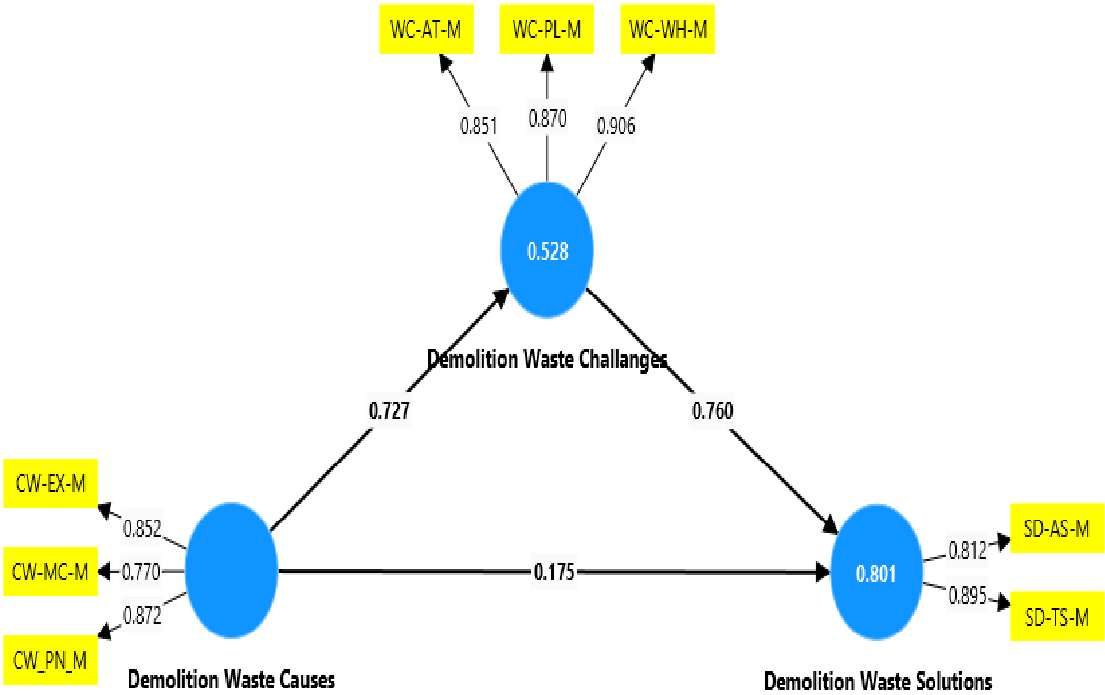

FIGURE 4.3: Research Model 2

This model aims to offer a comprehensive framework for improving demolition waste management practices. By focusing on the interrelationships between the causes of demolition waste, the challenges in its management and the potential solutions, the analysis seeks to provide sustainable and efficient strategies that can be implemented within the industry. PLS-SEM is applied for this analysis, as it is particularly suited to models of this complexity. The methodology enables the assessment of both direct and indirect relationships between the constructs and helps identify underlying patterns that might otherwise be overlooked. It also allows for the evaluation of both the measurement model, ensuring the constructs are adequately represented by their respective indicators and the structural model, which captures the relationships between these constructs. Through this analysis, the model aims to illuminate the links between the causes of demolition waste generation and the challenges faced in managing that waste. It also investigates how these challenges affect the identification and implementation of effective solutions. In doing so, this model offers valuable insights that can improve waste management strategies, shape policy decisions and promote best practices in the demolition and construction sectors.

4.4.1 Outer Loadings

In the next phase, the research elements underwent testing according to their associated research variables and proposed hypotheses. Initially, the chosen research variables were assessed for their internal consistency and the correlations among the respective research elements, focusing on factor loadings. With this in mind, [169] recommended that each research element should achieve a minimum factor loading of 0.6 or higher.

Consequently, Table 4.11 presents the outer loadings for Model M-2, which reflect the strength of the relationships between observed indicators (items) and their corresponding latent constructs. In PLS-SEM, outer loadings above 0.70 are generally considered acceptable, indicating that the indicator reliably represents the construct.

For the construct Demolition Waste Causes, all three indicators exhibit strong loadings: CW-EX-M (0.852), CW-MC-M (0.77) and CW-PN-M (0.872), suggesting high internal consistency and strong representation of the latent variable.

Within the Demolition Waste Challenges construct, all three indicators also demonstrate high loadings: WC-AT-M (0.851), WC-PL-M (0.87) and WC-WH-M (0.906). These values confirm that each item contributes significantly to measuring the construct and reinforces the reliability of the measurement model.

For Demolition Waste Solutions, the two indicators—SD-AS-M (0.812) and SD-TS-M (0.895)—exceed the minimum threshold, indicating that they are strong and valid indicators of the solutions construct in the model.

Overall, the outer loadings in Model M-2 confirm that all measurement items have a strong association with their respective constructs, ensuring adequate indicator reliability and supporting the validity of the measurement model.

TABLE 4.11: Outer Loadings-M-2

Items	**Demolition Waste Causes**	**Demolition Waste Challenges**	**Demolition Waste Solutions**
CW-EX-M	0,852		
CW-MC-M	0,77		
CW_PN_M	0,872		
SD-AS-M			0,812
SD-TS-M			0,895
WC-AT-M		0,851	
WC-PL-M		0,87	
WC-WH-M		0,906	

4.4.2 Instrument Reliability

Secondly, the statistical testing involved assessing the reliability of the research instruments to ensure accurate measurement of the respective phenomena associated with each variable, regardless of the testing environment. In this regard, Cronbach's alpha is widely accepted as a parameter to evaluate the reliability of the chosen research instruments [170, 171]. Table 4.12 presents the reliability and validity assessment of the measurement model in PLS-SEM (Model M-2), based on Cronbach's alpha, composite reliability, and average variance extracted (AVE). These metrics evaluate internal consistency reliability and convergent validity of the constructs.

TABLE 4.12: Instrument Reliability-M-2

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Demolition Waste Causes	0,777	0,786	0,871	0,693
Demolition Waste Challenges	0,848	0,85	0,908	0,767
Demolition Waste Solutions	0,637	0,667	0,844	0,731

For Demolition Waste Causes, the Cronbach's alpha is 0.777 and composite reliability is 0.871, both exceeding the acceptable threshold of 0.70, indicating good internal consistency. The AVE is 0.693, well above the 0.50 benchmark, confirming adequate convergent validity, meaning the items collectively capture the construct effectively.

The construct Demolition Waste Challenges shows even higher reliability, with a Cronbach's alpha of 0.848, composite reliability of 0.908 and an AVE of 0.767. These strong values suggest that the indicators are highly consistent and that the construct explains a substantial portion of the variance in its indicators.

For Demolition Waste Solutions, the Cronbach's alpha is 0.637, which is slightly below the conventional threshold of 0.70, suggesting moderate reliability. However, the composite reliability is 0.844 and AVE is 0.731, both of which are strong. This indicates that despite the lower alpha, the construct still demonstrates acceptable reliability and strong convergent validity, particularly given that Cronbach's alpha is a more conservative measure and may underestimate reliability in models with fewer items.

In summary, all three constructs in Model M-2 meet the minimum criteria for reliability and convergent validity. Demolition Waste Challenges and Causes show robust metrics, while Demolition Waste Solutions performs adequately, especially considering its fewer indicators.

4.4.3 Cross Loadings

Next, discriminant validity ensures that the selected research items within each variable are distinct from those of other variables in the study, thereby confirming there is no overlap or redundancy among the measured constructs. In the context of SEM, one of the parameters used to assess discriminant validity is cross-loading, which examines the correlation of each research item with its own corresponding variable compared to others in the study [172].

Table 4.13 presents the cross loadings for the measurement model in PLS-SEM (Model M-2), showing the correlations between observed items (indicators) and their corresponding latent constructs. In PLS-SEM, an indicator should load higher on its corresponding construct than on any other construct, which ensures discriminant validity.

For Demolition Waste Causes, the highest loadings are observed for CW-EX-M (0.852), CW-MC-M (0.77) and CW-PN-M (0.872). These values are strong, indicating that these items strongly represent the Demolition Waste Causes construct.

For Demolition Waste Challenges, the highest loadings are for WC-WH-M (0.906), WC-PL-M (0.87) and WC-AT-M (0.851). These loadings suggest that the items are strong indicators of the Demolition Waste Challenges construct, with WC-WH-M showing the strongest relationship.

TABLE 4.13: Cross Loadings-M-2

Items	**Demolition Waste Causes**	**Demolition Waste Challenges**	**Demolition Waste Solutions**
CW-EX-M	0,852	0,557	0,626
CW-MC-M	0,77	0,572	0,538
CW_PN_M	0,872	0,678	0,646
SD-AS-M	0,345	0,692	0,812
SD-TS-M	0,838	0,816	0,895
WC-AT-M	0,534	0,851	0,803
WC-PL-M	0,744	0,87	0,755
WC-WH-M	0,621	0,906	0,776

For Demolition Waste Solutions, the highest loadings are for SD-TS-M (0.895), SD-AS-M (0.812) and WC-AT-M (0.803). These values indicate that the items strongly represent the Demolition Waste Solutions construct. SD-TS-M shows the highest loading among them.

When comparing the loadings, Demolition Waste Causes items show higher loadings on their own construct than on the other constructs, confirming that the Demolition Waste Causes construct is well represented. Similarly, Demolition Waste Challenges and Demolition Waste Solutions items load higher on their own constructs compared to the other constructs, confirming the discriminant validity for these two constructs as well.

In summary, the cross loadings confirm that the measurement model in Model M-2 exhibits strong convergent validity, as each indicator loads significantly on its respective construct and discriminant validity, as no indicator loads higher on a construct other than its own.

4.4.4 Fornell-Larcker Criterion

In SEM, another parameter used to assess discriminant validity is the Fornell-Larcker Criterion. Table 4.14: Fornell-Larcker Criterion – Model M-2 presents the results for discriminant validity assessment using the Fornell-Larcker criterion, which compares the square root of the Average Variance Extracted (AVE) for each construct with the correlations between constructs.

For the Demolition Waste Causes construct, the square root of AVE is 0.832. This value exceeds the correlations between Demolition Waste Causes and the other constructs, which are 0.727 for Demolition Waste Challenges and 0.727 for Demolition Waste Solutions. This indicates that Demolition Waste Causes is distinct from the other constructs and satisfies the Fornell-Larcker criterion for discriminant validity.

TABLE 4.14: Fornell-Larcker Criterion-M-2

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Solutions**
Demolition Waste Causes	0,832		
Demolition Waste Challenges	0,727	0,876	
Demolition Waste Solutions	0,727	0,887	0,855

For Demolition Waste Challenges, the square root of AVE is 0.876, which is greater than the correlations with the Demolition Waste Causes (0.727) and Demolition Waste Solutions (0.887). This confirms that Demolition Waste Challenges is discriminant from the other constructs.

For Demolition Waste Solutions, the square root of AVE is 0.855, which is higher than the correlations with the Demolition Waste Causes (0.727) and Demolition Waste Challenges (0.887), thus meeting the Fornell-Larcker criterion.

In summary, Table 4.14 confirms that the constructs meet the Fornell-Larcker criterion, as each construct's square root of AVE is higher than its correlations with other constructs. This supports the discriminant validity of the model. [172].

4.4.5 HTMT- Heterotrait-Monotrait Ratio

Table 4.15: Heterotrait-Monotrait Ratio – Model M-2 presents the HTMT ratios for evaluating the discriminant validity between the constructs in the model.

The HTMT ratio helps assess whether the constructs are sufficiently distinct. Typically, an HTMT ratio below 0.90 suggests that the constructs are distinct, while a value above 0.90 indicates potential issues with discriminant validity.

TABLE 4.15: HTMT- Heterotrait-Monotrait Ratio-M-2

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Solutions**
Demolition Waste Causes			
Demolition Waste Challenges	0,887		
Demolition Waste Solutions	0,890	0,897	

For Demolition Waste Causes and Demolition Waste Challenges, the HTMT ratio is 0.887, which is below the 0.90 threshold, indicating that Demolition Waste Causes is sufficiently distinct from Demolition Waste Challenges. For Demolition

Waste Causes and Demolition Waste Solutions, the HTMT ratio is 0.890, which is also below 0.90. This confirms that Demolition Waste Causes is distinct from Demolition Waste Solutions. For Demolition Waste Challenges and Demolition Waste Solutions, the HTMT ratio is 0.897, which is just below the 0.90 threshold. This also indicates that these two constructs are distinct from each other, though they are somewhat closely related.

In summary, the HTMT ratios in Table 4.15 show that all three constructs—Demolition Waste Causes, Demolition Waste Challenges and Demolition Waste Solutions—are sufficiently distinct from each other. The values are below the 0.90 threshold, confirming that the constructs exhibit discriminant validity.

4.4.6 Variance Inflation Factor (VIF)

Once the reliability and validity of the research instrument have been verified, the next step involves evaluating the internal consistency of the research items in terms of Variance Inflation Factor (VIF). VIF measures the extent of correlation between variables and their respective indicators. For a research item to be considered acceptable, it should have a VIF value below 5 [172].

In this study, all research items met this criterion, indicating their suitability (See Table 4.16).

TABLE 4.16: Variance Inflation Factor (VIF)-M2

Item	**VIF**
CW-EX-M	1,831
CW-MC-M	1,396
CW_PN_M	1,848
SD-AS-M	1,279
SD-TS-M	1,279
WC-AT-M	1,953
WC-PL-M	1,999
WC-WH-M	2,552

4.4.7 Effect Size (f2)

Table 4.17: Effect Size (f^2) – Model M-2 presents the effect sizes (f^2) for the relationships between constructs in the model. The effect size (f^2) measures the magnitude of the relationship between variables.

In general, an f^2 value of 0.02 represents a small effect, 0.15 represents a medium effect and value of 0.35 represents a large effect.

Here are the f^2 values for the relationships between the constructs in the model:

Demolition Waste Causes → Demolition Waste Challenges: 1.118 Demolition Waste Causes → Demolition Waste Solutions: 0.073 Demolition Waste Challenges → Demolition Waste Solutions: 1.374

Interpretation: The relationship between Demolition Waste Causes and Demolition Waste Challenges has a large effect size ($f^2 = 1.118$), indicating a strong influence. The relationship between Demolition Waste Causes and Demolition Waste Solutions has a small effect size ($f^2 = 0.073$), indicating a minor effect. The relationship between Demolition Waste Challenges and Demolition Waste Solutions also shows a large effect size ($f^2 = 1.374$), suggesting a significant influence.

These values suggest that the causes and challenges of demolition waste have a more substantial impact on the solutions than the causes alone.

Table 4.17: Effect Size (f2)-M-2

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Solutions**
Demolition Waste Causes		1,118	0,073
Demolition Waste Challenges			1,374
Demolition Waste Solutions			

4.4.8 Coefficient of Determination (R^2)

Table 4.18: Coefficient of Determination (R^2) – Model M-2 shows the R-square and adjusted R-square values for the constructs in the model.

For Demolition Waste Challenges, the R-square value is 0.528, meaning 52.8% of the variance is explained by the independent variables in the model. The adjusted R-square value of 0.525 indicates a minor adjustment for model complexity.

For Demolition Waste Solutions, the R-square value is 0.801, indicating that 80.1% of the variance in the dependent variable is explained by the model. The adjusted R-square of 0.799 reflects a good model fit.

Overall, the model explains a significant portion of the variance, particularly for demolition waste solutions, with moderate explanation for the challenges.

Table 4.18: Coefficient of Determination (R^2)-M-2

	R-square	**R-square adjusted**
Demolition Waste Challenges	0,528	0,525
Demolition Waste Solutions	0,801	0,799

4.4.9 Assessment of PLS-SEM Path Model Results

In concluding that the current research model meets the fitness criteria of the measurement model, calculations related to the structural model were used to determine the impact of one variable on another, thereby assessing the most influential research variable in the study. The path coefficient serves as a key parameter to evaluate the magnitude of impact, ranging from -1 to +1, indicating the maximum negative or positive influence of a variable. Additionally, the significance of each impact is determined by its associated p-value being below 0.05 [173, 174].

Table 4.19: Assessment of PLS-SEM Path Model Results – Model M-2 presents the path model results for the relationships between the constructs in the study,

including the original sample (O), sample mean (M), standard deviation (STDEV), T-statistics and P-values.

Table 4.19: Assessment of PLS-SEM Path Model Results-M-2

	Original sample	**Sample mean**	**Standard deviation**	**T statistics**	**P values**
Demolition Waste Causes - Demolition Waste Challenges	0,727	0,729	0,031	23,624	0
Demolition Waste Causes - Demolition Waste Solutions	0,175	0,176	0,047	3,697	0
Demolition Waste Challenges - Demolition Waste Solutions	0,76	0,76	0,035	21,452	0

For the path from Demolition Waste Causes to Demolition Waste Challenges, the original sample value is 0.727, with T-statistics of 23.624 and a p-value of 0, indicating a strong positive relationship that is statistically significant ($p < 0.01$). For the path from Demolition Waste Causes to Demolition Waste Solutions, the original sample value is 0.175, with T-statistics of 3.697 and a p-value of 0, showing a moderate positive relationship that is statistically significant ($p < 0.01$). For the path from Demolition Waste Challenges to Demolition Waste Solutions, the original sample value is 0.76, with T-statistics of 21.452 and a p-value of 0, indicating a strong positive relationship that is highly significant ($p < 0.01$).

Summary: The results demonstrate significant and strong relationships between the constructs in the model. The relationship between Demolition Waste Causes and Demolition Waste Challenges is the strongest, followed by the relationships between Demolition Waste Challenges and Demolition Waste Solutions and Demolition Waste Causes and Demolition Waste Solutions, all of which are highly significant with p-values of 0.

4.4.10 Mediation Effect

Finally, the mediating effect of Demolition Waste between Causes of Demolition Waste Generation and Demolition Waste Management Challenges was assessed by calculating the specific indirect impact between these variables. Table 4.20: Mediation Effect – Model M-2 presents the results for the mediation effect in the path model. The mediation effect assesses how Demolition Waste Causes influences Demolition Waste Solutions through Demolition Waste Challenges.

TABLE 4.20: Mediation Effect-M-2

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Challenges - Demolition Waste Solutions	0,552	0,554	0,037	15,06	0

The results are as follows: Demolition Waste Causes → Demolition Waste Challenges → Demolition Waste Solutions Original sample: 0.552 T-statistics: 15.06 P-value: 0. This path shows a significant positive mediation effect, with a T-statistics value of 15.06 and a p-value of 0, indicating a strong and statistically significant mediation effect from Demolition Waste Causes to Demolition Waste Solutions through Demolition Waste Challenges.

Summary: The mediation effect is statistically significant, suggesting that Demolition Waste Causes influences Demolition Waste Solutions indirectly by affecting Demolition Waste Challenges. The strong effect and significance highlight the importance of addressing waste challenges in order to manage waste solutions effectively.

4.5 Results For Model-3 (M-3)

Model 3 as shown in figure 4.4, investigates the interconnected dynamics of demolition waste management by focusing on three key dimensions:

1.Causes of Demolition Waste Generation

2.Impact of Demolition Waste

3.Solutions for Demolition Waste Management

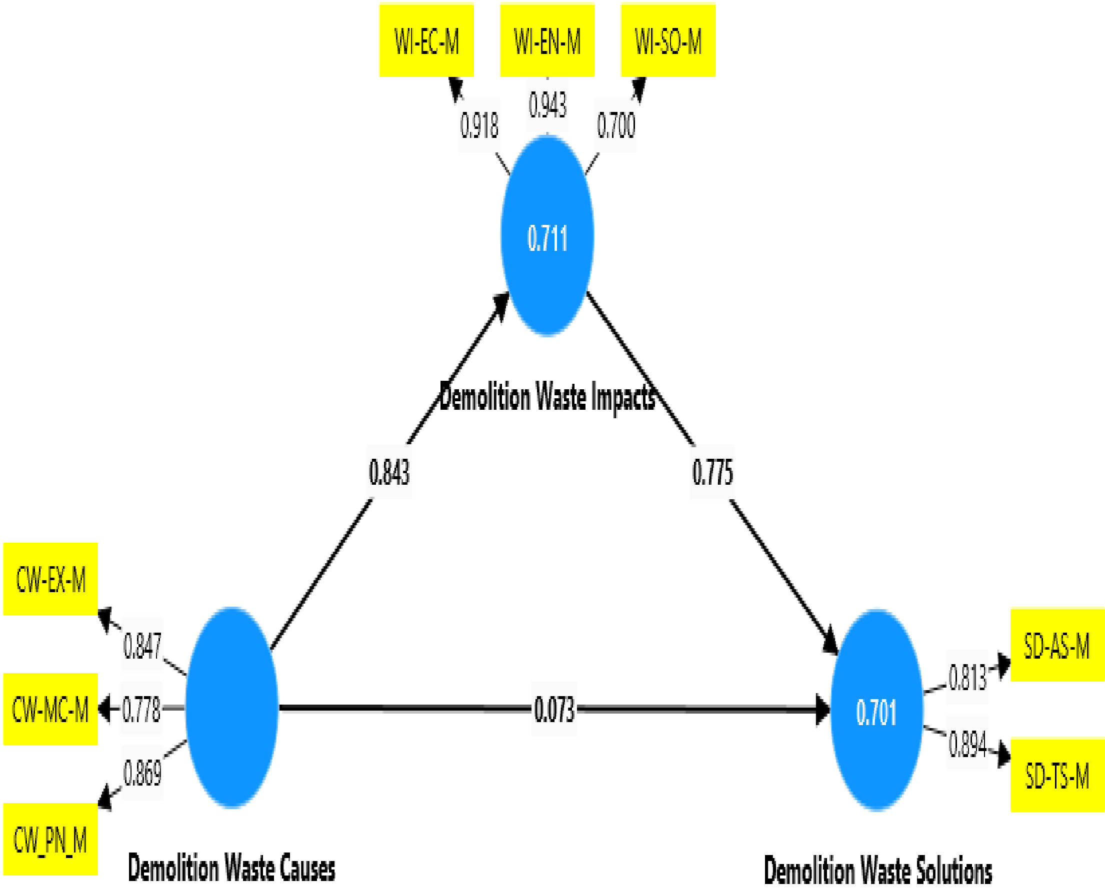

Figure 4.4: Research Model 3

This model explores the relationships between the causes, impacts and solutions in demolition waste management, aiming to provide a comprehensive framework for improving the overall practices in the industry. By examining how the causes of waste generation influence its impacts and the subsequent solutions, the model offers valuable insights that can contribute to sustainable construction practices. Using PLS-SEM for the analysis enables a robust examination of these relationships, providing a deeper understanding of the factors driving demolition waste and the effectiveness of potential solutions. This methodology allows for the identification of patterns and insights that may not be apparent through traditional methods, contributing to more informed policy decisions, better resource management and fostering best practices within the demolition and construction sectors.

4.5.1 Outer Loadings

Table 4.21: Outer Loadings – Model M-3 presents the outer loadings for the constructs in the model, representing the strength of the relationships between the indicators and their respective latent variables.

Table 4.21: Outer Loadings-M-3

Items	**Demolition Waste Causes**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
CW-EX-M	0,847		
CW-MC-M	0,778		
CW_PN_M	0,869		
SD-AS-M			0,813
SD-TS-M			0,894
WI-EC-M		0,918	
WI-EN-M		0,943	
WI-SO-M		0,7	

The outer loadings are as follows: Demolition Waste Causes: CW-EX-M: 0.847, CW-MC-M: 0.778, CW PN M: 0.869 Demolition Waste Impacts: SD-AS-M: 0.813, SD-TS-M: 0.894 Demolition Waste Solutions: WI-EC-M: 0.918, WI-EN-M: 0.943, WI-SO-M: 0.7

Summary: The outer loadings indicate strong relationships between the indicators and their respective constructs. The highest loadings are found for Demolition Waste Solutions, particularly for WI-EN-M (0.943) and WI-EC-M (0.918), indicating a very strong association between these indicators and the construct. All loadings are above the acceptable threshold of 0.7, showing reliable measurement of the latent variables.

4.5.2 Instrument Reliability

Table 4.22: Instrument Reliability – Model M-3 presents the reliability measures for the constructs in the model, assessing the internal consistency and validity of the measurement items.

Table 4.22: Instrument Reliability-M-3

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Demolition Waste Causes	0,777	0,783	0,871	0,693
Demolition Waste Impacts	0,825	0,908	0,894	0,741
Demolition Waste Solutions	0,637	0,666	0,844	0,731

The results are as follows: Demolition Waste Causes: Cronbach's alpha: 0.777, Composite reliability (rho a): 0.783, Composite reliability (rho c): 0.871, Average variance extracted (AVE): 0.693 Demolition Waste Impacts: Cronbach's alpha: 0.825, Composite reliability (rho a): 0.908, Composite reliability (rho c): 0.894, Average variance extracted (AVE): 0.741 Demolition Waste Solutions: Cronbach's alpha: 0.637, Composite reliability (rho a): 0.666, Composite reliability (rho c): 0.844, Average variance extracted (AVE): 0.731

Summary: The reliability analysis shows that Demolition Waste Causes and Demolition Waste Impacts have acceptable Cronbach's alpha and composite reliability values, indicating good internal consistency. However, Demolition Waste Solutions has a slightly lower Cronbach's alpha, suggesting that the reliability of its measurement items might need improvement. All constructs show acceptable AVE values above the 0.5 threshold, confirming sufficient convergent validity.

4.5.3 Cross Loadings

Table 4.23: Cross Loadings – Model M-3 presents the cross-loadings for the measurement items across the three constructs: Demolition Waste Causes, Demolition Waste Impacts and Demolition Waste Solutions.

The results are as follows: CW-EX-M has loadings of 0.847, 0.623 and 0.626 on Demolition Waste Causes, Demolition Waste Impacts and Demolition Waste Solutions, respectively. CW-MC-M has loadings of 0.778, 0.701 and 0.538. CW PN M has loadings of 0.869, 0.773 and 0.645. SD-AS-M has loadings of 0.346, 0.632 and 0.813. SD-TS-M has loadings of 0.837, 0.785 and 0.894. WI-EC-M has loadings of 0.701, 0.918 and 0.837. WI-EN-M has loadings of 0.926, 0.943 and 0.810. WI-SO-M has loadings of 0.459, 0.700 and 0.424.

Summary: The cross-loading table indicates that the items generally have the highest loadings on their intended constructs, suggesting good discriminant validity. However, some items like WI-SO-M have relatively lower loadings across all constructs, suggesting the need for further examination or potential improvement. The higher loadings on the relevant constructs also confirm that the items are more strongly related to their respective factors.

Table 4.23: Cross Loadings-M-3

Items	**Demolition Waste Causes**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
CW-EX-M	0,847	0,623	0,626
CW-MC-M	0,778	0,701	0,538
CW_PN_M	0,869	0,773	0,645
SD-AS-M	0,346	0,632	0,813
SD-TS-M	0,837	0,785	0,894
WI-EC-M	0,701	0,918	0,837
WI-EN-M	0,926	0,943	0,81
WI-SO-M	0,459	0,7	0,424

4.5.4 Fornell-Larcker Criterion

Table 4.24: Fornell-Larcker Criterion – Model M-3 presents the Fornell-Larcker values for the three constructs: Demolition Waste Causes, Demolition Waste Impacts and Demolition Waste Solutions. The diagonal values represent the square root of the Average Variance Extracted (AVE) for each construct, which are 0.832 for Demolition Waste Causes, 0.861 for Demolition Waste Impacts and 0.855 for Demolition Waste Solutions.

The off-diagonal values represent the correlations between the constructs, with Demolition Waste Causes and Demolition Waste Impacts having a correlation of 0.843, Demolition Waste Causes and Demolition Waste Solutions having a correlation of 0.726 and Demolition Waste Impacts and Demolition Waste Solutions having a correlation of 0.836. The Fornell-Larcker criterion indicates that the square root of AVE for each construct is greater than its correlations with other constructs, suggesting that discriminant validity is achieved. This means that each construct is sufficiently distinct from the others, confirming the validity of the measurement model.

TABLE 4.24: Fornell-Larcker Criterion-M-3

	Demolition Waste Causes	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes	0,832		
Demolition Waste Impacts	0,843	0,861	
Demolition Waste Solutions	0,726	0,836	0,855

4.5.5 HTMT- Heterotrait-Monotrait Ratio

Table 4.25: HTMT (Heterotrait-Monotrait Ratio) – Model M-3 shows the HTMT values for the relationships between the constructs: Demolition Waste Causes, Demolition Waste Impacts, and Demolition Waste Solutions.

TABLE 4.25: HTMT- Heterotrait-Monotrait Ratio-M-3

	Demolition Waste Causes	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes			
Demolition Waste Impacts	0,896		
Demolition Waste Solutions	0,891	0,879	

The HTMT value between Demolition Waste Causes and Demolition Waste Impacts is 0.896, between Demolition Waste Causes and Demolition Waste Solutions is 0.891, and between Demolition Waste Impacts and Demolition Waste Solutions is 0.879. These HTMT values are all below the typical threshold of 0.90, indicating that the constructs are sufficiently distinct and exhibit discriminant validity. Therefore, the constructs of Demolition Waste Causes, Demolition Waste Impacts, and Demolition Waste Solutions can be considered as distinct in this model, without concerns about high multicollinearity or overlap.

4.5.6 Variance Inflation Factor (VIF)

Table 4.26: Variance Inflation Factor (VIF) – Model M-3 presents the VIF values for various items in the model. The VIF values for the items are as follows: CW-EX-M (1.831), CW-MC-M (1.396), CW PN M (1.848), SD-AS-M (1.279), SD-TS-M (1.279), WI-EC-M (2.911), WI-EN-M (3.178) and WI-SO-M (1.429).

Table 4.26: Variance Inflation Factor (VIF)-M-3

Item	**VIF**
CW-EX-M	1,831
CW-MC-M	1,396
CW_PN_M	1,848
SD-AS-M	1,279
SD-TS-M	1,279
WI-EC-M	2,911
WI-EN-M	3,178
WI-SO-M	1,429

VIF values below 5 generally indicate that multicollinearity is not a major concern. In this case, the VIF values for most items are below the threshold of 5, with the exception of WI-EC-M and WI-EN-M, which have VIF values of 2.911 and 3.178, respectively. These values are still within acceptable limits, suggesting that there is no significant multicollinearity among the items in this model.

4.5.7 Effect Size (f2)

Table 4.27 presents the Effect Size (f^2) for Model 3.

TABLE 4.27: Effect Size (f2)-M-3

	Demolition Waste Causes	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes		2,455	0,005
Demolition Waste Impacts			0,581
Demolition Waste Solutions			

The effect size from Demolition Waste Causes to Demolition Waste Impacts is 2.455, indicating a very large effect and highlighting that causes strongly influence the impacts of demolition waste. The effect size from Demolition Waste Causes to Demolition Waste Solutions is 0.005, reflecting a negligible influence. Finally, the effect size from Demolition Waste Impacts to Demolition Waste Solutions is 0.581, which represents a large effect, signifying that the impacts of demolition waste substantially influence the development of effective solutions.

4.5.8 Coefficient of Determination (R^2)

To determine the overall predictability or impact percentage of endogenous variables, the coefficient of determination (R^2) is employed [173, 174]. This parameter quantifies the proportion of variance in an endogenous variable that is explained by its predictors.

Table 4.28 presents the Coefficient of Determination (R^2) for Model 3. The R-square value for Demolition Waste Impacts is 0.711, with an adjusted R-square of 0.709. This indicates that approximately 71.1% of the variance in demolition waste impacts can be explained by the model. For Demolition Waste Solutions, the R-square value is 0.701 and the adjusted R-square is 0.697, suggesting that 70.1% of the variance in proposed solutions is accounted for by the explanatory variables in the model.

TABLE 4.28: Coefficient of Determination (R^2)-M-3

	R-square	**R-square adjusted**
Demolition Waste Impacts	0,711	0,709
Demolition Waste Solutions	0,701	0,697

4.5.9 Assessment of PLS-SEM Path Model Results

TABLE 4.29: Assessment of PLS-SEM Path Model Results-M-3

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Impacts	0,843	0,844	0,015	54,53	0
Demolition Waste Causes - Demolition Waste Solutions	0,073	0,072	0,081	0,895	0,371
Demolition Waste Impacts - Demolition Waste Solutions	0,775	0,777	0,067	11,523	0

Table 4.29 presents the assessment of the PLS-SEM path model results for Model 3. The path from Demolition Waste Causes to Demolition Waste Impacts shows a strong and significant relationship, with an original sample value of 0.843, a t-statistic of 54.53, and a p-value of 0.000, indicating high statistical significance. However, the path from Demolition Waste Causes to Demolition Waste Solutions has a low coefficient of 0.073 and a non-significant p-value of 0.371, suggesting no direct significant effect. Conversely, the path from Demolition Waste Impacts to Demolition Waste Solutions is statistically significant with a coefficient of 0.775, a t-statistic of 11.523, and a p-value of 0.000, indicating that impacts significantly influence the formulation of solutions.

4.5.10 Mediation Effect

Table 4.30: Mediation Effect - Model 3 (M-3), This table presents the results of the mediation analysis assessing the indirect relationship between Demolition Waste Causes and Demolition Waste Solutions through Demolition Waste Impacts.

TABLE 4.30: Mediation Effect-M-3

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Impacts - Demolition Waste Solutions	0,653	0,656	0,058	11,217	0

The original sample coefficient is 0.653, with a very close sample mean of 0.656, indicating consistency in the bootstrapping estimates. The standard deviation is 0.058, resulting in a t-statistic of 11.217, which is significantly higher than the critical value. The corresponding p-value is 0, which confirms that the mediation effect is statistically significant.

The results provide strong evidence that Demolition Waste Impacts significantly mediate the relationship between Demolition Waste Causes and Demolition Waste Solutions. This implies that addressing the causes of demolition waste indirectly enhances the adoption of effective solutions by first influencing the impacts.

4.6 Results For Model-4 (M-4)

Model 4 as shown in figure 4.5, provides a comprehensive framework that integrates four key dimensions of demolition waste management:

1.Causes of Demolition Waste Generation
2.Impact of Demolition Waste
3.Challenges in Demolition Waste Management
4.Solutions for Demolition Waste Management.

Using PLS-SEM, this model aims to explore the relationships between these dimensions and examine the dynamics of demolition waste management holistically. PLS-SEM is well-suited for this analysis because it allows for the exploration of both direct and indirect relationships among the constructs, providing insights into how the causes of waste generation influence its impacts, the challenges in managing it and the effectiveness of proposed solutions. The analysis assess the measurement model, ensuring that each construct is properly represented by its indicators and evaluate the structural model to understand the complex interactions among the causes, impacts, challenges and solutions. By doing so, Model 4 aims to uncover valuable insights into the factors contributing to the successful management of demolition waste, inform policy and enhance decision-making in the demolition and construction industries.

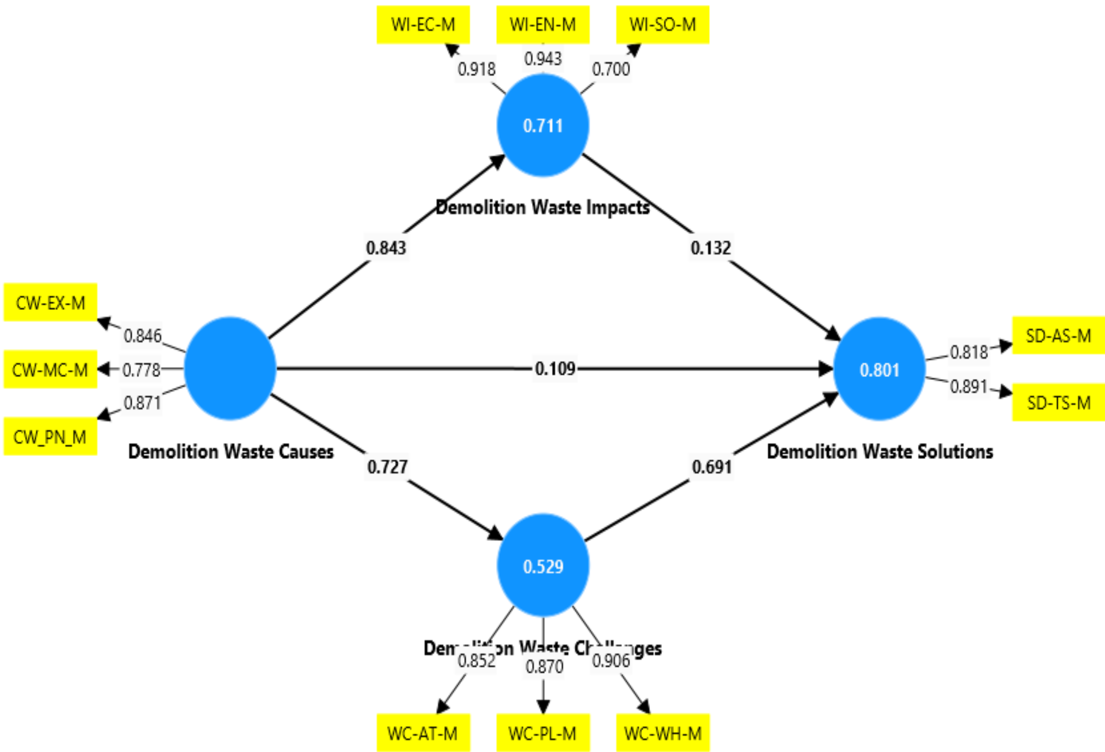

FIGURE 4.5: Research Model 4

4.6.1 Outer Loadings

Table 4.31 displays the outer loadings for each observed item under the fourth measurement model (M-4) used in the PLS-SEM analysis. Outer loadings represent the correlation strength between each indicator (question or item) and its corresponding latent construct (unobserved variable).

Loadings above 0.70 are generally deemed acceptable, suggesting that the item reliably contributes to measuring its associated construct. For the Demolition Waste Causes construct, the items CW-EX-M (0.846), CW-MC-M (0.778) and CW PN M (0.871) show strong outer loadings, all exceeding the 0.70 threshold. This indicates a solid correlation between these items and the underlying construct, confirming their validity in capturing the causes of demolition waste.

In terms of Demolition Waste Challenges, the indicators WC-AT-M (0.852), WC-PL-M (0.870) and WC-WH-M (0.906) also demonstrate high outer loadings. These values confirm that the items are effective in reflecting the challenges encountered in demolition waste management, with each item exhibiting a high level of reliability. For the Demolition Waste Impacts construct, WI-EC-M (0.918), WI-EN-M (0.943) and WI-SO-M (0.700) are the respective loadings. While WI-SO-M is right at the threshold, the other two indicators show extremely strong associations, further validating the measurement model for this construct.

Lastly, Demolition Waste Solutions is measured by SD-AS-M (0.818) and SD-TS-M (0.891), both of which exceed the standard cutoff, confirming that these items are reliable indicators of proposed solutions to manage demolition waste.

Overall, the measurement model in M-4 demonstrates strong reliability and validity, as evidenced by the high outer loadings across all constructs. This affirms that the indicators are appropriate and effective in representing the theoretical concepts under investigation.

Table 4.31: Outer Loadings-M-4

Items	**Demolition Waste Causes**	**Demolition Waste Challenges**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
CW-EX-M	0,846			
CW-MC-M	0,778			
CW_PN_M	0,871			
SD-AS-M				0,818
SD-TS-M				0,891
WC-AT-M		0,852		
WC-PL-M		0,87		
WC-WH-M		0,906		
WI-EC-M			0,918	
WI-EN-M			0,943	
WI-SO-M			0,7	

4.6.2 Instrument Reliability

Table 4.32 presents the results of the reliability and validity assessment for the measurement model (M-4) constructs using four key indicators: Cronbach's Alpha, Composite Reliability (rho-a and rho-c) and Average Variance Extracted (AVE). These metrics help determine whether the items consistently measure the constructs they are intended to represent.

TABLE 4.32: Instrument Reliability-M-4

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Demolition Waste Causes	0,777	0,784	0,871	0,693
Demolition Waste Challenges	0,848	0,85	0,908	0,767
Demolition Waste Impacts	0,825	0,907	0,894	0,741
Demolition Waste Solutions	0,637	0,66	0,844	0,731

For Demolition Waste Causes, Cronbach's Alpha is 0.777 and the composite reliability (rho-a = 0.784; rho-c = 0.871) exceeds the accepted threshold of 0.70, indicating acceptable internal consistency. The AVE of 0.693 suggests that the construct explains a substantial proportion of variance in its indicators, thus confirming convergent validity.

Demolition Waste Challenges shows strong reliability, with Cronbach's Alpha of

0.848 and composite reliability values of rho-a = 0.850 and rho-c = 0.908. The AVE value of 0.767 further confirms that the indicators adequately capture the essence of this construct.

In the case of Demolition Waste Impacts, the reliability indicators are also strong: Cronbach's Alpha is 0.825, rho-a is 0.907 and rho-c is 0.894. An AVE of 0.741 demonstrates good convergent validity, implying that the latent construct accounts for a significant portion of the variance in its observed measures.

Finally, Demolition Waste Solutions presents a slightly lower Cronbach's Alpha of 0.637, which is below the ideal threshold but still within acceptable bounds for exploratory research. However, composite reliability (rho-a = 0.660; rho-c = 0.844) and AVE (0.731) remain well above the minimum standards, indicating that the construct maintains reasonable internal consistency and convergent validity.

In summary, all four constructs in model M-4 exhibit adequate to strong reliability and validity, supporting the robustness of the measurement model.

4.6.3 Cross Loadings

Table 4.33 presents the cross-loadings for research Model M-4, showing how each item correlates with the different constructs of Demolition Waste Causes, Challenges of demolition waste management , Impacts and Solutions. The values indicate strong associations for most items with their intended constructs. For instance, items like CW PN M (0.871), SD-TS-M (0.838) and WC-WH-M (0.906) show high loadings on their respective constructs, demonstrating clear relationships. However, some items, like SD-AS-M (0.345) under Demolition Waste Causes, show weaker correlations, indicating that these items might not be as closely related to their respective constructs. Additionally, WI-SO-M has lower loadings across all constructs, particularly with Demolition Waste Causes (0.46), which suggests that this item may not perform as well in the model. Overall, the cross-loadings indicate generally strong construct-item relationships, with a few exceptions.

Table 4.33: Cross Loadings-M-4

Items	Demolition Waste Causes	Demolition Waste Challenges	Demolition Waste Impacts	Demolition Waste Solutions
CW-EX-M	0,846	0,557	0,623	0,623
CW-MC-M	0,778	0,572	0,701	0,536
CW_PN_M	0,871	0,678	0,773	0,641
SD-AS-M	0,345	0,692	0,632	0,818
SD-TS-M	0,838	0,816	0,785	0,891
WC-AT-M	0,535	0,852	0,801	0,805
WC-PL-M	0,743	0,87	0,722	0,751
WC-WH-M	0,624	0,906	0,809	0,776
WI-EC-M	0,702	0,872	0,918	0,836
WI-EN-M	0,926	0,843	0,943	0,808
WI-SO-M	0,46	0,502	0,7	0,426

4.6.4 Fornell-Larcker Criterion

Table 4.34 presents the results of the Fornell-Larcker criterion for Model M-4. The Fornell-Larcker criterion is used to assess discriminant validity by comparing the square root of the Average Variance Extracted (AVE) for each construct with its correlations with other constructs. In this case, the diagonal values represent the square root of the AVE for each construct, and the off-diagonal values represent the correlations between constructs. Demolition Waste Causes has a strong discriminant validity with a square root of AVE value of 0.832, which is higher than its correlations with other constructs (0.727 with Demolition Waste Challenges, 0.843 with Demolition Waste Impacts and 0.723 with Demolition Waste Solutions). Demolition Waste Challenges shows a square root of AVE value of 0.876, indicating strong discriminant validity and higher than its correlations with the other constructs. Demolition Waste Impacts and Demolition Waste Solutions similarly show good discriminant validity, with their AVE values (0.861 and 0.855, respectively) being higher than the correlations with other constructs.

Overall, the Fornell-Larcker criterion indicates that the constructs in this model are well differentiated, as each construct's AVE is higher than its correlations with other constructs. This suggests that the model has good discriminant validity.

TABLE 4.34: Fornell-Larcker Criterion-M-4

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes	0,832			
Demolition Waste Challenges	0,727	0,876		
Demolition Waste Impacts	0,843	0,886	0,861	
Demolition Waste Solutions	0,723	0,887	0,835	0,855

4.6.5 HTMT- Heterotrait-Monotrait Ratio

Table 4.35 presents the HTMT (Heterotrait-Monotrait) ratios for Model M-4. The HTMT ratio is a measure used to assess discriminant validity, specifically checking whether the constructs in the model are sufficiently distinct from one another. According to the HTMT criterion, values greater than 0.85 indicate potential discriminant validity issues, suggesting that the constructs may not be sufficiently distinct from each other.

In this table, the HTMT values are as follows: The HTMT value between Demolition Waste Causes and Demolition Waste Challenges is 0.887, which is below the

0.85 threshold, indicating that these two constructs are sufficiently distinct. The HTMT value between Demolition Waste Causes and Demolition Waste Impacts is 0.896, which is above 0.85 but not overly high, suggesting that there might be some overlap but still maintaining reasonable discriminant validity.

TABLE 4.35: HTMT- Heterotrait-Monotrait Ratio-M-4

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes				
Demolition Waste Challenges	0,887			
Demolition Waste Impacts	0,896	0,893		
Demolition Waste Solutions	0,891	0,899	0,898	

The HTMT value between Demolition Waste Causes and Demolition Waste Solutions is 0.891, which again is slightly above the threshold but not excessively so. The HTMT values between Demolition Waste Challenges and Demolition Waste Impacts (0.893) and Demolition Waste Challenges and Demolition Waste Solutions (0.899) both remain below 0.90, which is acceptable for discriminant validity. The HTMT value between Demolition Waste Impacts and Demolition Waste Solutions is 0.898, which is also just under the 0.90 threshold, indicating an adequate level of distinctiveness.

Overall, the HTMT values indicate that while some constructs show marginal overlap, they generally maintain acceptable discriminant validity, confirming that the constructs are sufficiently distinct from each other.

4.6.6 Variance Inflation Factor (VIF)

In this table, the VIF values for various items are as follows: CW-EX-M (1.831), CW-MC-M (1.396), CW PN M (1.848), SD-AS-M (1.279), SD-TS-M (1.279), WC-AT-M (1.953), WC-PL-M (1.999), WC-WH-M (2.552), WI-EC-M (2.911), WI-EN-M (3.178), and WI-SO-M (1.429).

All VIF values in this table are below the commonly used threshold of 5, indicating that there is no severe multicollinearity issue within the model. The VIF values range from 1.279 to 3.178, suggesting that the predictor variables are not excessively correlated with each other, ensuring the stability and reliability of the statistical analysis.

Table 4.36: Variance Inflation Factor (VIF)-M-4

Item	**VIF**
CW-EX-M	1,831
CW-MC-M	1,396
CW_PN_M	1,848
SD-AS-M	1,279
SD-TS-M	1,279
WC-AT-M	1,953
WC-PL-M	1,999
WC-WH-M	2,552
WI-EC-M	2,911
WI-EN-M	3,178
WI-SO-M	1,429

4.6.7 Effect Size (f2)

In Table 4.37, the effect size (f^2) values for the various relationships are as follows:

For Demolition Waste Causes, the effect sizes are 1.123 for Demolition Waste Challenges, 2.461 for Demolition Waste Impacts and 0.017 for Demolition Waste

Solutions. For Demolition Waste Challenges, the effect size with Demolition Waste Impacts is 0.514 and for Demolition Waste Impacts, the effect size with Demolition Waste Solutions is 0.011.

These values represent the effect size of the relationships in the model. Effect sizes greater than 0.35 indicate a large effect, values between 0.15 and 0.35 indicate a medium effect and values below 0.15 indicate a small effect. In this case, the relationships between Demolition Waste Causes and both Demolition Waste Challenges and Demolition Waste Impacts show large effect sizes, while the other relationships have small to medium effects, indicating varying degrees of influence between the variables.

Table 4.37: Effect Size (f2)-M4

	Demolition Waste Causes	**Demolition Waste Challenges**	**Demolition Waste Impacts**	**Demolition Waste Solutions**
Demolition Waste Causes		1,123	2,461	0,017
Demolition Waste Challenges				0,514
Demolition Waste Impacts				0,011
Demolition Waste Solutions				

4.6.8 Coefficient of Determination (R^2)

In Table 4.38, the Coefficient of Determination (R^2) and Adjusted R^2 values for the model are as follows: Demolition Waste Challenges has an R^2 of 0.529 and

Adjusted R^2 of 0.526, Demolition Waste Impacts has an R^2 of 0.711 and Adjusted R^2 of 0.709 and Demolition Waste Solutions has an R^2 of 0.801 and Adjusted R^2 of 0.798.

These values represent the proportion of variance in the dependent variables that can be explained by the independent variables in the model. An R^2 value of 0.529 for Demolition Waste Challenges indicates that approximately 53% of the variation in this variable is explained by the model. An R^2 value of 0.711 for Demolition Waste Impacts indicates a higher level of explanatory power, with around 71% of the variation in this variable being explained. The R^2 value of 0.801 for Demolition Waste Solutions indicates the highest explanatory power, with about 80% of the variation in this variable being explained. The adjusted R^2 values, which account for the number of predictors in the model, are very close to the R^2 values, suggesting that the model is well-specified and the addition of predictors does not unnecessarily inflate the explanatory power.

TABLE 4.38: Coefficient of Determination (R^2)-M-4

	R-square	**R-square adjusted**
Demolition Waste Challenges	0,529	0,526
Demolition Waste Impacts	0,711	0,709
Demolition Waste Solutions	0,801	0,798

4.6.9 Assessment of PLS-SEM Path Model Results

Table 4.39 presents the results from the assessment of the PLS-SEM path model. It reports the original sample (O), sample mean (M), standard deviation (STDEV), T statistics and P-values for the relationships between the constructs.

The results indicate that the path coefficient between Demolition Waste Causes and Demolition Waste Challenges is 0.727, with a very high t-statistic of 23.525 and a p-value of 0, suggesting a statistically significant and strong relationship between these variables. For the path from Demolition Waste Causes to Demolition Waste Impacts, the path coefficient is 0.843, with an even higher t-statistic of 54.959 and a p-value of 0, indicating a highly significant and very strong relationship.

Table 4.39: Assessment of PLS-SEM Path Model Results-M-4

	Original sample	**Sample mean**	**Standard deviation**	**T statistics**	**P values**
Demolition Waste Causes - Demolition Waste Challenges	0,727	0,729	0,031	23,525	0
Demolition Waste Causes - Demolition Waste Impacts	0,843	0,844	0,015	54,959	0
Demolition Waste Causes - Demolition Waste Solutions	0,109	0,108	0,006	1,823	0,068
Demolition Waste Challenges - Demolition Waste Solutions	0,691	0,691	0,057	12,19	0
Demolition Waste Impacts - Demolition Waste Solutions	0,132	0,134	0,074	1,772	0

The path from Demolition Waste Causes to Demolition Waste Solutions has a path coefficient of 0.109, with a t-statistic of 1.823 and a p-value of 0.068. This p-value is close to the significance threshold of 0.05, suggesting a marginally significant relationship. The path between Demolition Waste Challenges and Demolition Waste Solutions has a path coefficient of 0.691, with a t-statistic of 12.19 and a p-value of 0, showing a strong and statistically significant relationship. Finally, the path from Demolition Waste Impacts to Demolition Waste Solutions has a path coefficient of 0.132, with a t-statistic of 1.772 and a p-value of 0.000, suggesting a highly significant relationship despite the relatively lower coefficient.

Overall, the majority of paths show strong and significant relationships, with the exception of the path between Demolition Waste Causes and Demolition Waste Solutions, which is marginally significant.

4.6.10 Mediation Effect

Table 4.40 displays the mediation effects for two paths in the model.

The first mediation path, from Demolition Waste Causes to Demolition Waste Impacts and then to Demolition Waste Solutions, has the following values: Original sample (O) = 0.111, Sample mean (M) = 0.113, Standard deviation (STDEV) = 0.063, T-statistics = 1.769, and P-value = 0.000. The p-value of 0.000 indicates a highly significant mediation effect. Despite the T-statistics being relatively low, the very small p-value suggests that this mediation effect should be considered important in the model.

The second mediation path, from Demolition Waste Causes to Demolition Waste Challenges and then to Demolition Waste Solutions, has the following values: Original sample (O) = 0.502, Sample mean (M) = 0.504, Standard deviation (STDEV) = 0.049, T-statistics = 10.293 and P-value = 0. The second path also shows a highly significant mediation effect, as evidenced by the very low p-value and high T-statistics. The larger original sample value further supports the strength of this mediation effect.

In summary, both mediation paths show strong significance, but the second path has a larger effect size and is more robust statistically.

TABLE 4.40: Mediation Effect-M-4

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Demolition Waste Causes - Demolition Waste Impacts - Demolition Waste Solutions	0,111	0,113	0,063	1,769	0
Demolition Waste Causes - Demolition Waste Challenges - Demolition Waste Solutions	0,502	0,504	0,049	10,293	0

4.7 Summary of Hypotheses Acceptance and Rejection

The research conducted on demolition waste management in road projects has identified several key relationships between causes, impacts, challenges and solutions. Through testing these hypotheses, the study aimed to better understand the dynamics of waste generation, its effects and how to effectively address the challenges and devise practical solutions. Below are the accepted and rejected hypotheses, along with their impact on the overall research.

TABLE 4.41: Summary of Hypotheses Acceptance and Rejection

Hypothesis	**P-Value**	**Result**
Demolition Waste Causes → Demolition Waste Challenges (M1)	0.234	Rejected
Demolition Waste Causes → Demolition Waste Impacts (M1)	0	Accepted
Demolition Waste Impacts → Demolition Waste Challenges (M1)	0	Accepted
Demolition Waste Causes → Demolition Waste Solutions (M1)	0	Accepted
Demolition Waste Causes → Demolition Waste Challenges (M2)	0	Accepted
Demolition Waste Causes → Demolition Waste Solutions (M2)	0	Accepted
Demolition Waste Challenges → Demolition Waste Solutions (M2)	0	Accepted
Demolition Waste Causes → Demolition Waste Solutions (M3)	0.371	Rejected
Demolition Waste Impacts → Demolition Waste Solutions (M3)	0	Accepted
Demolition Waste Causes → Demolition Waste Challenges (M4)	0	Accepted
Demolition Waste Causes → Demolition Waste Impacts (M4)	0	Accepted
Demolition Waste Causes → Demolition Waste Solutions (M4)	0.068	Rejected
Demolition Waste Challenges → Demolition Waste Solutions (M4)	0	Accepted
Demolition Waste Impacts → Demolition Waste Solutions (M4)	0	Accepted

4.7.1 Accepted Hypotheses

a. Demolition Waste Causes → Demolition Waste Impacts (M1)

This hypothesis is accepted with a p-value of 0, indicating that the causes of demolition waste have a direct impact on the environmental, social and economic consequences of waste generation. This finding aligns with the understanding that waste generation during construction or demolition activities leads to significant negative impacts, including resource depletion, pollution and other environmental harms.

b. Demolition Waste Impacts → Demolition Waste Challenges (M1)

The accepted hypothesis (p-value = 0) reveals that the negative impacts of demolition waste, such as environmental degradation, fuel the challenges faced in managing the waste. These impacts contribute to the complexity of waste management in road projects.

c. Demolition Waste Causes → Demolition Waste Challenges (M2), Demolition Waste Causes → Demolition Waste Solutions (M2)

Both hypotheses are accepted, with p-values of 0, suggesting a strong connection between the causes of demolition waste and the challenges or solutions for managing it in Model 2. This supports the idea that addressing the causes of waste generation early on can help mitigate the challenges and lead to better management strategies.

d. Demolition Waste Causes → Demolition Waste Solutions (M4), Demolition Waste Impacts → Demolition Waste Solutions (M4)

These hypotheses are accepted (p-value = 0), emphasizing that the identification of waste causes and understanding their impacts are critical to formulating effective solutions. By addressing the root causes and impacts, it is possible to develop targeted solutions that improve waste management practices.

4.7.2 Rejected Hypotheses

a. Demolition Waste Causes → Demolition Waste Challenges (M1)

This hypothesis is rejected (p-value = 0.234). This suggests that, in Model 1, the causes of demolition waste do not have a direct relationship with the challenges faced in waste management. It is likely that other factors, such as the complexity of project planning, policy constraints, or logistical issues, are more significant in influencing challenges than the initial causes of waste generation.

b. Demolition Waste Causes → Demolition Waste Solutions (M3&4)

With a p-value of 0.371 & 0.068, these hypothesis were rejected. This indicates that in Models 3&4, the causes of demolition waste do not strongly influence the proposed solutions. This could be because solutions are more directly influenced by the severity of the impacts and challenges faced rather than the causes alone. A broader perspective may be necessary to develop more comprehensive solutions.

4.7.3 Impact on Research

The findings underline the interconnected nature of the factors affecting demolition waste management, specifically how causes lead to impacts, which in turn contribute to challenges and drive the need for effective solutions. The research highlights the importance of addressing waste generation at early stages of road projects to minimize its negative consequences. Additionally, it shows that solutions are not solely derived from the causes of waste but also require an understanding of the broader impacts and challenges faced in the management process.

The study also suggests that more comprehensive and context-sensitive strategies, involving all stakeholders (government, designers, contractors, etc.), are required to achieve optimal outcomes in waste management. Future research may further explore these interdependencies and identify more precise variables to improve management strategies for road construction and demolition waste.

4.8 Interpretation of the Results Obtained from Model 1, 2, 3 and 4

The models presented in this section are designed to offer a structured framework for understanding the complex dynamics of demolition waste management, focusing on the causes, impacts, challenges and potential solutions. These models aim to provide a systematic analysis of how various factors interact and influence one another, ultimately leading to a better understanding of how to effectively manage demolition waste in road construction projects. Each model builds upon the previous one, refining the relationships between key components and offering deeper insights into the processes that drive waste generation, its environmental and social impacts and the effectiveness of waste management solutions.

The progression of the models from Model 1 to Model 4 reflects a continuous improvement in analytical complexity. In Model 1, a foundational framework is introduced to capture the basic relationships between causes, impacts, challenges and solutions. Model 2 enhances this framework by incorporating stronger mediation effects, particularly through the role of challenges in shaping waste management solutions. Model 3 takes this further by deepening the mediation analysis, with a stronger focus on the minimal direct effects of causes on solutions, emphasizing the central role of impacts. Finally, Model 4 represents the most advanced level of analysis, integrating both impacts and challenges into a comprehensive mediation framework that guides the development of targeted waste management strategies.

Together, these models form a robust foundation for interpreting the critical factors influencing demolition waste management in road construction and provide valuable insights that inform both theoretical understanding and practical applications in the field. The following sections present the detailed overview and insights derived from each of the models, starting with Model 1.

Model 1 provides a foundational understanding of the relationships between demolition waste causes, impacts, challenges and solutions. It confirms that demolition waste impacts play a significant mediating role between causes and solutions. The

model showed strong validity and reliability, but the "Demolition Waste Solutions" construct had a slightly lower reliability (Cronbach's alpha = 0.64), indicating some inconsistency.
Demolition Waste Impacts act as a crucial mediator between causes and solutions, suggesting that effective waste management must address these impacts before focusing on solutions.

Building on Model 1, Model 2 introduces stronger mediation effects, particularly through the relationship between Demolition Waste Causes, Challenges and Solutions. The model reinforces the importance of challenges in shaping waste management solutions. Reliability remains acceptable, but Demolition Waste Solutions still exhibits lower consistency.
Demolition Waste Challenges play a pivotal role in shaping solutions, emphasizing that both impacts and challenges must be understood for effective waste management.

Model 3 refines the mediation effects and deepens the analysis of relationships between causes, impacts and solutions. It confirms that Demolition Waste Impacts are a strong mediator, with minimal direct effect between causes and solutions. The model supports the view that focusing on the consequences of demolition waste is critical for developing effective solutions.
The minimal direct effect from causes to solutions reinforces the idea that solutions are more influenced by impacts than causes themselves, emphasizing the need to address the broader environmental and social consequences of demolition.

Model 4 represents the most advanced analysis, providing a more detailed understanding of the relationships. It reinforces the importance of Demolition Waste Impacts and Challenges in shaping waste management strategies. The mediation analysis shows that both impacts and challenges significantly influence the development of solutions.
The model strengthens the view that Demolition Waste Impacts, along with the associated challenges, are central to shaping waste management solutions. It emphasizes the importance of considering both factors when developing strategies.

4.9 Comparison with other Studies

This section presents a detailed comparative analysis between the previous studies as discussed in Section 2.10. A comparison is drawn between the framework developed in this study for demolition waste management in road projects and frameworks proposed in previous studies from various countries, including Malaysia, the UK, Egypt and China. While international studies provide valuable insights into aspects of waste management, such as sustainability, circular economy, Building Information Modeling (BIM) and waste disposal, their frameworks tend to be focused on specific components of the issue or apply to a broader construction context. In contrast, this study offers a comprehensive and context-specific framework, addressing the causes, impacts, challenges and solutions for demolition waste in road projects. The methodology used in this research allows for a deeper exploration of waste in road projects, making the framework more applicable to the unique challenges faced by developing countries like Pakistan.

TABLE 4.42: Comparison with other Studies

Aspect	**This Study**	**Findings from Other Studies**
Causes of Waste	Identified causes specific to road projects, including poor planning, design inefficiencies, lack of skilled labor and weak enforcement of regulations.	General causes include inefficient construction practices, poor waste categorization and lack of awareness (e.g., Malaysia, Egypt, etc.[118]).
Impacts of Waste	Comprehensive evaluation of environmental, economic and social impacts, including emissions, landfill pressure and public health issues.	Other studies highlight general environmental impacts but lack detailed LCA evaluations (e.g., Beijing focuses on CDW flows[26]).

Challenges in Waste Management	Explored administrative, technical and policy challenges, such as limited recycling facilities, weak regulatory frameworks and funding gaps.	Challenges regarding waste in global studies often revolve around behavioral barriers (UK), regulatory issues (Egypt), or technology adoption (BIM-based frameworks[79]).
Proposed Solutions	Provides comprehensive solutions, including administrative reforms, technical advancements (recycling and reuse) and policy recommendations specific to road projects.	Solutions focus on circular economy principles (Beijing), BIM-based tools (BIM framework) and categorization of waste (Malaysia)[126].
Framework Validation	Framework tested using Focus Group Discussions (FGD), pilot studies and PLS-SEM, ensuring practical applicability in road projects.	Other frameworks, such as Malaysia's and BIM-based frameworks, validate findings using EAHP or PLS-SEM but lack integration of multiple dimensions[152].
Technological Integration	Explored advanced PLS-SEM and field observations to ensure data-driven framework development. No heavy reliance on other technologies like BIM.	Studies like the BIM-based framework focus heavily on integrating specific tools but lack holistic technological approaches for road projects[153].
Sustainability Focus	Strong emphasis on waste reduction, recycling and addressing life-cycle impacts to promote sustainable waste management.	Circular economy studies (e.g., Beijing) emphasize sustainability but primarily from a waste flow perspective[154].

Geographic Focus	Designed specifically for Pakistan and similar developing countries, addressing unique challenges like weak governance, infrastructure gaps and low awareness.	Focused on global contexts or specific countries, such as Malaysia, Egypt and the UK, with limited relevance to developing countries[151].
Key Findings	Highlights the need for tailored administrative and technical solutions for road projects, considering local challenges and real-world data from Pakistan.	General findings revolve around broader frameworks, waste categorization, or isolated management practices (e.g., waste behavior, disposal analysis)[155].

This comparison highlights that while previous studies offer significant contributions to the field of demolition waste management, they often lack the holistic approach that is critical for addressing the multifaceted challenges of road construction in developing countries. By providing a comprehensive framework that integrates various aspects of waste management and utilizes advanced methodologies, this study makes a valuable contribution to the existing body of knowledge. It not only improves the understanding of waste management in road projects but also offers practical, actionable solutions for practitioners, policymakers and researchers, promoting sustainable practices in the road construction sector in developing contexts.

4.10 Validation of Modified Framework

The validation of the proposed framework was carried out using Partial Least Squares Structural Equation Modeling (PLS-SEM) to assess the robustness and predictive capability of the conceptual model tailored for demolition waste management. This model shown in below figure 4.6, incorporated four key constructs:

Demolition Waste Causes, Demolition Waste Impacts, Demolition Waste Challenges and Demolition Waste Solutions. Data were collected from stakeholders engaged in road construction and demolition projects across Pakistan. SmartPLS software was utilized to run the algorithm and perform bootstrapping, facilitating the evaluation of the measurement and structural model in terms of reliability, validity and hypothesized causal relationships.

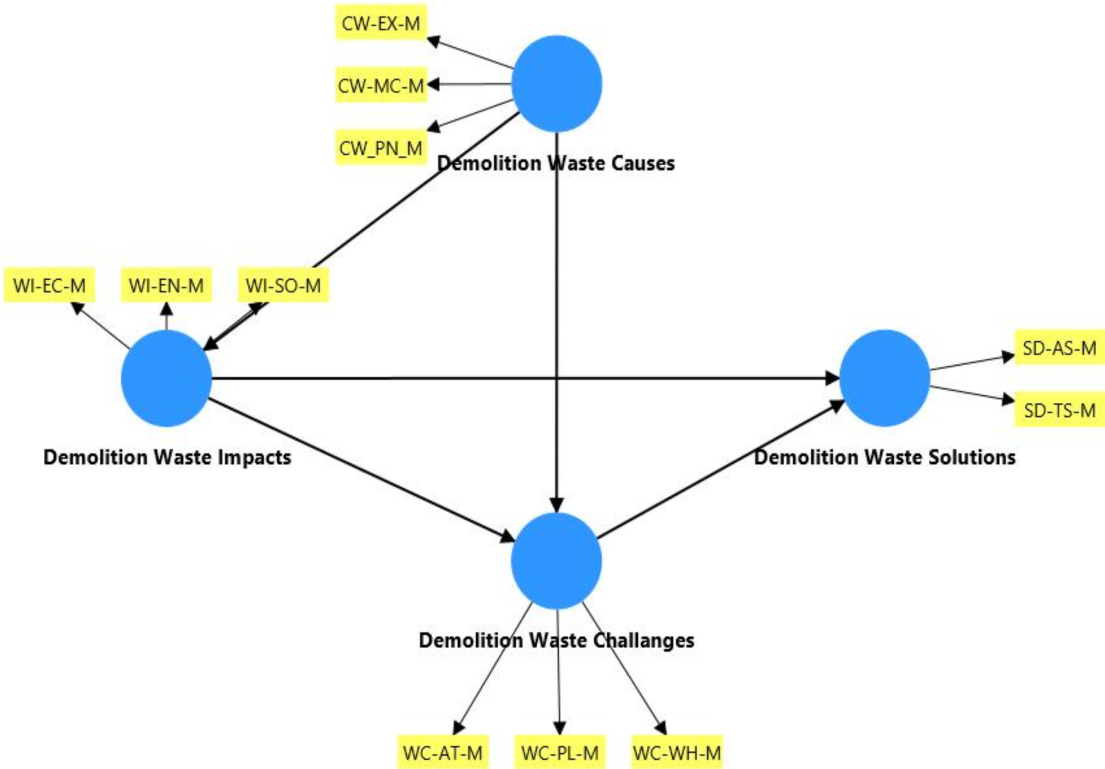

Figure 4.6: Modified Model

4.10.1 Path Coefficients and Hypothesis Testing

The structural model analysis demonstrated several critical relationships among the constructs. The path coefficient from Demolition Waste Causes to Demolition Waste Impacts was 0.811, representing a strong and statistically significant direct effect. Similarly, the relationship from Demolition Waste Impacts to Demolition Waste Challenges related to road projects showed an even stronger positive relationship with a coefficient of 1.057, indicating that increasing impacts significantly escalate the challenges. Furthermore, the link between Demolition Waste Challenges and Demolition Waste Solutions was observed with a coefficient of 0.623, suggesting that understanding the challenges leads to more effective solutions. Although the path from Demolition Waste Causes to Demolition Waste Challenges had a lower coefficient of 0.148, it remained statistically significant with a T-value of 2.279 and a p-value of 0.023, validating its presence in the model. These findings substantiate the hypothesized causal relationships and emphasize the mediating role of Impacts within the framework.

4.10.2 Outer Loadings

Outer loadings confirm the strength of the indicators for each construct. For Demolition Waste Causes, the loadings were CW-EX-M (0.831), CW-MC-M (0.878) and CW-PN-M (0.682). For Demolition Waste Challenges, loadings included SD-AS-M (0.912), SD-TS-M (0.909), WC-AT-M (0.967), WC-PL-M (0.878) and WC-WH-M (0.923). Demolition Waste Impacts had loadings from WI-EC-M (0.945), WI-EN-M (0.975) and WI-SO-M (0.784). These values demonstrate strong indicator reliability across constructs.

4.10.3 Predictive Power (R^2 and f^2)

The model's predictive power was validated through R^2 and f^2 statistics. For Demolition Waste Challenges related to road projects, the R^2 value was 0.886, meaning that 88.6% of the variance was explained. Demolition Waste Impacts regarding road projects had an R^2 of 0.658, while Demolition Waste Solutions showed an R^2 of 0.814, reflecting a high degree of explained variance across all constructs. Regarding effect sizes, the path from Causes to Impacts recorded a large f^2 value of 3.358, while Impacts to Challenges also demonstrated a large effect size of 1.925. These findings indicate that the model exhibits strong predictive power and explanatory capacity.

4.10.4 Reliability and Convergent Validity

The measurement model displayed high internal consistency and convergent validity. All constructs recorded Cronbach's Alpha (a) and Composite Reliability (CR) values above the threshold of 0.7. Specifically, Causes had = 0.715 and CR = 0.842; Challenges had = 0.913 and CR = 0.945; Impacts had = 0.889 and CR = 0.931; and Solutions had = 0.793 and CR = 0.906. Moreover, the Average Variance Extracted (AVE) for all constructs exceeded the 0.6 benchmark, confirming convergent validity. AVEs were as follows: Causes = 0.642, Challenges = 0.852, Impacts = 0.819 and Solutions = 0.829.

4.10.5 Discriminant Validity and Cross-Loading Analysis

Discriminant validity was assessed using the Fornell-Larcker criterion and HTMT ratio. According to the Fornell-Larcker results, all constructs met the criterion where the square root of AVEs exceeded the inter-construct correlations. The square root of AVEs were Causes (0.801), Challenges (0.923), Impacts (0.905) and Solutions (0.910). Corresponding inter-construct correlations were lower, for instance, Causes to Challenges (0.710), Causes to Impacts (0.811), Challenges to Impacts (0.937) and Challenges to Solutions (0.897), confirming discriminant validity. However, HTMT ratios revealed a potential issue between Causes and Impacts with a value of 0.994, slightly exceeding the 0.90 threshold. Other high HTMT values included Causes and Solutions (0.995), Challenges and Impacts (0.992), Challenges and Solutions (0.996) and Impacts and Solutions (0.991). These elevated values suggest some overlap and while not disqualifying, they indicate a need for careful interpretation. The cross-loading analysis showed that indicators loaded highest on their respective constructs. For example, CW-EX-M loaded 0.831 on Causes, SD-AS-M loaded 0.912 on Challenges, WI-EN-M loaded 0.975 on Impacts and indicators such as SD-TS-M and WI-EC-M showed strong loadings on their intended constructs as well. Despite some moderate cross-loadings, these patterns support indicator reliability.

4.10.6 P-Value and Hypothesis Significance Testing

All proposed relationships within the structural model were tested for statistical significance. The path from Demolition Waste Causes to Demolition Waste Challenges had a T-statistic of 2.279 and a p-value of 0.023, confirming its significance. The path from Causes to Impacts was highly significant (T = 38.459, p = 0.000), as was the path from Challenges to Solutions (T = 6.527, p = 0.000). Moreover, Impacts to Challenges (T = 21.181, p = 0.000) and Impacts to Solutions (T = 3.012, p = 0.003) were also statistically significant. These results provide robust empirical support for the model's hypothesized relationships.

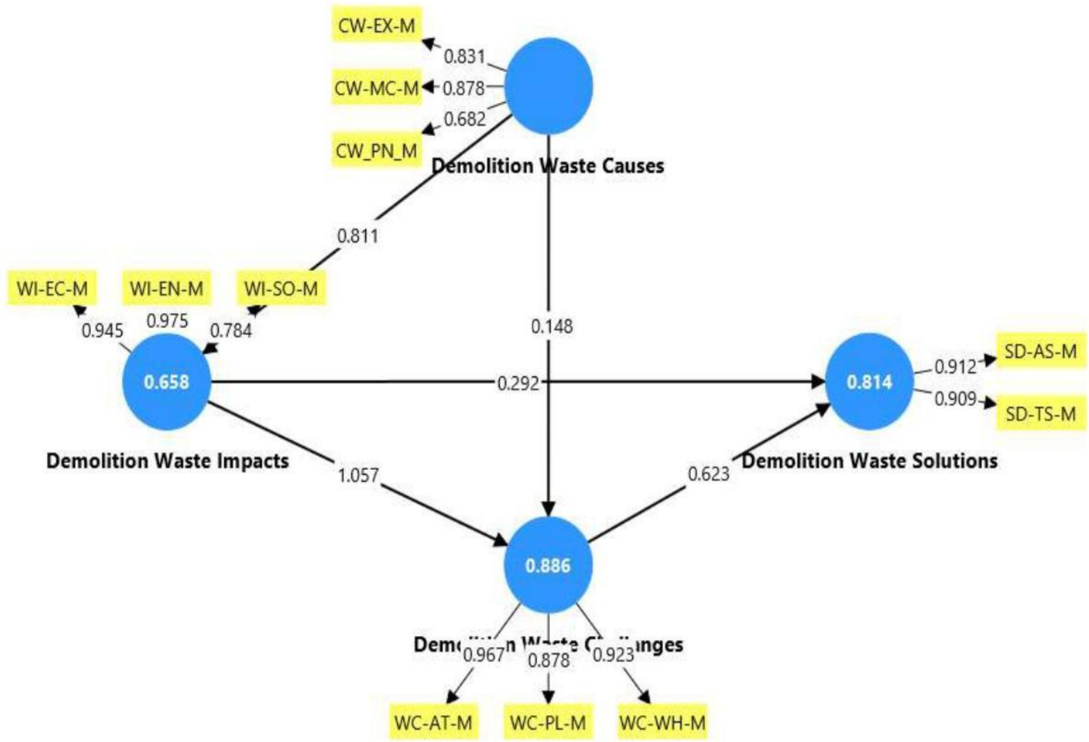

Figure 4.7: Modified Model Based upon PLS-SEM

4.11 Comparison with Modified Framework

When compared across all four models and the modified framework, the validated model shows strong alignment with the hypothesized pathways and underlying theoretical framework. The conceptual model proposed that the causes of demolition waste influence both its impacts and associated challenges, which subsequently shape potential solutions. Empirical validation confirmed all these relationships and, importantly, underscored the mediating role of Impacts—identified as the most influential construct—affecting both Challenges and Solutions. The validation results confirmed the theoretical and empirical strength of the model. All evaluation standards in PLS-SEM—such as Cronbach's Alpha, Composite Reliability, AVE, Fornell-Larcker, HTMT, R^2, path coefficients (β), effect sizes (f^2) and statistical significance (p-values)—were met, reinforcing the soundness of the framework.

In conclusion, the validation results confirm that the modified framework is both statistically robust and theoretically coherent. The model demonstrates high reliability, as well as strong convergent and discriminant validity, with significant path relationships supported by substantial effect sizes and strong predictive power. This empirical foundation lends credibility to the framework and supports its application in future policy development and management strategies—particularly in addressing demolition waste management within road construction projects in developing countries.

4.11.1 Answers the Research Questions

This section provides answers to the research questions, derived from the insights obtained through data analysis. Each answer reflects the findings that emerged from the models and hypotheses tested in the study, which focuses on understanding demolition waste generation and management in road construction projects in Pakistan.

Q.1: What are the causes road waste generation in Pakistan at different stages of the life cycle?

Answer:

On the basis of this study and as illustrated in Figure 4.8, the causes of demolition waste generation have been ranked based on focus group discussions, pilot study, PLS-SEM analysis and validation of the final model. The results are supported by responses from 163 participants through a structured questionnaire. The identified causes vary in their level of significance across different stages of the road project life cycle.

The most critical factor is the "coordination and communication gap among stakeholders (CW-PN-7)". Inadequate coordination between contractors, consultants, regulatory authorities and suppliers often leads to miscommunication, project delays and execution errors, which ultimately result in significant demolition waste.

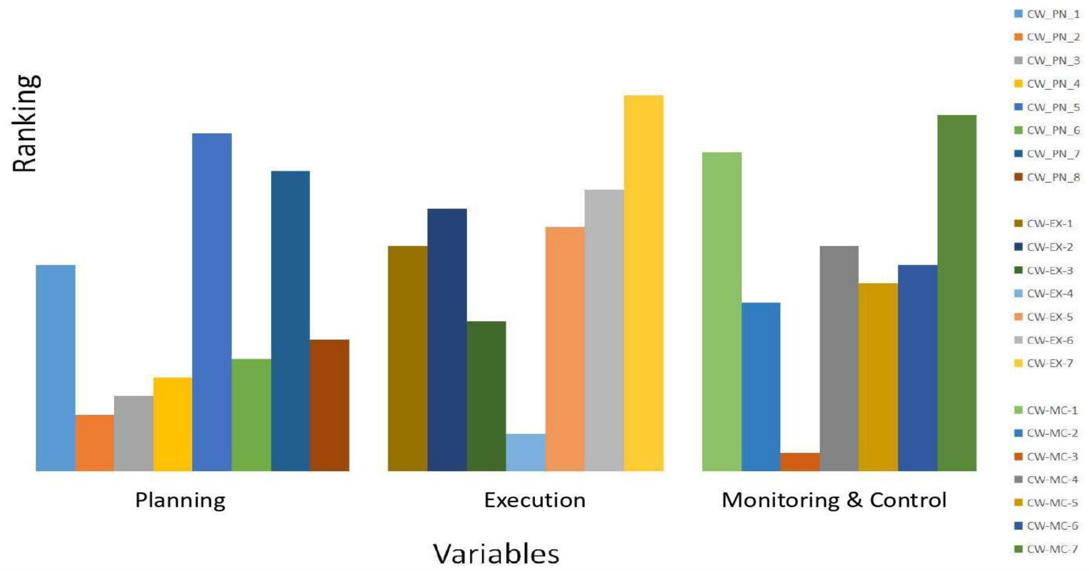

Figure 4.8: Causes of demolition waste Generation

"Scope and design changes (CW-PN-5)" emerged as the second most influential contributor. Frequent modifications during the planning or execution phases—whether due to evolving project requirements or unforeseen site conditions—often necessitate the demolition of completed work, thereby generating avoidable waste.

Another prominent cause is the "inadequate identification and quantification of demolition waste(CW-MC-7)". The absence of proper assessment and forecasting during early planning hinders the application of effective waste management strategies, such as reuse and recycling, resulting in increased waste accumulation.

Among the 20 causes analyzed, the "utilization of substandard materials (CW-MC-3)" was found to have the least impact. Nevertheless, it still contributes to demolition waste, as the use of low-quality construction materials can lead to early failures and defects, requiring demolition and rework and consequently adding to the overall waste volume.

Q2: What are the impacts of demolition waste of road projects in Pakistan?
Answer:
On the basis of this study, and as illustrated in Figure 4.9, the impacts of demolition waste management have been ranked. The most critical impact identified is "resource consumption (WI-EN-5)". Demolition waste management requires significant use of natural and manufactured resources, including energy, water and raw materials, thereby placing a burden on environmental sustainability and project economics.

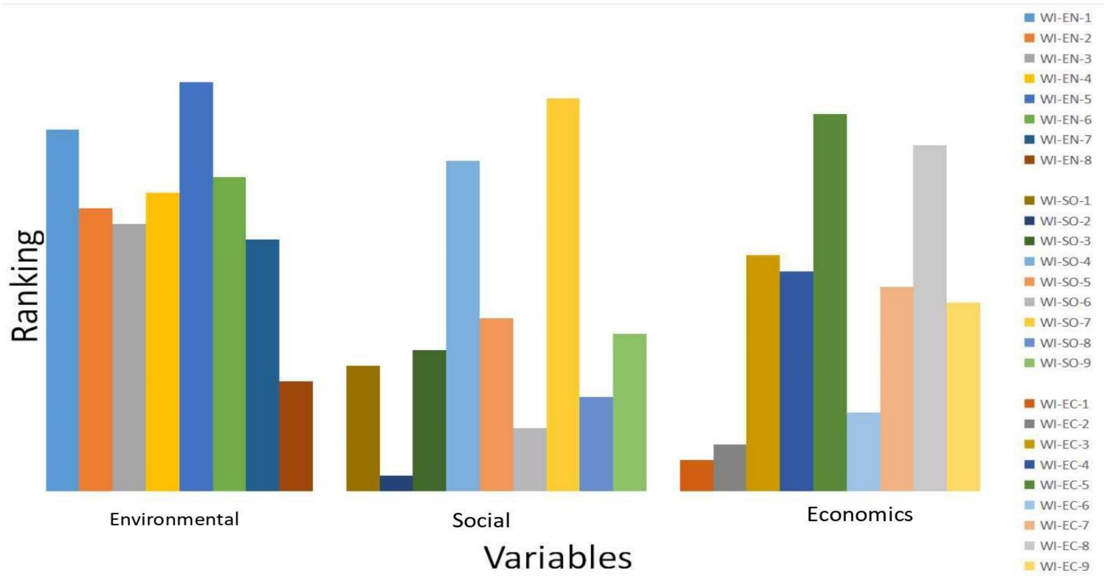

FIGURE 4.9: Impacts of demolition waste Management

"Health and safety impacts (WI-SO-7)" emerged as the second most influential contributor. Exposure to dust, debris, hazardous materials and unsafe demolition practices can pose serious risks to workers and surrounding communities, making this a key concern in waste management. Another prominent impact is the "cost associated with the disposal of waste (WI-EC-7)". The financial burden of transporting, handling and disposing of demolition waste—particularly in the absence of efficient recycling systems—can significantly affect project budgets.

Among the 26 impacts analyzed, "additional human resource consumption(WI-SO-2)" was found to have the least impact. Nevertheless, it still contributes to the overall burden of demolition waste management. Inadequate planning or poor-quality materials may necessitate rework, leading to increased labor demands and reduced project efficiency.

Q3: What are the main challenges in managing road demolition waste in the study area?
Answer:
On the basis of this study, and as illustrated in Figure 4.10, the challenges of demolition waste management have been ranked. The most critical challenge identified is the "engagement of all types of social media to promote demolition waste management(WC-PL-2)". The lack of awareness campaigns and limited use of digital platforms hinder public understanding and stakeholder participation, thereby reducing the effectiveness of sustainable waste practices.

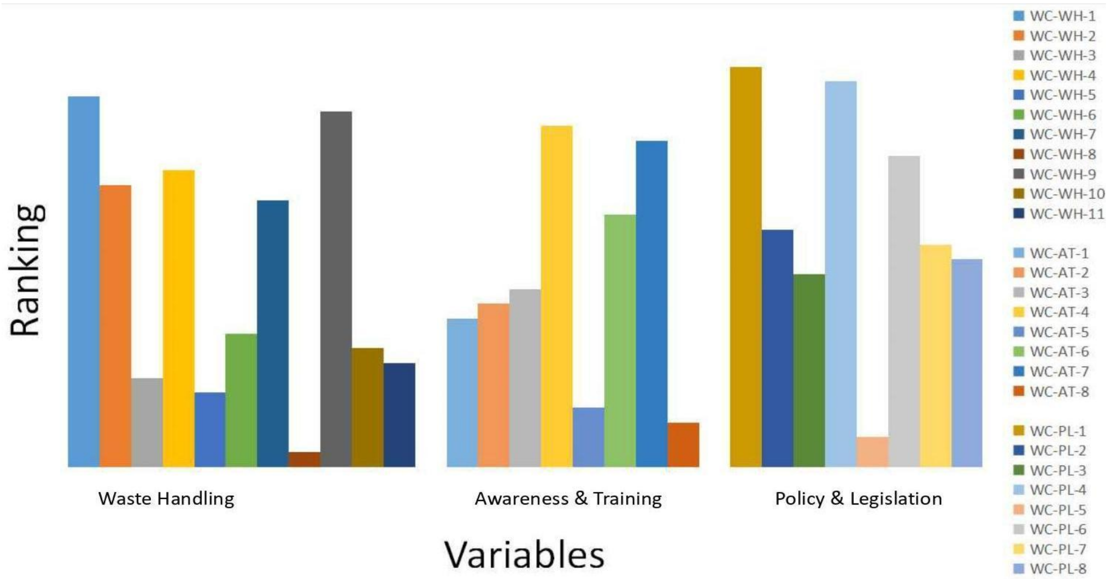

FIGURE 4.10: Challenges of demolition waste Management

The "level of enforcement of waste management plans (WC-PL-4)" emerged as the second most influential challenge. Weak regulatory enforcement and inconsistent monitoring mechanisms allow non-compliance to go unchecked, ultimately contributing to poor implementation of demolition waste strategies.

Another prominent challenge is the "illegal dumping of demolition waste(WC-WH-1)". Inadequate supervision and limited designated disposal sites often lead to unauthorized waste dumping, posing serious environmental and public health risks.

Among the 27 challenges analyzed, "industry support for the effective utilization of demolition waste(WC-WH-8)" was found to have the least impact. Nevertheless, its role remains relevant, as insufficient industry engagement can limit the adoption of innovative reuse and recycling technologies. This indirectly contributes to increased waste generation through rework and inefficient material usage.

Q4: What solutions and management strategies can be proposed at the local/national level for better waste management in road projects?
Answer:
On the basis of this study, and as illustrated in Figure 4.11, the solutions for demolition waste management have been ranked. The most critical solution identified is "continuous and effective supervision at the site level(SD-TS-8)". Active monitoring ensures proper implementation of demolition waste management practices, minimizes on-site errors and enhances compliance with environmental and safety standards.

The "3R strategy—Reduce, Reuse, Recycle (SD-TS-6)"— emerged as the second most influential contributor. This integrated approach promotes sustainable material use by minimizing waste generation, encouraging the reuse of existing resources and enhancing recycling practices within the construction sector.

Another notable solution is the "continuous improvement in environmental management through the 3R framework(SD-AS-8)". This involves regularly updating practices, policies and technologies to align with sustainability goals, thereby enhancing overall waste management performance.

Among the 20 solutions analyzed, "poor implementation of demolition waste management (DWM) laws and regulations(SD-AS-11)" was found to have the least impact. Nonetheless, weak enforcement continues to contribute to demolition waste by allowing the use of substandard materials and practices that result in early failures, rework and additional waste generation.

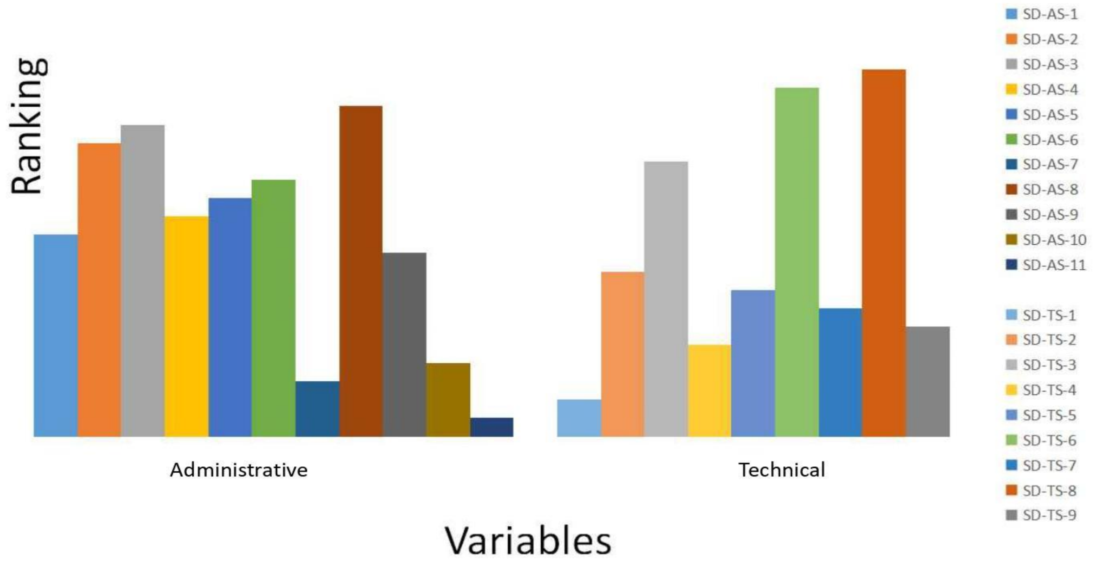

Figure 4.11: Solutions of demolition waste Management

Q5: Is there any connection between the causes of waste, its impact, the challenges and solutions?

Answer:

This study confirms that demolition waste dynamics are interconnected through a complex cause-impact-challenge-solution chain. Using rigorous statistical modeling (PLS-SEM), the research shows that understanding one component in isolation is insufficient—interventions must be systems-based.

Key connections include:

Causes → Impacts:

Strong path coefficients ($\beta = 0.843$) show that the more frequent or severe the causes, the greater the environmental and social impacts.

Impacts → Challenges:

The study found the strongest empirical link here ($\beta = 0.972$), suggesting that impacts significantly exacerbate management challenges.

Challenges → Solutions:

Statistically robust links (β= 0.760) highlight that addressing challenges such as policy gaps and resource limitations is key to solution development.

Causes → Solutions:

This pathway was statistically insignificant, indicating that knowing the causes alone does not automatically lead to effective solutions.

Integrated Viewpoint:

The validated framework supports a holistic and evidence-based Environmental Management Framework, ensuring sustainable and practical interventions.

4.11.2 Response to the Research Aims and Objectives

The overarching aim of this research was to develop a comprehensive Environmental Management Framework (EMF) specifically tailored for demolition waste (DW) generated during road projects in Pakistan. The study responds to a critical policy and operational gap by addressing how demolition waste contributes to environmental degradation and how its effective management can promote sustainability. Through empirical modeling, stakeholder engagement and literature triangulation, this aim was fully realized in the form of a robust, multi-dimensional EMF.

Objective 1: Investigate the Causes of Demolition Waste Generation at Various Stages of Road Projects.

This objective was comprehensively achieved through a structured and multi-phase research approach. Initially, 20 potential causes of demolition waste were identified through a detailed literature review. These causes were further validated and refined through focus group discussions with industry experts and a pilot study. A structured questionnaire was then administered to 163 professionals engaged in road construction projects across Pakistan. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), four models were developed and tested to assess the strength and significance of relationships between causes and other key variables. The final modified model was statistically validated, confirming the relevance and impact of each cause. The analysis revealed that coordination and communication gaps among stakeholders were the most critical causes of demolition waste, followed by frequent scope and design changes, and inadequate forecasting of waste. Even lower-impact causes such as the use of substandard materials were found to contribute to waste generation. Therefore, the objective of investigating causes was successfully fulfilled through empirical analysis and model validation.

Objective 2: Assess the Environmental, Social and Economic Impacts of Demolition Waste.

This objective was met by identifying 26 impact factors through the literature and validating them via expert consultations and pilot testing. These factors were included in the main survey and statistically assessed using PLS-SEM modeling. The final validated model provided a reliable ranking of these impacts in terms of their significance. The most critical environmental impact was found to be the excessive consumption of natural and manufactured resources such as energy, water, and raw materials. Socially, the exposure to hazardous materials and unsafe demolition practices posed serious health and safety concerns for both workers and communities. Economically, the cost of transporting, handling, and disposing of demolition waste, especially in the absence of efficient recycling systems, imposed a heavy financial burden on project budgets. Even the lowest-ranked impact, increased human resource consumption due to rework, contributed to overall inefficiency. Thus, the environmental, social, and economic dimensions of demolition waste impacts were thoroughly analyzed, fulfilling this objective.

Objective 3: Analyze the Challenges Associated with Demolition Waste Management for Road Projects

This objective was addressed by identifying 27 key challenges from the literature review, which were then evaluated and refined through stakeholder focus groups and a pilot study. The validated questionnaire used in the main survey enabled detailed feedback from industry professionals.

Using the same PLS-SEM approach, the challenges were statistically tested and incorporated into four successive model iterations. The final validated model identified the lack of awareness campaigns and inadequate use of social media as the most significant challenge. This was followed by weak enforcement of waste management plans and illegal dumping, all of which present serious threats to sustainable waste practices.

While limited industry support for reuse and recycling technologies had the least direct impact, it was still acknowledged as a contributing factor to inefficient waste handling.

In conclusion, this objective has been comprehensively addressed by identifying, evaluating, and ranking the major barriers to effective demolition waste management.

Objective 4: Explore Solutions for Demolition Waste Management for Road Projects.

This objective was fulfilled by identifying 20 potential solutions from the literature and refining them through stakeholder input and survey responses. These solutions were assessed within the PLS-SEM framework and ranked according to their effectiveness in addressing the identified challenges. The analysis revealed that the most impactful solution was continuous and effective on-site supervision, which ensures adherence to demolition waste management practices and minimizes errors. The adoption of the 3R strategy—Reduce, Reuse, and Recycle—emerged as the second most effective solution, promoting sustainable use of materials and minimizing waste. Regular improvement in environmental management practices, driven by updates in policy and technology, was also found to be a significant contributor. Although the poor implementation of existing laws was statistically the least impactful, it remains a concern as it allows non-compliance and encourages the use of substandard materials. Overall, the objective of identifying and evaluating practical solutions was thoroughly achieved.

Objective 5: Develop an Environmental Management Framework (EMF) for Road Projects, Providing Actionable Recommendations for Policymakers and Stakeholders.

The Environmental Management Framework (EMF) was developed by synthesizing the findings from the validated PLS-SEM model, which established clear relationships among causes, impacts, challenges, and solutions. The study confirmed a strong connection between causes and impacts ($\beta = 0.843$), impacts and challenges ($\beta = 0.972$), and challenges and solutions ($\beta = 0.760$). Interestingly, the link between causes and solutions was statistically insignificant, highlighting the need for a systems-based approach rather than isolated interventions. The EMF integrates these findings into a coherent strategy that promotes sustainable demolition waste management in road projects. It recommends stronger supervision practices, the application of the 3R strategy, improved regulatory enforcement, and greater public and stakeholder engagement. These recommendations provide actionable guidance for policymakers, contractors, consultants, and environmental regulators. Thus, the development of a holistic and evidence-based EMF completes the final objective of the research.

4.12 Final Environmental Management Framework

The Integrated Environmental Management Framework for Demolition Waste in Road Projects addresses critical issues related to waste generation, management and sustainability in Pakistan's infrastructure sector. This framework provides a comprehensive understanding of the causes of demolition waste, its environmental, social and economic impacts and proposes innovative solutions to enhance waste management practices in road projects. Based on this research, the proposed Environmental Management Framework (EMF), illustrated in Figure 4.8, serves as a cornerstone for addressing these challenges.

This research has provided valuable insights into the complexities and opportunities within sustainable demolition waste management in road projects. By utilizing a questionnaire survey-based methodology and Partial Least Squares Structural Equation Modeling (PLS-SEM), the study identified key interrelationships among the causes, impacts, challenges and solutions related to demolition waste. The findings emphasize the importance of addressing challenges in waste management to develop effective solutions. Specifically, the study highlights the need for proactive measures to reduce waste generation at its source, enhance regulatory frameworks and promote technological innovations in recycling and waste processing. These efforts are critical for minimizing environmental impacts, realizing economic benefits and fostering a sustainable construction industry.

The study identifies multiple causes of demolition waste across various stages, including planning, design, execution, monitoring and maintenance. Key factors contributing to waste generation include poor planning, design inefficiencies, the use of substandard materials, lack of skilled labor and limited awareness of effective waste management practices. These issues collectively exacerbate inefficiencies throughout the life cycle of road projects.The impacts of demolition waste are extensive. Environmentally, it contributes to resource depletion, pollution and increased greenhouse gas emissions. Socially, it poses health hazards to workers and nearby communities, alongside public inconvenience due to improper disposal practices. Economically, the financial burden is magnified by inefficient recycling systems and material wastage.

The study also identifies significant challenges to effective demolition waste management. These challenges include inadequate waste handling, insufficient training and awareness and gaps in policy and legislation. Specific technical barriers include ineffective waste sorting and recycling technologies. Administrative challenges involve weak regulatory frameworks and lack of enforcement mechanisms, while logistical obstacles stem from limited waste collection and transportation infrastructure. Financial constraints, such as inadequate funding and incentives for sustainable practices, further complicate the issue. These challenges highlight the need for holistic and targeted interventions.

To overcome these challenges, the study proposes innovative solutions, such as advanced recycling technologies, on-site waste segregation systems and the development of sustainable materials like recycled aggregates and eco-friendly concrete. Policy recommendations include enforcing mandatory recycling and promoting sustainable practices in road projects. Capacity-building initiatives are also suggested to educate and train stakeholders on effective waste management strategies.

The proposed Environmental Management Framework (EMF) offers a strategic approach to managing demolition waste throughout the project life cycle. It integrates environmental, economic and social considerations to guide road projects toward sustainability. A significant finding of this study is the strong correlation between waste sources, impacts, challenges and solutions. Addressing these components holistically enhances efficiency and sustainability. The framework emphasizes the integration of policies and findings serving as the basis for national guidelines. Pilot projects are recommended to test and refine proposed strategies, supported by public-private partnerships to ensure funding and implementation of sustainable practices.

In conclusion, the framework underscores the importance of a multidisciplinary approach to demolition waste management. By reducing waste generation, minimizing environmental impacts and fostering sustainability, it provides actionable insights for policymakers, engineers, stakeholders, contractors and subcontractors in Pakistan. Furthermore, this research lays the foundation for improving demolition waste management in Pakistan's road construction sector.

By adopting a holistic approach that addresses environmental, logistical and financial challenges, the study offers innovative solutions to promote sustainability. The EMF provides a crucial tool for achieving sustainable outcomes in road projects, contributing to a greener and more resource-efficient future for infrastructure development in Pakistan. Additionally, the framework serves as a model for other developing countries facing similar challenges in infrastructure development and waste management.

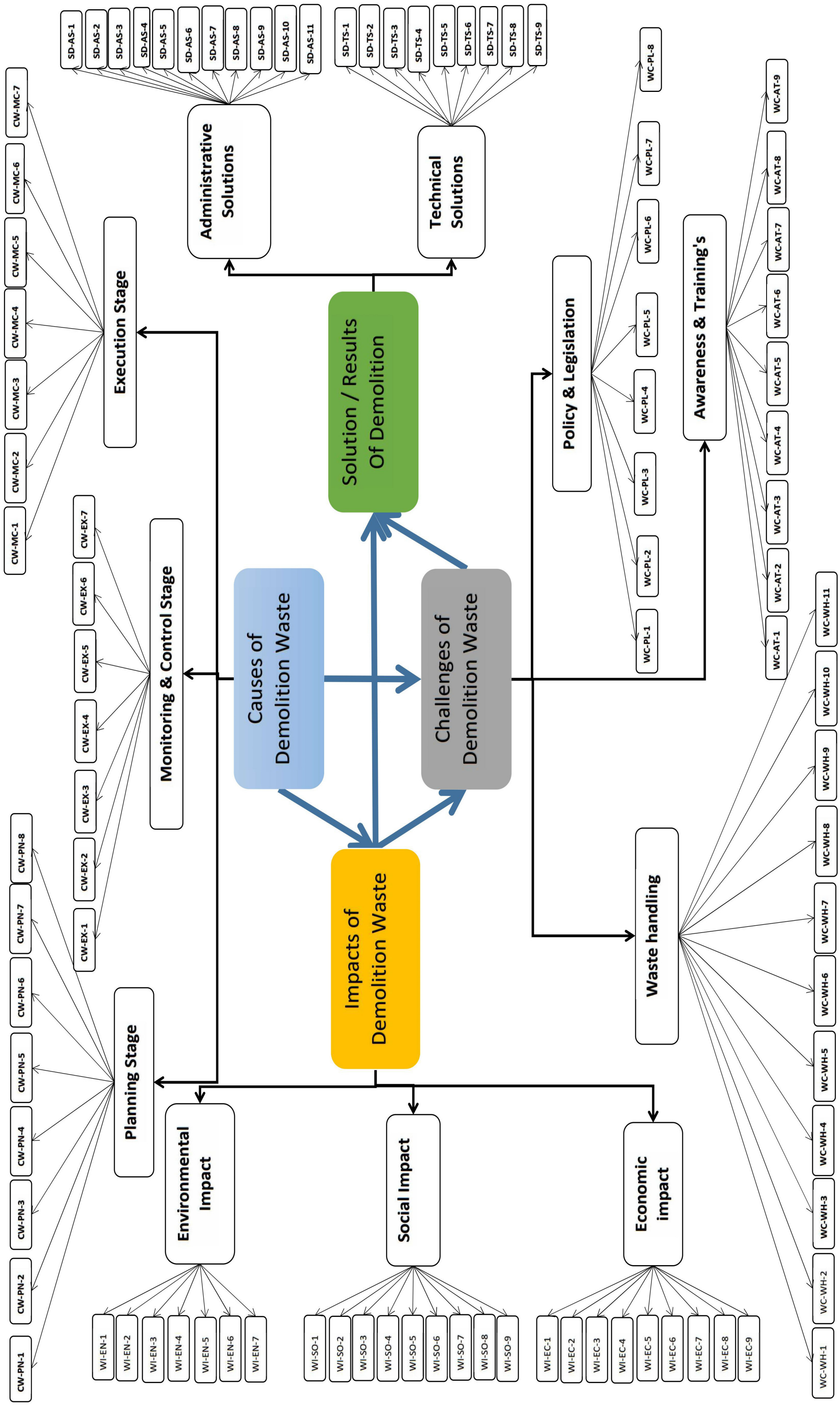

FIGURE 4.12: Environmental Management Framework (EMF)

4.13 Summary

Chapter 4 provides a comprehensive analysis of the data and results obtained from the application of Partial Least Squares Structural Equation Modeling (PLS-SEM). The chapter begins by offering a detailed demographic classification of the sample population, providing a solid foundation for understanding the characteristics of the respondents. This is crucial for ensuring that the data is relevant and applicable to the study's objectives.

The chapter then proceeds to present the results of four distinct models, each assessed using a variety of PLS-SEM criteria. These criteria include outer loadings, instrument reliability, cross loadings, the Fornell-Larcker criterion, the HTMT ratio, Variance Inflation Factor (VIF), effect size (f^2), coefficient of determination (R^2), path model evaluation and mediation effects. The results of each model are thoroughly analyzed to ensure the validity and reliability of the constructs and their interrelationships. This detailed evaluation allows for a comparative understanding of the performance and insights provided by each model.

The chapter concludes by summarizing the hypotheses that were accepted or rejected, highlighting the key findings from the analysis. It includes a comparison of the study's findings with previous frameworks, offering insights into how the results contribute to existing knowledge in the field. The chapter emphasizes the broader implications of the study, particularly its potential contributions to economic and environmental sustainability. By validating the models and linking the findings to real-world applications, the chapter underscores the study's ability to influence waste management strategies and promote sustainable practices in road construction projects.

Chapter 5

Conclusions & Recommendations

5.1 Conclusion

This Chapter marks the culmination of this research, consolidating the key insights and findings derived from the comprehensive analyses presented in the preceding chapters. It synthesizes these results to provide clear, evidence-based conclusions on sustainable demolition waste management within the context of road construction projects. Building on these conclusions, the chapter offers practical and actionable recommendations aimed at improving existing waste management practices, enhancing resource efficiency and supporting environmental sustainability. Recognizing the ongoing developments and emerging challenges in the field, this chapter also proposes potential directions for future research to foster continued innovation and advancement in demolition waste management strategies.

This study comprehensively examined how the causes, impacts, challenges and solutions of demolition waste (DW) management are interconnected within the context of road construction projects in Pakistan. Through a combination of in-depth literature review, focus group discussions,Pilot study and advanced empirical testing using Partial Least Squares Structural Equation Modeling (PLS-SEM), it was determined that there is currently no comprehensive framework available to manage demolition waste effectively in road projects. This critical gap in the existing management practices highlights the urgency and necessity of developing a comprehensive Environmental Management Framework (EMF) tailored to the needs of Pakistan's road construction sector.

To explore the interrelationships among demolition waste causes, impacts, challenges and solutions, four structural models were developed and empirically tested. Out of 19 research hypotheses proposed, 16 were found to be statistically significant. This high success rate reflects the robustness and reliability of the theoretical model and validates the proposed causal pathways. Each model underwent rigorous statistical validation, demonstrating strong internal consistency, construct validity (convergent and discriminant) and freedom from multicollinearity. The models' Composite Reliability (CR) values exceeded the threshold of 0.7 and Average Variance Extracted (AVE) values surpassed 0.5, indicating a high degree of measurement accuracy.

Importantly, the study revealed that understanding the causes of demolition waste alone is insufficient to drive effective solutions. The direct relationship between causes and solutions was found to be statistically insignificant in both Model 3 (β = 0.073, p = 0.371) and Model 4 (β = 0.109, p = 0.068). Instead, impacts emerged as a key mediating factor. The strong path coefficients from causes to impacts (β = 0.843 across models) and from impacts to solutions (Model 3: β = 0.775; Model 4: β = 0.740; both p = 0.000) confirm that the severity and recognition of DW impacts are pivotal in formulating sustainable solutions. Furthermore, the analysis highlighted that challenges—such as weak policies, limited enforcement, technical constraints and low stakeholder awareness—significantly influence the development and implementation of solutions. This was supported by strong statistical associations between challenges and solutions (Model 3: β = 0.691; Model 4: β = 0.760; both p = 0.000).

These findings stress the need to overcome systemic and institutional barriers to improve DW management outcomes. The explanatory power of the models further reinforces the reliability of the framework. High R^2 values were achieved across all constructs: Causes: 70.1% Impacts: 71.1% Challenges: 72.2% Solutions: 80.1%

These values indicate that the models are capable of capturing the complexity of DW management with high predictive accuracy. The path analysis revealed several novel insights: A strong positive relationship between causes and impacts ($\beta = 0.843$) confirms that increases in DW-generating activities intensify negative consequences.A statistically significant link between causes and challenges ($\beta = 0.727$) suggests that unmanaged causes contribute directly to the emergence of operational and policy hurdles. The impacts to challenges path ($\beta = 0.972$) was among the strongest, revealing that as DW impacts intensify, so do the management difficulties.

Based on these empirical findings, the study proposes a comprehensive Environmental Management Framework (EMF) that provides a practical roadmap for sustainable demolition waste management. This framework promotes: Waste minimization and reuse through technical solutions. Environmental protection via policy reforms and enforcement mechanisms. Stakeholder collaboration among government agencies, construction companies and local communities. The EMF integrates administrative, technical and policy-level strategies, making it a flexible and scalable model for Pakistan and other developing nations facing similar infrastructural challenges. Ultimately, this research offers a scientifically validated, context-sensitive approach to tackling the growing problem of demolition waste in road construction. It supports informed policymaking, capacity building and the establishment of a resilient waste management infrastructure. The proposed framework contributes not only to environmental sustainability but also to economic efficiency and social well-being—paving the way for a greener, more sustainable construction industry in Pakistan and beyond.

5.2 Recommendations

In light of the findings from this research—highlighting the lack of a comprehensive demolition waste management system in road construction projects—this section provides detailed recommendations for key stakeholders. These recommendations are grounded in empirical evidence derived from the study's validated structural models and expert input and aim to support the development of a sustainable, efficient and practical demolition waste management framework in Pakistan and similar developing contexts.

5.2.1 Government and Policymakers

Governments and regulatory bodies have a pivotal role in creating an enabling environment for sustainable demolition waste management. A critical starting point is the standardization of recycling, reuse and disposal regulations across the country. At present, Pakistan lacks a uniform national policy, which leads to inconsistent practices at the provincial and municipal levels. Standardized policies should define specific requirements for waste sorting, material recovery thresholds, disposal methods and penalties for non-compliance. This would provide legal clarity and operational consistency for all involved actors. Moreover, the government should provide financial incentives to stimulate the adoption of sustainable waste practices in construction. These can include tax relief for companies using recycled materials, funding support for research and development in green construction technologies and preferential treatment in public procurement for contractors with sound waste management records. Investment in waste sorting and recycling infrastructure is another critical recommendation. Establishing regional facilities for sorting, crushing and reprocessing demolition waste can significantly reduce the burden on landfills and increase material recovery. These facilities should be accessible and technologically equipped to process various types of road demolition materials, including asphalt, concrete and metals. To guide informed decision-making and promote long-term environmental accountability, the government should implement Life Cycle Assessment (LCA) guidelines. LCA tools evaluate the environmental impacts of materials and processes from cradle to grave. Making LCA mandatory in public road projects would encourage planners and engineers to select low-impact alternatives and justify their material choices based on sustainability criteria.

5.2.2 Designers and Consultants

Designers are instrumental in influencing material choices, construction methodologies and waste generation levels from the early planning stages. It is strongly recommended that design teams incorporate recycled materials and modular designs wherever feasible. Recycled aggregates, reclaimed asphalt pavement and reused steel components not only reduce environmental impact but also lower project costs. Modular design, on the other hand, allows for easier assembly and disassembly, enabling materials to be reused in future projects. A proactive design approach also involves thorough site investigations to better understand the ground realities and anticipate waste-generating conditions. This helps minimize rework and design changes during execution, both of which are known contributors to waste generation. Another key recommendation is for designers to develop detailed waste management plans as part of the initial design package. These plans should outline potential waste types and volumes, proposed handling strategies and coordination mechanisms with contractors. Waste management planning should be treated as a design responsibility rather than an afterthought or construction phase issue..

5.2.3 Contractors and Sub-contractors

The role of contractors and sub-contractors is central to the practical management of demolition waste. They are responsible for implementing on-site strategies that can significantly influence waste outcomes. One of the most effective interventions is the implementation of on-site recycling and waste segregation systems. By separating materials like concrete, asphalt, wood and metals at the source, contractors can improve recovery rates and reduce the cost of disposal. Dedicated waste zones, clear signage and proper bin labeling are essential components of an efficient segregation system. Additionally, contractors must invest in workforce training focused on sustainable construction practices. Many laborers are unaware of the environmental impacts of waste or the correct ways to handle different materials. Regular workshops, certifications and awareness sessions can enhance their understanding and commitment to responsible waste management. Embracing digital tools and technologies can also lead to significant improvements in material use and waste reduction. Construction management software can help track inventory, forecast material needs and monitor real-time waste generation. Using building information modeling (BIM) and other smart technologies enables better planning and optimization, minimizing surplus and off-cuts during construction.

5.3 Future Research Directions

Despite the important findings of this study, there remain several critical areas where further investigation is required to advance sustainable demolition waste management practices in road construction. These future research directions emphasize the need for long-term, interdisciplinary and context-specific studies to reinforce and expand the framework developed in this research.

5.3.1 Long-Term Impact Assessment of Sustainable Waste Utilization

One of the primary limitations in current demolition waste management practices is the lack of longitudinal studies that evaluate the long-term performance and environmental outcomes of utilizing recycled demolition materials in road construction. Future research should aim to track the structural durability, maintenance frequency and lifecycle cost of roads built with alternative materials, such as recycled concrete aggregate or reclaimed asphalt pavement. Moreover, researchers should assess the environmental performance over time, focusing on indicators such as carbon footprint reduction, emissions during usage, soil and groundwater quality and ecosystem impacts. Such long-term studies are essential for generating evidence-based benchmarks and performance indicators that can be used by policymakers and practitioners to evaluate the effectiveness of waste reuse strategies.

This data will also help determine the true environmental and economic value of sustainable practices, thereby encouraging wider adoption across the industry.

5.3.2 Innovation in Recycling Technologies and Material Science

With technological advances transforming the construction and waste sectors, there is significant scope for future research to focus on innovative, high-efficiency recycling technologies. These could include smart sorting systems using artificial intelligence, robotics for material separation and thermal or chemical processing methods for more complex waste streams. Additionally, researchers should investigate new material formulations, such as geopolymer concrete or bio-based binding agents, that can incorporate demolition waste without compromising structural performance. Another emerging area worth exploring is the integration of digital technologies such as Building Information Modeling (BIM) and Internet of Things (IoT) for real-time waste tracking, optimization of material flows and predictive maintenance of infrastructure. Evaluating the technical feasibility, economic viability, energy consumption and environmental risks associated with these new technologies in the context of Pakistan and similar developing countries will be critical for their effective deployment.

5.3.3 Strengthening Inter-Sectoral Collaboration Models

Sustainable demolition waste management requires strong coordination among different sectors, including government agencies, construction firms, environmental regulators, research institutions and civil society organizations. Future research should examine the institutional, financial and legal frameworks that can facilitate such cooperation. This could involve conducting comparative case studies of successful collaboration models from other countries and adapting them to the socio-political and economic realities of Pakistan. There is also a need to develop stakeholder engagement models that define the roles, responsibilities and accountability mechanisms of each actor in the waste management ecosystem. Exploring tools such as public-private partnerships (PPPs), inter-agency task forces and shared data platforms can provide a more integrated approach to managing demolition waste in road projects.

5.3.4 Enhancing Public Engagement and Education

An often-overlooked but crucial aspect of sustainable waste management is public awareness and community participation. Future research should explore the sociocultural barriers and behavioral drivers that influence public perceptions and practices related to demolition waste. This includes studying attitudes toward recycled construction materials, understanding the factors that encourage or hinder community involvement and identifying the most effective communication strategies to promote sustainable practices. Efforts should also focus on developing educational interventions at different levels—from primary and secondary schools to universities and vocational training institutions. Creating interactive learning modules, community outreach programs and awareness campaigns can significantly improve understanding and acceptance of sustainable demolition waste practices. Furthermore, researchers should evaluate the impact of public education efforts on waste generation behavior, segregation practices and support for policy reforms. These findings can help tailor communication and engagement strategies to different demographic groups and regions within the country.

5.3.5 Policy-Oriented Research and Regulatory Innovation

In addition to the above areas, future research must contribute to the development of evidence-based policy frameworks. There is a pressing need to evaluate the effectiveness of existing demolition waste regulations and propose reforms that promote standardization, enforcement and incentivization. Researchers can explore the role of life cycle assessment (LCA) in policy decision-making, the introduction of mandatory waste audits for large-scale road projects and the development of performance-based standards for recycled construction materials. Studies should also consider the implications of emerging global trends, such as the circular economy, green public procurement and climate adaptation goals, in shaping Pakistan's waste management strategies. Collaborative research involving economists, legal experts and environmental scientists can yield actionable policy recommendations that align local priorities with international sustainability commitments.

5.3.6 Case study project using complete Life cycle.

This framework serves as the foundational key to developing and implementing effective demolition waste management that incorporates the 3R principles (Reuse, Recycle, Reject/Landfill) across various types of construction projects. By testing this framework through pilot projects in diverse urban contexts, it will allow for the identification of sector-specific challenges and the formulation of tailored solutions.

These future research directions emphasize the dynamic and evolving nature of demolition waste management and the critical need for interdisciplinary, multi-level and practice-oriented investigations. By exploring long-term performance metrics, technological innovations, institutional collaborations, public engagement strategies and policy interventions, future research can significantly enhance the effectiveness and scalability of the Environmental Management Framework proposed in this study. Ultimately, such efforts will contribute to building a resilient, low-waste and sustainable road infrastructure sector in Pakistan and other developing countries facing similar challenges.

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.1 Appendix A (Questionnaire)

Department of Civil Engineering

Framework Development for Life Cycle Environmental Management of Demolition Wastes for Road Projects

(QUESTIONNAIRE)

Sajjad Shuker Ullah, PhD Scholar (DCE-183001)

Disposing of demolition waste has huge environmental impacts and can cause serious problems. Needless to say, the most important reason for proper waste management is to protect the environment and for the health and safety of the population.

Having a proper waste management can result in the availability of valuable materials to reuse. This can save money while potentially creating new jobs and business opportunities. Reducing, reusing and recycling your waste is important for the environment, but it can also be profitable. It decreases the amount of waste for disposal, saves space in landfills, and conserves natural resources.

Proper waste management is essential in construction projects to ensure legal compliance, protect the health and safety of workers and the public, reduce the environmental impact, achieve cost savings, and enhance reputation and brand image. By implementing recycling and waste reduction programs, using proper disposal practices, and promoting responsible waste management practices, construction companies can benefit the industry and the environment.

In this regard, I am conducting research in order to develop a Framework Development for Life Cycle Environmental Management of Demolition Wastes for Road Projects in Pakistan. Main variables include causes of demolition waste generation, Impacts, challenges and solution for better management and utilization of road projects waste.

In the Light of above elaboration, I am administering a research questionnaire which comprises of two parts i.e., demographic data and the Demolition Waste Management framework. The first partrequires information about the respondent which will be used only for research purposes. The secondpart requires the respondent to give general information on their familiarity with DWM technique. It also includes Demolition Waste Management in which you are requested to rate the impact of each variable.

I shall be highly obliged if you can spare some time and share your valuable feedback on Demolition Waste Management for road Projects in Pakistan.

Part 1:

DEMOGRAPHICAL DATA:

Generic:

Company name (Optional): ____

Respondent name (Optional): ____

1. Type of Organization?

   Client/Owner ( ) Consultant ( ) Contractor ( ) others.................................

2. Your job title?

   C.E.O/ Managing Director ( ) Project Manager ( ) Project Architect ( )

   Project Quantity Surveyor ( ) Project Engineer ( ) Others ....

3. Your experience related to construction industry?

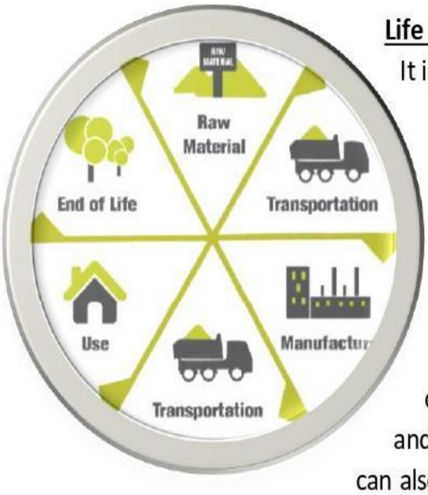
   0-5 years ( ) 6-10 years ( ) 11-15 years ( ) 16-20 years ( ) Over 20 years ( )

4. Type of Projects handled?

   Traditional contract ( ) Design and build ( ) Turnkey ( ) Management contract ( )

   Others ....

Part 2:



Life Cycle Environmental Management of Demolition wastes.

It is the process of management of demolition waste for the road projects starts from raw material extraction, transportation, manufacturing, transportation, use & maintenance to end of life. In first step, Causes of Waste from road works is calculated from (Project Life Cycle) planning, execution and Monitoring. Secondly, demolition waste impact and challenges highlighted and thirdly, solution regarding Demolition Waste Management observed. This can save money while potentially creating new jobs and business opportunities. Reducing, reusing and recycling your waste is important for the environment, but it can also be profitable. It decreases the amount of waste for disposal, saves space in landfills, and conserves natural resources.

Are you familiar with the concept of Demolition Waste Management? Yes No

If yes;

1) Do you think Demolition Waste Management of Road is necessary?

   Absolutely Yes ( ) Yes but not absolute ( ) No at all ( ) Do not know ( )

2) Have you ever done a project in which Demolition Waste Management (Reduce & Reuse) was made part of the project? Yes No

3) Do you Think Demolition Waste Management plan should be the part of contract? Yes No

Keeping in view your experience please evaluate the impact of the following decision-making aspects to develop framework for Life Cycle Environmental Management of Demolition Wastes for Road Projects. The framework has been divided into four sections, each variable needs to be ranked on Likert scale of 1 to 5.

(1) represents **very low impact**, (2) represents **Low impact**, (3) represents **Moderate impact**, (4) represents **high impact**, (5) represents **very high impact**.

Based upon your knowledge and experience, feedback is requested on below.

S.No	Variables	Code	Ranking (✓)				
A	**Causes of Demolition Waste Generation**	**CW**	**1**	**2**	**3**	**4**	**5**
	i. Planning Stage	**CW-PN**					
1.	Discrepancies in Bidding document	**CW-PN-1**					
2.	Promoting sustainable material while designing	**CW-PN-2**					
3.	Incorporation of Demolition Waste Management in bidding process.	**CW-PN-3**					
4.	Incomplete Bidding documents before tendering	**CW-PN-4**					
5.	Scope/design Changes	**CW-PN-5**					
6.	Pre-Demolition audit at planning stage.	**CW-PN-6**					
7.	Coordination and Communication Among Stakeholders.	**CW-PN-7**					
8.	Implementation of lesson learnt.	**CW-PN-8**					
	ii. Execution Stage	**CW-EX**					
1.	Inadequacy of implementation in waste management plan.	**CW-EX-1**					
2.	Role of supervision Skills	**CW-EX-2**					
3.	Contract modification due to discrepancies.	**CW-EX-3**					
4.	Impact of eleventh-hour change of scope.	**CW-EX-4**					
5.	Consideration of site storage and space availability.	**CW-EX-5**					
6.	Waste generation due to poor workmanship.	**CW-EX-6**					
7.	Coordination and Communication gap among stakeholders.	**CW-EX-7**					
	iii. Monitoring & Control Stage	**CW-MC**					
1.	Role of 3R (Reduce, Reuse, Recycle) strategy.	**CW-MC-1**					
2.	Role of I. T in Demolition Waste Management mechanism.	**CW-MC-2**					
3.	Utilization of sub-standard materials resulting in wastage.	**CW-MC-3**					
4.	Inappropriate storage for unused construction materials.	**CW-MC-4**					
5.	Impact of on-Site Sorting Techniques.	**CW-MC-5**					
6.	Impact of sub-letting / subcontracting.	**CW-MC-6**					
7.	Identification and quantification of Demolition waste.	**CW-MC-7**					

	Variables	Code	Ranking (✓)				
B	**Demolition Waste Impacts**	**WI**	1	2	3	4	5
	i. Environmental Impacts	**WI-EN**					
1.	Green House Gas Emissions.	**WI-EN-1**					
2.	Leaching effect (Soluble Chemical and mineral carrier into liquid by rainwater) e.g Acid.	**WI-EN-2**					
3.	Water Contamination	**WI-EN-3**					
4.	Air Contamination due to Pollution and Dust Generation.	**WI-EN-4**					
5.	Natural resources Consumption (i.e Construction material)	**WI-EN-5**					
6.	Green Land Utilization, Soil Contamination	**WI-EN-6**					
7.	Barrier to recharge for water table.	**WI-EN-7**					
8.	Indirect Impact on creation Climate Change (e.g Methine Gas etc)	**WI-EN-8**					
	ii. Social Impacts	**WI-SO**					
1.	Health Hazards to near communities.	**WI-SO-1**					
2.	Additional Human resource consumption	**WI-SO-2**					
3.	Requirement of Energy Consumption	**WI-SO-3**					
4.	Project Stakeholders Attitude Towards DW Management	**WI-SO-4**					
5.	Sustainable Development	**WI-SO-5**					
6.	Vibrations and Noise Pollution impacting society.	**WI-SO-6**					
7.	Health And Safety Impacts	**WI-SO-7**					
8.	Lack of awareness of social impacts of demolition wastes.	**WI-SO-8**					
9.	Level of motivation for waste sorting.	**WI-SO-9**					
	iii. Economic Impacts	**WI-EC**					
1.	Promotion and utilization of recycled Materials.	**WI-EC-1**					
2.	Economic impact of additional Incentive required for proper Waste Management.	**WI-EC-2**					
3.	Financial Impact of Recycling Plants and Material Stockpiled.	**WI-EC-3**					
4.	Impact of Management and Operation Costs	**WI-EC-4**					
5.	Costs associated with disposal of waste	**WI-EC-5**					
6.	Financial aspect of creating awareness towards demolition Management.	**WI-EC-6**					
7.	Limited knowledge of waste recycling/reuse	**WI-EC-7**					
8.	Resources required for creating designated dumping zone.	**WI-EC-8**					
9.	Job Creation Opportunities	**WI-EC-9**					

	Variables	Code	Ranking (✓)				
C	**Demolition Waste Management Challenges**	**WC**	1	2	3	4	5
	i. Demolition Waste Handling	**WC-WH**					
1.	Illegal dumping of Demolition Waste.	**WC-WH-1**					
2.	Strategic plans for effective Demolition Waste Management.	**WC-WH-2**					
3.	Acceptance of Stakeholders for demolition waste as recycling material.	**WC-WH-3**					
4.	Promotion of Collaboration among stakeholders	**WC-WH-4**					
5.	Arrangement for Designated Landfill sites	**WC-WH-5**					
6.	Role of regulatory control and Government Legal Enforcement	**WC-WH-6**					
7.	Issues With Supply Chain Management	**WC-WH-7**					
8.	Industry support for effective utilization of Demolition waste.	**WC-WH-8**					
9.	Limited of Specialized Demolition Waste Handling Companies.	**WC-WH-9**					
10.	Demolition Waste Management Budget allocation.	**WC-WH-10**					
11.	Level of support by Government agencies for Environmental Protection Promotion	**WC-WH-11**					
	ii. Awareness & Training's	**WC-AT**					
1.	Knowledge of supplier's Co-Operation towards waste material utilization.	**WC-AT-1**					
2.	Role of project executing staff towards Demolition Waste Management.	**WC-AT-2**					
3.	Implementation of existing practice and policies (EPA) to protect Environment.	**WC-AT-3**					
4.	Role of Technological Support for Smart Construction	**WC-AT-4**					
5.	Arrangement of In-House Training on Environmental Management	**WC-AT-5**					
6.	Role of Awareness and Training for Environmental Protection	**WC-AT-6**					
7.	Impact of industrial focus on cost and time rather than Demolition Waste Management etc.	**WC-AT-7**					
8.	Level of Demolition Waste Management by Trained Staff and Expertise personals as per contract Document.	**WC-AT-8**					
	iii. Policy & Legislation	**WC-PL**					
1.	Inadequacy of Industry Norms	**WC-PL-1**					
2.	Engaging all types of social media for promoting Demolition Waste Management	**WC-PL-2**					
3.	Demolition Waste Management consideration in Project Life Cycle.	**WC-PL-3**					
4.	Level of enforcement Waste Management Plan.	**WC-PL-4**					
5.	Penalization mechanism for generating demolition waste and damaging environment.	**WC-PL-5**					
6.	Role of Legislation for enforcing Policies to protect environment.	**WC-PL-6**					
7.	Enforcement of Legal Requirements on Environmental Protection.	**WC-PL-7**					
8.	Industry Culture of incentives policies to promote utilization of Demolition Waste Management.	**WC-PL-8**					

	Variables	Code	Ranking (✓)				
D	**Solutions/Results of Demolition Waste Management**	**SD**	1	2	3	4	5
	i. Administrative Solutions	**SD-AS**					
1.	Proper documentation of Demolition data.	**SD-AS-1**					
2.	Imposing Responsibilities to All the stakeholders for considering waste management plan in the project lifecycle.	**SD-AS-2**					
3.	Training and education programs	**SD-AS-3**					
4.	Enhancing Priority level of Demolition Waste Management	**SD-AS-4**					
5.	Utilization of waste in Contribution to environmental protection.	**SD-AS-5**					
6.	Enforcing Protecting Environment on Managerial Staff	**SD-AS-6**					
7.	Improvements in health and safety level due to proper Demolition Waste Management implementation.	**SD-AS-7**					
8.	Continuous Improvement in Environmental Management through 3R (Reduce, Reuse, Recycle) Strategy.	**SD-AS-8**					
9.	Improving Corporate Image and Business Competitiveness in Environmental Performance	**SD-AS-9**					
10.	Promote incentive and Penalty Polices regarding Demolition Waste Management.	**SD-AS-10**					
11.	Proper implementation of Demolition Waste Management laws and regulations.	**SD-AS-11**					
	ii. Technical Solutions	**SD-TS**					
1.	Application of advanced technologies.	**SD-TS-1**					
2.	Preserve or save the natural resources-raw materials	**SD-TS-2**					
3.	Consideration of Environmental Management Strategy as part of contract documents.	**SD-TS-3**					
4.	Promotion of recycled product and apply new technologies in Demolition Waste Management	**SD-TS-4**					
5.	Establish prefabricated design and construction technologies	**SD-TS-5**					
6.	Promoting Potential cost savings strategy due to 3R (Reduce, Reuse, Recycle) elements.	**SD-TS-6**					
7.	Additional revenue by selling material.	**SD-TS-7**					
8.	Continuous and effective supervision at site level.	**SD-TS-8**					
9.	Innovating Existing Practice and policies elevating awareness regarding demolition waste.	**SD-TS-9**					

Additional remarks (if any) ____

____

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Thank You for completing the questionnaire.