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Development of Policy Framework for Waste Minimization on Building Projects: A Step Towards Circular Economy

by

Muhammad Usman Shahid

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Development of Policy Framework for Waste Minimization on Building Projects: A Step Towards Circular Economy

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This humble effort is dedicated to my mother for her visionary sacrifices to bring the best out of me. Further, it is dedicated to my father and my wife for their soulful prayers and their faith in me. At last but not the least, this dissertation is dedicated to my supervisor Engr. Prof. Dr. Majid Ali, for his persistent concern to make it possible.

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CERTIFICATE OF APPROVAL

This is to certify that the research work presented in the dissertation, entitled "**Development of Policy Framework for Waste Minimization on Building Projects: A Step Towards Circular Economy**" was conducted under the supervision of **Dr. Majid Ali**. 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 **September 17, 2025**.

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List of Publications

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

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Abstract

Construction waste minimization (WM) and circular economy (CE) have been extensively studied in developed countries, resulting in well-defined policy guidelines and strategies focused on reduction, reuse, and recycling. However, such efforts are largely absent or underdeveloped in developing nations, where construction activities contribute to a significant proportion of total solid waste. Around 30 million tons of solid waste is generated annually in Pakistan, 9 million tons of this waste is coming from construction sites and 4 million tons is generating from building projects only. So, there is an immediate need to identify the root-cause barriers which hinder the adoption of WM practices. In addition, there remains a critical research gap in understanding the perceptions of various construction industry stakeholders regarding WM barriers, especially through a comparative lens. Furthermore, existing studies about WM policies often overlook the cultural and operational diversity that characterizes construction practices in developing regions. Therefore, there is a need to conduct more studies regarding WM policies in each of these developing countries including Pakistan. While numerous studies have proposed WM strategies, few have validated their effectiveness through implementation in real-time construction projects. Quantifiable outcomes, such as the amount or percentage of waste reduced through applied strategies, can significantly enhance stakeholder confidence in adopting WM and CE practices.

This study addresses these gaps through a comprehensive, three-phase research design focused on Pakistan. Phase 1 began with a systematic literature review to identify recurring 41 WM barriers, which were ranked based on frequency. A structured and pilot-tested questionnaire was distributed among key stakeholders. Their responses were analyzed using the fuzzy DEMATEL method to identify root cause barriers along with comparative analysis among the perception of stakeholders. Phase 2 developed targeted strategies to address these barriers and promote CE principles. Semi-structured interviews with 24 experts were conducted until saturation point was reached. As a result, macro and micro levels WM strategies along with a formal policy framework and its implementation guidelines were developed. Phase 3 involved the validation of the proposed WM strategies through implementation on an actual building project for 10 construction materials. The performance of this project was compared to other conventional projects.

Commonly agreed barriers to WM practices included lack of rules and regulations, unclear specifications, financial issues, illogical design, poor awareness, and low penalties for illegal dumping. Agreement levels varied, highest between contractors and regulators (69%), followed by client-consultant and client-regulator groups (62%), and lowest between consultants and contractors (38%). Subsequently, developed framework included macro-level interventions such as government financial incentives (14.6%), awareness programs (11.2%), curriculum integration (3.5%), and regulatory updates (3.3%) were found to exert greater influence (68.2%) compared to micro-level measures (18.4%). At the project level, strategies such as building information modeling (BIM), low-waste design approaches, material segregation, reuse, and improved storage techniques were also emphasized. Furthermore, implementation guidelines of proposed framework were also provided. Design integration using BIM, helped to identify and correct design errors. Multiple waste reduction strategies including prefabrication, reuse of materials (brick ballast, concrete, steel, sand), and dumping waste at designated dumping sites were implemented on building project. As a result, the project achieved waste generation rates of less than 4% across all materials, significantly lower than the national average of over 13% for similar projects. Specifically, 5.2% of brick waste, 6.1% of concrete, 0.52% of steel, and 0.22% of sand were reused, while post-construction waste was repurposed or sold for future use. Overall, the study recorded approximately 71% reduction in material waste. Overall, the findings of this research offer actionable insights for policymakers, industry leaders, and practitioners seeking to implement effective WM strategies and foster a CE practices in construction sector.

Keywords: Waste Minimization, Circular Economy, Fuzzy DEMATEL, Barriers, Thematic Analysis, Enablers, Policy framework, Validation of WM strategies

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Abbreviations

ADB	Asian Development Bank
AHP	Analytical Hierarchy Process
ANP	Analytical Neural Process
BIM	Building Information Modelling
BoQ	Bill of Quantities
CE	Circular Economy
CFA	Confirmatory Factor Analysis
Cft	Cubic feet
CPEC	China-Pakistan Economic Corridor
CWM	Construction Waste Management
DEMATEL	Decision Making Trial and Evaluation Laboratory
GIS	Geo-Informatics System
GPS	Global Positioning System
HI	High Influence
HK	Hong Kong
Inv	Inventory
IPCs	Interim Payment Certificate
IRP	Incentive Reward Program
Kg	Kilogram
LC	Lean Construction
MCDM	Multiple Criteria Decision Making
NI	No Influence
PEC	Pakistan Engineering Council
PSDP	Public Sector Development Program

RFID	Radio Frequency Identification Method
RBP	Recycled Brick Powder
SC	Sustainable Construction
SDGs	Sustainable Development Goals
SEM	Structural Equation Modelling
Sft	Square feet
SOPs	Standard Operating Procedures
TFNs	Triangular Fuzzy Numbers
UN	United Nations
USA	United States of America
VL	Very Low
WGRs	Waste Generation Rates
WM	Waste Minimization
WMPs	Waste Management Plans
ZW	Zero Waste
ZWM	Zero Waste Management

Symbols

D	Sum of all rows
$D + R$	Prominence
$D - R$	Net effect
Inv	Inventory data of store
K	Number of experts
l_{ij}^{k}	Lower bound values
minl_{ij}^{k}	Smallest of all lower bound values
Mp	Purchased quantity
$Mreused$	Reused quantity of materials
Mu	Used quantity
m_{ij}^{k}	Most likely value
R	Sum of all columns
s	Scaling factor
T	Total relation matrix
u_{ij}^{k}	Upper bound values
X	Normalized direct matrix
xrs_{ij}^{k}	Right normalized values
xls_{ij}^{k}	Left normalized values
Z_{ij}^{k}	Crisp values
Z_{ij}	Aggregate values
Δ_{min}^{max}	Maximum and minimum difference

Chapter 1

Introduction

1.1 Prologue

Over the past decade, rapid urbanization and large-scale development initiatives have significantly increased construction activities worldwide [1]. On average, the construction industry contributes about 10% to a country's economic growth [2]. However, this sector remains heavily dependent on natural resources, which are finite and can eventually deplete [3, 4]. Consequently, it is essential to use these resources efficiently for sustainable growth. Despite this need, the construction sector often fails to implement sustainable practices, leading to substantial resource wastage. It is estimated that approximately 200 million tons of waste are produced annually in the UK, with 59% originating from the construction sector and especially from building projects [5]. Similarly, approximately 2 billion tons of waste are generated annually in China [6]. Furthermore, construction waste fills up the landfill sites by 29%, 40%, 44%, 27%, and 29% in USA, Brazil, Australia, Canada, and Hong Kong, respectively, where building projects constitute 40% of this construction waste [7]. It means almost half of the construction waste is generating from building projects. A recent special issue of Nature on the circular economy (CE) highlights how the large volumes of waste, particularly from construction, pose a serious threat to global sustainability [8]. This issue stems largely from the linear economy model dominant in the industry, in which materials are produced, used, and discarded. To address this, the construction and especially the building sector must shift towards CE principles that emphasize reducing, reusing, and recycling resources to maximize their utility. CE represents a systemic shift in how materials are produced, circulated, consumed, and recovered, with the ultimate goal of conserving natural resources through efficient material utilization [9, 10]. However, implementing CE and waste minimization (WM) practices presents several challenges. In this context, numerous studies have identified the barriers to adoption as well as strategies to promote CE and WM practices on building projects, particularly in developed countries [11–13]. However, there is little research available on a global scale, that provides a comparative analysis of how different stakeholders perceive and rate WM and CE barriers. Understanding how stakeholder perceptions vary in rating these barriers is crucial, as it reveals the level of consensus among key stakeholders in identifying root cause barriers. Therefore, there is a strong need for more comprehensive studies to identify WM barriers specific to each developing country along with the comparative analysis among the perception of key stakeholders while rating the barriers to WM and CE practices on building projects.

In terms of WM policies and strategies, several studies have been conducted in developed countries to promote CE practices on building projects [12, 14–18]. In these studies, the principles of WM (reduce, reuse, and recycle) remained a key focus. In developing countries, there have been limited studies that outline the potential enablers that could counter the challenges of WM and CE [19–26].These studies showed a variation in WM strategies for each of these countries. This variation is due to the change in construction practices and cultural values. Kolupaieva and Lindahl [27] suggested policy recommendations for the Ukrainian construction industry, including green financing, digital transformation, and stakeholder collaboration. Another study conducted in Nigeria's construction industry identified the key enablers of WM, such as the development of recycling facilities, the use of renewable and sustainable materials, and designs for disassembly [20]. Furthermore, education, financing, labor attitudes, and government support were identified as major contributors to waste reduction within South Africa's construction industry

[21]. Additionally, the strict supervision of construction activities, the allocation of space for material storage, and stakeholder involvement to promote WM were identified as key enablers in the construction industry of Bangladesh [28]. These studies reveal that strategies to reduce waste generation vary significantly from country to country, primarily due to differences in construction practices and cultural values [29, 30]. This highlights the need for further studies to be conducted within the context of each of these developing countries. The case of Pakistan (a developing country) is even worse than other developing countries because thirty (30) million tons of solid waste is generated every year, nine (09) million tons of this waste comes from the construction sector and four (04) million tons of it comes from building projects [31]. As per the report of the Asian Development Bank, the construction sector in Pakistan immediately requires the development of WM policy guidelines, as the current waste generation rates pose a significant threat to the environment and resource sustainability [31]. Therefore, there is an immense need to conduct a detailed study to outline WM strategies at macro and micro levels and develop policy framework in the context of Pakistan, which can be helpful for other developing countries with similar construction practices.

In the context of implementing proposed WM strategies on building projects, only a limited number of studies have been reported in the existing literature. Lu et al. [32] conducted research in China involving two case studies, a bridge and a university building. In both cases, existing structures were dismantled and the demolition waste was reused. Approximately 43,400 tons of waste from the demolished bridge and 660,000 cubic meter from the university building were reused for pavement construction. Similarly, Chen et al. [33] implemented a bar code system to track material usage on a building project. This study also introduced an incentive reward program (IRP) on one project, while another project followed traditional methods. Upon completion, the IRP-based project yielded a net saving of HK 550,000 dollars. Further, Tam et al. [34] compared waste generation between prefabrication and cast-in-situ techniques. The prefabricated approach produced significantly less waste: 93% less plaster, 81% less timber, 56% less concrete, and 45% less reinforcement compared to the traditional method. While these studies successfully demonstrated the application of specific WM strategies on real-time construction projects, each focused on individual or isolated strategies. None attempted to implement multiple WM strategies simultaneously on a newly constructed project throughout its entire lifecycle. As a result, the cumulative effectiveness of a multi-strategy approach to waste reduction remains largely unexplored. Addressing this gap is crucial, as studies based on real-time data provide more compelling evidence than theoretical models. So, quantifiable outcomes by implementing and validating the WM strategies on a newly constructed building project is required, which can significantly strengthen stakeholder confidence in adopting CE practices.

1.2 Research Motivation and Problem Statement

The construction industry worldwide generates around 50% of total waste and occupies the largest share of landfill space [35]. Building projects alone account for 40% of this construction waste. In Pakistan, more than 30 million tons of waste are produced annually, with approximately 9 million tons originating from construction projects and 4 million tons from building projects [31]. Furthermore, China will be investing around 60 billion dollars under China-Pakistan Economic Corridor (CPEC) by 2030. In this program, number of multistory buildings, power and infrastructure projects will also be executed. Moreover, a number of other ongoing building projects are also planned under the Public Sector Development Program (PSDP), with funding of 4,224 billion rupees allocated for the 2025-26 fiscal year. These projects will generate tons of material waste on construction sites. Unfortunately, this waste will not only cause depletion of natural resources but also damage the environment in the absence of proper WM policies. [36]. Therefore, minimizing waste from building projects can significantly contribute to overall WM and CE practices in the construction sector. Thus the problem statement is as follows:

Construction industry in developing countries, particularly Pakistan, faces disproportionately high waste generation rates, yet the root causes of material waste remain underexplored. Additionally, very limited studies on comparative analyses of *stakeholder perspectives are available. The Asian Development Bank identifies construction waste as a major environmental threat in Pakistan, stressing the urgency for policy development [31]. Although, there are number of policy documents available for waste management in Pakistan [37, 38] , but these are generic in nature and do not provide any policy guidelines about construction waste management. Therefore, there is an urgent need to develop comprehensive policy framework and guidelines for construction sector of Pakitan.*

So, current study provides a policy framework along with detailed guidelines for WM in construction sector of Pakistan.

1.2.1 Research Questions

1. What are the significant barriers to WM practices on building projects to initiate CE culture in local context?

2. What are the level of agreement and disagreement among the perception of stakeholders as a result of comparative analysis while rating the barriers to WM and CE on building projects?

3. What are the policy factors/strategies which are important for waste control against identified barriers at macro level and micro/project level to initiate WM and CE culture?

4. What will be the framework for WM to adopt CE culture on building projects?

5. What will be the waste generation rates (%) as a result of application of WM strategies identified at micro/project level to promote CE culture on building projects?

6. How effective is the developed framework for WM and CE compared to traditional building projects reported in past studies?

1.3 Overall Goal of the Research Program and Specific Objectives of this Doctoral Research

The overarching aim of this study is to advance the implementation of CE principles in the construction sector by systematically identifying and evaluating the key barriers to effective WM, assessing stakeholder consensus on these barriers, formulating optimized WM strategies and policy recommendations, and validating the practical impact of these strategies through project-level quantification of material waste reduction.

The specific objectives of this doctoral research are:

1. *To evaluate significant barriers/factors associated with the WM practices and identify the level of agreement among stakeholders while rating these barriers for building projects to promote CE culture (Phase 1).*
2. *To determine the effective macro and micro level WM strategies (optimizing factors) against identified barriers and develop a policy framework to adopt CE culture on building projects (Phase 2).*
3. *To apply and validate the effectiveness of micro/project level WM strategies for CE culture by quantifying the waste reduction rates of different building materials in comparison to traditional projects from past studies (Phase 3).*

1.4 Scope of Work and Study Limitations

The scope of this research is confined to investigating barriers to WM and the adoption of a CE culture within the context of building projects in Pakistan. The geographical focus is limited to Rawalpindi and Islamabad, where representative multi-storey building projects (ranging from B+G+2 or G+3 to B+G+5 or G+6, etc.) were considered. The study addresses both macro-level (national, industrial, organizational) and micro-level (project, site-specific) perspectives, but does not extend to other sectors such as infrastructure or industrial facilities. The research emphasizes the identification of barriers, development of strategies and policy recommendations, and validation of a practical framework for WM in the building sector. Further, considering the number of experts which were selected for research in previous studies vary between fifteen to thirty experts [39–41], so in this research, data was collected from thirty different experts and fuzzy DEMATEL techniques was applied to identify root-cause barriers. While data was collected from 24 participants in phase-2 of this study, each having a minimum of ten years of experience. Stakeholder perspectives were captured primarily from contractors, consultants, contractors and regulators with extensive professional experience in the industry. The study incorporates qualitative insights, its findings are designed to provide sector-level policy and managerial guidance. The final framework was validated at the project level to assess its practical applicability.

For current study, data were collected from building projects only from twin cities of Pakistan. Further, proposed framework was validated only at micro/project level, since macro level efforts/measures/strategies are linked to organizations, construction industry and national governments which are beyond the control of authors and this study. The study was conducted in Pakistan using data from local industry experts and building projects; thus, findings may not be fully generalizable to other developing countries as results may vary to some extent for other countries.

1.4.1 Rationale Behind Selection of Research Variables

It is necessary to identify the root causes/barriers which are causing hindrance in following CE strategies in order to develop a construction WM policy framework of building projects in Phase-1. Frequency analysis was used as a method to shortlist the barriers in this study. Given the large number of potential barriers identified, it would have been impractical and burdensome to ask field experts to evaluate each barrier separately, as doing so would have required them to respond to hundreds of questions. This could have led to respondent fatigue, reduced response quality, and lower participation rates. To manage this challenge efficiently and maintain the reliability of the data, frequency analysis served as a useful preliminary screening tool to identify the most commonly cited or significant barriers. This approach not only reduced the number of items to a manageable level but also ensured that the most relevant barriers were retained for further evaluation. Notably, this method of shortlisting barriers has also been employed in several previous studies, which lends additional credibility to its use in the current research [42–44].

Since the data is of qualitative nature and there can be vagueness in the opinion of field experts, therefore, Fuzzy based DEMATEL tool is used to remove such vagueness [39, 40] and determine most significant barriers through cause and effect results. Further, the rationale for using fuzzy DEMATEL is that: (1) it is challenging to examine interactions between waste management barriers because of their subjective nature, (2) fuzzy DEMATEL offers a quantitative examination of waste management barriers and (3) the cause-and-effect connections between these obstacles can aid in the development of regulatory initiatives by decision-makers. Respondents of the survey include key stakeholders, comprising clients, consultants, contractors, and representatives from regulatory agencies. These experts were carefully selected to ensure comprehensive input from all major stakeholders directly involved with WM issues in the country in the light of previous studies [40, 45, 46]. Each participant held at least a bachelor's degree and had a minimum of ten years of professional experience [40, 45, 46], since respondents with less than ten years of experience are unlikely to make informed decisions [29]. The decision to involve thirty experts was guided by methodologies adopted in previous studies [40, 41, 45–48]. One of the biggest advantage of using fuzzy DEMATEL quationnaire, it is normally conducted face to face just like structured interviews and reliability of data is much higher compared to other traditional questionnaires. All of these interviews lasted for more than an hour. Further, it is also due to the advantage of DEMATEL over other systems is its confidence in its ability to produce possible results with the least amount of data. Further, statistical power is not relevant in fuzzy DEMATEL as emphasizes is on the expert-driven analysis under uncertainty, without concern for sample size or power analysis typical of inferential statistics. Moreover, fuzzy DEMATEL uses a small, purposively selected group of domain experts; highlights that structural insights matter. Therefore, it uses a small but well-informed expert panel to uncover the most influential competency factors, stressing clarity over quantity. Therefore, in this study, experts had more than 10 years experience.

After identifying the problems, next phase was how to optimize these problems. So, in next stage (Phase-2), the opinion of field experts was collected through a semi-structured interviews. Rationale behind selection of these variables are provided as follows: Data were collected from experts until saturation of ideas is achieved [49]. In this regard, a study was conducted to decide saturation point for qualitative data, where it was mentioned that coding saturation is reached after nine interviews, while saturation point for meaning was reached after twenty four interviews [50]. Then thematic analysis was performed to work out the major and sub themes from collected data. Ultimately, at the end of second stage, strategies to deal waste control, were identified. After that, a framework to implement those strategies was formulated with the help interviews [51, 52].

Finally, the proposed framework was validated thorough a case study in Phase 3. One project was completed under the guidelines of proposed strategies for WM at micro level and, it was then compared with traditional projects of local construction industry along with other developing and developed countries [33].

1.5 Brief Methodology

This study followed a process-based approach as illustrated in Figure 1.1. The entire research was divided into three phases. In Phase 1, significant barriers to WM and CE practices on building projects were identified. In the second phase, strategies and policy framework to address these barriers were developed to promote CE principles. In the final phase, a policy framework was validated at micro/project level by implementing proposed WM strategies on a real-time newly constructed building project.

In Phase 1 of this research, barriers to WM in building projects were identified through an in-depth literature review. Subsequently, two step filtering process was

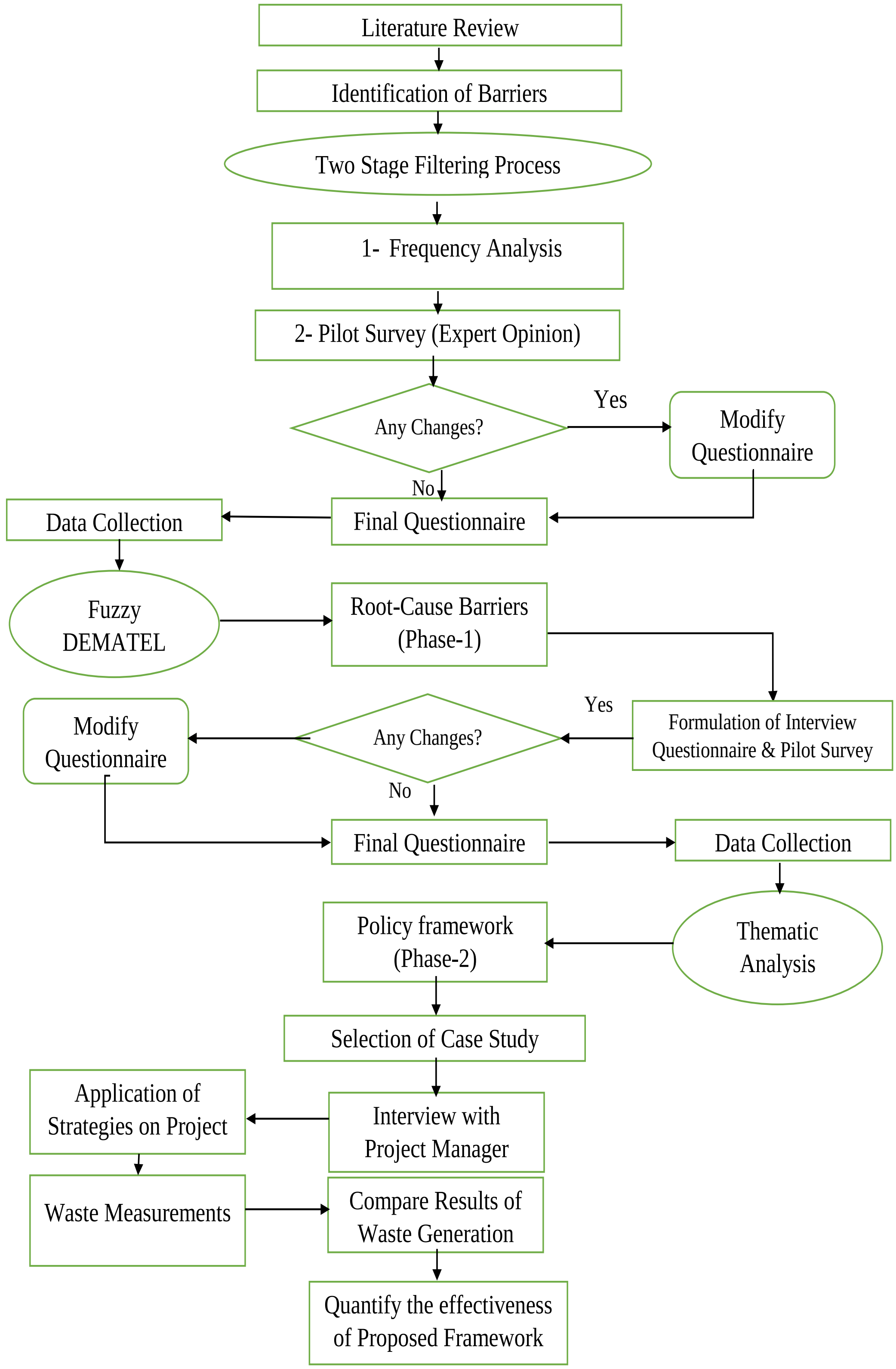

FIGURE 1.1: Brief Methodology for Research

adopted to shortlist the barriers. In the first step, a frequency analysis was conducted to identify the most significant factors. The selection criterion was based on frequency factors occurring more frequently were considered more important. Based on this, the high frequency factors were shortlisted. In the second step, a questionnaire was developed, and a pilot survey was conducted with field experts and regulatory bodies to validate the questions and to identify any important barriers that may have been overlooked during the frequency analysis. Following validation and necessary modifications, the structured interview was conducted with face to face interactions, to key stakeholders in the construction industry, including clients, consultants, contractors, and environmental agencies. At least thirty (30) valid responses were collected. The fuzzy-based DEMATEL technique was chosen for analyzing the qualitative data.

In the second phase of the research, strategies against the identified barriers for the local construction industry were identified. After identifying the most influential barriers to WM, appropriate strategies were developed to address them. For this purpose, semi-structured interviews were conducted. These interviews allowed experts not only to share their opinions on the issues presented but also to contribute additional insights beyond the scope of the original questions. Interviews continued until no new information emerged, reaching a saturation point after approximately twenty-four interviews. A thematic analysis was then carried out on the collected data to identify WM strategies and develop a policy framework, proposed by industry stakeholders. These strategies are linked to macro level efforts as well as project level efforts. Macro-level efforts are more related to governments, while micro-level efforts are linked to project.

In the final step, the proposed framework was partially validated at micro/project level to demonstrate its impact and significance. This was achieved by implementing the framework on a building project and comparing its waste generation rates with traditional projects from past studies based on 10 key construction materials. Results were finally compared and waste reduction rates as a result of application of WM strategies were calculated to quantify the effectiveness of proposed framework.

1.6 Research Impact on Industry

In this section, impact of current study on industry is discussed with different prespectives such as novelty, research significance, practical implementation, national impact, global impact and research deliverables.

1.6.1 Novelty and Research Significance

This study makes a significant and novel contribution by presenting a comparative analysis of stakeholder perceptions to uncover cause-and-effect relationships among the barriers to construction WM within the specific context of Pakistan. Unlike previous research that has primarily focused on developed nations with established WM frameworks, this study addresses a critical gap by highlighting the lack of formal WM policy guidelines in Pakistan. It provides empirical evidence to support the development of Pakistan-specific policies tailored to its regulatory, economic, and industrial conditions. Moreover, the research advances the field by evaluating the practical implementation of WM strategies across all major phases of building projects including design, construction, and post-construction. It offers quantifiable insights into the effectiveness of these strategies, shedding light on an underexplored area and delivering actionable recommendations for improving WM in resource-constrained environments like Pakistan. So, this research mainly deal with three different aspects which contribute to the global body of knowledge.

Moreover, the study identifies key barriers commonly faced by multistory building projects and explores the challenges that hinder effective WM. These findings support the development of a comprehensive framework aimed at assisting policymakers in regulating and reducing construction waste. By integrating CE principles, the framework promotes sustainability and minimizes the environmental impact of construction activities. A key strength of the research lies in the validation of this proposed framework, which confirms its practical applicability and builds confidence among policymakers, industry professionals, and other stakeholders. This validation reinforces the frameworks value as a reliable tool for improving WM practices and fostering sustainable construction. The study offers multiple practical benefits, including enhanced material utilization efficiency, reduced project costs, and lower environmental footprints. It also contributes to the formulation of effective policy guidelines for WM and CE, serving as a vital resource for improving environmental regulations and sustainability strategies within the construction sector.

1.6.2 Research Challenges

During the course of this study, several challenges were encountered. These challenges were primarily associated with participant selection, data collection, and case study identification across the three phases of the study. The most significant difficulty arose in engaging field experts for data collection. Many potential participants either declined to take part or did not respond to repeated requests, largely due to their demanding professional commitments. Since the research required inputs from highly experienced specialists with practical exposure to WM and CE practices, the pool of eligible experts was already limited. This challenge was compounded by the fact that the study design relied heavily on their judgments for the Fuzzy DEMATEL analysis in Phase 1 and the development of strategies in Phase 2. Securing thirty experts for Phase 1 and achieving data saturation during the interviews in Phase 2 therefore required persistent follow-ups and leveraging professional connections. Moreover, the length and complexity of the questionnaire (156 items) in Phase 1 placed additional burden on participants, resulting in longer interview times (often more than one hour per session) and making scheduling even more difficult.

These factors collectively extended the overall data collection timeline. The third phase presented a different but equally critical challenge: identifying a suitable real-world project to validate the proposed framework. In Pakistan, there are no formal policy guidelines that obligate contractors, consultants, or clients to implement systematic WM strategies on construction projects. As a result, most ongoing projects did not provide an adequate basis for testing the framework. The selection process therefore required extensive screening and consultation to identify a project where the client demonstrated a genuine interest in applying WM practices. Ultimately, the chosen case study was influenced by the willingness of the projects client to adopt structured waste minimization measures, which not only enabled practical validation of the framework but also highlighted the importance of client motivation in driving sustainable practices in the local construction industry.

1.6.3 Ethical and Management Considerations

As the current case study involves human participation and the collection of personal opinions, ethical approval was obtained from the relevant institutional review board prior to the commencement of the research. In each phase of the study, participants were required to sign an informed consent form, which assured them of the confidentiality of their identities and personal information. Participants were also informed that there were no associated risks in sharing their views with the research team. To ensure methodological rigor and project efficiency, the study was planned and executed in a structured manner from the outset. A schedule baseline was established to minimize the risk of delays and to ensure that all research milestones were achieved within the designated timeframe. In order to obtain valid results for current research, input from all key stakeholders such as clients, consultants, contractors and regulators were taken.

1.6.4 Research Deliverables

This research delivers a comprehensive and context-specific framework for construction WM in developing countries. It identifies key barriers, WM policy framework, and practical applications of selected strategies including BIM-led design improvements, reuse of materials, and selling of waste for recycling, helped to achieve lower waste generation rates. These waste generations rate is significantly lower from other traditional projects in Pakistan and other developing countries and very much comparable to developed countries.

The outcome of this study which is a WM policy framework for construction sector, can be adopted by other developing countries with similar construction practices. Further, the results of this study can help to achieve united nation sustainable developments goals such as SDG-11, SDG-12 and SDG-13. These insights can power awareness campaigns, industry workshops, and strategic partnerships with governments and academic institutions.

1.7 Dissertation Layout

The dissertation consists of six chapters, out of which Chapter 3 to 5 are aimed for independent journal articles. However, slight modifications (in original paper format) are made to keep the write-up in line with dissertation layout. Accordingly, the dissertation is organized in the following way:

Chapter 2 presents the literature review regarding the construction waste generation and its management. The literature review presented in this dissertation is broadly classified into three main aspects; i. barriers to WM and CE on building projects, ii. strategies to control these barriers; and iii. framework development and validation on building projects. In the end, major research gaps are identified, which are the basis for selection of objectives for this research.

In Chapter 3, explains the analytical tool which is used for identification of these barriers.

Chapter 4 focuses on identifying the strategies and policy framework against those identified barriers by conducting semi-structured interviews from field experts. Thematic analysis is conducted on the collected data to get the required results.

Chapter 5 portrays the significance of using WM policy framework by validation on a real time building project.

Finally, this study includes conclusions and future recommendations in Chapter 6, followed by a list of references and appendices.

Chapter 2

Literature Review

2.1 Background

This section presents a comprehensive review of previous research, with a focus on identifying critical knowledge gaps relevant to the current study from the dual perspectives of WM and the CE within the context of the building industry. The review addresses several key areas including the rates of material waste generation in building projects, prevailing barriers to effective WM and CE implementation, as well as strategies, tools, techniques, and validated frameworks aimed at enhancing sustainability in construction practices. To establish a solid foundation for identifying the research gap, a comprehensive literature review was carried out using multiple reputable academic databases, including Scopus, Web of Science (WoS), ScienceDirect, Google Scholar, and the ASCE Library. The search strategy involved a combination of relevant keywords such as construction waste management , construction WM , developing countries, Pakistan, barriers ,challenges , stakeholder perceptions, etc. The search was limited to peer-reviewed journal articles published between 2010 and 2025, written in English, and focused on construction waste management practices, challenges, strategies, and stakeholder perspectives, particularly within developing countries and the South Asian region. The initial search yielded approximately 200 journal articles. A two-stage screening process was employed to refine the selection. In the first stage, titles and abstracts were reviewed to eliminate studies that were clearly out of scope.

In the second stage, a full-text review was conducted to ensure that the selected articles were methodologically robust and directly relevant to the research objectives. As a result, 30 high-quality journal articles were shortlisted for in-depth analysis. These articles served as the basis for identifying key research gaps, particularly highlighting the absence of formal waste management policy guidelines in Pakistan, limited practical implementation of WM strategies, and varying stakeholder perceptions, areas that remain underexplored in the current literature. An overview of the distribution of these journals is presented in Figure 2.1, highlighting the prominence of certain sources such as the Journal of cleaner production, Waste management, Resources, conservation and recycling, Sustainability, Buildings, and Construction engineering and management. These journals were particularly influential due to their relevance and high volume of contributions to the topics of WM and CE in construction.

Through a detailed analysis of the selected literature, recurring patterns, key aspects, and associated sub-aspects were systematically identified. These are visually summarized in Figure 2.2, which serves as a roadmap for the subsequent discussion and analysis in this chapter. By presenting the review in a systematic and hierarchical manner, the figure helps readers easily navigate the interconnections between concepts, themes, and variables. This structured approach not only promotes a clear and coherent understanding of the existing body of knowledge but also provides a logical pathway for identifying underexplored areas and specific research gaps that the present study seeks to address. The literature review is organized around three overarching aspects: (1) barriers to WM and CE practices and their impact on building projects, (2) enablers for construction waste minimization, and (3) waste minimization frameworks for CE culture and their validation. Each of these aspects is further divided into three sub-aspects, which are themselves broken down into two to three sub-sub-aspects, allowing the discussion to progress from broad thematic areas to more specific, actionable insights.

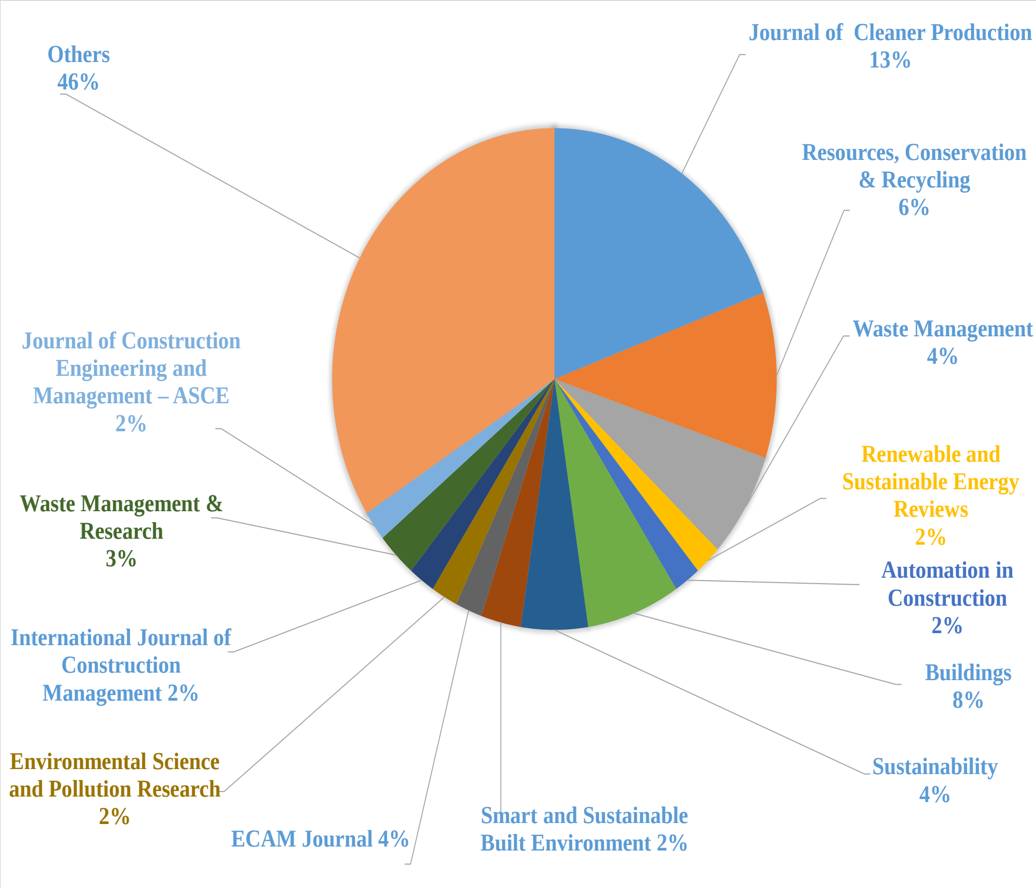

FIGURE 2.1: Summary of Journals Consulted for This Study

2.2 Barriers to WM and CE Practices and its Impact on Building Projects

In this section, barriers to WM and CE, impact of poor WM practices on waste generation rates of different building materials and some recent tools and techniques to workout significant barriers to WM in the building industry are being discussed. Waste Minimization which follows the basic principle of 3 R's (reduce, reuse and recycle) for material utilization, has not been got the due attention as it should have. Further, major principles of CE are based on 10 R's (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) [53, 54]. While many developed countries are moving to 10 R's approach, many developing countries including Pakistan hasn't excelled the basic 3 R's approach yet. Past studies reported that major reasons to this were, non-availability of

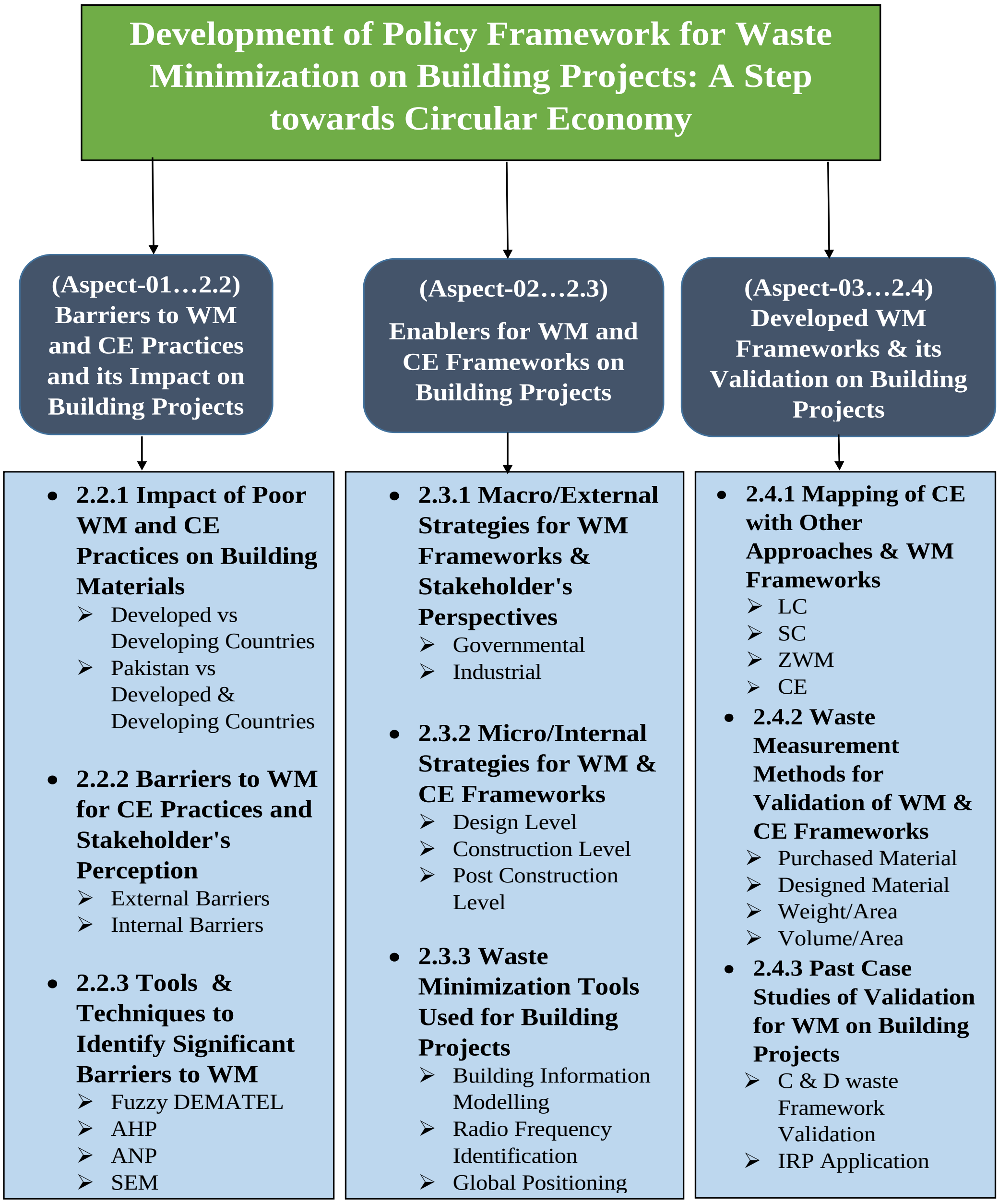

FIGURE 2.2: Different Aspects and Sub/Sub-Sub Aspects of Literature Review

rules, regulations, lack of support from governments [55, 56]. It means formulation of policy guidelines and financial supports from governments are essential to reduce waste on construction sites. Due to these reasons, millions of tons waste was generated on buildings sites. Tools which have been used in past to identify the barriers in waste control include fuzzy methods, analytical hierarchy process, analytical network process, etc. So, it is need of current time to identify the barriers with the help of these tools and control waste generation of building materials on construction sites.

2.2.1 Impact of Poor WM and CE Practices on Building Materials

This section is explaining the past studies which identified the waste generation rates of some important building materials as a result of poor WM and CE practices. There are multiple studies which measured wastes generation rates of materials on building projects. These studies include the research studies from different developing as well as developed countries as shown in Table 2.1. Table 2.1 presents the waste generation rates (WGRs) of various building materials reported in both developing and developed countries. These studies highlight considerable variation in waste levels, largely attributed to weak WM and CE practices along with other factors. Waste rates can be measured in multiple ways, such as by comparing the percentage of purchased versus used material, calculating waste per unit area of the building, or estimating waste volume generated per unit construction area. Each method has its own accuracy limitations, yet all consistently reveal that WGRs vary widely across countries due to factors such as lack of awareness, absence of waste control policies, and poor enforcement mechanisms. The data in Table 2.1 clearly shows that WGRs in such as Pakistan, Jordan, Nigeria are significanlty higher for all listed materials. For example, bricks waste in Pakistan is reported between 10-13.7% while in Nigeria (14.15%) and Jordan (17%). Similar trends are observed for tiles, steel, and blocks.

Further, WGRs in Pakistan's construction industry were reported as (9.33-13.5%), bricks (10-13.7%), wood (36.2%), steel (4.5-5.2%), concrete blocks (14.5%) and false ceiling boards (13.6%). Major reasons to these WGRs in Pakistan were reported as improper worker's skills, poor supervision to control on-site waste, equipment malfunction and lack of waste reduction plans [59]. In case of Malaysia, WGRs of concrete (7.5%), tiles (2.6%), bricks (5.8%), wood (49%), steel (4.4%) and ceiling boards (0.4%) were reported. The reason for high WGRs of wood was found as excessive use of wood in scafolding and formworks. So, cutting wood to adjust these elements as per site conditions were the major cause of waste generation [60].

Table 2.1: Waste Generation Rates (%) of Building Materials for Developing and Developed Countries

Material	[57]	[39]	[58]	[59]	[60]	[61]	[62]	[63]
	Pakistan	Jordon	Nigeria	Pakistan	Malaysia	China	South Korea	Australia
Concrete	-	-	14.13	-	7.5	2.3	2	1.8
Tiles	13.5	15.6	21.38	9.33	2.6	-	2.5	3.6
Mortar	-	-	14.91	10	-	-	0.3	-
Bricks	13.7	17	14.15	10	5.8	-	3	6.9
Wood	36.2	19.49	-	-	49	33	13	49
Steel	4.5	16.91	19.03	5.2	0.9	4.4	-	7.2
Blocks	14.5	17.05	-	-	-	-	3	-
Ceiling Boards	13.6	20.70	15.70	-	0.4	-	-	19.3

Furthermore, reason of higher WGRs of concrete were reported as over-ordering of concrete and poor workmanship during pouring [60]. Similarly in China, WGR of wood was reported as (33%), major reason to this much WGR was identified as mishandling of formwork for concrete activities [61]. Moreover, wood (49%) and ceiling boards (19.3%) were identified as the most wasteful materials in Australia, major causes to higher WGRs of wood was large quantities of timber which were used not only in formwork but also in internal walls and joists as well [63]. Further, reason for waste of ceiling boards was identified as improper handling during placing. Overall, waste levels of mutiple materials in different countries remain high as reported above. So, higher WGRs of building materials demand focused interventions. These findings highlight the need to identify and address the root-cause barriers that hinder the adoption of WM and CE practices in Pakistan's construction industry as well. These barriers can be linked to macro-level issues as well as micro-level barriers.

2.2.2 Barriers to WM and Stakeholders' Perception

This section outlines the major barriers to adopting WM and CE practices in the building industry. In the past, quantification of material waste remained an area of research for a long time but with the increase of environmental challenges day by day, the optimum utilization of resources is considered a potential area of study in developing as well as developed countries in recent times. In this regard, number of studies have been conducted to identify the major barriers in implementation of WM and CE strategies as a first step to highlight the key problems. Forty one (41) barriers which were identified in past researches can be categorized into two major parts such as external and internal barriers with the respect to the project as reported in Appendix-A and Appendix-B. So, a frequency analysis was performed based on sixty past papers. Barriers having a frequency rate more than 10% have been shortlisted for next stage of this study. Top thirteen (13) most frequently occuring barriers are listed in Table 2.2.

This paragraph explains the major barriers which are identified in past studies. Many of these barriers were related to the macro/external factors as shown in Table 2.2. Detailed list of external barriers is shown as Appendix-A. These factors include the problems that construction industry faces at national and industrial level. National level problems include; weak political will to implement WM techniques in construction industry [30]. Further, non-availability of environmental bylaws, lack of financial support from governments in the form of subsidies, shortage of infrastructure to deal wasted materials, lack of awareness and illegal dumping sites due to low waste disposal fines are also considered as potential barriers to waste control culture. These are some of the significant barriers which exist at national levels throughout the world. Further, construction industry culture matters a lot to promote the CE practices [64]. So, industrial level barriers which were frequently reported in past studies include; high upfront cost, lack of operational weaknesses, poor training and education, confidence on quality of recycled materials, poor business models, non-seriousness from clients to follow waste management culture, etc. It can be synthesized that controlling these barriers can have significant impact on improving the waste control practices at macro as well as micro levels. Therefore, there is a need to control these barriers at each level either it is a macro or micro level.

TABLE 2.2: Frequently Occurring Barriers to Waste Control Practices

Rank	Barrier's Name	Details of Barrier	Frequency
1.	Rules and regulations	Lack of environmental and waste control policies	45%
2.	Financial issues	High upfront cost, lack of subsidize	40%
3.	Poor awareness of stakeholders	Lack of trainings and education	33%
4.	Legal enforcement	Poor implementation of rules and regulations	30%
5	Shortage of resources	Lack of recycling plants, infrastructure, qualified labour	28%
6.	Lack of collaboration	Poor communication among different departments	27%
7.	Low cost for waste disposal	Fines for illegal dumping are very low	27%
8.	Poor construction practices	Improper handling of materials, poor supervision	25%
9	Illogical Design	Errors, Omissions, Clashes among drawings	23%
10.	Lack of innovation in design	Least waste design options	22%
11.	Poor behavior of stakeholder	Waste control is not a preference	20%
12	Unclear specifications	Change of drawings	18%
13.	Lack of use of modern tools	BIM, GPS, RFID, etc.	17%

Next are the micro/internal barriers which exist at project level such as barriers which can occur during design, execution and post construction phases of a project. These barriers could be further categorized into three; 1) design phase barriers; 2) construction phase; and 3) post construction phases barriers of a project. In term of design phase, major barriers include; illogical design, design and detailing errors, unclear specifications, clash leading to reworks, design changes, complex designs, scope changes, lack of innovation in product design, lack of building design standard, lack of attention to design buildings with least waste generation option, lack of modular design, and lack of prefabrication practices and designers behavior [26, 65, 66]. So, controlling these barriers can cut off the waste from its source. Because design is that phase of project where vigilant decision can reduce or prevent significant amount of waste from its generation. Next is the construction phase, where number of problems arose during execution of activities such as lack of supervision, poor behavior of contractors, ineffective sorting, transporting, and recovering processes of materials, lack of effective waste management practices, lack of space for onsite storage, lack of time needed for material separation, lack of contractual requirement for reusing materials and off-site construction are not practiced [67]. Detailed list of internal barriers is shown as Appendix-B.

Since all these barriers demand significant amount of capital for their control, so industry is usually reluctant to put some efforts in controlling these issues. Lastly, post construction phase of project include; lack of waste auditing, insufficient logistics, illegal waste dumping, no recyclable infrastructure, non-availability of GPS for designation of dumping sites as a potential barriers [68]. The involvement of all stakeholders like client, consultant and contractors in removing these barriers is also very important. These barriers exist at macro as well as at micro levels. In terms of stakeholders' perspectives, one study reported where barriers to WM of solid waste were reported [46]. But in this study, experts from only governmental projects & technology providers were considered and their perceptions were compared. Removing these barriers would help countries to align their construction practices with SDGs 11, 12 and 13. In the context of developing countries, the body of knowledge is very limited in providing the insight about barriers and policy guidelines for WM. Few studies have been reported in terms of barriers identification in these countries. Hasan et al. [28] identified barriers to WM in Bangladesh as negligence of workers, poor supervision, unskilled labour, lack of on-site materials storage. In another study conducted by Kumarasiri and Dissanayake [69], in Sri Lanka identified major barriers as lack of support from governments, high investment and operational cost, lack of knowledge among experts. Further, organizational resistance to change, unwillingness from stakeholders, complex documentation process and difficulties to deal environmental issues found as important barriers in Nigeria [70]. It can be concluded that the barriers to WM identified across various studies differ significantly. This variation is largely attributed to differences in construction practices and unique cultural values in each country [29].

2.2.3 Tools and Techniques to Identify Significant Barriers to WM

Major tools and techniques which have been used to identify the barriers in WM on building projects are discussed in this section. There were number of methods which had been used to analyze qualitative data. Since the qualitative studies have an element of subjectivity. Therefore, to deal with that subjectivity, multiple tools were being employed in different studies. It includes analytical hierarchy process (AHP), analytical network process (ANP), structural equation modelling (SEM) and fuzzy decision making trial and evaluation laboratory (DEMATEL) as shown in Table 2.3. Analytical Hierarchy Process is a well-known multi criteria decision making method (MCDM) technique [71] that has garnered a lot of interest from several industries, including construction, throughout these years. There are a lot of different decision-making components, and that these components interact in complex and frequently nonlinear ways. AHP is a formidable tool for strategic decisions in the construction industry[72] . [72] suggested that three steps make up the AHP: (1) hierarchy formation: the decision goal was contained in the top level of the hierarchy, while the lower levels represent the progressive breakdown of the decision criteria, sub criteria, and alternatives for achieving the decision goal,

(2) pairwise comparisons: decision-makers (who are frequently subject-matter experts) were asked to complete pairwise comparisons of the elements at each level of the hierarchy, assuming the elements are independent of each other. comparisons of the relative weights of each pair of criteria at the second level of the hierarchy were made in light of this and the decision goal, and (3) verification of consistency - expert judgments were required to establish the relative weights of each criterion and any potential alternatives to accomplishing the hierarchy's decision aim. However, AHP does not provide any interdependencies between and among the variables, rather used to draw the hierarchical structure of the variables [73].

While the Analytical Neural Process (ANP) provides complicated interactions between decision levels and attributes, the AHP represents a unidirectional hierarchical relationship. There are four primary steps in the ANP. A decision problem is approached using both qualitative and quantitative methods in the ANP. [72] suggested the four main phases for the qualitative component such as (1) determine the decision-making problem: the choice issue would be to "select the highest scored construction project" if a client wants to choose the project with the greatest score out of several feasible construction projects, (2) verify that ANP could solve the decision-making problem: when solving decision problems involving a network structure, the ANP is appropriate. AHP can resolve issues with a basic hierarchical model, (3) break down the unstructured issue into a number of controllable and quantifiable stages, and (4) determine who should be in charge of making the choice. Usually, a small group of top management or subject matter specialists was enough to deliver pertinent information. ANP can show interdependencies between and among the variables, but because of its complexity, this approach is less popular [74].

Next tool is structural equation modelling (SEM), which is a multivariate method for examining and analysing the relationship between variables [11]. Regression analysis, factor analysis, multiple correlations, and path analysis are all included in SEM, making it a powerful tool. [75] found that SEM addresses measurement error and had the ability to estimate and graphically depict numerous connected interactions. SEM had been utilised to investigate important design solutions for reducing waste in construction projects because to its capacity to estimate and graphically portray numerous and connected variables. Confirmatory Factor Analysis (CFA), a key advantage of SEM in this study, assisted in validating the association between measured variables and waste-efficient design method as an independent variable. Based on the strength of the established correlations between measured, first and second-order variables, the tool assisted in determining the significant variable.

The 'a priori' method of SEM is mostly employed for theoretical development but large sample sizes are needed for SEM [73]. Another technique to analyse the barriers for waste control is fuzzy based multi-criteria decision making technique. In a study by [76] explained that Fuzzy logic is an arithmetic technique which enables computer programmes to approximate real world issues. Every element in a fuzzy environment is defined by the degree to which it belongs, and logical reasoning is regarded as a limiting indication of indicative thinking. The vagueness of the situation frequently arises in real-world issues. It is acceptable in fuzzy logic to perform the appropriate computations in situations where the problem's intentions and restraints cannot be precisely stated or expressed. It is suggested applying the idea of fuzzy sets as a modelling tool for complex systems that are very likely to be under human control but are hard to literally qualify to handle high-quality, incorrect information or even poorly structured conclusion difficulties. The method known as fuzzy-based multi-criteria decision analysis enables the decision-maker to formulate the issue using fuzzy logic by fuzzification in order to rank the alternatives [77].

So, fuzzy DEMATEL is fuzzy based multi-criteria decision making technique and this approach relies on human assessments regarding variables that are typically ambiguous and challenging to predict using precise numbers. The DEMATEL approach is expanded with the fuzzy set theory and employed in this study since the interaction between the barriers impacting the zero-waste methods cannot be described numerically. The rationale for using fuzzy decision making trial and evaluation laboratory (DEMATEL) is that: (1) it is challenging to examine interactions between waste management obstacles because of their subjective nature,

Table 2.3: Assessment Tools Used in Past Studies for Barrier's Identification

Sr. No.	Tool Name	Advantages/Strengths	Disadvantages/Limitations	Reference
1	Fuzzy DEMATEL	Excellent in mapping causal relationships among barriers: which barriers are root causes (cause group) vs which are effects. Helps in prioritizing which barriers to tackle first. Visual representation (causeeffect diagrams.	May not capture the hierarchical structure (levels) of barriers well. If many criteria, pairwise relation assessments can be cumbersome.	[40, 46, 55, 78–81]
2	AHP	Intuitive and relatively easy to use; good for structuring complex decision problems in a hierarchical way.	Assumes criteria are independent (no interrelationships). In waste management many barriers interact; AHP may oversimplify, pairwise comparisons become difficult and burdensome when many criteria/subcriteria.	[82–84]
3	ANP	Can handle interdependencies / feedback among criteria and between criteria and alternatives; more realistic for barrier systems. Captures more complexity, more accurate weighting when dependencies exist.	More complex than AHP: setting up the network, constructing the supermatrix, ensuring convergence etc. More computationally heavy; greater demand on expert time and data.	[85]
4	SEM	Allows modeling of latent variables (barriers that cannot be directly observed) and measurement error. Provides statistical fit indices to evaluate how well model fits data. Good when you have sufficient data.	Requires large sample sizes, especially if many variables/latent constructs. Needs strong theoretical foundation (model specification) to avoid misspecification.	[86, 87]

(2) fuzzy DEMATEL offers a quantitative examination of waste minimization barriers and (3) the cause-and-effect connections between these obstacles can aid in the development of regulatory initiatives by decision-makers using MS Excel as tool to analyse the data. However, in real-world decision-making situations, decision-makers or experts always communicate their opinion of qualitative criteria verbally rather than using numerical figures. Such verbal evaluations are imprecise, which makes it difficult to compute additional analyses.

As a result, a fuzzy set theory could be used to quantify ambiguous ideas linked to subjective assessments [40]. However, the method is not without limitations. One major concern is its reliance on expert opinion, which introduces the possibility of subjectivity and cognitive bias. Even though fuzzy extensions are often employed to reduce this uncertainty, the initial judgments remain dependent on the perspectives and experience levels of the selected experts. Overall Fuzzy DEMATEL is an effective tool to deal with the complexity of subjectivity and finding out the cause-effect relations. So, in the light of above discussion, it can be established that higher waste generation rates in local context demands a detailed investigation into the root causes in terms of barriers either they are external or internal. Further, higher waste generation of construction materials can be controlled on building projects by finding out the root causes of its generation in the form of barriers through fuzzy decision making trial and evaluation laboratory (DEMATEL) technique. This can solve the problems of waste generation at both macro and micro levels by proposing the WM strategies against identified barriers to promote CE culture.

2.3 Enablers for WM and CE Frameworks on Building Projects

Following the identification of key barriers to WM and the adoption of a CE culture in building projects, it is essential to explore potential strategies for addressing these challenges. The factors reviewed and analyzed in the previous sections not only highlight the critical issues faced by the construction industry but also serve as the foundation for the development of interview questions used in the subsequent empirical phase of this study. Thematic analysis was performed on the collected data in the past studies [88]. There are number of softwares available which can perform thematic analysis on collected data. These softwares include:

1. MAXQDA, is a powerful and user-friendly qualitative and mixed-methods analysis software. It supports importing and organizing diverse data types, coding and categorizing qualitative information, AI-assisted analysis, automatic transcription of audio and video files, and the use of visualization tools. In addition, it facilitates mixed-methods analysis by integrating qualitative and quantitative findings within a single platform.

2. ATLAS, is a comprehensive software for qualitative data analysis that enables importing diverse data types, structuring information through coding and memos, and leveraging AI tools for automatic coding and sentiment analysis. It also provides visualization features such as word clouds and network diagrams, supports the development of conceptual networks, and facilitates real-time collaboration among research teams.

3. QDA Miner is a mixed-methods software for qualitative data analysis that supports data import, manual and automatic coding, and retrieval and analysis of coded segments. It also offers a variety of visualization tools, including charts, maps, and network graphs, to help interpret and present research findings.

4. NVivo which enables researchers to import and organize diverse unstructured data (text, audio, video, social media), apply qualitative coding to identify themes, explore insights through queries and visualizations, collaborate within teams, and generate structured reports to support qualitative and mixed-methods research) [89]. So following section explains in detail about the methods how CE can be promoted through WM on building projects in construction industry.

Although all four software packages offer robust support for thematic analysis, NVivo has clear advantages that justify its preference in academic research. First, it can handle a wide range of unstructured data sources, which makes it suitable for modern qualitative studies that increasingly rely on diverse datasets [90]. Second, NVivo provides advanced features such as matrix coding queries, cluster analysis, and rich visualization tools that allow researchers to uncover deeper thematic patterns [91]. Third, it is the most commonly cited software in qualitative research publications, demonstrating its strong acceptance and credibility in the academic community [92]. Fourth, NVivo supports collaborative projects by enabling teamwork across dispersed research groups and offering cloud integration, which is particularly valuable for multi-country or interdisciplinary studies [93]. Finally, NVivo ensures transparent and rigorous research processes through its structured reporting and output functions, aligning with the increasing demand for replicability in qualitative studies [94]. These strengths make NVivo particularly suitable for thematic analysis of semi-structured interviews, ensuring robust, credible, and methodologically rigorous outcomes.

2.3.1 Macro/External Strategies for WM Frameworks and Stakeholder's Perspectives

In this section external/macro level strategies which provide the basis of framework for WM and CE on building projects are explained in details with respect to past studies. External WM and CE strategies can be further divided into two sublevels. One is at the national or governmental levels in the form of polices and other is at industrial level. Governmental efforts to ensure WM practices are being followed on building projects, is very important. In this regard, multiple past studies were consulted and reported over here. In any industry, there is always a commitment which is required from the policy makers or top management. Same is the case for WM culture. In order to implement WM practices in construction industry, there should be some serious actions required at governmental level in the form of policies and its enforcement. So, a frequency analysis of external strategies was performed based on past studies. So, in the past studies as shown in Table 2.4, some of the most important strategies which were reported include governmental support to promote WM, SOPs, environmental management system, legislation and policies, financial support for CE research, provide subsidize on projects where recycled materials were used, duty and tax relaxation for green practices, policies for recycled materials, designated public and landfilling areas [95–97]. So all these methods can persuade the stakeholders in the industry to follow the guidelines of WM. Therefore, external strategies can have large impact in terms of development and implementation of CE culture through WM in building industry. It can force the stakeholders to follow CE practices. Detailed list of strategies reported in different studies is shown as Appendix-C.

Industrial strategies mean WM methods are implemented by building industry at organizational levels. Because industrial level is the second most important tier after government that could have substantial impact to implement WM practices. Efforts which were reported in past studies include business models for facilitating CE culture [98] such as material recycling plant and selling of recycled material. Application of external strategies is important to develop a WM culture, because commitment and enforcement from top level stakeholders can be more effective in this regard.

Further, application of digitization like use of RFID, GIS and GPS etc., [99], incentives for procurement of recycled materials, green behaviour of contractors, public private partnership programs, preference of stakeholders especially client, collaboration among stakeholders also have substantial impact in waste reduction on construction sites [100]. All the above mentioned strategies can motivate the organizations to bring a culture of waste management on all projects. These technologies are important but at the same time very important ones.

Strategies at governmental level in the form of regulations and efforts by organizations can be effective ways to develop and implement WM practices in the construction industry. These studies reveal that strategies to reduce waste generation vary significantly from country to country, primarily due to differences in construction practices and cultural values [29, 30]. This highlights the need for further studies to be conducted within the context of each of these developing countries to adopt WM and CE cultures on building projects in construction industry.

Table 2.4: External Strategies for Waste Minimization

Rank	Strategy	Details	Frequency
1	Financial Support	Incentives for recycled materials, To provide subsidize	58%
2	Education and training	For awareness among stakeholders	47%
3	Legislation	Policies for waste management in country	42%
4	Designated public and landfilling areas	To manage waste efficiently	32%
5	Business Model	Business models to support the recycled materials	26%
6	Cultural Practices	Industry preference Issues	26%
7	Recyclable infrastructure	Availability of recycling plants	26%
8.	Environmental Awareness	Few environmental regulations for waste control	26%
9	High cost for waste disposal	Fines for waste dumping are very low	21%
10	Information Management System	To save environment & depletion of resources	21%
11	Governmental Support	Facilitating policies	15%
12	Collaboration among stakeholders	Consultation among different departments	15%
13	An advanced research	To explore more information to reduce waste	10%

2.3.2 Micro/Internal Strategies for WM and CE Frameworks

After the external strategies (macro level), internal strategies (micro level) are very specific to the project nature and requirements. So, efforts are required to control waste on each phase throughout the project lifecycle. Project can be divided into three major phases such as design phase, construction phase and post construction phase. Details of each strategy for waste control in each phase are provided in next sections. The most important phase during project is the design phase because designer has number of alternate options to design a building component or use alternate material with the perspective of having of less waste generation. In terms of waste control practices, different studies suggested some of the significant strategies for construction waste management as shown in Table 2.5. Further, frequency analysis of internal strategies based on past studies. These strategies include modular design to construct elements in assembles rather than individual components, use of prefabricated structure to avoid in situ construction practices, design for standardization like using standard size elements and keeping the dimension of designed elements accordingly. Further, fewer design changes during execution to avoid any kind of rework, designers attitude and commitment towards waste control is also very important. Moreover, use of building information modelling (BIM) as a tool for design, avoid detailing errors in drawings and follow detailed design drawings were considered as significant methods to promote CE practices in construction industry. So, design phase strategies can be more effective to control material waste as compare to other phases of a project [12]. Because there can be very high probability to cut off waste from its source during this phase of a project. Once this phase passed, waste could have reduced with change of design option, could not be claimed later. A list of internal strategies from past literature is presented in Appendix-D.

Second important phase to reduce and reuse construction materials is the execution or construction phase. In this phase, designed elements are constructed as per specifications. There are multiple techniques which were being reported in different studies to improve the practices of waste control to achieve CE culture on building projects. These practices include waste management plans which were being followed on construction sites. These plans guide the construction workers on site how to perform different activities while keeping the wastage of materials as low as possible.

Other techniques include labor attitude, proper handling and avoid under and over ordering of materials. Because if materials is not ordered in right quantity, number of transport trips would increase and it would result in waste generation during loading and unloading of materials. Moreover, purchase of low quality materials, materials with less packaging waste, reuse of materials, storage of materials at safe places should be ensured. Contractual binding of contractors to ensure the material saving could also be an effective technique, because it bound the contractors to follow waste management plans on construction sites.

So, construction phase strategies can actually save substantial amount of on-site waste of materials. After construction phase, project closure starts. So, this is, where wasted materials need to be handled properly. Normally, materials are sorted into different inert and non-inert categories [101]. Then these materials are sent out to recycling plants for recycling purpose. Ultimately, these recycled materials are sent back to the market for reuse on some other projects. So, other techniques to deal wasted materials include storage of material in separate area, waste segregation, provide bins for materials storage, waste auditing and recycling targets.

Subsequently, recycled materials have been used in various construction applications, for example, recycled brick powder (RBP) has been utilized within sustainable alkali-activated RBP-based geopolymer production [102]. Furthermore, recycled aggregate concrete has demonstrated significant improvements in toughness under constant load cycling [103]. So, post construction activities focus on dealing with wasted materials at the end of project, either it should go for recycling unit or for landfill. So, comprehensive strategies to address the issue of waste generation in developing countries must be defined as per industry requirements. This can be possible by taking inputs from all key industry stakeholders.

Table 2.5: Most Significant Internal Strategies for Waste Control

Rank	Strategy	Details	Frequency
1	Use of latest technology	Like BIM, RFID, GPS	74%
2	Design out waste	Like modular design options	42%
3	Waste auditing	Waste targets and monitoring	37%
4	Construction practices	Offsite construction, material with less packaging waste	32%
5	Waste handling requirements	Provide sufficient space for waste handling	26%
6	Fewer design changes	Detailed and final design, so less changes occur	26%
7	Reuse of materials	At planning stage, identify materials which can be reused	26%
8	Attitude of workforce	Cultural issue	21%
9	Follow waste management plans	On site waste control plans	16%
10	Contractual binding	Contractor binding to handle waste on site	16%
11	Avoid under and over ordering of materials	Order in right quantity	10%
12	Store material in separate area	To save from weather effects	10%
13	Incentives for labour	To change their behaviour	10%

2.3.3 Waste Minimization Tools Used for Building Projects

In recent times, technological advancement has shown significant changes in all industries. Construction industry is no more different than other industries in this regard. Multiple tools have been used now a days for different purposes. Same is the case of waste minimization, where number of tools such as building information modelling (BIM), radio frequency identification (RFID), global positioning system (GPS) and geo-informatics have been used to control waste on building projects and promote WM and CE cultures [26, 99, 104–106]. In previous studies, usage of these tools have been reported as shown in Table 2.6. Following paragraphs will discuss in detail the usage of these tools at different levels on a building project.

Latest studies are focusing on management of these wastes with the help of advance technologies. In this regard, BIM has been proved a potential tool to design out waste at planning stage as well as during execution phase. BIM could reduce waste during planning and design stage by accurate estimation, better collaboration, feasibility analysis, using multiple possible design options, modular design, removing any clashes at early stage of project. Similar kind of results were also found in Malaysian construction industry [107]. Further, BIM used to reduce construction waste by 15% by using its characteristics of clash detection, identification of discrepancies and errors and omissions [108]. Moreover, BIM was used for planning of tiles by developing algorithm to design out waste through proper selection of cutting. Waste reduced almost from 5 to 15% [26]. So, this reduction of waste of different materials will improve the efficiency of these materials and reduce the burden on natural resources. Therefore, BIM can have large impacts to control material waste during design and execution phases of a building project.

Radio frequency identification (RFID) is a good tool since it can record data accurately and deliver real-time information. At the exits and entrances of building sites, RFID readers or writers can be deployed. On objects like transport vehicles or other objects, RFID tags can be implanted. The RFID tags can store data such as the date and time of garbage disposal, the type of waste, the volume of waste being transported, and the location. Reading and writing happen automatically and without any lag time. As a result, there were fewer human errors and high efficiency. A system that employs RFID to record research data, including position, volume, weight, and inventory tracking as well as data on cargo container movement [109]. The same attributes of RFID can be used to locate the positions of construction materials as well as wastes. The collected data can be entered into a management program to help decision-makers with analysis, planning, and tracking. The use of this system in a case study demonstrated the effectiveness of RFID technology in obtaining timely and accurate information, which was the foundation of this system. So, RFID technology can be used at construction and post construction phases of project.

TABLE 2.6: Latest Tools Used for Waste Control

Sr. No	Tools	Used for	Phase of Project	References
1	BIM	Enables design-out waste during planning and design stages through clash detection, modular design, and feasibility analysis. Provides accurate estimation of material quantities, reducing over-ordering and material waste. Supports multiple design options, minimizing design-related waste.	Design & Construction	[26, 104, 108]
2	RFID	Utilized to track construction materials. Proven effective in case studies for accurate record-keeping and monitoring. & labour	Construction	[106, 109]
3	GIS	Used for illegal waste disposal points. Enables real-time monitoring of vehicles transporting construction waste.	Post Construction	[29, 105, 110]

Next is the GIS, which offers significant advantages for data collection, archival, correlation, processing, and analysis. GIS is a tool for environmental impact assessments in addition to its purpose for estimating the generated demolition waste. Recently, GIS used to pinpoint the locations where construction waste was illegally disposed [110] . Further, [111] integrated GPS and GIS technology with M&E management system. Although there was little information now available on GPS applications in C&D waste management, the location system was crucial to the practice of C&D waste management. For instance, GPS could be integrated into the vehicles used for construction waste transportation to allow for real-time monitoring. Therefore, inclusion of latest tools during project design, construction and post construction phases can provide good results in waste control. Based on the above discussions, it can be established that reported studies reveal that strategies to reduce waste generation vary significantly from country to country, primarily due to differences in construction practices and cultural values [29, 30].

Overall, BIM is found as more impactful tool for WM in construction, because it can deal poor planning and design inefficiencies. Further, BIM holds a clear preference over RFID and GPS in construction waste management as it addresses the problem at its root by minimizing waste during the planning and design phases. Unlike RFID and GPS, which mainly serve reactive roles in tracking and managing waste after its generation, BIM proactively prevents waste through accurate estimation, clash detection, modular design, and feasibility analysis. This proactive approach enables significant reductions in material waste.

2.4 Developed WM Frameworks for CE Culture and its Validation on Building Projects

Considering the above discussion about material wastages. It is the need of every developed and developing country to have some WM and CE policies to improve efficiency of resources. Since the contribution of building sector is significant in waste generation. So, there should be some guidelines for development of policy framework for a building industry. Therefore, following section will highlight different approaches, previous frameworks, and methods of material waste measurements and validation of some frameworks from past studies.

2.4.1 Mapping of CE with Other Approaches and Developed Frameworks for WM

There are number of approaches which have been used to reach out the goal of WM on building projects such as lean construction, sustainable construction, zero waste management and CE. All these approaches have been used with a single goal of reducing waste and conserving natural resources. Each of these approaches have its own scope and limitations. First one is the application of lean thinking to the design and construction phases of a project results in better project delivery, which meets client needs and boosts contractor profitability. This is known as lean construction [112]. The investigation of lean construction's fundamental components reveals how its many elements can be categorised into six main areas: waste reduction, process focus in production planning and control, end-user focus, ongoing improvements, collaborative partnerships, and systems perspective [113]. The lean philosophy is normally applied in construction sectors, to improve system performance in terms of cost, time, quality and environmental effect [114]. All this to improve value of the project. But here the waste is defined as overproduction, waiting time, and inventory expenditure by drawing demand from the consumer [115]. So, lean construction deals with waste in tangible as well as non-tengible forms.

Further, the lean philosophy was evolved early in 1990s but it did not get required acceptance in construction sector even after 30 years since its inception. It is due to flow and conversion activities involve a complicated combination of labour, components, and materials relevant to construction sector [114]. Also construction projects are larger and more complicated than manufacturing, application of lean mindset becomes more challenging. Number of research studies have been reported the lack of awareness about lean construction and resistance of construction stakeholders to accept the practice of lean philosophy in construction industry [116–118]. Next approach to control waste is sustainable construction. Sustainability is a state in which human activity is carried out in a way that preserves the ecosystems' capacities on earth or it is a shift in how people live that maximizes the possibility that their circumstances will always support security, and health, especially by preserving the availability of non-replaceable goods and services [119]. There are studies which focused on achieving the sustainability in construction industry by minimizing material wastes on construction projects, which is known as sustainable construction. Such as a study was conducted by [120] and determined the sustainable construction waste management factors. In terms of sustainable construction waste management factors which were related to environment includes greenhouse emissions, resources and raw material depletion, effects of unlawful dumping in the neighborhood, etc. Further, economic factors were related to materials cost, energy cost, labour, equipment costs, transport cost, disposal, landfilled costs and reuse and recycling costs.

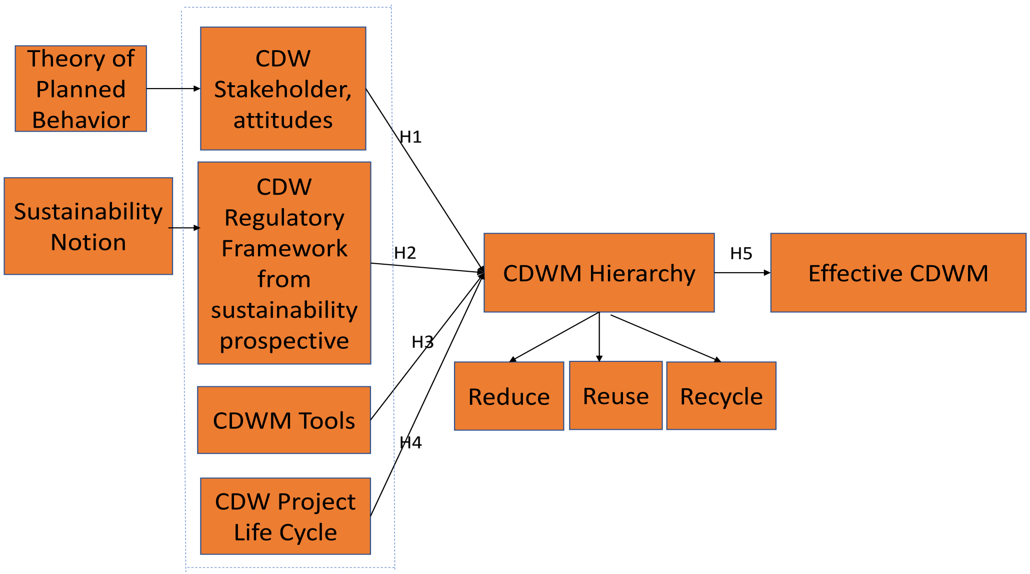

FIGURE 2.3: Construction Waste Management Framework [12] *CDW= Construction and demolition waste

Zero waste management is another approach for waste control. It prohibits incineration and landfills in general, zero waste aspires to use waste-to-energy technologies. However, the zero waste concept still needs to be broadened to reach its widespread applicability [121]. A study conducted in Shenzan City [32], China, where they developed an analytical framework to reach out zero waste generation.

In this framework, input was taken from the original or virgin construction materials, then it was used on construction site, waste control strategies were applied there. Then surplus wasted material went off site, where it was recycled. After that recycled material was sent to materials market to use it on some other project. This way, no material goes into the landfill. Ultimately, this framework promotes the concept of zero waste generation on construction sites. Waste management plans (WMPs) are becoming more popular as a useful strategy for aiding construction stakeholders in anticipating and formally observing the quantity and types of waste. This plan is concentrated on the lifecycle of the construction project, from the planning and designing stage through the demolition stage. In several countries, WMP is a legal necessity for construction activities [122].

Further, hierarchy of construction waste management include reduction of waste at design as well as construction phases, then reuse the materials and in the end the recycling of wasted materials and they are brought back to reuse again. This concept is very much similar to CE, where materials are produced, used, reused, recycled and again bring them back to that cycle to optimize its usefulness. A study which was conducted in Australia [12], developed a construction waste management framework. This framework mainly depended on four major factors such as 1) attitude of stakeholders, 2) tools for construction and demolition waste management, 3) sustainability perspective and 4) construction and demolition waste project lifecycle as shown in Figure 2.3. Further, attitude of stakeholders is related to theory of planned behavior. Similarly, Figure 2.4 shows another construction waste management framework which was developed by [32]. Overall scope of the cycle included six different steps which showed how waste was generated, collected, transported, inspected, recycled, reused and finally disposed off into the landfill areas. Mainly, framework focused on the processes which were developed for C&D waste management and deficiencies and improvements necessary to enhance the entire system. All these frameworks provide the basis for policy guidelines and very much generic in nature. More comprehensive frameworks need to be developed for construction of new buildings. Summarized list of different waste management frameworks is reported in Table 2.7.

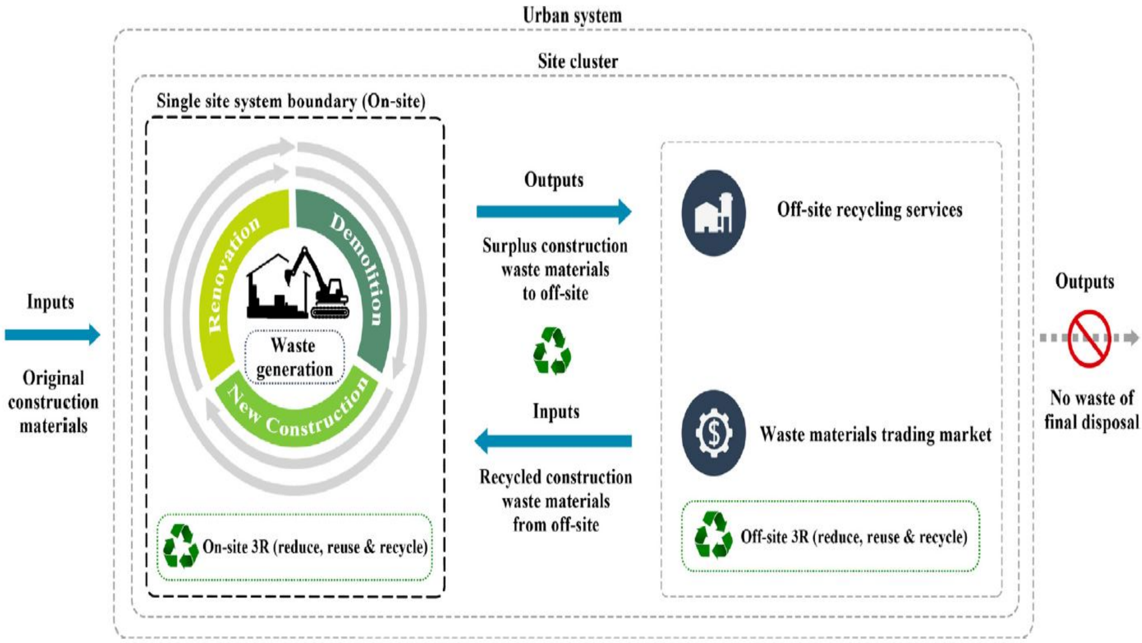

FIGURE 2.4: Zero Construction Waste Framework [32]

On the other hand, CE is a systematic shift through the process of production, circulation, consumption and recovery of materials with the ultimate aim to conserve the natural resources by efficient utilization of materials in global terms [9, 10]. In this regard, cross sectoral approach is required which demands the integration of different industries [123], like use of material waste of one industry as an input to another industry. This way, material utilization is maximized and it is the ultimate goal of CE. Major elements of CE are; priorities those materials which are regenerative, extend the lifespan of material through its proper maintenance, reuse materials after its wastage, design the materials to generate less waste, development of business models, incorporation of latest digital technology, conduct advance research to enhance CE methods and collaborate with other industries to shift with a systematic change[124, 125]. Further, major principles of CE are based on 10 R's (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) [53, 54] . So, CE is a complete systematic shift which includes efforts at macro as well as at micro levels in any industry. CE at macro levels mainly requires development of business models which support CE initiatives like building recycling units near construction sites, building material markets where recycled materials can be sold out, technologies to reduce the material waste at manufacturing units, etc. At micro level, CE includes all those efforts or techniques to save the material on building projects throughout its lifecycle from start (design) to the very end (post construction phase).

Although the concept of CE is very much new in construction industry. But it has been used in different other industries long time ago. All of the above mentioned approaches have positive synergy with CE one way or the other. There are positive synergies exist between CE and lean construction such as value addition and WM [114]. But the difference is, lean construction does not define the waste in physical terms only such as material waste but it covers all those activities which are extra in terms of time, cost, quality and environment [113]. But on the other hand CE purely focus on optimum utilization of material through 10 R's principle. Further, lean construction did not get the acceptance in construction sector [117] even after 30 years since its inception but CE has got substantial attention in construction industry to save materials even its concept was emerged in 2015 [126]. All this due to the compatibility of CE with the construction sector [127] as compare to lean construction. Then next is the comparison between sustainability and CE.

CE covers the two major dimensions of sustainability (economic and environmental) by conserving the natural resources. In a study, where research focused on the similarities and differences of sustainability and CE debated that CE is a part of sustainability because it focuses on two dimensions (economy and environment) of sustainability [119]. But most of previous studies only covered two dimensions of sustainability i.e. economic and environment [43]. Social well being is normally missed in these studies which is an essential element of sustainability. This is due to the fact that major dimensions which are linked with material saving, are economic and environmental. Since the current study is purely related to minimization of material waste, so it is better to use the concept of CE which also supports sustainable constructions as well. At last, zero waste management mainly supports the goals of CE such as reduction in waste, conserving materials by optimum use of resources [40]. So, it can be established that all of the approaches for waste control are linked with each other one way or the other. However, CE is a better approach to control material waste on construction sites due to its good compatibility with construction processes.

Table 2.7: Construction Waste Management Frameworks in Past Studies

Sr. No.	Framework	Country	Details	Reference
1	Zero Waste	China	Most of the demolished materials from already built buildings, were reused on project while remaining went off the site to recycling unit and then to the market	[32]
2	Construction Waste Management	Australia	This framework provides the guidelines at macro as well as micro level but not that much comprehensive	[12]
3	Construction Waste Management Framework	UAE	On-site collection, segregation and transportation had been discussed in detail at project level. Finally, using this waste for waste to enrgy, recycling or dumping to deignated landfill, is ensured.	[128]
4	Waste Managent Framework for Construction Sector	Brazil	Framework identifies the processes to be developed in construction waste minimization, and the deficiencies and improvements necessary to enhance the entire system. It also improves the productivity, recycling rate, and the quality of recycled products.	[129]
5	Optimizing Construction Waste Management	Sri-Lanka	Study identified 15 waste management issues during the construction and renovation stage, each paired with suitable mitigation strategies. Additionally, eight issues were found in the use and operation stage of buildings.	[130]

Coming towards the local industry, construction industry in Pakistan is growing day by day due to the immense need of development projects including buildings, infrastructure works, etc. But it is contributing significant amount of material wastes in landfill sites. About 30 million metric tons of solid waste is generated on yearly basis and 30% of that waste comes from construction industry [31]. So, it means that about 9 million metric tons of waste is generated by construction projects. Considering the need of the time, recently studies are conducted on quantification of material wastes on construction projects [57]. Further, few policy documents are also prepared by some agencies such as (1) solid waste management sector in Pakistan, a reform road map for policy makers: this document was prepared by Asian Development Bank [31], where it was emphasized on the importance of solid waste management including construction waste and urged the local stakeholders to formulate policies to control waste for every sector of Pakistani industry.

Since, there are very few guidelines for solid waste management in Pakistan till date [31], (2) national hazardous waste management policy-2022: this was prepared by Ministry of Climate Change, where policy measures for hazardous waste including plastic, hospital, agricultural, glass, textiles, etc. were discussed [37]. This document mainly focused on industries where the generated waste was chemically reactive and non-inert in nature. But still, no policy guidelines were provided in this document for building industry of Pakistan. And (3) sectorial guidelines for environmental reports, housing estates and new town development: These guidelines were provided by Pakistan Environmental Protection Agency, where agency has discussed about the impact of housing projects on the environment like ground water contamination, soil erosion, air contamination, loss of agricultural areas, etc [38]. But the impact of material waste which can directly generate on building or housing projects, was not being considered in these guidelines. So, it is immense need of current time, to develop a policy framework for construction projects especially for building projects because almost 40% of total material is used by building industry as compare to other construction projects. These policy guidelines can be used as a reference on other construction projects as well. So, overall, all these frameworks or guidelines mainly focus to deal waste control either at macro level or micro level and are very generic in nature. Comprehensive framework covering both levels at the same time, needs to be developed. Further, effectiveness of these frameworks through validation on real time projects is also missing in these studies. Currently, there is not a single formal policy exist at local level which force the local stakeholders to control waste in building sector.

2.4.2 Waste Measurement Methods for Validation of WM and CE Frameworks

There are number of ways by which waste can be measured on construction projects. But it depends on the construction practices, waste management methods and availability of field data to decide which of the methods would be most feasible for construction waste measurement. So, different studies measured quantities of waste by using different methods as shown in Table 2.8. These methods can be categorized into four sub categories. Details of each is given in the relevant section. First method is percent of purchased material, data is collected from field in the form of interim payment certificates (IPCs) and storage data from inventory.

During the execution of a project, in and out of each material is noted. At the end of project, total purchased material is measured along with IPCs. Then waste is calculated by using the formula given in Table 2.8. Normally, this kind of waste measurement methods are used where proper waste collection and landfill sites are not available. Otherwise, waste can be collected in the form of weights or volume. These methods have been used in different research studies in Hong Kong and Pakistan.

In percent of designed method, accuracy of estimation is also considered because waste is calculated with respect to designed or estimated material. So if there is any error in the estimation, it will be treated as a waste. By using the formulate given in Table 2.8, is used to measure the waste quantity. Such kind of studies were found in Hong Kong and Brazil. So, over and under estimation can be a reason of waste generation due to ordering errors.

Table 2.8: Material Waste Measurement Methods for Validation of WM Strategies

Reference	Country	Measurement Method	Overall Methodology
[12]	Netherlands	Percent of purchased/used material	Materials were sorted and weighed. Waste was quantified as a percent of total waste as well as percent of purchased materials.
[57]	Pakistan	Percent of purchased/used material	Data was collected through direct observation and IPCs. Waste was calculated as a percent of used material
[120]	Brazil	Percent of designed/estimated material	Data was collected through direct observation and contractor's record. Waste was calculated as a percent of designed material
[131]	Malaysia	Weight/Area	Waste was quantified as tons per hectare.
[132]	Spain	Volume/Area	Waste was quantified as volume of waste /Covered Area.

In the third method of waste measurement, waste was calculated directly by visiting the construction sites. Normally, such kind of studies were conducted where proper waste management methods are available such as on site waste sorting, collecting and designated dumping sites. So, weight of material was measured directly on the weighing balance and then it was divided by total are from where this waste was generated. So, waste is measured in the form of ton/m^2 or kg/m^2, etc. This kind of studies were conducted in China and Malaysia. Fourth method of waste measurement is same as of the third method the only difference over here was waste quantity is measured in the form of volume instead of weight over the total area from where it was generated. Volume could be measured by collecting wasted materials at one place and store them in some kind of geometrical shape. Then using the relevant geometrical formulae, volume of waste was determined. These kind of method had been used in Spain and Malaysian construction industries. These methods can be used depending upon the availability of relevant data in the field, however, volume per unit area and weight per unit area are more accurate methods in comparison to others.

2.4.3 Past Case Studies of Validation for WM on Building Projects

Although most of the previous studies are mostly related to quantification of waste generation and development of WM frameworks. But there are very few studies which apply the proposed framework on real time project and validate its significance. In this regard, a study provided a comparison between modular construction and traditional methods of construction [133]. It was identified that concrete waste through modular construction (6 kg per sq. meter) was significantly lower than traditional project (29.8 kg per sq. meter). Similarly, steel waste through modular construction (5.2 kg per sq. meter) and traditional projects (12.1 kg per sq. meter) were reported. Overall, 78.8% waste was reduced through modular construction as compare to traditional projects.

In another study [63], where modular construction was adopted as a major strategy to reduce waste. It was found that concrete quantities on modular construction was used 0.6 cubic meter and on conventional project was 37 cubic meter. Further, steel quantity used on modular project was 0.04 ton while on conventional project was 0.83 ton. In terms of formwork, modular project used 1.5 sq. meter quantity of wood while conventional project used 9.5 sq. meter. Same is the case for plasterboards where 105 sq. meter was used on modular project while 211 sq. meter was reported on conventional project. Overall, it is reported that 83% was reduced as compare to traditional project. So, significant waste reduction can be observed by WM strategies.

In terms of validation of WM strategies, as study was conducted in Hong Kong [33], where WGRs of two projects were compared. On one project of multistory building, IRP was implemented, where workers were assured to pay some remuneration for waste control. On the other project, traditional methods were applied and no workers was given any incentives in case of material saving. It was identified that steel quantity used on conventional project was 1795 ton while on IRP-based project was 1706 ton. Further, 31,715 ton of cement was used on coneventional project while 31591 ton was used on IRP-based project. Similar trend was observed for all other materials as well, where more quantities were used on conventional project as compare to IRP-based project, So, overall, net saving of HK$550,000 was made on the project by team who was given incentive for material savings. So, giving some financial benefit to workers can change their attitudes towards control waste on construction sites.

Overall, studies in terms of validation of WM strategies are still very limited. Therefore, more studies are required in support of validation of frameworks, so that it can improve the confidence all stakeholders about its effectiveness.

2.5 Summary

Based on detailed literature of previous studies, different aspects and sub-aspects are discussed with respect to the WM and CE perspectives in building industry. These aspects/sub-aspects include materials waste generation rates, its controlling methods, tools and techniques, and frameworks which were developed in past studies, are also discussed in details to establish the research gap for current study. Based on the previous literature following major gaps are identified. (1) High waste generation rates of building materials demand a detailed investigation into the root causes in terms of barriers to WM and CE practices either they are external or internal. Further, a comparative analysis among the perception of key industry stakeholders while rating these barriers is also missing in global context. (2) Currently, body of knowledge is very limited in terms of WM frameworks for developing countries. Further, there is no formal policy exist which guides the control of material waste on building projects in local context. So, there is a need to develop construction WM guidelines to initiate CE culture in local context. (3) Moreover, it has been established based on past research studies that most of the proposed were not validated on some real time building projects. Further, there is no study currently available to implement multiple WM strategies simultaneously on a newly constructed project throughout its entire lifecycle, which is necessary to check the effectiveness of framework and build the confidence of stakeholders. In this regard, next chapters will explain the barriers, strategies and its validation which are required to be implemented for waste control practices in local construction industry. The findings of this research would improve the construction practices by responsible consumption of materials (SDG-12), making the cities sustainable (SDG-11) and reducing the impact of waste on climate (SDG-13).

Chapter 3

Barriers to WM and CE for Building Projects

3.1 Background

After, establishing the research gaps, this chapter focuses on first phase of this research study. In phase-1, barriers to WM and CE practices on building projects in local construction industry, are identified. Further, it discusses about the use of fuzzy decision making trial and evaluation laboratory (DEMATEL) method to explore cause and effect diagram factors along with comparison among the perception of key stakeholders while rating these barriers. In the end, practical implications of the findings of phase-1, are also discussed in detail.

3.2 Research Process

The study was carried out as illustrated in Figure 3.1. A total of forty one (41) barriers were identified by reviewing approximately sixty of the most relevant research papers published in reputable journals, each highlighting various challenges related to WM in building projects. A two-stage filtering process was adopted. In the first stage, a frequency analysis of peer-reviewed literature was conducted to identify the most commonly reported barriers across multiple studies, ensuring empirical relevance and alignment with prevailing trends in the field. Then a second stage involving expert validation through pilot survey was implemented. In this phase, a panel of four (04) industry experts including client, consultant, contractor and regulator in construction WM and the CE reviewed the shortlisted barriers in details as pilot survey. Similar to current study, another study where fuzzy DEMATEL technique was applied to identify the barriers to waste management, had used three (03) experts for pilot survey [81]. Furthermore, seven (07) experts were consulted for pilot survey to finalize the questionnaire in another study [134]. Insights of field experts from pilot survey were crucial in refining the list by confirming the relevance of key barriers, merging overlapping items, and ensuring that less frequently cited yet important barriers were not excluded. Few modifications in the names of these barriers were suggested and incorporated in the final questionnaire.

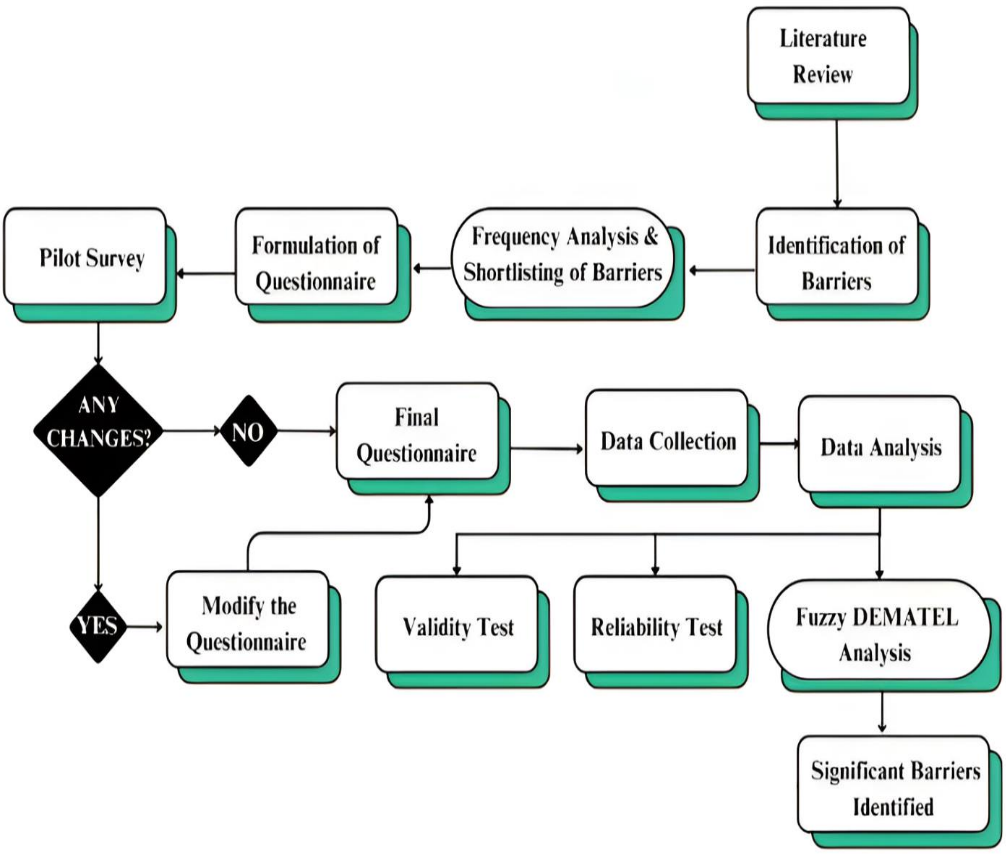

Figure 3.1: Flow Chart for Identification of Barriers to WM and CE

3.2.1 Identification of Barriers to WM and CE

Given the large number of potential barriers identified, it would have been impractical and overly burdensome to ask large number of field experts to evaluate each one individually, as this would have required responding to hundreds of questions. Such an approach could have led to respondent fatigue, reduced the quality of responses, and negatively affected participation rates. To address this challenge efficiently while maintaining data reliability, frequency analysis was employed as a preliminary screening tool to identify the most commonly cited or significant barriers in the literature. This method not only reduced the number of items to a manageable level but also ensured the retention of the most relevant and widely recognized barriers for further evaluation. Importantly, this approach has been adopted in several previous studies [42–44], lending additional credibility to its use in the present research. Frequency analysis involves systematically scanning multiple research papers, case studies, and industry reports to identify and compile all mentioned barriers. Each barrier is then tallied based on how frequently it appears across different sources. The underlying assumption is that the more frequently a barrier is cited in the literature, the more likely it is to be practically relevant and impactful.

3.2.2 Questionnaire Formulation

Following the frequency analysis, the questionnaire was validated through a pilot survey involving four key stakeholders from the construction industry. During this stage, few modifications were made to the names of some barrier items based on expert suggestions. As a result of this combined process of frequency analysis and expert validation, the thirteen (13) most frequently cited barriers, each with a frequency rate exceeding 10%, were identified and are presented in Table 2.2. The rationale of choosing 13 barriers also supported by past studies where number of selected barriers vary between 6 to 16 as presented in Table 3.1. These barriers inlcude macro level issues such as non-availability of rules and regulations (B1), lack of financial support from governments (B2) as well as micro level barriers such as illogical design (B9) and poor construction practices (B8), etc. Then a final questionnaire was developed on the basis of these selected barriers.

3.2.3 Data Collection

The final questionnaire was shared with a diverse group of experts using purposive and snowball sampling, non-probability methods suited for qualitative research where random sampling is not favorable to get the required output. Purposive sampling targeted individuals with higher experience to ensure meaningful insights [135–137]. Another study, where eight experts from three different countries were chosen through purposive sampling.

This approach was preferred over statistically representative sampling to ensure the participation of individuals with similar backgrounds, enabling the acquisition of deeper insights [80]. Since the objective of current study was to collect data from participants with more than ten years experience and BS degree, so purposive sampling was more appropriate method instead of random sampling. These initial participants then referred others with similar qualifications through snowball sampling to identify more participants for this survey, expanding the sample effectively. Finally, the data were collected through face to face kind of interaction, where questions were directly asked from these experts.

3.2.4 Selection of Analytical Tool for Barrier's Identification

There are number of multi-criteria decision making tools reported in past studies such as AHP, ANP, SEM and fuzzy DEMATEL. Each of these tools has its own advantages and disadvantages. But when it comes to to identify the root-cause barriers along with frequency of using one tool as compare to others, fuzzy DEMATEL appear a better tool as discussed in detail in section 2.2.3. Overall, fuzzy DEMATEL is preferred from these discussions.

3.2.5 Selection of Sample Size

After selection of fuzzy DEMATEL technique for identification of the root-cause barriers, sample size for data collection from experts was decided based on the past studies. These experts were carefully selected to ensure comprehensive input from all major stakeholders directly involved with WM issues in the country in the light of previous studies [40, 45, 46] as shown in Table 3.1. Questionnaire was sent to approximately 45 experts, of whom 34 responded, yielding a response rate of 76%. Data was collected through one to one interaction with all these participants. Out of these, 30 responses were deemed valid, while 4 were excluded based on specific criteria. Responses were considered invalid if the questionnaire was incomplete, if the respondent answered nearly all questions with the same rating (such as consistently using a 4 or 5), indicating a lack of seriousness, or if significant inconsistencies were identified during cross-questioning as shown in Appendix-E. The valid responses of the survey were then completed by thirty (30) stakeholders, comprising clients (23%), consultants (30%), contractors (27%), and representatives from regulatory agencies (20%). The rationale for selecting 30 experts from the field is as followed:

- The choice of a sample size of 30 experts in this study is methodologically justified and consistent with prior applications of the fuzzy DEMATEL technique. The objective of this research was to identify the root-cause barriers in construction WM practices, which requires collecting deep insights from informed experts rather than pursuing statistical generalization. Since fuzzy DEMATEL is a qualitative, expert-driven approach, it fundamentally relies on the judgment and experience of specialists to derive causal relationships and system dynamics under uncertainty, rather than on large random samples or statistical power analysis [138].

- Unlike inferential statistical techniques, DEMATEL does not require large sample sizes or power analysis, as its primary aim is to extract causal relationships and understand system dynamics under uncertainty through informed expert judgment [139].

Table 3.1: Sample Size Used in Past Research Studies for fuzzy DEMATEL

Sr. No	Purpose of study	Sample size	No. of Barriers	Country	Reference
1	To evaluate barriers in blockchain technology for sustainable waste management in construction sector	11	14	Australia	[78]
2	Provide findings about root-cause barriers in circular economy adoption	20	12	Turkey	[40]
3	Barriers to green construction for promotion of sustainable growth were identified	20	15	Iran	[79]
4	To identify root-cause barriers to smart waste management	6	10	India	[46]
5	Root-cause barriers to construction waste management and circular economy	24	5	Kazakistan, Turkey & Malaysia	[80]
6	Finding the barriers to solid waste management practices	11	16	Bangladesh	[81]
7	To identify regulatory barriers to waste management in construction sector	15	14	Somaliland	[55]

- In this study, the face to face kind of interaction was adopted to collect data, questionnaire consisted of 156 detailed questions, making it both impractical and unnecessary to involve very large samples. Instead, a purposive and snowball sampling strategy was adopted to assemble a panel of 30 experts with substantial professional experience in construction waste management, ensuring the inclusion of highly relevant and credible perspectives. This sample size represents a balance between diversity of viewpoints and feasibility of data collection, while also providing sufficient coverage to strengthen the reliability of results [137].

- Further, the level of effort involved to collect data is also a key issue due to whcih sample size is usually lower in this technique. All these interviews almost continued around one hand half hours.

- Lastly, the adequacy of this sample size is further supported by evidence from previous research employing fuzzy DEMATEL Table 3.1. Studies in various countries addressing similar issues-have all relied on small but focused expert panels, often ranging between 6 and 24 participants. Compared to these, the present studys sample size of 30 experts is relatively larger, enhancing robustness and representativeness without compromising methodological alignment.

Therefore, drawing on both the nature of the fuzzy DEMATEL method and the precedent set in prior literature, the inclusion of 30 experts is not only adequate but also ensures that the findings are both credible and contextually grounded for identifying root-cause barriers in WM practices. So, the emphasis was placed on the quality and relevance of expert input over quantity, which aligns with the methodological intent of fuzzy DEMATEL. After confirming the reliability and validity of the collected data, the fuzzy DEMATEL technique was applied to identify the causal and effect relationships among the barriers to WM. Additionally, a comparative analysis was conducted across all four stakeholder groups based on the fuzzy DEMATEL results.

3.2.6 Cronbach's Alpha Test for Internal Consistency

Cronbach's Alpha is used to evaluate the internal consistency and its reliability of collected data. Reliability is more about the respondents input. Reliability means the same outcomes would be reached if the testing procedure were repeated with a different sample of respondents. Cronbach's alpha is widely regarded as one of the most reliable and commonly used measures of internal consistency for assessing the reliability of scales and questionnaires in research. It evaluates the extent to which items on a test or scale measure the same underlying construct, ensuring homogeneity among the items. The popularity of Cronbach's alpha stems from its straightforward computation, interpretability, and its ability to indicate how well a set of items captures a latent construct, making it especially suitable for studies involving multi-item Likert-scale instruments [140].

As such, its use in this study is justified to confirm that the survey items consistently represent the intended variables and constructs, ensuring measurement accuracy and credibility of the results. In this study, cronbach's alpha value for all thirteen (13) different barriers was 0.8 as shown in Figure 3.2. While the minimum acceptable value of alpha should be greater than 0.7 for data to be reliable [29]. Since the value is greater than 0.70, hence the collected data is moderately reliable.

Cronbach's Equation		
$$\alpha = \frac{k}{k-1}\left(\frac{1-\sum \sigma i^2}{\sigma t^2}\right)$$		
K	No of Participants	30
$\sum \sigma_i{}^2$	Sum of Variances	15.81
$\sigma_t{}^2$	Variances of Total	70.37
α	Cronbach's Alpha	0.80

FIGURE 3.2: Cronbach's Alpha Test Results

3.2.7 Validity Test on Collected Data

Validity is an essential criterion in assessing the quality of any measurement tool, as it reflects the extent to which the instrument accurately measures the constructs it was designed to capture. A valid tool ensures that the findings derived from it are credible, generalizable, and meaningful for both theoretical and practical applications [141–143]. In the present study, the validity of the questionnaire was examined using factor loadings and variance-based measures. The analysis revealed that the average factor loading values for all components were above the commonly accepted threshold of 0.7. This indicates that each item included in the questionnaire had a strong relationship with the underlying construct it was intended to represent. High factor loadings imply that the observed variables are reliable reflections of their latent dimensions, thereby strengthening the evidence for the overall validity of the tool.

Validity Test Results		
Average Factor Loading of Component 1 =	0.7	
Average Factor Loading of Component 2 =	0.7	Should be About 0.7
Average Factor Loading of Component 3 =	0.8	
Average Factor Loading of Component 4 =	0.7	

Figure 3.3: Validity Test Results

In addition, the results of variance comparisons provided further confirmation of validity. Specifically, the average variance extracted (AVE) for each construct was found to be greater than the squared correlations between constructs. This statistical condition demonstrates that each construct explains a greater proportion of variance in its own indicators than it shares with other constructs. In practical terms, this means the instrument was not only precise in capturing the intended concepts but also ensured clear conceptual distinction among different dimensions being measured. Taken together, these results provide strong support for the validity of the measurement model. The instrument employed in this study can therefore be regarded as a sound and dependable tool for capturing the intended variables within the research context.

3.2.8 Application of Fuzzy DEMATEL for Cause Barriers

Fuzzy DEMATEL technique is helpful for qualitative studies since it removes the vagueness from the data. The rationale for using fuzzy DEMATEL is that: (1) it is challenging to examine interactions between WM barriers because of their subjective nature, (2) fuzzy DEMATEL offers a quantitative examination of WM barriers and (3) the cause-and-effect connections among these barriers can aid in the development of regulatory initiatives by decision makers. The process of fuzzy DEMATEL which was adopted in number of past studies was described in following paragraphs as shown in Figure 3.4 [40, 45, 46].

Fuzzy based DEMATEL technique is helpful for qualitative studies since it removes the biasness in the data [40]. Further, this technique also provides an insight about the cause and effect analysis. This way, most influential factors can be easily identified. Step 1: Transferring the linguistic variables into triangular fuzzy numbers (TFNs): Expert opinion on each variable is given in the form of linguistic language, which is not easy to interpret quantitatively, therefore, these linguistic variables are converted into triangular fuzzy numbers as shown in Table 3.2.

TABLE 3.2: Triangular Fuzzy Numbers (TFNs) and Linguistic Variables [40]

Abbreviation	Linguistic Preference	Corresponding TFNs
NI	No Influence	(0.0, 0.1, 0.3)
VL	very low influence	(0.1, 0.3, 0.5)
I	Influence	(0.3, 0.5, 0.7)
HI	High Influence	(0.5, 0.7, 0.9)
VH	Very High Influence	(0.7, 0.9, 1.0)

Step 2: Normalizing these TFN: In this step, those TFNs are normalized by using equation 3.1-3.3.

$$\mathrm{xl}_{ij}^{k} = \frac{(\mathrm{l}_{ij}^{k} - \mathrm{minl}_{ij}^{k})}{\Delta_{min}^{max}} \tag{3.1}$$

where l_{ij}^{k} is the lower bound value of triangular fuzzy number (TFN) assigned by experts, representing the influence of i barrier on j. Here, xl_{ij}^{k} shows the lower bound normalized value, Δ_{min}^{max} shows the maximum and minimum range of TFNs.

$$\mathrm{xm}_{ij}^{k} = \frac{(\mathrm{m}_{ij}^{k} - \mathrm{minl}_{ij}^{k})}{\Delta_{min}^{max}} \tag{3.2}$$

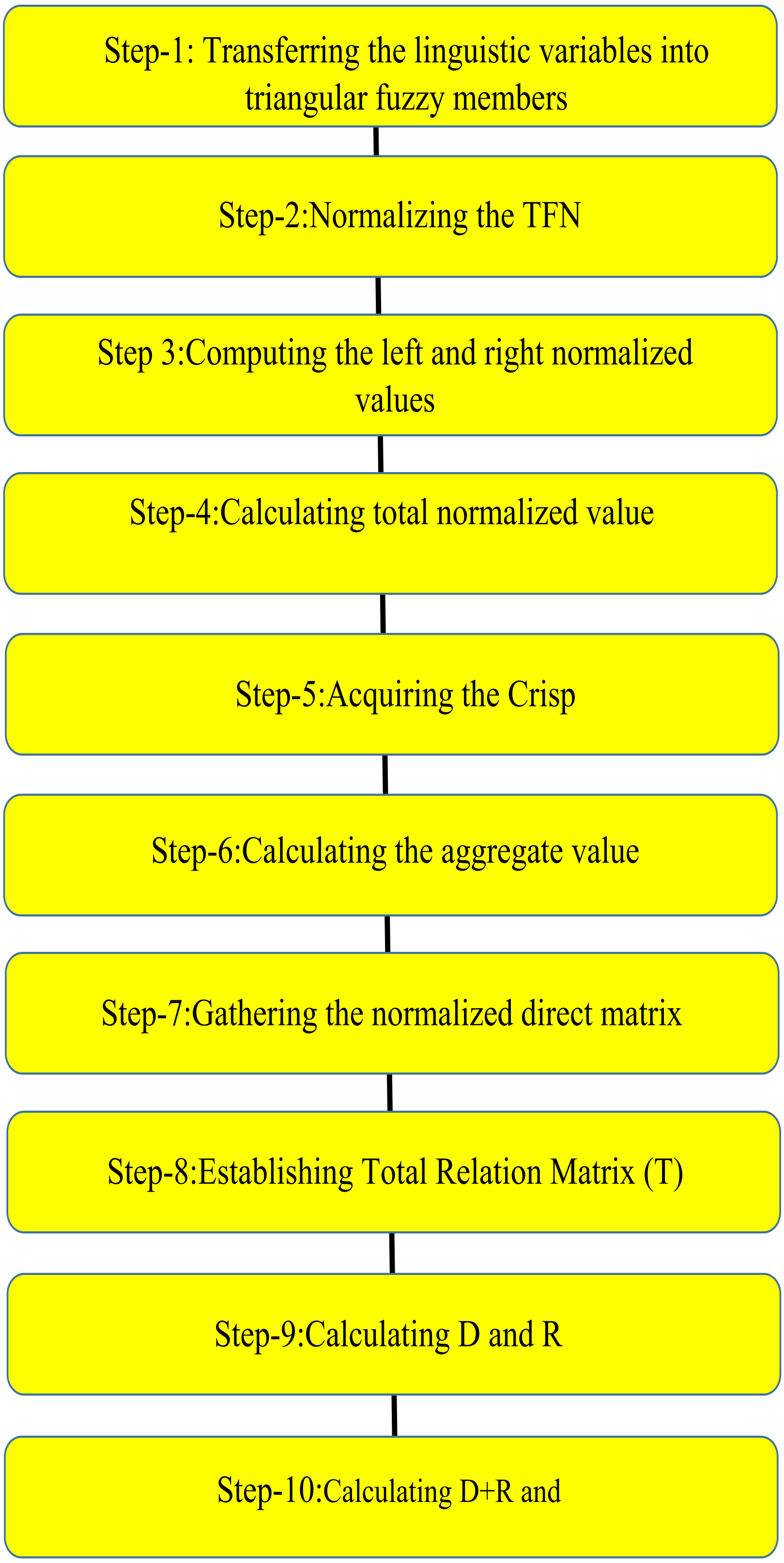

Figure 3.4: Flow Chart of Fuzzy DEMATEL Method

and xm_{ij}^{k} is the medium bound normalized value, m_{ij}^{k} is the medium value of TFNs assigned by experts, representing the influence of i barrier on j.

$$\mathrm{xu}_{ij}^{k} = \frac{(\mathrm{u}_{ij}^{k} - \mathrm{minl}_{ij}^{k})}{\Delta_{min}^{max}} \tag{3.3}$$

where xu_{ij}^{k} is the upper bound normalized value, u_{ij}^{k} is the upper value of TFNs assigned by experts, representing the influence of i barrier on j.

Step 3: Computing the left and right normalized values by using equation 3.4-3.5.

$$\mathrm{xrs}_{ij}^{k} = \frac{\mathrm{xu}_{ij}^{k}}{1 + (\mathrm{xu}_{ij}^{k} - \mathrm{xm}_{ij}^{k})} \tag{3.4}$$

xrs_{ij}^{k} is the right normalized value, xu_{ij}^{k} is the upper bound normalized value and xm_{ij}^{k} is the medium bound normalized value.

$$\mathrm{xls}_{ij}^{k} = \frac{\mathrm{xm}_{ij}^{k}}{1 + (\mathrm{xm}_{ij}^{k} - \mathrm{xl}_{ij}^{k})} \tag{3.5}$$

xrs_{ij}^{k} is the left normalized value, xm_{ij}^{k} is the medium bound normalized value and xl_{ij}^{k} shows the lower bound normalized value.

Step 4: Calculating total normalized values by using equation-3.6.

$$\mathrm{x}_{ij}^{k} = \frac{[\mathrm{xls}_{ij}^{k}(1\text{-}\mathrm{xls}_{ij}^{k})\text{+}\mathrm{xrs}_{ij}^{k} \text{ x } \mathrm{xrs}_{ij}^{k}]}{[1 - \mathrm{xls}_{ij}^{k} + \mathrm{xrs}_{ij}^{k}]} \tag{3.6}$$

x_{ij}^{k} is total normalized value obtained from the direct relation matrix.

Step 5: Acquiring the crisp values: Crisp values are more quantitatively measurable in comparison to linguistic ones. Crisp values are calculated through equation-3.7.

$$\mathrm{Z}_{ij}^{k} = \mathrm{minl}_{ij}^{k} + \mathrm{x}_{ij}^{k} * \Delta_{min}^{max} \tag{3.7}$$

Here, Z_{ij}^{k} crisp value (defuzzified score) for the influence of barrier i on j. Further, z,j and k are the corresponding fuzzy values.

Step 6: Calculating the aggregate values by using equation-3.8.

$$Z_{ij} = \frac{1}{K}(Z_{ij}^{1} + Z_{ij}^{1} + ... + Z_{ij}^{K}) \tag{3.8}$$

Where "K" is the number of experts and Z_{ij} aggregated fuzzy direct-relation score for barrier i on j.

Step 7: Gathering the normalized direct matrix [X]: These normalized direct matrix is obtained.

$$X = (s^{*}D) \tag{3.9}$$

X is the normalized direct-relation matrix, D direct-relation matrix (expert-assigned influence scores and s shows normalization coefficient ensuring all elements fall within [0,1].

Step 8: Establishing Total Relation Matrix (T) by using equation-3.10, as shown in Table 3.3.

$$T = \frac{X}{1 - X} \tag{3.10}$$

Step 9: Calculating D and R: Accumulating the horizontal rows produce "D" and sum of columns produce "R".

Step 10: Calculating D+R and D-R: Ultimately, a graph is plotted between D+R and D-R values to get cause and effect diagram.

So, most influential barriers against WM and CE in building sector are identified at the end of this analysis. A sample of detailed report generated at the completion of this analysis has been presented in Appendix H. It is pertinent to mention that values below threshold value i.e. 0.325 have been shown as zero but they have been considered for calculation of D+R and D-R.

3.2.9 Comparative Analysis among Stakeholder's Perception for WM and CE Barriers

After completing the fuzzy DEMATEL analysis, a comprehensive comparative study was conducted to identify the similarities and differences in how various stakeholder groups perceive the barriers to WM. For this purpose, separate datasets were analyzed for each stakeholder category, namely clients, consultants, contractors, and regulatory authorities.

Specifically, the questionnaires completed solely by clients were processed using the fuzzy DEMATEL method to determine how they rated the cause-and-effect relationships among WM barriers. This same process was independently repeated for the other stakeholder groups. Following these individual analyses, a comparative evaluation was carried out to assess the level of consensus or divergence among the stakeholders. This comparison was conducted in groupings of two. The findings from this analysis offer valuable insights into the varying perceptions of key players within Pakistan's construction industry.

3.3 Results and Discussions

After analysis of fuzzy DEMATEL and comparison among the perception of key stakeholders, detailed results are presented in following sections.

3.3.1 Results of Significant Barriers

Based on the fuzzy DEMATEL analysis, a multi-level conceptual framework was developed to clarify the causal relationships and relative prominence of barriers hindering WM and CE adoption in building projects. While some of the identified barriers such as non-availability of rules and regulations (B1), financial issues (B2), and poor stakeholder awareness (B3) are consistent with challenges commonly reported in developing countries, the added value of fuzzy DEMATEL lies in its ability to distinguish between causal and effect-type barriers and to model interdependencies across macro- and micro-levels as shown in Figure 3.5 and Table 3.4. For instance, unclear specifications (B12), a project-specific factor, emerged as the most influential causal barrier (highest D-R value), highlighting how technical ambiguities at the project level can trigger downstream inefficiencies even when macro-level issues are addressed. The framework distinguishes macro-level structural barriers (e.g., institutional gaps, inadequate enforcement, economic disincentives) from micro-level operational inefficiencies (e.g., design flaws, poor collaboration).

Importantly, the analysis revealed that macro-level weaknesses particularly regulatory voids and financial constraints tend to influence negatively, intensifying project-level challenges as shown in Figure 3.5. Further, it can be observed from Figure 3.5 that non-availability of rules (B1) and financial issues (B2) are significantly influencing other barriers, proving B1 and B2 are the most important root-cause barriers. This systems-oriented perspective moves beyond merely listing known issues to provide a diagnostic hierarchy of control points for intervention.

These theoretical underpinnings not only help interpret the results in a deeper manner but also provide basis for policy makers to counter these barriers by formulating effective strategies in local context. In terms of CE, this insight is critical: CE adoption is not only constrained by technical feasibility at the project level, but also by the lack of enabling institutions and financial models that support circular practices such as reuse, recycling, or design-for-deconstruction. The results also align with institutional theory, where the absence of coercive (rules, enforcement) and normative (awareness, industry norms) pressures limits the adoption of CE practices. While it may be expected that regulatory and financial barriers are dominant, their quantified causal prominence (D-R scores) in this analysis

Table 3.3: Total Relation Matrix of fuzzy DEMATEL Method

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1	0	0.354	0.363	0.375	0.359	0.353	0.347	0.363	0	0.337	0.369	0	0.333
B2	0.347	0	0.356	0.364	0.377	0.338	0.334	0.365	0.325	0.343	0.356	0	0.334
B3	0.356	0.343	0	0.363	0.350	0.336	0.330	0.357	0	0.325	0.356	0	0.320
B4	0.352	0.335	0.344	0	0.343	0.328	0.338	0.346	0	0.319	0.351	0	0
B5	0	0.336	0.329	0.332	0	0	0	0.328	0	0	0.324	0	0
B6	0.334	0.325	0.332	0.338	0.333	0	0	0.334	0	0	0.332	0	0
B7	0.333	0.321	0.323	0.342	0.324	0	0	0.325	0	0	0.332	0	0
B8	0.324	0.323	0.326	0.329	0.328	0	0	0	0	0	0.324	0	0
B9	0	0	0	0	0.324	0	0	0.333	0	0	0.323	0	0
B10	0	0	0	0	0	0	0	0.317	0	0	0	0	0
B11	0.350	0.343	0.349	0.360	0.347	0.335	0.339	0.354	0	0.328	0	0	0.320
B12	0	0	0	0	0	0	0	0.331	0	0	0.331	0	0
B13	0	0	0	0	0	0	0	0.329	0	0.320	0.325	0	0

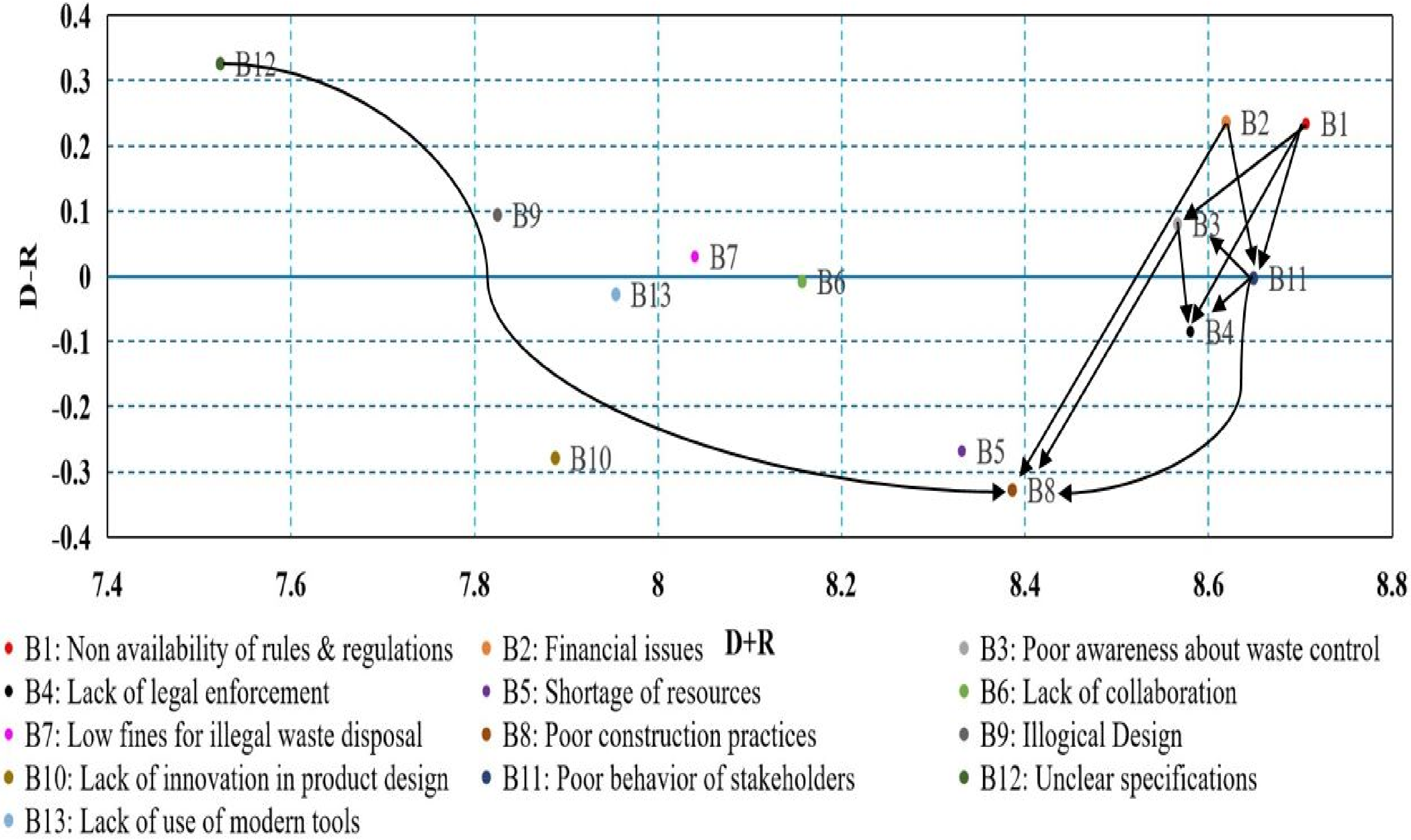

Figure 3.5: Significant Barriers to WM and CE Practices on Building Projects

Table 3.4: Most Prominent Cause-Effect Barriers to WM based on All Stakeholder's Responses

ID	Barrier Name	R	D	D + R	D - R
B1	Lack of rules & regulations	4.236	4.47	8.706	0.234
B2	Financial issues	4.192	4.427	8.619	0.236
B3	Poor awareness of stakeholders	4.243	4.323	8.566	0.08
B4	Lack of legal enforcement	4.332	4.247	8.58	-0.085
B5	Shortage of resources	4.299	4.032	8.331	-0.268
B6	Lack of collaboration	4.083	4.074	8.157	-0.008
B7	Low fines for illegal waste disposal	4.005	4.035	8.04	0.03
B8	Poor construction practices	4.357	4.029	8.386	-0.328
B9	Illogical Design	3.866	3.959	7.825	0.094
B10	Lack of innovation in design	4.084	3.805	7.888	-0.279
B11	Poor behavior of stakeholder	4.326	4.323	8.649	-0.003
B12	Unclear specifications	3.599	3.924	7.523	0.326
B13	Lack of use of modern tools	3.991	3.963	7.954	-0.028

justifies focusing reform efforts on policy-level interventions such as financial incentives for circular construction methods, mandatory CE-oriented design guidelines, or stricter enforcement of WM bylaws. Similar results have been reported in other studies [144]. Thus, this study's contribution lies not in identifying familiar challenges, but in clarifying their hierarchical influence and systemic interactions, offering practical and theoretical implications. By visually mapping these interdependencies, the framework highlights where policy action can unlock important benefits throughout the construction process.

3.3.2 Comparison of Stakeholders' Perception

The findings of the fuzzy DEMATEL analysis offer valuable insights into the perspectives of various industry stakeholders by highlighting both the commonalities and disparities in their evaluations of the identified barriers. This method not only helps in understanding which barriers are perceived as most critical across the board but also reveals the degree of alignment or divergence in stakeholder opinions, which is also very important [145].

3.3.2.1 Client's Perspective

As a result of applying fuzzy DEMATEL to the data collected from clients, the cause-and-effect diagram is presented in Figure 3.6. The values of D+R represent the overall importance/prominence of each factor, while D-R indicates the relationships between barriers, identifying them as either causes or effects. Positive D-R values signify causal factors, whereas negative values denote effect factors [78, 134]. In Figure 3.6, "Unclear specifications (B12)," "Low fines for illegal dumping (B7)," and "Lack of rules and regulations (B1)" emerge as the most influential barriers with B11 and B3 as the most prominent cause barriers which are hindering the adoption of WM practices. Among the various barriers to effective WM, unclear specifications stand out as a significant contributor to waste generation. Ambiguities in contract documents often lead to misunderstandings and misinterpretations, resulting in frequent rework and material wastage. In addition, the enforcement of waste disposal laws remains weak, with low or non-existent penalties for illegal dumping serving as a major factor behind widespread waste accumulation. Contractors typically face minimal legal consequences for failing to dispose of construction waste at designated sites, which undermines efforts to promote responsible waste management practices [146]. A further critical barrier is the absence of robust rules and regulations governing construction waste. This issue is not unique to Pakistan's construction industry but is also prevalent across many other developing countries, where regulatory frameworks are poorly enforced [147]. Due to the absence of legal obligations to follow WM practices,

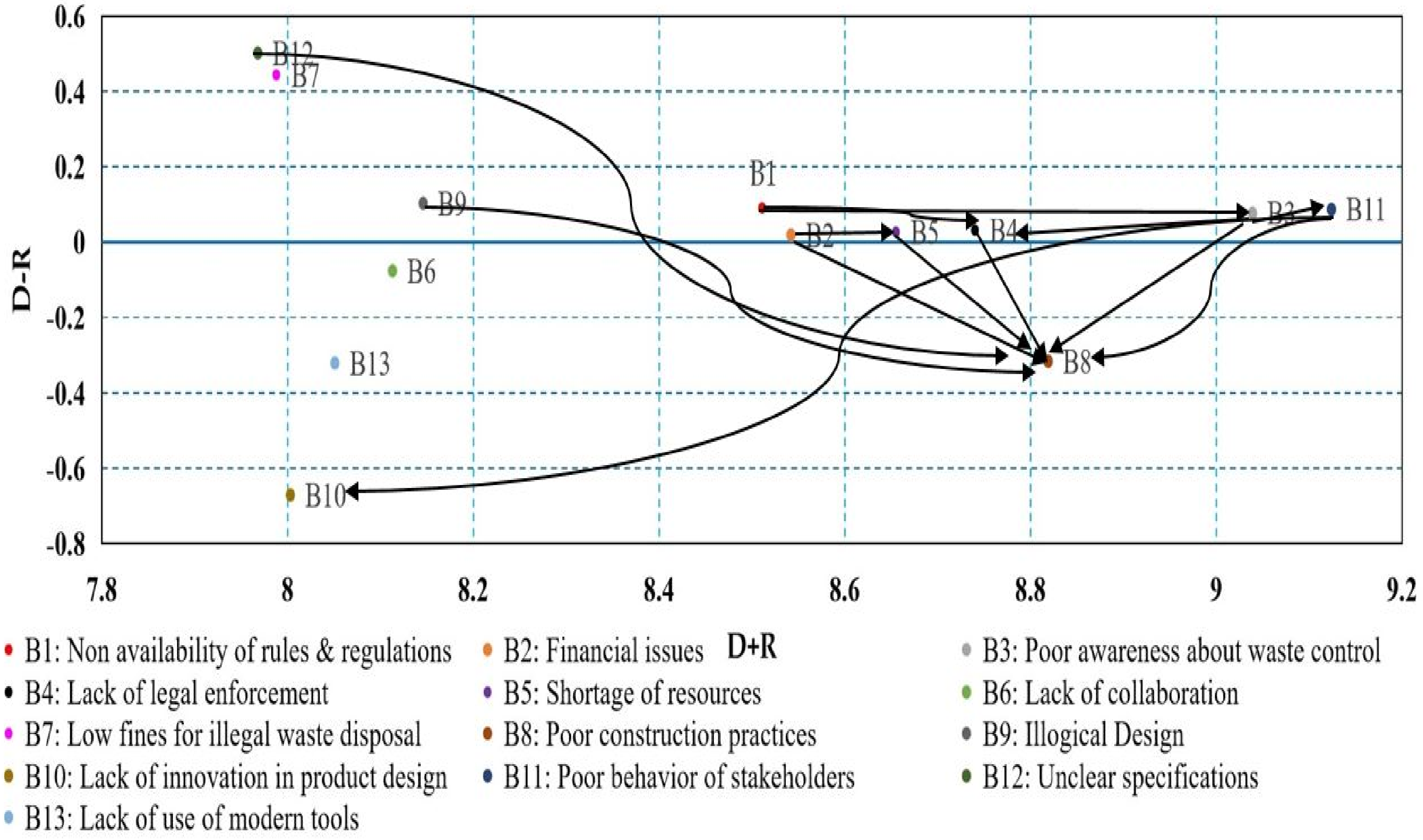

Figure 3.6: Cause-effect Diagram of Barriers to WM and CE on Building Projects (Client's Perspective)

stakeholders often fail to take the issue seriously. Other significant barriers to effective WM include financial constraints, a lack of awareness among stakeholders regarding waste control, and poor design practices. Among these, design plays a pivotal role in influencing a project's entire lifecycle. Poor design decisions made early in the planning phase can lead to excessive material usage and construction waste. Similar findings have been reported by [17] in the Nigerian construction industry.

Therefore, the most significant barriers to WM are unclear specifications, low fines for illegal dumping of waste materials, and lack of environmental bylaws [148, 149]. This shows the urgent need to develop comprehensive policy guidelines for WM. Additionally, B11 and B3 are the most prominent barriers, with values of 9.124 and 9.039, respectively, whereas B8 is the most prominent barrier, with an 8.819 value of D+R in Table 3.5. The prominence of unclear specifications and poor design (B12 and B3) highlights missed opportunities for integrating CE principles at the design stage, where waste can be prevented rather than managed. Likewise, the weak regulatory framework undermines enforcement mechanisms essential for implementing CE-aligned practices such as resource recovery, material reuse, and life cycle-based procurement strategies. This suggests that strengthening institutional frameworks and embedding CE principles in construction project planning and policy can play a pivotal role in overcoming systemic WM challenges. Notably, financial issues (B11) and lack of awareness (B8) also rank highly, with D+R values of 9.124 and 8.819 as shown in Table 3.5 respectively, indicating their broad influence across the network of barriers. While these are generic challenges, fuzzy DEMATEL quantifies their relative prominence and centrality, helping prioritize intervention areas. In sum, although the identified barriers may appear intuitive, the fuzzy DEMATEL analysis adds analytical value by mapping causal relationships and highlighting leverage points for CE-based policy and practice reforms. While these findings align with known and expected issues in many developing countries, such as financial constraints, lack of regulatory enforcement, and poor stakeholder awareness, they raise an important question about the value added by fuzzy DEMATEL. These barriers have been widely recognized in prior literature and could arguably be identified without the need for complex modeling. However, fuzzy DEMATEL offers an important advantage in establishing the causal structure and interdependencies among barriers something traditional identification methods often overlook. For example, the model reveals how upstream policy-level issues (e.g., lack of regulations) directly influence project-level practices (e.g., unclear specifications and poor design integration), thereby offering a systems-level understanding critical to policy and intervention design. Furthermore, linking these findings to the CE concept provides additional insight. CE emphasizes minimizing waste through lifecycle thinking, closed-loop resource use, and systemic transformation of production-consumption patterns.

3.3.2.2 Consultant's Perspective

From the consultant perspective, the most important cause barriers are "Illogical design (B9)", "Financial issues (B2)", and "Lack of collaboration (B6) among departments" with B2 and B3 are found as the most prominent ones with the highest D + R values, as shown in Figure 3.7. Financial constraints (B2) and low awareness (B3), with D+R values of 5.512 and 5.378 respectively from Table 3.5, emerge as prominent barriers. These findings reinforce the need for investment in infrastructure and capacity building to support CE implementation. The lack of collaboration (B6) highlights the importance of cross-sector coordination in integrating CE principles such as resource efficiency and design for reuse. Effect barriers like lack of legal enforcement (B4) and low fines for illegal dumping (B7) reflect downstream consequences of weak governance. The alignment between client and consultant perspectives particularly on design flaws, financial limitations, and regulatory gaps suggests a shared understanding of the systemic changes needed to promote WM and CE adoption in construction projects. Other barriers include poor behavior of stakeholders (B11) towards waste control, lack of awareness (B3), and lack of rules and regulations (B1). Financial issues are very common among all developing countries [21] because a substantial amount of investment is required to build new infrastructure for developing a CE culture in the country. The lack of collaboration among departments is also a major reason

Table 3.5: Comparison of the Most Prominent Cause and Effect Barriers to WM based on Individual Stakeholders Input

Barrier ID	**Barrier Name**	**Clients Perspective**		**Consultants Perspective**		**Contractors Perspective**		**Regulators Perspective**	
		D + R	D - R	D + R	D - R	D + R	D - R	D + R	D - R
B1	Lack of rules & regulations	8.511	0.092	5.219	0.111	6.892	0.063	4.470	0.311
B2	Financial issues	8.542	0.018	5.512	0.307	6.818	0.247	4.431	0.568
B3	Poor awareness of stakeholders	9.039	0.078	5.378	0.164	6.541	-0.135	3.829	0.008
B4	Lack of legal enforcement	8.740	0.031	5.346	-0.061	6.675	-0.064	3.956	-0.126
B5	Shortage of resources	8.655	0.026	5.005	-0.520	6.402	-0.120	4.025	0.007
B6	Lack of collaboration	8.113	-0.076	4.792	0.194	6.782	-0.161	3.790	-0.074
B7	Low fines for illegal waste disposal	7.988	0.444	5.147	-0.113	6.132	0.226	3.787	-0.328
B8	Poor construction practices	8.819	-0.316	4.775	-0.016	6.691	-0.515	4.067	-0.180
B9	Illogical Design	8.146	0.104	4.459	0.357	6.218	-0.244	3.883	-0.085
B10	Lack of innovation in design	8.003	-0.670	4.755	-0.245	6.202	0.051	3.750	-0.093
B11	Poor behavior of stakeholder	9.124	0.088	5.083	0.153	7.145	-0.098	3.881	-0.268
B12	Unclear specifications	7.968	0.501	4.427	-0.109	6.140	0.457	3.340	0.126
B13	Lack of use of modern tools	8.051	-0.321	5.106	-0.221	5.793	0.293	3.798	0.131

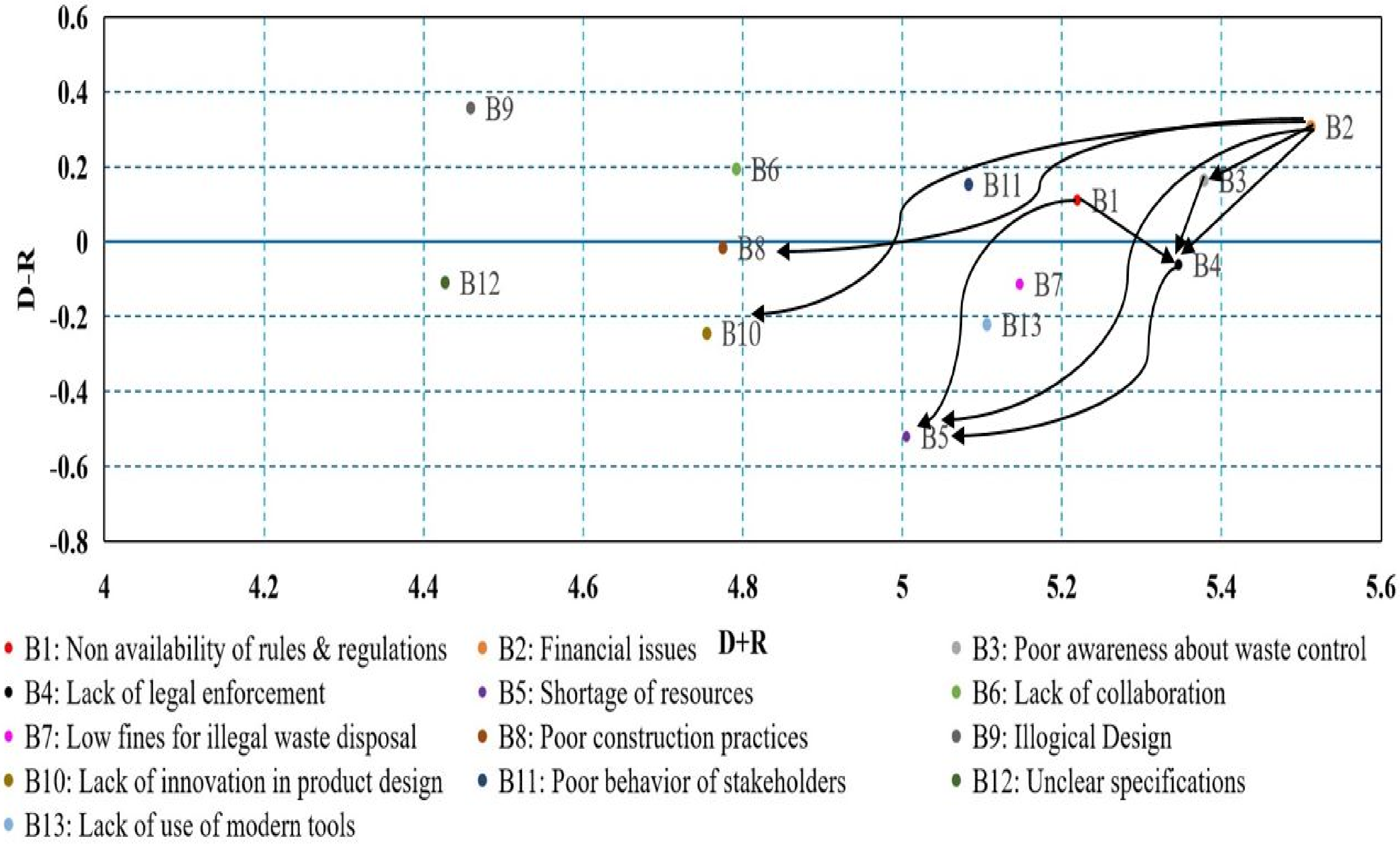

Figure 3.7: Cause-effect Diagram of Barriers to WM and CE on Building Projects (Consultant's Perspective)

for waste generation. Governments must address this issue to ensure effective coordination among stakeholders. Further, poor behavior and lack of awareness are serious concerns because both issues are linked to cultural issues [150, 151].

Therefore, the industry needs to put some effort into developing a WM culture through regular training and seminar sessions. Thus, there is so much similarity in the perception of client and consultant perspectives because both think that the lack of rules and regulations, illogical design, financial issues, and poor awareness of waste control among stakeholders are the main barriers to adopting WM culture. This shows that most of the time, clients and consultants have the same opinion because both have common interests in a project. This study also shows that there is a significant similarity between the perceptions of clients and consultants. This study also shows that there is a significant similarity between the perceptions of clients and consultants. In terms of the prominence factors from Table 3.5, B2 and B3, with D+R values of 5.512 and 5.378, respectively, are identified as the most prominent barriers. Therefore, consultants believe that financial issues and poor awareness among stakeholders are major issues hindering the adoption of WM practices in the construction sector.

Furthermore, a lack of legal enforcement (B4), with a D+R value of 5.346, is identified as the most prominent effect barrier as per the perceptions of consultants. Moreover, low fines on illegal dumping (B7) constitute another important effect barrier, which is identified with a D+R value of 5.147. Therefore, all these barriers need to be addressed vigilantly by stakeholders, especially regulators. While these are well-known challenges in developing countries, the fuzzy DEMATEL method adds value by mapping how these barriers interconnect and influence one another, providing a systemic understanding rather than a list of generic issues. Furthermore, poor behavior and a lack of awareness among industry stakeholders are serious concerns because both of these issues are linked to cultural issues within the industry. So, the industry needs to put some effort into developing a WM culture through regular training and seminar sessions. This way culture of WM and CE can be promoted in local construction sector and this culture must be initiated by the top management within industry.

3.3.2.3 Contractor's Perspective

Considering the opinions of contractors, significant cause barriers to WM are "Unclear specifications (B12)", "Lack of modern tools usage (B13)" and "Financial issues (B2)" with B1 and B2 as the most prominent cause barriers as presented in Figure 3.8 and Table 3.5. In addition, other barriers include low fines for illegal dumping (B7), lack of rules (B1), and lack of innovation in design (B10). Most of the barriers identified by contractors were related to clients & consultants.

This shows that contractors think that waste is generated due to negligence from clients and consultants, not providing financial resources, and following poor design practices. Most of the time, each stakeholder tries to blame other stakeholders to avoid responsibility. Furthermore, low fines of illegal dumping are also rated as a cause barrier. Governments must address this issue through their regulatory agencies. Poor construction practices (B8) and illogical design (B9) are rated as effective barriers that arise as a result of barriers. These results are also supported by another study conducted by [144], where illogical design and construction practices were rated as effect barriers.

Contractors believe that waste generation at construction sites is mainly triggered by the negligence of other stakeholders [152]. This is a serious concern because contractors often perceive that a substantial portion of construction waste is generated due to the carelessness or negligence of clients and consultants, rather than acknowledging and addressing their own role in waste creation. Such a perception fosters a blame-shifting mindset, where accountability is externalized instead of being shared among all project stakeholders. This attribution pattern is not only indicative of fragmented responsibility but also reflects a broader systemic tendency to deflect ownership of problems, which in turn weakens the collaborative spirit required for effective CE adoption. In particular, the analysis revealed that B1 and B2 emerged as the most critical barriers, exhibiting the highest D+R values, signifying their strong influence and interdependence within the network of challenges. Additionally, B11 and B6 were identified as significant barriers with notable effect, meaning their resolution could trigger positive impacts on others.

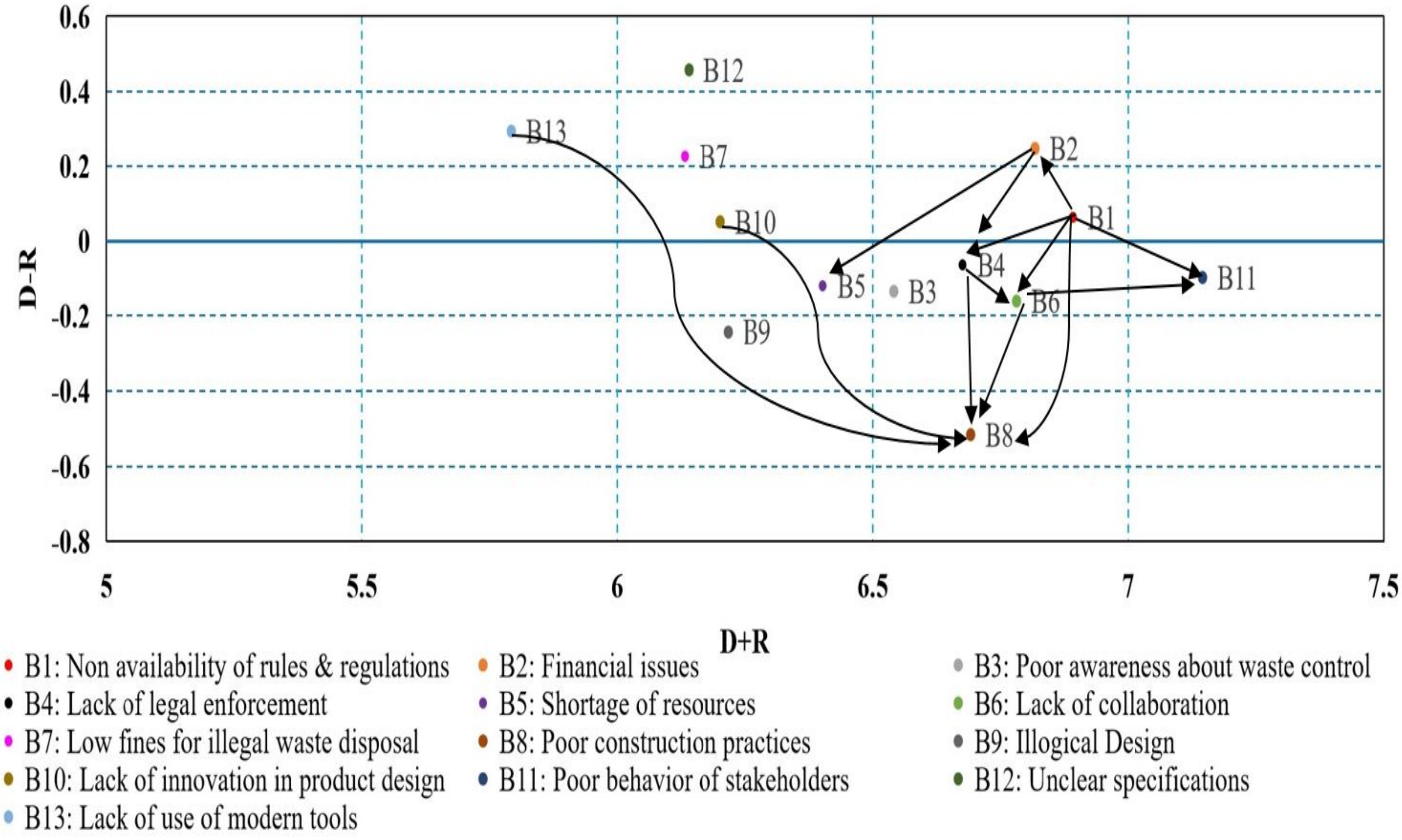

Figure 3.8: Cause-effect Diagram of Barriers to WM and CE on Building Projects (Contractor's Perspective)

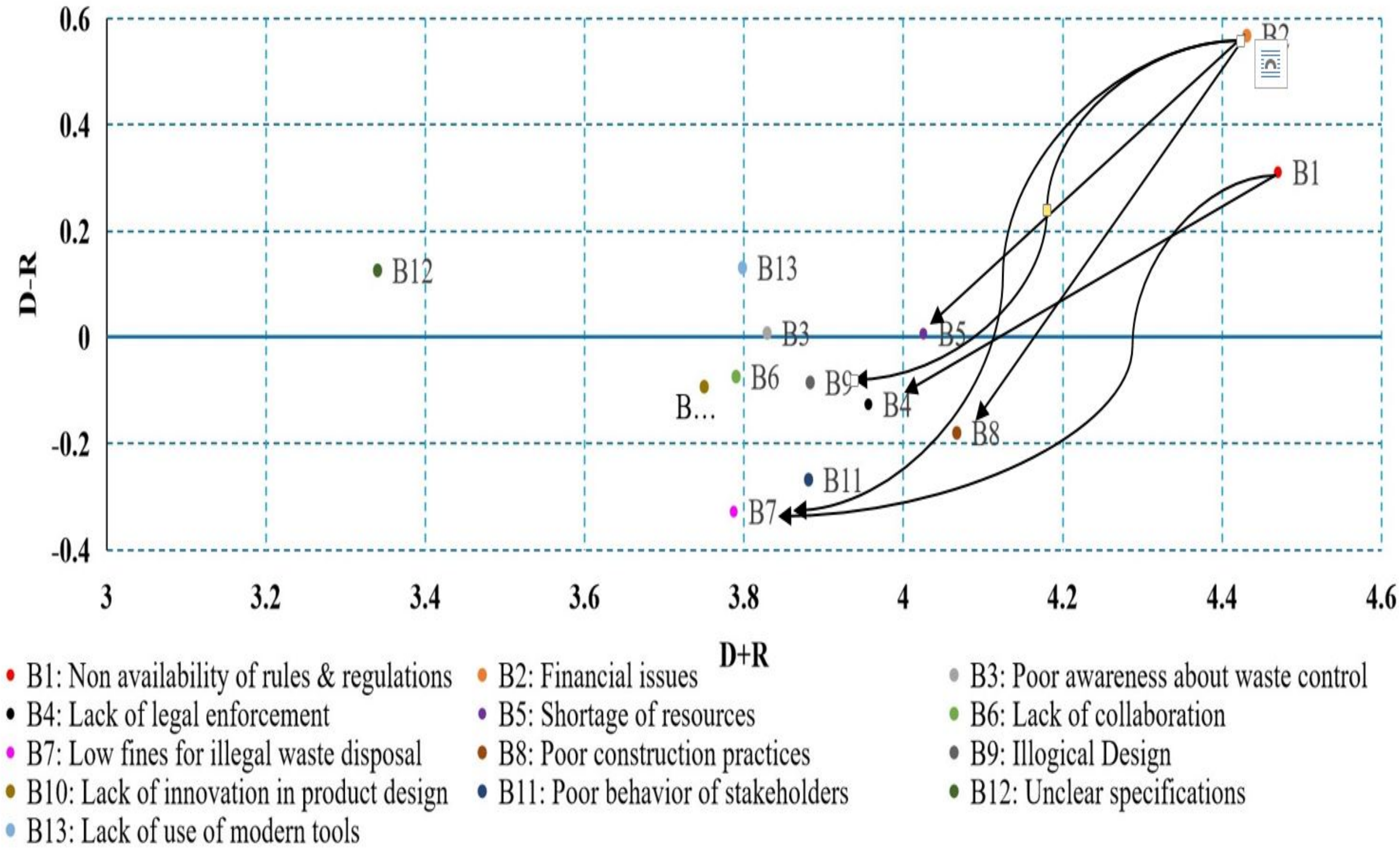

FIGURE 3.9: Cause-effect Diagram of Barriers to WM and CE on Building Projects (Regulator's Perspective)

3.3.2.4 Regulator's Perspective

Regulators and environmental agencies are also major stakeholders in the development of waste control culture in a country. Therefore, the perception of regulators is important, as shown in Figure 3.9. According to regulators, significant barriers to WM are "Financial issues (B2)", "Lack of rules (B1)", "Unclear specifications (B12)", "Lack of use of modern tools (B13)", "Shortage of resources (B5)", and "Poor awareness (B3)" with B1 and B2 are found as the most prominent cause barriers. Therefore, the perceptions of contractors and regulators in terms of cause barriers to WM are very similar to each other [21]. However, financial issues and the unavailability of rules and regulations are rated as important barriers by all industry stakeholders. Both these barriers are considered serious issues in developing countries because they require a lot of financial capital to support different initiatives, such as providing subsidies for recycled materials, construction new recycling units, and constructing landfill sites. On the other hand, the dividing line of D-R is the effect barrier. Therefore, regulators rated low fines on illegal dumping of waste as an effective barrier. Regulators acknowledge the lack of rules as a major reason for waste generation. This shows regulators awareness of their importance and sense of responsibility. This shows regulators awareness of their importance and sense of responsibility [153]. Therefore, regulators are required to develop policies to promote CE practices on building projects.

3.3.2.5 Comparison among All Stakeholder's Perspectives

On the basis of the analysis of stakeholders interactions and their perceptions of key issues (B1 to B13), several important findings emerge, as provided in Table 3.6 and Figure 3.10. The strongest alignment is observed between the contractor and regulator, with a 69% agreement rate. These two groups show consensus on critical issues such as the lack of rules and regulations (B1), financial issues (B2), unclear specifications (B12), and the lack of use of modern tools (B13), among others, as reported in Table 3.6. The reason of their agreement is, both think that major barriers are linked to the top hirarchy of country such as governmental agencies and decision makers. So, these barriers must be addressed by these stakeholders accordingly. However, they diverge on issues such as poor awareness among stakeholders (B3), a shortage of resources (B5), low fines for illegal dumping (B7) and a lack of innovative design (B10), indicating areas that may require negotiation or policy adjustment. Both the client and consultant group and the client and regulator group relationships show moderate agreement at 62%.The client and consultant align on core systemic concerns, including regulatory issues (B1), financial constraints (B2), stakeholders awareness (B3), illogical design (B9), and stakeholders behavior (B11), but disagree on matters related to poor implementation of WM regulations (B4), shortage of resources (B5), lack of collaboration among stakeholders (B6), low fines for illegal dumping (B7) and unclear specifications (B12). Similarly, the client and regulator share views on barriers (B1, B2, B3, B5, B6, B8, B10, and B12) but differ in (B4, B7, B9, B11, B13).

The consultant and regulator pair demonstrates a slightly lower agreement at 54%, with a consensus around a lack of regulations (B1), financial issues (B2), and stakeholders awareness (B3), but a disagreement on a shortage of resources (B5), lack of collaboration among departments (B6), illogical design (B9), and B11, B12 and B13. This indicates that, most of the time, all these stakeholders agree with each other. In contrast, the client and contractor group and consultant and contractor group relationships reflect lower levels of agreement, 46% and 38%, respectively, indicating potential collaboration challenges. The analysis reveals notable patterns of agreement and divergence among key stakeholders groups. The client and contractor demonstrate consensus on several critical barriers, including regulatory inadequacy (B1), financial challenges (B2), low penalties for noncompliance (B7), and unclear specifications (B12). However, their perspectives diverge on a range of other barriers, namely, B3, B4, B5, B6, B9, B10, B11, and B13, suggesting differing priorities or experiences related to these issues.

In contrast, the consultant and contractor exhibit the least alignment, sharing common views only on a limited set of barriers: regulatory inadequacy (B1), financial constraints (B2), legal enforcement (B4), resource shortages (B5), and poor construction practices (B8). This implies a gap between regulatory intentions and the on-ground technical insights consultants bring to projects. Significantly lower alignment is observed between clients and contractors (46%), and consultants and contractors (38%). While they agree on broad issues such as regulatory and financial constraints, they differ on nearly all other barriers. Contractors tend to emphasize executional and logistical constraints such as lack of collaboration (B6), behavioral issues (B11), and limited use of modern tools (B13) which may not be fully appreciated by clients and consultants operating in more strategic or design-focused roles. This divergence indicates deeper misalignments in priorities and expectations, with contractors often working reactively within constraints set by others due to their own interests on the project, while clients and consultants focus more on upstream planning and policy considerations.

Table 3.6: Comparison among the Perception of Stakeholders for WM and CE Barriers on Building Projects

Sr. No	Stakeholder Group	Common Cause Barriers	Common Effect Barriers	Percent Similarity
1	Client-Consultant	B1, B2, B3, B9, B11	B8, B10, B13	62%
2	Client-Contractor	B1, B2, B7, B12	B6, B8	46%
3	Client-Regulator	B1, B2, B3, B5, B12	B6, B8, B10	62%
4	Consultant-Contractor	B1, B2	B4, B5, B8	38%
5	Consultant-Regulator	B1, B2, B3	B4, B7, B8, B10	54%
6	Contractor-Regulator	B1, B2, B12, B13	B4, B6, B8, B9, B11	69%

These findings reveal that divergences among stakeholders are not incidental but arise from structurally different positions within the project lifecycle. Such differences must be acknowledged in the design of WM and CE policies. For example, regulators should co-develop flexible and enforceable standards with input from both contractors and design professionals. Clients and consultants should involve contractors earlier in the project planning process to anticipate and mitigate practical challenges. Moreover, capacity-building initiatives for contractors focused on CE principles, digital tools, and sustainable construction practices can help align their daily operations with broader environmental goals. Importantly, the barriers most consistently recognized across all stakeholders namely, the lack of clear regulations (B1) and financial constraints (B2) can serve as foundational priorities for policy reform. However, these must be addressed not in isolation, but as part of a more nuanced, stakeholder-sensitive strategy. Ultimately, improving WM and advancing the CE in the construction sector will depend not only on identifying common ground but also on bridging perceptual and operational gaps between stakeholder groups. regulators perceptions. In contrast, the client and contractor group and consultant and contractor group relationships reflect lower levels of agreement, 46% and 38% respectively, indicating potential collaboration challenges.

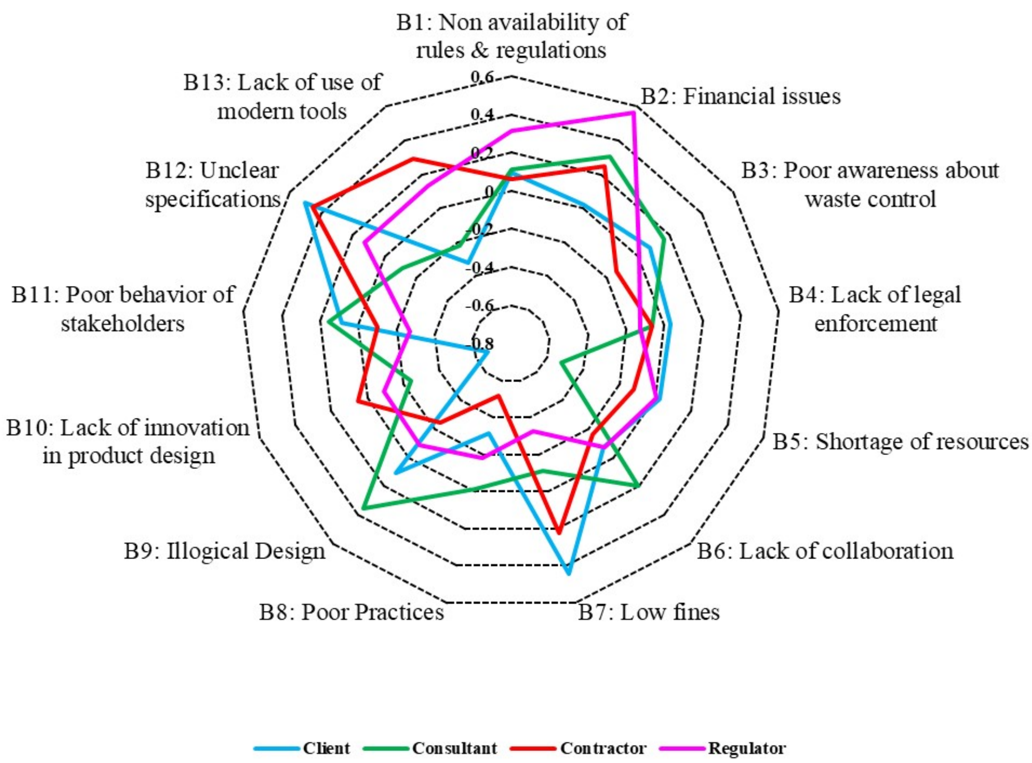

Figure 3.10: Comparison among Stakeholder's Perception for WM Barriers

The analysis reveals notable patterns of agreement and divergence among key stakeholder groups. The client and contractor demonstrate consensus on several critical barriers, including regulatory inadequacy (B1), financial challenges (B2), low penalties for non-compliance (B7), and unclear specifications (B12). However, their perspectives diverge on a range of other barriers, namely B3, B4, B5, B6, B9, B10, B11, and B13, suggesting differing priorities or experiences related to these issues. In contrast, the consultant and contractor exhibit the least alignment, sharing common views only on a limited set of barriers: regulatory inadequacy (B1), financial constraints (B2), legal enforcement (B4), resource shortages (B5), and suboptimal construction practices (B8). This limited overlap indicates a significant gap in understanding or emphasis between these two groups, which could hinder collaborative efforts to improve waste management if not addressed. So, these findings show that contractor is mostly on opposite side as compare to client and consultant during rating these barriers. It shows that difference of opinion mainly exist among these key stakeholders and the major stakeholder identified as contractor for such difference of opinion. Overall, the most widely acknowledged issues across stakeholders are the lack of rules and regulations (B1) and financial issues (B2), which appear as common points of agreement. These findings highlight the importance of fostering better communication and strategic alignment, particularly in areas where perspectives diverge significantly.

3.4 Practical Implications of Current Study's Results about WM and CE Barriers

The current study identifies several critical barriers to effective WM within the construction industry. These barriers, however, are not insurmountable. By formulating and implementing strategic interventions in the form of well-structured policies, these challenges can be systematically addressed. Such policy-driven strategies have the potential to exert control over construction waste generation and management at a broader, macro level, such as across cities or regions, while also enabling their adaptation and application at the micro or project level. This dual approach ensures both top-down policy guidance and bottom-up implementation in real-world projects, resulting in more comprehensive and sustainable outcomes. A notable contribution of this research is its provision of a detailed and comparative analysis of the perspectives held by various key stakeholders in the industry, including clients, consultants, contractors, and regulatory authorities. Through the application of the fuzzy DEMATEL methodology, the study was able to accurately identify and prioritize the root causes of the barriers to effective WM. The results not only shed light on which obstacles are most influential but also help in understanding the interrelationships among these factors. The identification of these root causes provides a valuable foundation for the development of targeted policy measures aimed at mitigating the barriers at multiple administrative levels, local, provincial, and national. This multi-level policy approach ensures that solutions are contextually appropriate and effectively aligned with the specific conditions and regulatory environments of each region. Beyond its immediate relevance to the local context, the findings of this study offer insights that can be extrapolated to other developing nations facing similar challenges in their construction industries. Ultimately, this research also contributes to global sustainability efforts, particularly in alignment with the UN-SDGs. By promoting sustainable construction practices and advocating for efficient waste management policies, the study supports goals related to responsible consumption and production, sustainable cities and communities, and climate action.

3.5 Summary

The present study seeks to offer policy guidelines for developing countries, where waste generation poses a significant environmental threat. This objective of phase-1 was achieved by identifying the key barriers to WM and CE practices on building projects.

- Based on Figure 3.5 and Table 3.3, a framework showing cause-effect relationship among WM barriers is presented in Figure 3.11. It can be observed

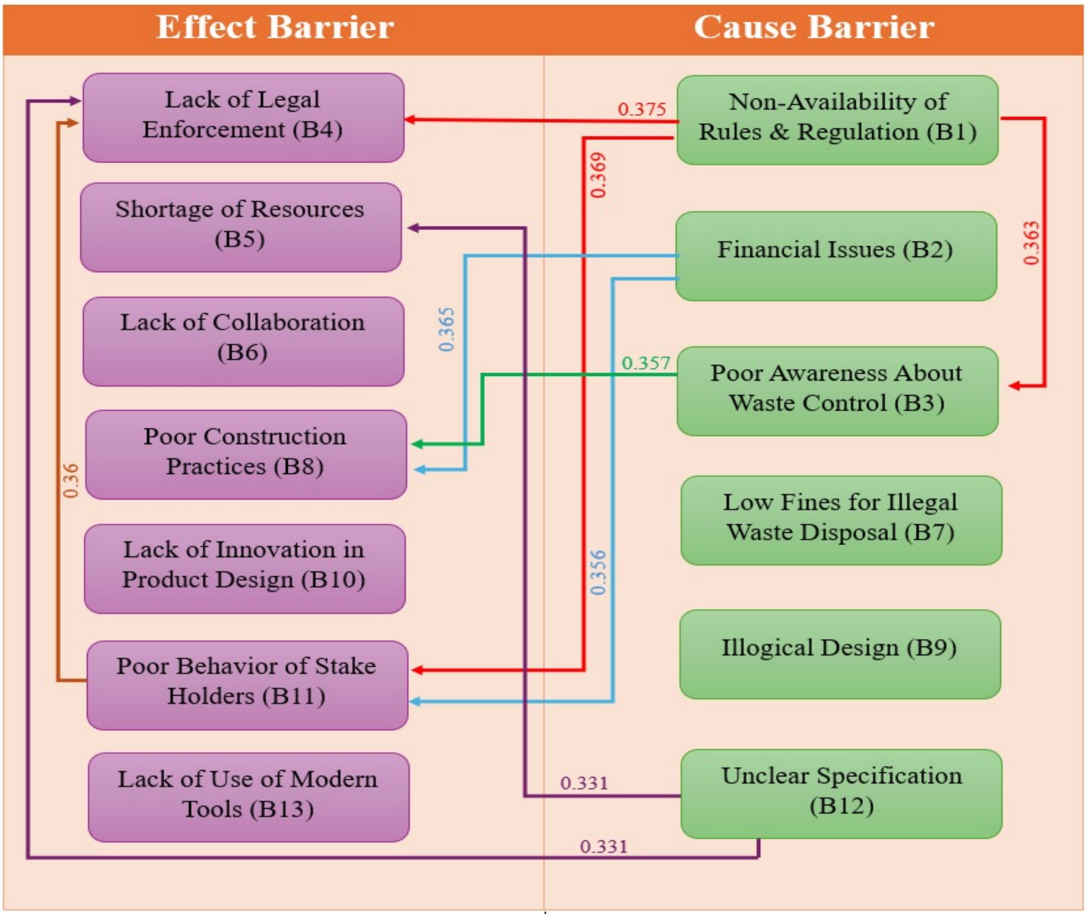

FIGURE 3.11: Cause-Effect Relationship Framework for WM Barriers

from Figure 3.11 that non-availability of rules and regulations (B1) and financial issues (B2) are found as the most influential root-cause barriers effecting other barriers.

- In terms of comparative analysis among the perceptions of these stakeholders. The contractor-regulator pair shows the highest alignment (69%) while client-contractor (46%) and consultant-contractor (38%) show the least alignment, indicating major gaps in collaboration and construction practices.

The study identifies critical barriers to effective construction WM and CE practices on building projects. Using fuzzy DEMATEL, the research highlights the most influential root causes and their interrelations, enabling precise policy targeting. The findings are relevant not only locally but also to other developing countries with similar conditions. These barriers can be addressed through strategic, policy-driven interventions. By leveraging a dual approach-macro-level policy implementation and micro-level project application-more sustainable outcomes can be achieved.

Chapter 4

Enablers/Policy Measures for WM and CE Frameworks

4.1 Background

In the previous chapter, major barriers to WM and CE for building projects were discussed. Now, this chapter is about the solution to these barriers. These solutions are provided in the form of strategies. Since, barriers need to be tackled at macro as well as micro levels, therefore strategies are also devised at external and internal levels. Following sections will provide details about the semi-structured interviews for strategies development, thematic analysis and practical implementation of current study.

4.2 Research Method for Identification of WM and CE Enablers

This section explains the research design, respondent profile, data collection, analytical techniques, and procedures for developing the theoretical framework. Details are provided in the following sections. The research design used in this study was based on Saunder's research onion model, as shown in Figure 4.1. The research onion model has been used in multiple studies to create the research design [57, 154, 155]. All of these previous studies shared several prominent similarities. Among these studies, Saunder's research onion model was used. This model illustrates a systematic approach to designing research that carefully combines aspects such as research philosophy, strategy, and methods of data collection. In line with these previous studies, the current research similarly utilizes Saunder's research onion framework to systematically select the research variables, incorporating aspects of research philosophies, theoretical approaches, methodological choices, strategies, time horizons, and data collection techniques and procedures. Furthermore, each of these studies also tackles practical, industry-related issues, such as the impact of employee training on entrepreneurship [154], the quantification of materials waste on building projects [57], the relationship between corporate issues and the behavior of workers [57], the relationship between corporate issues and the behavior of workers [155], and methodological challenges encountered during the COVID-19 pandemic, thereby emphasizing their relevance to real-world problems. Similarly, the current study also addresses the issue of waste generation by developing policy guidelines for building projects in the construction sector.

The current study was conducted under the philosophy of interpretivism because of the presence of qualitative data collected through semi-structured interviews [156]. Moving to the next layer of Saunder's model, an abductive approach was adopted in this study. The research started with predefined themes (a deductive approach), but later, new themes (an inductive approach) emerged at the end of data analysis. Therefore, the method used was a mixture of deductive and inductive approaches, and an abductive approach was selected [157]. The next layer is methodological, in which the qualitative method (qualitative) was selected. The grounded theory was then selected as a strategy because it is directly linked to the development of themes/theories from the collected data [158]. As data were collected from construction experts in Pakistan during the same period, a cross-sectional approach was considered in the current study. The last layer of this model was the analytical method; therefore, thematic analysis was applied considering the qualitative nature of the collected data. The data used for the current study were collected through semi-structured interviews and were primary. Further details about the respondents and the analysis are provided in the following sections.

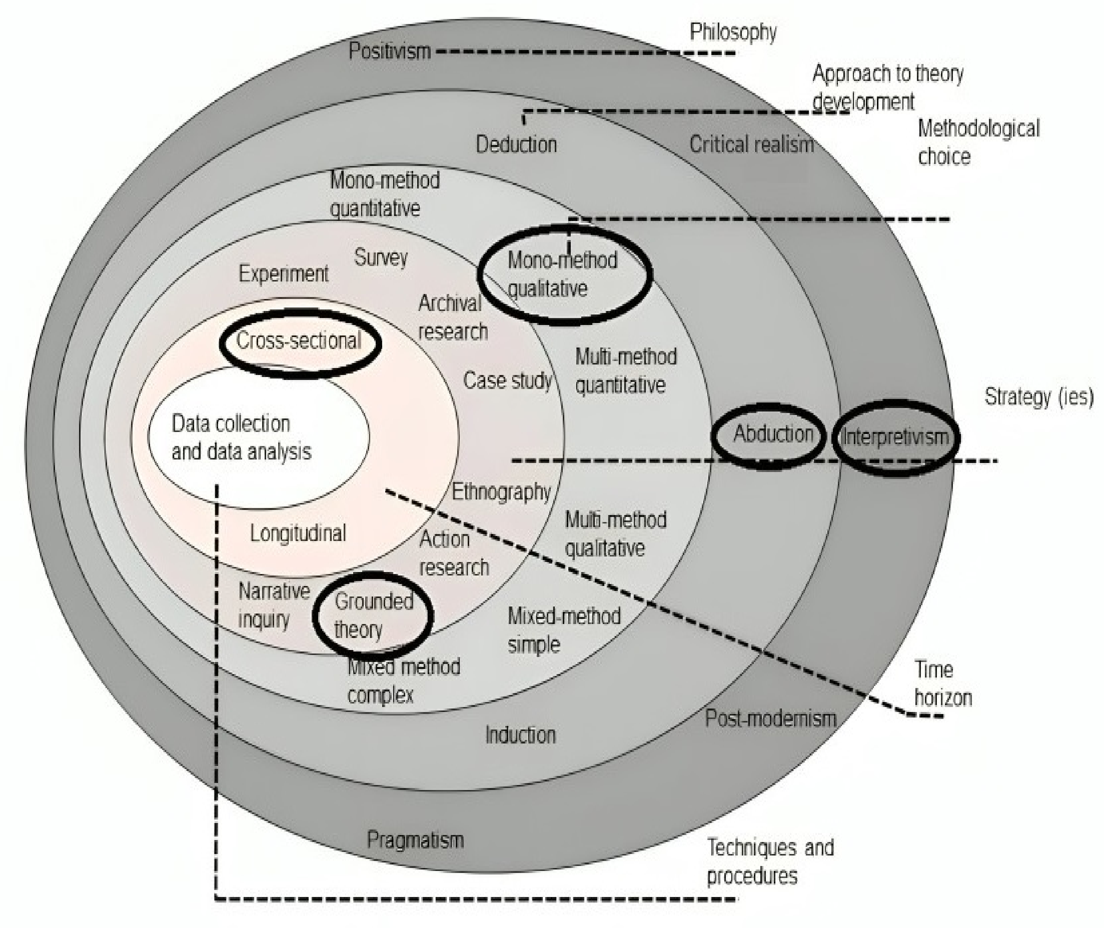

FIGURE 4.1: Research Design based on Saunder's Research Model [57]

4.2.1 Sample Selection and Respondent's Profile

After the identifying the WM barriers in Phase-1 of this research, another questionnaire was formulated for Phase-2. The questions were mainly linked how to address the identified barriers, then a pilot survey was conducted from four (04) experts before finalizing the questionnaire from field experts, similar to Phase-1. The final questionnaire include questions as provided under Table 4.2. In order to develop a comprehensive theoretical framework for CE and WM in the construction sector, data were collected from field experts in Pakistan through semi-structured interviews.

Stakeholder disagreements often pose challenges to implementing waste minimization policies, but these were addressed through inclusive and participatory approaches. Therefore, input from all these major stakeholders were incorporated during formulation of policy makers. The semi-structured interview method was selected because it not only allowed the experts to express their views on relevant issues, but it also gave them the flexibility to add more information beyond what was included in the interview questionnaire [159].

Table 4.1: Respondents Profile for Study on WM and CE Enablers

Sr. No.	Characteristics of Respondents	Frequency	Percentage
1	Clients	05	21%
2	Consultants	05	21%
3	Contractors	08	33%
4	Regulators	06	25%

Current study opted for purposive and snowball sampling (non-probability) methods instead of random (probability) sampling to address the challenge of participant selection. Purposive and snowball sampling are important techniques for gathering significant data in qualitative research when random sampling is very difficult. Purposive sampling entails selecting participants based on certain criteria to identify individuals or groups most relevant to the research question, particularly those with relevant experience who can offer rich, in-depth insights.

As a non-probability approach, it focuses on units possessing key characteristics that align with the study's emphasis [160]. Thus, the initial participants were selected based on criteria having some background knowledge of WM through the purposive sampling method. Subsequently, snowball sampling was employed to reach specific participants by requesting that initial participants suggest others who fit the study's criteria or have relevant experience [161].

Thus, the interview process proceeded until the saturation point was reached [162]. The saturation point is categorized into two types: coding and meaning saturation [50]. In the current study, saturation points for meaning and coding were reached after 24 interviews, similar to another study [50]. Moreover, data were collected from all key stakeholders, which comprised clients (21%), consultants (21%), contractors (33%), and regulators (25%), to guarantee a thorough understanding of the issues surrounding WM as shown in Table 4.1. In phase-2, 70 to 80% selected participants were same as of Phase-1 (barrier's identification). The remaining 20-30% were not available to provide their inputs for formulation of policy framework due to their busy schedule. Therefore, 20-30% new participants were included in Phase-2.

The selection process for different types of stakeholders was deliberate, as every stakeholder group provides a unique and vital perspective on WM practices. Clients typically influence project specifications and funding priorities; consultants offer technical expertise and design solutions; contractors are accountable for the practical implementation and operational management; and regulators create the legal and compliance frameworks that govern WM practices. By integrating feedback from all these groups, this study sought to attain a well-rounded perspective on the challenges and opportunities within WM, reducing bias and ensuring that the results are reflective of the wider industry context. Among 24 interviwees, (42%) had Bachelors and (58%) had Masters degrees. Further, these professionals also had at least ten years of field experience. Experts must have at least ten years of field experience, since respondents with less than ten years of experience are unlikely to make informed decisions [29]. Therefore, the data for the current study were collected from all key stakeholders with different field experiences to incorporate the maximum input for the development of policy guidelines.

4.2.2 Data Analysis for WM and CE Enablers

A number of analyses were performed on the collected data, including word frequency analysis, cluster analysis, and ultimately thematic analysis using NVivo software. NVivo was preffered over qualitative data analysis (QDA), MAXQDA and ATLAS.ti softwares. Detailed justification of using NVivo over other softwares were discussed under section 2.3 of literature review chapter.

4.2.2.1 Word Frequency and Cluster Analyses for WM and CE Enablers

Word frequency analysis is an in-depth technique used to investigate the most frequently utilized words and phrases in qualitative data, such as interview transcripts. Word frequency analysis in semi-structured interviews helps to identify the most recurring issues and priorities expressed by stakeholders regarding policy making for construction waste management. By highlighting commonly used words and concepts, it provides an initial indication of dominant themes, such as regulation, enforcement, etc. which reflect the concerns and focus areas of participants. Ultimately, the analysis ensures that policy recommendations are grounded in the issues most frequently emphasized by stakeholders, thereby enhancing the relevance and applicability of the findings. In the context of construction waste management, this analysis is crucial for revealing stakeholder priorities and perspectives. In the current study, once the data of the semi-structured interviews were coded in the Nvivo software, word frequency analysis of the interviews was performed by setting the word length to 10 and the number of words to 20. Running the query and adding a few words such as the, and, etc., to the stop list provided a tree structure of high-frequency words. This analysis has also been used in other studies to obtain an overview of interviews [18]. Therefore, this analysis provided insight into the words that were mostly discussed during the interviews. The more frequently a word is discussed, the more important that word will be. A highly frequent word was allowed more space in the word frequency diagram and vice versa.

Second was the cluster analysis, which provides in-depth insight into the underlying nature of the enablers highlighted by interview transcripts, as well as cross-validating the findings. By clustering similar responses, it becomes easier to identify how different themessuch as regulatory measures, financial incentives, enforcement mechanisms, or awareness campaigns-are interconnected. This approach helps in simplifying large volumes of qualitative data, highlighting associations that may not be obvious through word counts alone. Cluster analysis has been used in previous studies to determine waste reduction enablers [163, 164]. The findings are typically presented as a dendrogram, in which the distance is represented by the points where the codes are connected (from left to right). The more closely connected the codes are, the more relevant they are to each other.

4.2.2.2 Thematic Analysis of Stakeholder's Perceptions and Development of Framework

Data were collected from the key stakeholders through semi-structured interviews. Semi-structured interviews are effective tools for gathering respondents opinions on complicated issues, such as enablers or policy guidelines for WM [165]. Compared to other tools, such as surveys or structured interviews, experts are allowed to express themselves more freely through semi-structured interviews [165]. The questionnaire survey was formulated around findings of phase 1 results, as illustrated in Table 4.2. The few of the most important questions asked in these interviews are given in Table 4.2. These questions were categorized into two main sections: the micro-level and the macro-level. The interviews were held either in person or via Zoom. The duration of the interviews ranged from 50 to 90 min depending on the expertise of the participants. Audio data from the interviews were intricately transcribed before the research team checked the quality of the textual data. The transcripts were examined using the NVivo 15 tool, which helps codify text-based qualitative data.

Using the NVivo software, a deductive (theory-driven) coding scheme was used, and themes developed in earlier research on WM and CE served as the basis for the deductive coding. Furthermore, several new themes emerged inductively from the interview data. Thematic analysis was performed on the collected data. The thematic analysis procedure involved different stages, such as 1) familiarization with the collected data, 2) the generation of initial codes from the interviewees statements, and 3) a detailed search for themes. More themes were extracted from the statement; 4) a review of the extracted themes to identify whether there is any theme left; and 5) the addition or deletion of themes based on their relevance to the topic.

TABLE 4.2: Overview of the Questions Used in the Interview

Sr. No	Scope	Questions
1.	Micro level	How can the issues of poor design practices and unclear specifications for waste generation be avoided?
2.		What measures contractor should take to reduce and reuse the materials during the construction phase of a project and develop a culture of WM?
3.		Do you think any measure, which effectively manages waste during post-construction phase of a project, especially to avoid illegal dumpings?
4.	Macro level	How construction industry can develop a waste minimization culture and improve the awareness of stakeholders at a macro level?
5.		What policy measures the government should take to ensure waste management practices in the construction sector? Is there any fiancial model required to support WM practices and what should it be

The frequency distributions of the different types of themes found in the interviews served as the primary method for these comparisons [89]. After consulting these experts, a policy framework was proposed to develop WM and CE cultures in the context of Pakistan. After consulting these experts, a policy framework was proposed to develop WM and CE cultures in the context of Pakistan.

The data collected from semi-structured interviews is first transcribed into text format. All the received answers were arranged into an excel file. Detailed reply of each participant was described in this file. Then, data in the form of sentences were entered into the NVivo software. Each sentence mean one data point, which linked to one theme at a time. Each transcript is treated as a source document and coded by highlighting and assigning relevant portions of text to nodes that represent emerging concepts or themes [166]. Through this coding process, the enablers mentioned by participants are identified and organized, providing a structured representation of their views. NVivos analytical functions, such as word frequency queries and cluster analysis, further support the exploration of relationships between themes and the verification of the prominence of specific enablers [167, 168]. This structured approach ensures that qualitative insights from interviews are rigorously captured and translated into meaningful categories that can inform effective policy making for construction waste management.

4.3 Results and Discussion

After completing the thematic analysis of the transcripts of all the interviews, the results are discussed in detail in the following sections.

4.3.1 Results of Word Frequency and Cluster Analyses

The analysis of word frequency provided valuable insights into the key themes and main points raised during the expert interviews. As illustrated in Figure 4.2, different words are represented visually within rectangular boxes of varying sizes. The size of each box directly corresponds to how frequently that word appeared throughout the interviews, the bigger the box, the more frequently that word was mentioned.

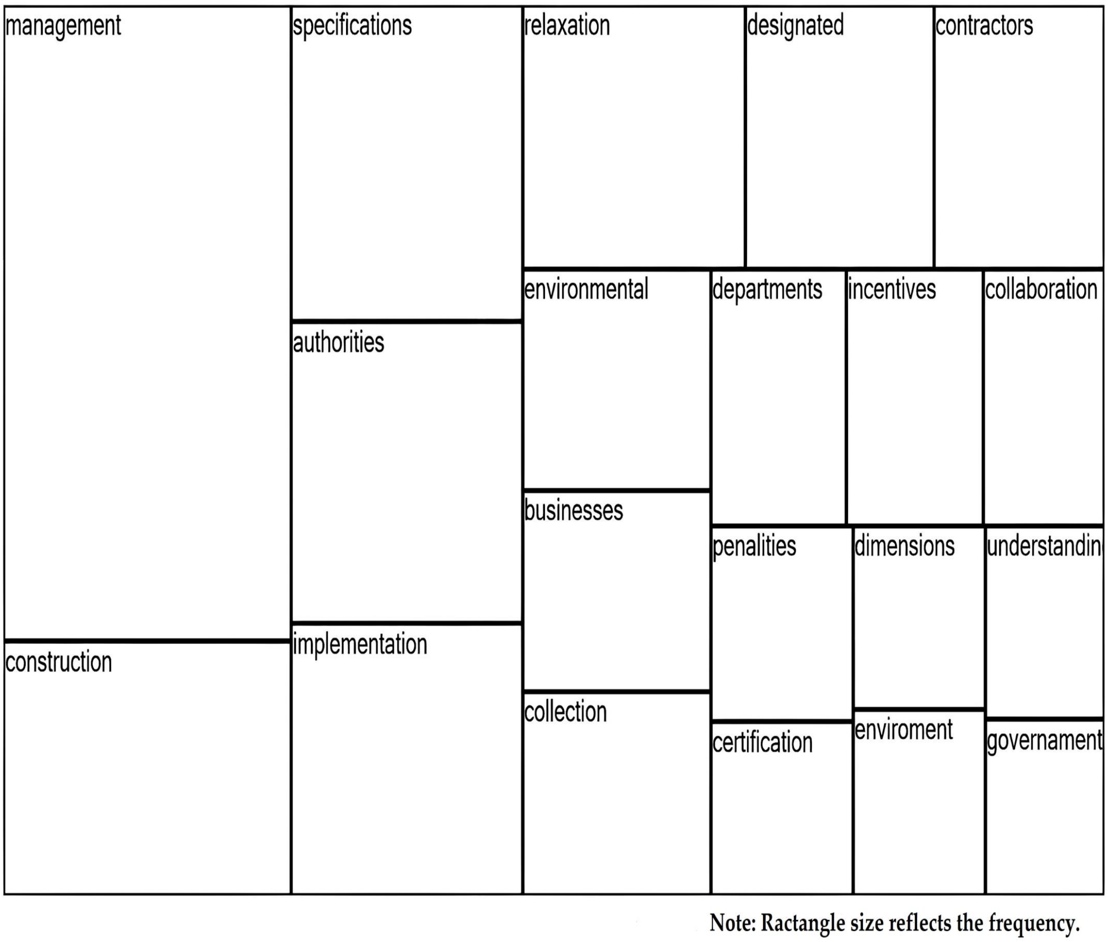

FIGURE 4.2: Tree Structure of High-Frequency Words for WM and CE Enablers

Specifically, terms like "management", "construction", "specifications", "authorities", "implementation", "understanding", and "relaxation" have the largest boxes, indicating that these subjects were most commonly highlighted by the interviewees. This indicates that these terms signify important and recurring ideas associated with construction WM. Statistical results reinforce this observation, with high frequency terms also including "designated", "business", "collection", and "incentives". Together, these words create important thematic clusters that experts underscored during their conversations about enhancing environmental policies in the construction industry. The prominence of these terms indicates that stakeholders regard several enablers as essential when developing effective WM policies. Key aspects involve improving construction WM systems, ensuring adherence to environmental regulations, optimizing waste collection methods, designating landfill sites, fostering business growth in the waste management sector, reducing tax burdens, and providing financial incentives. Therefore, word frequency analysis offers a clear yet powerful way to identify and articulate the themes arising from qualitative data, allowing researchers and policymakers to focus on the most discussed and influential factors in future waste reduction policy-making for the construction sector.

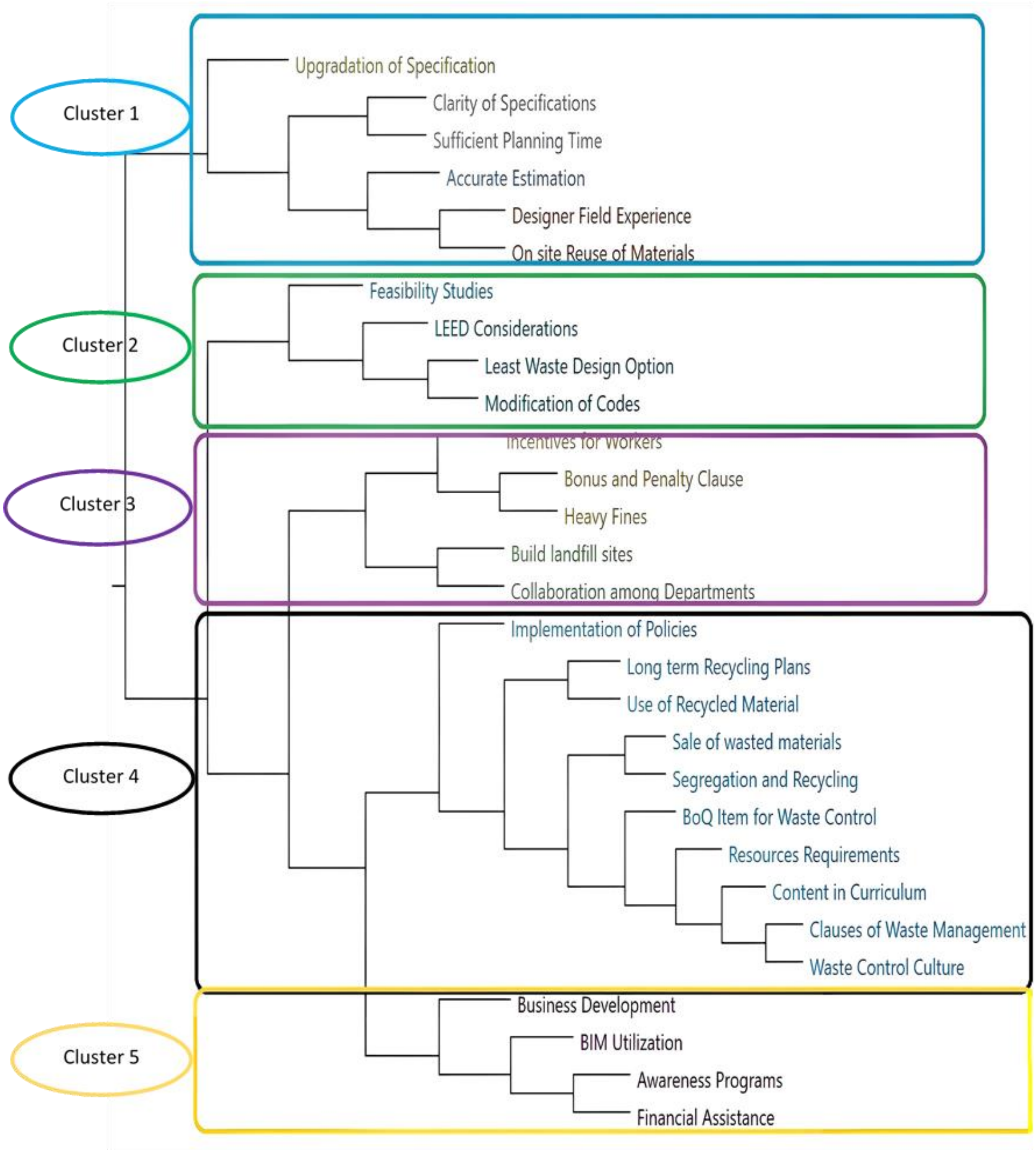

FIGURE 4.3: Results of Cluster-Based Analysis for WM and CE Enablers

Second is the cluster analysis, which provides in-depth insight into the underlying nature of the enablers highlighted by interview transcripts and also cross validates the findings [163, 169]. As illustrated in Figure 4.3, five clusters were identified as a result of agglomerative hierarchical clustering. Cluster 1 shows the codes that are closely linked to the development of bidding documents, such as the up-gradation of specifications, sufficient planning time, accurate estimation of materials, and designers field experience. Similar findings were reported in other studies [159, 170]. In Cluster 2, enablers that are linked to the least waste-generating options through code design or modification are grouped. Further, bonuses and penalties, fines, and incentives are grouped under Cluster 3, since these themes are more closely linked with each other. Cluster 4 is more about the implementation of WM strategies during the execution of a project, such as the segregation of materials, reduction and reuse, waste control culture, recycling materials, and the sale of waste materials. Finally, Cluster 5 provides details about WM enablers through BIM adoption, awareness programs, and financial assistance from governments for business development. All these enablers emerged from the interviews and were linked to the development of a policy framework for WM in the building sector of a developing country. These proposed clusters must be considered in the linkage of development of framework for the construction sector of Pakistan.

4.3.2 Enablers for WM and CE Culture- Stakeholder's Perspectives

Through an in-depth thematic analysis of the qualitative data obtained from semi-structured interviews, a range of distinct and meaningful themes emerged. These themes were meticulously identified through a systematic coding process facilitated by NVivo software, which enabled efficient organization and interpretation of large volumes of textual data. The primary aim of this thematic exploration was to uncover key enablers as perceived by the interview participants, particularly in the context of their suggestions for policy enhancements related to WM. The analysis was conducted with rigor and attention to detail, ensuring that the emergent themes were both representative and analytically sound. As a result of this comprehensive process, more than twenty-six (26) individual themes were identified. To ensure focus on the most salient insights, themes with a coding reference or coverage of more than 1% were categorized as significant and warranting closer attention. These prominent themes are systematically presented in Table

4.3, reflecting the frequency and emphasis placed on them by participants during the interviews.

In thematic analysis, percent coverage denotes the proportion of the dataset that is coded under a specific theme relative to the total data analyzed. In this study, one dataset corresponds to a single sentence, with a total of 244 sentences examined. Accordingly, a theme with 1% coverage represents three or fewer sentences linked to that theme. Using this approach, the percentage coverage for each theme was calculated. A higher percentage indicates that a greater number of sentences were associated with the theme, thereby reflecting its relative prominence and importance within the dataset.

Building upon the percentage coverage of the themes proposed by all four stakeholders, a formal policy framework was developed, which is illustrated in Figure 4.4. Within this framework, the enabler that had the highest percentage coverage, such as financial assistance, was deemed the most critical policy measure for waste management, as it was consistently emphasized by all stakeholders. The logical structuring of the extracted themes led to the creation of a thematic tree consisting of four layers. At the top of this tree is the coat hanger node, which serves as the foundational starting point for the framework. The second layer of the tree includes the grouping nodes or parent nodes, which conceptually categorize the themes into two main groups. Figure 4.4 clearly illustrates these two parent nodes: macro-level factors, which account for 68.4% of the theme coverage, and micro-level factors, which represent 18.4% of the coverage.

These groups were made based on the fact that these enablers either are required by the industry, organizations or national governments. So, all these enablers are kept under the head of macro-level factors. Furthermore, few of the enablers are closely linked to planning, execution and post construction of a project, so these were categorized under micro-level factors. Macro-level factors mean which exist at national, organizational and industrial levels. On the other hand micro-level enablers include strategies at project level. All of them must be addressed at appropriate levels.

Table 4.3: Percent of Coded Themes on WM and CE Enablers

Sr. No.	Themes	Percent	Sr. No.	Themes	Percent
1.	Financial Assistance	14.6%	11.	Clauses of Waste Management	3.7%
2.	Awareness Programs	11.2%	12.	Content in Curriculum	3.5%
3.	Collaboration of Departments	7.3%	13.	Modification of Codes	3.3%
4.	Heavy Fines	5.5%	14.	Designer Field Experience	2.7%
5.	BIM Utilization	5.0%	15.	Implementation of Policies	2.3%
6.	Waste Control Culture	5.0%	16.	Least Waste Design Option	2.3%
7.	Clarity of Specifications	4.1%	17.	Segregation and Recycling	2.0%
8.	Resources Requirements	4.1%	18.	On-site Reuse of Materials	2.0%
9.	Build Landfill Sites	4.1%	19.	Bonus and Penalty Clause	1.3%
10.	Long-term Recycling Plans	3.9%	20.	Business Development	1.1%

The higher percentage of coverage for macro-level factors indicates their greater importance, as they typically involve policy initiatives driven by governments and organizations. These initiatives, in turn, have a broader impact at the micro level, affecting the day-to-day operations and practices within the construction industry [171]. Further, in Figure 4.4, relationship lines connect parent nodes to children nodes. Each parent node had three child nodes. Among children nodes, national, industrial, and organizational efforts are more important than design, execution, and post-construction level enablers. At level 4, each child node has multiple sub-child nodes.

Table 4.4: Themes Missed with Percent Coverages

Sr. No.	Themes	Percent	Sr. No.	Themes	Percent
1.	Capacity Building of Labor	0.9%	2.	Use of Smart Technologies	0.8%
3.	Eco-friendly Materials Promotion	0.7%	4.	Incentives for Waste Reduction	0.6%
5.	Cross-sector Partnerships	0.5%	6.	Long-term Monitoring	0.5%

During the initial coding process, nearly twenty-five themes were identified; however, only twenty were formally reported in the final framework. The remaining six were excluded because each accounted for less than 1% of the coded data and, more importantly, they overlapped conceptually with broader themes that were already included as presented in Table 4.4. For example, the theme of capacity building of labor was noted in a few responses, but this naturally falls within the scope of awareness programs, which already emphasize training and skill development. Similarly, suggestions for the use of smart technologies such as IoT and digital tracking were identified but were more appropriately represented under BIM utilization, as both address technology-driven solutions for waste minimization.

The call for promotion and certification of eco-friendly materials was also recorded, yet this aligned closely with business development, which highlights the growth of sustainable markets and practices. Likewise, references to contractual incentives for waste reduction were subsumed under bonus and penalty clauses, which capture the wider framework of contractual enforcement mechanisms. A few respondents also mentioned cross-sector partnerships such as publicprivate collaborations, but these were considered part of the broader theme of collaboration of departments. Finally, long-term monitoring and evaluation mechanisms appeared as a minor theme, but these were deemed integral to implementation of policies rather than a stand-alone area. By merging these low-frequency themes into the twenty reported ones, the final framework avoids redundancy while still ensuring that no insights are lost. This consolidation approach is consistent with best practices in thematic analysis, where minor or overlapping codes are integrated into higher-order categories to produce a clear, comprehensive, and policy-relevant framework for waste minimization in the construction sector of Pakistan.

Detailed discussions of each of proposed policy measures in the form of enablers are presented in the following sections.

4.3.2.1 National-Level Enablers

At the national level, major enablers include financial assistance (14.6%) in the form of subsidies, the relaxation of taxes, low-interest rate loans, and a reduction in import duties for machinery, and these can substantially improve WM culture in the construction sector. Financial support would encourage local investors to establish businesses that are linked to WM, such as building a recycled material market and establishing recycling plants. Furthermore, the imposition of heavy fines (5.5%) for illegal dumping is very necessary. The amount of these fines must be greater than the cost of transporting waste materials to the dumping sites. This encourages contractors to prioritize dumping at designated landfills rather than paying low fines. In addition to heavy fines, designated dumping sites (4.1%) must also be established by governmental agencies at appropriate distances from potential construction sites. In this regard, the use of geo-informatics systems should be employed to identify suitable landfill sites within a city [172]. Thus, efforts to trace waste materials should become easier. Long term recycling targets (3.9%) should be set for each developing country. In this regard, the interviewees agreed that the country must have a thirty year plan for waste reduction gradually, and recycling targets should be further divided every five years. Most developed countries have set and achieved such targets to promote WM and CE cultures in their countries [173, 174]. The efforts at the macro level have a significant effect on the micro-level culture of projects; therefore, these enablers must be imposed to achieve better results. Furthermore, the local construction sector, as well as other industries facing comparable challenges, can benefit from the deployment, growth, and customization of the suggested WM framework, which can help improve resource consumption.

Collaboration among departments (7.3%) such as regulators (Paksitan Engineering Council, Ministry of Climate Change) should work in close relation to development authorities (CDA,FDA, LDA), further these departments work in close relation to local authorities (WASA, TMA) to handle waste each level. However, the Pakistani framework deviates in its stronger emphasis on policy formulation and regulatory clarity reflecting the absence of formal WM legislation locally whereas in developed contexts, enforcement mechanisms and compliance auditing are already well-established. This tailored focus ensures the framework addresses structural governance gaps while drawing on globally recognized best practices.

While the proposed WM policy framework is tailored to Pakistan's construction sector, its principles share commonalities with frameworks implemented in countries such as the United Kingdom, Australia, and Singapore, where integrated waste management plans, stakeholder accountability, and regulatory enforcement are central components. For example, the UK's Site Waste Management Plans (SWMP) emphasize pre-construction planning and on-site segregation, which closely align with the proactive planning and monitoring elements in currently proposed framework [175]. Similarly, Australia's National Waste Policy highlights the importance of life-cycle thinking and industry collaboration, paralleling the multi-stakeholder engagement aspect of current study approach [98].

4.3.2.2 Organizational-Level Enablers

Regarding macro-level factors, the organizational culture is important in promoting CE practices at construction sites. Industry stakeholders were keen to suggest enablers at the organizational level. These enablers include experienced designers (2.7%), business development (1.1%), the implementation of WM policies (2.3%), and waste control culture (5%). One of the field expert highlighted "Cheap loans as compare to market rates must be issued to businesses linked with waste management programs like solar panels subsidize". Business models must be developed with financial incentives. Most of the interviewees emphasized the field experience of designers because irregular sizes of building components were designed owing to a lack of practical experience. These irregular sizes lead to the generation of waste.

Experienced designers must know the availability of standard size materials in the market and design components accordingly. In contrast to this approach, involving suppliers in the early phase of the design process can help resolve issues related to material size selection [176]. However, it is often more effective to rely on experienced designers to make such informed decisions, rather than involving additional stakeholders in the project, as doing so may introduce other complications. The next step is to develop businesses linked to WM, such as building recycling units and recycled markets. It is important to develop businesses that support CE culture in the construction sector [177]. Furthermore, each organization must ensure the implementation of WM policies in its projects and develop a waste control culture within the company. The role of top management in developing such a culture is critical [178]. This would not only improve the company's reputation but also save millions of currency units. It is estimated that WM could save up to 3% of total project costs [179]. Thus, adopting WM practices helps develop sustainable cultures within organizations.

4.3.2.3 Industrial-Level Enablers

Most of the experts proposed a number of strategies at the industrial level, such as awareness programs (11.2%), clauses of WM (3.7%), bonus and penalty (1.3%), contents of WM in the curriculum of BS programs (3.5%) and modification of building codes (3.3%). Awareness programs must start in the form of workshops, seminars, and training to improve WM knowledge among all stakeholders. It is important to understand waste control and its benefits. Most of the time, waste is generated because of poor awareness among stakeholders [180]. Further, interviewees were also intrigued by existing codes of building design. They wanted to include criteria for the least waste generating options in designing building components. This observation was similar to that of another study, where the modification of codes was suggested as a measure of WM [181]. The next is the clauses of WM, which must be added to the standard bidding documents of construction projects. Three major caluses have been suggested; one is about introduction of marks for contractor's selection, second is bounding the contractor to provide and implement WMP on sites, and including 5-10 markes in the selection criteria of contractors.

Imposing bonus and penalty (1.3%) must be a part of contract documents. This is because contractors do not bother to perform any task until they are bound by the contract. In this regrad, it was suggested that up to 5% of total project cost can be treated as bonus or penalty, depending upo the handling of waste by contractors. A similar strategy for promoting WM culture has been reported in other studies [182, 183]. Finally, WM content must be added to the BS curriculum. The inclusion of WM topics in student curricula was also highlighted in another study [184]. This approach is intended to raise awareness among students, equipping them with the knowledge and mindset necessary to consider WM options in their future decision-making processes. Several interviewees emphasized the importance of integrating WM education into undergraduate studies. Some proposed the introduction of standalone courses dedicated to WM, while others recommended incorporating relevant content into existing modules, such as project management. Both strategies were seen as viable means to enhance engineers awareness and understanding of WM practices from the outset of their careers. Furthermore, fostering this awareness at the grassroots level aligns with the ethical responsibility of engineers to contribute to environmental sustainability and uphold their moral obligation to maintain a clean and healthy environment.

4.3.2.4 Enablers at Planning/Design Phase

The planning and design phases of a project are important because they can remove waste from its source. Once this phase is passed, waste cannot be controlled in the later stages of a project [120]. Therefore, the policy measures suggested in the planning and design phase are presented in Figure 4.4. Field experts in the local construction industry have suggested several measures to control waste during the planning and design phases of projects. These enablers include the use of BIM (5%), the clarification of specifications of contract documents (4.1%), and the consideration of the least waste-generating options (2.3%). The use of BIM in the planning phase allows stakeholders to identify clashes, discrepancies, and errors in drawings. One of the expert was of the opinoin "BIM must be used to avoid waste generation. BIM also helpful to control cost and time. Attributes like clash detection can be helpful to avoid rework. Accurate quantity takeoff will improve the materials efficiency". So, instead, they tend to rework in the later stages of a project and thus generate large amounts of waste.

Consideration of the least waste design option, along with the use of BIM, was also reported as a key enabler for minimizing waste during the design phase of a project [185]. Furthermore, BIM reduces waste during the execution phase of a project because it provides alternate options in working methodologies to reduce waste on-site. Several studies have used BIM to reduce the waste of tiles, dry walls, and reinforcements [186–188]. Next is the consideration of the least wasteful design options to be used during component design. These options include the use of prefabricated structures and designing building components of standard sizes based on their availability in the market. Prefabricated structures promote off-site construction where components are constructed with the minimum utilization of materials as compared to on-site in situ options.

Further, designers must be mindful of the availability of material sizes in the market while designing different components. For example, steel is available in 40-foot lengths, so this must be considered by consultants to design components accordingly rather than cutting them into pieces, which will generate waste.

Lastly, clarity in specification must be ensured, because revised specification often cause rework on construction sites as well. Therefore, it was suggested to provide sufficient time at planning phase of project for formulation of project specifications.

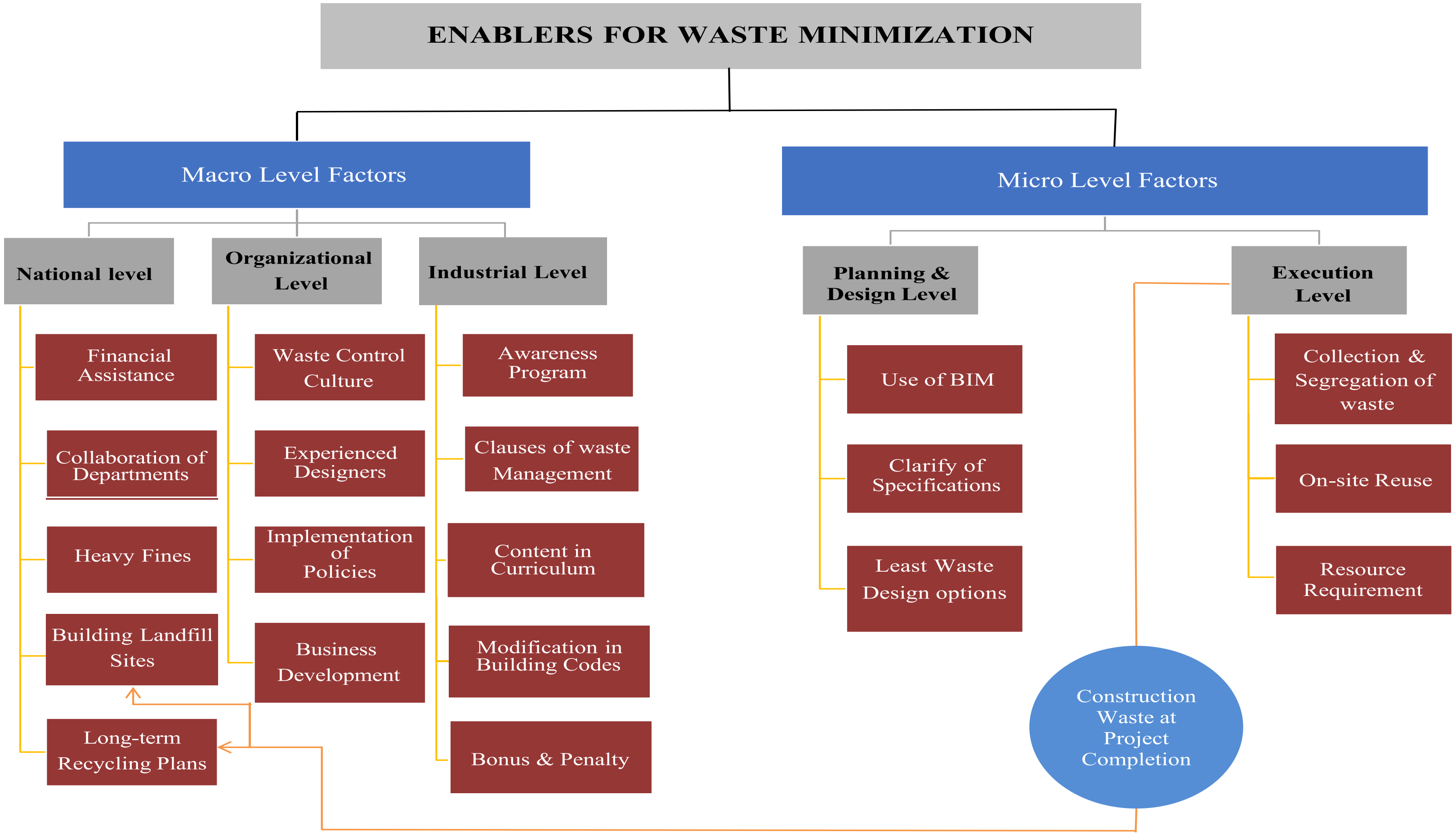

FIGURE 4.4: Enablers for WM and CE Culture on Building Projects in Construction Sector

4.3.2.5 Enablers at Execution Phase

The second phase of the project lifecycle is the execution or construction phase. This is the phase where physical waste must be controlled. The stakeholders were asked to provide strategies for on-site waste control. Based on the CE principle, enablers were suggested. In terms of resources requirement (4.1%) at the project level, effective construction waste handling and management requires a combination of human, financial, technological, and infrastructural resources. Skilled personnel such as site engineers, waste management officers, and trained labor are essential to oversee segregation, collection, and proper disposal of waste materials. Financial resources are required to cover the costs of waste storage facilities, transportation and disposal in compliance with regulatory frameworks. Technological resources, including tools like Building Information Modeling (BIM), waste tracking software help in planning, monitoring, and minimizing waste generation. Physical resources such as designated storage bins, skips, compactors, and safety equipment ensure that waste is stored and handled properly without creating hazards.

Furthermore, it is a fact that a minimum amount of waste is still generated from construction activities, even with maximum WM efforts. Therefore, the generated waste needs to be collected and segregated depending on its properties. Some waste can be reused in the same project, such as bricks reused for flooring as aggregates. Therefore, project managers must try to maximize the reuse of materials on site. Several studies have reported a significant reduction in the amount of waste through the reuse of materials [189]. Reusing the materials on the same site , also improves the performance in terms of material effeciency. Therefore, the construction phase of a project deals with physical waste in real time. By implementing these principles, WM and CE can be ensured in building projects.

Waste must be dealt with carefully during post construction (after completion) phase of project. The generated waste must be collected and it should be decided whether it should go to landfill site or recycling facilities . Dumping sites are classified into two major categories: public filling and landfill. Waste can be classified into two major types: inert materials and non-inert materials [57]. Inert materials such as concrete, bricks, and sand are chemically non-reactive and do not cause environmental pollution. On the other hand, non-inert materials are chemically reactive and pollute the environment through leaching action. These materials include wood, plastics, and other organic matter. Therefore, inert materials are dumped in public filling areas, while non-inert waste is disposed of in landfills [13].

The materials delivered to recycling facilities can be recycled and reused in other projects. It was also found that stakeholders emphasized the utilization of recycled materials in all projects "Recycling targets must be set. Recycling target is 60% to 70% for coming years." This enforcement is due to the high cost of recycled materials compared to virgin materials. Otherwise, no contractor would use recycled materials in projects until this was enforced. Previous studies also showed that the use of different recycled materials, such as recycled brick powder and recycled aggregate concrete, were used in multiple construction processes to improve the properties of different elements [102, 103]. The third principle is recycling, which means waste that was not avoided and reused on a project must be recycled and brought back again into the market as recycled materials. Thus, the philosophy of the CE is fulfilled, and nothing goes out of the loop from production to consumption [190]. Therefore, using recycled materials in projects would slow the depletion of natural resources and improve resource efficiency.

4.3.3 Developed Policy Framework for WM and CE Practices

The guidelines for implementation of policy framework as shown in Figure 4.5, illustrates the causal relationships influencing WM in construction sector is a systemic challenge that cannot be resolved through isolated interventions. These interactions have been divided into three major relationships, such as strong, medium and week. It depends which factors affect how to others. So, strong relations are treated as the most important ones.

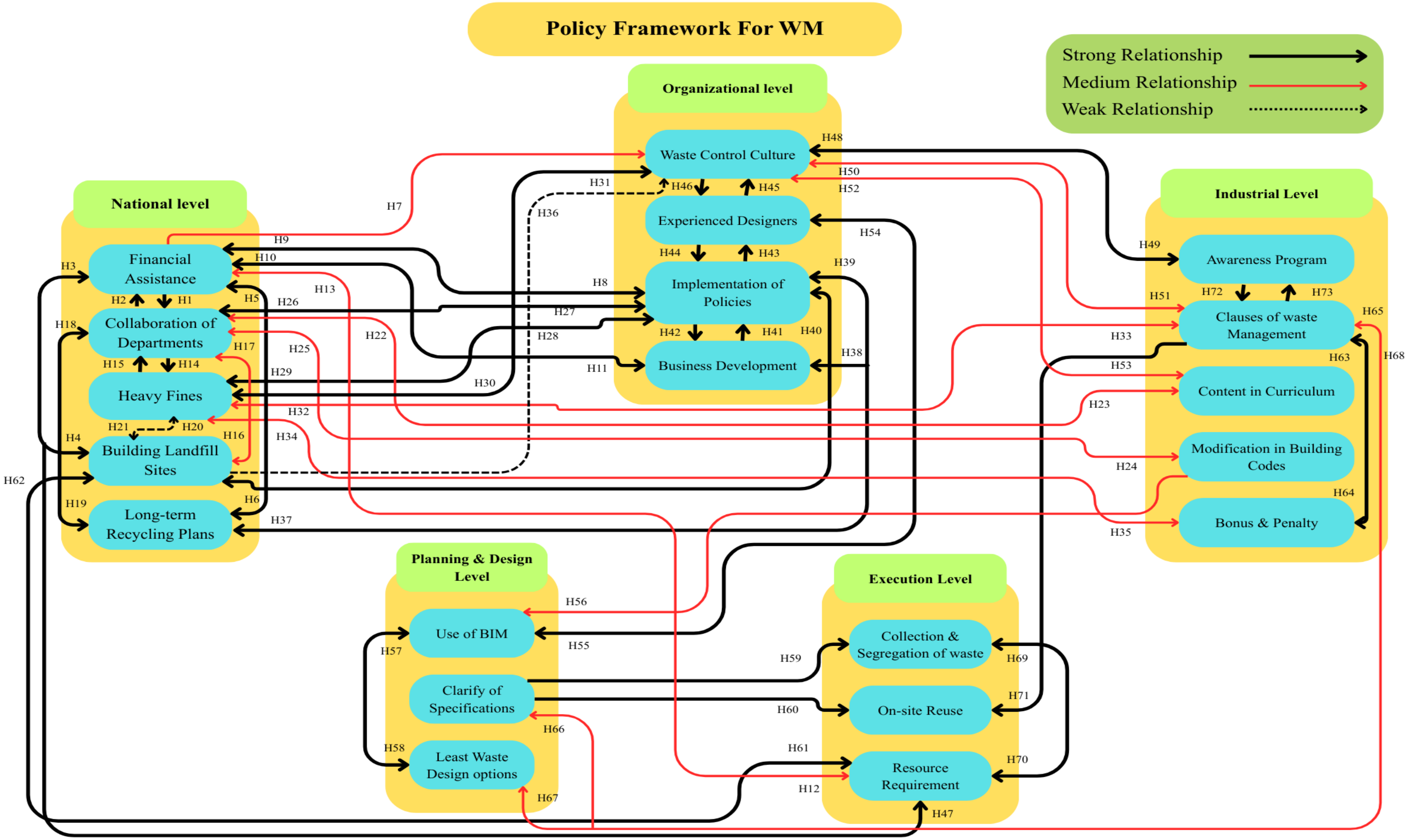

FIGURE 4.5: Developed Policy Framework

Instead, it requires a multi-level policy framework where enablers at the national, industrial, organizational, planning & design, and execution levels interact dynamically to influence outcomes. The figure 4.5 provided illustrates these interconnections, showing how strong, medium, and weak relationships across levels collectively determine the efficiency of WM strategies. The national level establishes the policy and regulatory backbone for construction waste management. Key enablers include financial assistance, collaboration among departments, heavy fines, establishment of landfill sites, and long-term recycling plans.

Financial assistance (H1-H13) in the form of subsidies, grants, and tax incentives encourage firms to invest in waste-reducing technologies, such as BIM, recycling plants, and prefabrication methods. These interventions strengthen organizational adoption and reduce barriers for smaller firms. Heavy fines (H14-H17) in the form of penalties for non-compliance, illegal dumping, or excessive landfill use act as strong deterrents, pushing firms to adopt industry guidelines and on-site waste segregation practices. Collaboration of departments (H18) among ministries (construction, environment, education) ensures alignment between regulations, curricula, and infrastructure development.

This has a cascading effect, fostering industrial-level awareness programs and curricular integration. Long-term recycling plans (H19) at national strategies for recycling and landfill planning are crucial for market development, ensuring that industry and execution-level practices (segregation, reuse) have reliable outlets. National-level enablers have the strongest top-down influence, shaping industrial policies, organizational priorities, and ultimately design and site practices. For example, landfill bans combined with financial assistance create direct demand for BIM-based clash detection and prefabrication, thereby linking high-level regulation to low-level design outcomes.

At the industrial level, sectoral capacity building and market-oriented mechanisms support national directives. These enablers include awareness programs, curricular integration, clauses of waste management in contracts, modifications in building codes, and bonus-penalty systems.

Awareness programs (H49) in the form of nationwide campaigns inform contractors, designers, and site workers about sustainable practices, increasing compliance and adoption rates. Curricular content (H53) by embedding waste management into engineering curricula ensures that future professionals enter the workforce with waste-conscious skills. Clauses of waste management (H51-H65) is required by industrial bodies develop standard clauses for contracts, compelling contractors to adopt segregation, recycling, and reporting practices. Bonus and penalty schemes (H64) by performance-based incentives encourage firms to exceed minimum compliance, rewarding innovation and high recycling rates. Industrial-level enablers serve as a medium-strength bridge between national policies and organizational practices. For instance, when curricula incorporate BIM for waste minimization, organizations benefit from a skilled workforce capable of applying design-stage interventions

Organizations act as the operational core, translating policies and industry guidelines into project-level practices. Key enablers include waste-control culture, experienced designers, policy implementation, and business development.

Waste-control culture (H48) fosters employee accountability and ensures that waste minimization is integrated into daily workflows. Experienced designers (H45-H46) in the form of skilled professionals apply BIM and specify least-waste materials, reducing errors that cause rework. Implementation of policies (H39-H44) by internal enforcement mechanisms align with industry standards and national laws, ensuring consistency across projects. Business Development (H40-H42) by firms that expand into recycling services, prefabrication, or waste auditing diversify their revenue streams while supporting broader waste minimization goals. Organizational enablers form strong links with design-level practices. Without organizational leadership and culture, tools such as BIM or segregation systems are underutilized. Conversely, organizational successes provide evidence for policymakers, reinforcing feedback loops to national and industrial levels

The design phase is critical because most waste is determined before construction begins. Enablers include use of BIM, clarity of specifications, and least-waste design options.

Use of BIM (H56-H57) by BIM supports clash detection, precise quantity take-offs, and construction sequencing, thereby preventing material waste due to design errors or rework. Clarity of Specifications (H55) reduce ambiguity, prevent over-ordering, and ensure compatibility with recycling and reuse requirements. Least-Waste Design Options (H58-H66) by choices such as modular construction, prefabrication, and standardization of dimensions directly lower waste generation. The design level is directly influenced by organizational capacity and industrial education, while exerting strong influence on execution practices. For example, BIM-enabled coordination reduces rework on-site, while modular design facilitates material reuse. At the project delivery stage, enablers such as waste collection and segregation, on-site reuse, and resource allocation operationalize upstream strategies.

Collection and segregation (H59-H69) streams improve the recyclability of materials and support compliance with contractual waste clauses. On-site Reuse (H60-H71) by salvaging and reusing materials on-site reduces the demand for new inputs and keeps waste out of landfills. Resource requirement (H61-H70) such as staffing, equipment, and logistics are essential to implement waste minimization plans effectively.

Execution-level practices are strongly dependent on upstream enablers. Without clear designs, organizational support, and industrial recycling infrastructure, site-level segregation and reuse have limited impact. At the same time, site-level data on waste diversion provides weak but critical feedback loops to industry and national policymakers, helping refine future strategies. The construction WM policy framework highlights that effective waste reduction is a result of synergistic interactions rather than isolated interventions. National regulation creates the enabling environment, industry ensures capacity building and compliance, organizations embed WM into culture and strategy, design-level enablers prevent waste at its source, and execution-level practices operationalize these strategies while providing feedback. Ultimately, the framework demonstrates that a multi-level, interconnected policy approach is essential to achieving sustainable construction practices.

4.3.4 Policy Guidelines for Construction WM in Pakistan

4.3.4.1 Preface

The construction industry in Pakistan contributes significantly to the national economy, accounting for nearly 10% of GDP and employing millions of workers. However, it also generates an estimated 33% of total solid waste annually, of which a major portion is recyclable [31]. Non-availability of policy guidelines, lack of financial support, poor design practices, unclear specifications and ineffective enforcement have exacerbated the problem. Recognizing these challenges, this research consolidates insights from industry experts, clients, consultants, contractors and regulators who participated in semi-structured interviews. Their recommendations based on practical challenges and opportunities, form the basis of these policy guidelines. The aim is to establish a comprehensive policy framework for waste reduction in construction sector of Pakistan.

4.3.4.2 Scope of Policy Guidelines

These guidelines are applicable to all stakeholders involved in construction projects across Pakistan, including: designers/architects (responsible for sustainable design, BIM adoption, and accurate estimation), contractors (responsible for on-site waste minimization, segregation, and reuse), clients/developers (responsible for enforcing waste management clauses in contracts), regulatory Authorities (PEC, CDA, RDA, TMA, EPA, WASA, Ministry of Climate Change, local governments), academia (responsible for education and awareness through BS/MS curricula). The guidelines cover all national, industrial, organizational and project level aspects.

But these policies are developed based on the input of stakeholder interviews from building projects. There may be some variation up to some extent depnding upon the nature of projects, area of project. Enforcement will depend on political will, financial resources, and inter-agency collaboration. Waste reduction targets, bonus and penalty amounts, fines for illegal dumpings, etc. are indicative and may be revised based on regional contexts and recycling capacity.

4.3.4.3 Detailed Policy Guidelines

So, policy guidelines for waste minimization (WM) in construction sector of Pakistan are hereby outlined in the form of Do's and Don'ts.

1. Provide tax rebates up to 25% to companies which are following WM stategies on its projects. Futhermore, duty-free recycling machinery imports must be ensured for building recycling units in Pakistan.

2. The policy makers such as PEC, EPA and Ministry of Climate Change should work in close relation to impelementation departments (CDA, LDA, FDA, etc.). Further, these departments should work in co-ordination with local authorities in each city such TMA and WASA to deal construction waste at each level.

3. Heavy fines should be imposed for any kind of illegal dumping of waste materials. These fines can vary from 0.1% to 1% of total project cost depending upon the quantity of waste.

4. Landfill sites must be build near to those areas where construction activities are expected in next 5-10 years in each city.

5. Set national recyling targets for next 30 years. It is expected, 10-15% reduction of waste in next 5 years, 50% reduction in 15 years and zero-waste target in 30 years.

6. Conduct CPD trainings, seminars, and awareness campaigns; these must be arranged by PEC on regular basis.

7. Consultant's should hire designers with atleast five (05) years relevant field experience. So that, they can have knowledge about the availability of different materials and its sizes.

8. Governments must provide easy loans for establishing businesses linked to WM such as building recycling units, establishing recycled markets. Intrest amount can be up to 5% but should not be more than that. Further, duty free imports of equipments should also be ensured.

9. In contract/bidding documents four (04) major clauses must be introduced. 1) There should be 5-10 marks in the selection criteria of contractors for following WM practices on previous projects. 2) Waste Management Plans (WMPs) must be submitted at planning phase and followed during execution phase of projects. 3) 25% of total project quantity of materials should be used as recycled material to promote recycled industry and businesses. 4) Include bonus and penalty clauses: it can vary between 1 to 5% of total project cost.

10. Topics regarding waste reduction, reuse and recycle should be introdued in BS curriculumn of Civil Engineers.

11. There should be a criteria regarding least waste design option, introduced in the exsiting buidling code of Pakistan.

12. Latest tools such as building information modelling (BIM) must be introduced during planning phase of project. In this regard, BIM experts must be hired and training of existing designers should be ensured.

13. Avoid vague specifications, therefore, copy paste of these specifications from previous projects should be avoided.

14. Promote prefabrication/modular construction/off-site construction as it can reduce significant waste.

15. On site collection and segregation of waste and further its reuse must be ensured by clients.

16. Training of workers to enhance the skilled labour in the market, is also compulsory.

17. Avoid issuing completion certificates without waste audits.

18. At the completion of project, waste either go to recycling unit or should be dumped at designtated landfill sites.

19. All these guidelines must be followed in true letter and spirit to ensure the required results.

In conclusion, by integrating the interview-based insights into practice, Pakistan has the opportunity to transform its construction sector into a sustainable industry.

4.4 Implications of WM Enablers

Further, the proposed WM framework can help policymakers develop CE culture in the local context as it guides the role of different stakeholders in preventing waste generation in construction projects. In managing construction waste, every stakeholder plays a crucial role in advancing sustainability. The client should set the overall direction by funding waste management and sustainability efforts, allocating resources appropriately, and enforcing waste-related provisions in contracts. They should also encourage collaboration among various departments and implement penalties or rewards based on waste management performance. Consultants should assist both the client and contractor by incorporating waste management strategies into project design, using tools such as BIM to enhance material efficiency. They should promote awareness and ensure adherence to sustainable practices, thereby nurturing a culture of waste control. Contractors are responsible for executing waste management practices at the job site, which includes waste segregation, recycling, and appropriate disposal methods. Regulators should formulate and enforce regulations regarding WM.

Collectively, these roles contribute to the effective management of waste and the promotion of sustainability within construction projects. From local to global contexts, the results of the current study have important consequences at the district, provincial, federal, and global scales. Local governments can take advantage by incorporating WM provisions into construction contracts, conducting awareness campaigns, and setting up community landfills and recycling centers.

These local initiatives will aid in addressing the micro-level deficiencies identified in the research. At the provincial level, the findings indicate the necessity of updating building regulations, revising engineering and architecture educational programs to incorporate WM practices, and providing financial incentives to promote sustainable construction methods. Provincial governments are also in a position to strengthen collaboration among departments, which is identified as a crucial macro-level enabler.

On the federal front, the research highlights the critical need for establishing a comprehensive national waste management strategy, focusing on financial support, interagency collaboration, and technological advancements. A coordinated national strategy would ensure uniformity across provinces and amplify the effects of macro-level initiatives, which were found to have a significantly stronger impact compared to micro-level actions.

Lastly, on the global stage, the current study also supports the United Nations Sustainable Development Goals (UN-SDGs), particularly in the area of development of sustainable cities (SDG-11), by minimizing environmental pollution on construction sites by facilitating the responsible consumption of natural resources (SDG-12), i.e., construction materials in current study, and mitigating the impacts of climate change (SDG-13) by curbing the depletion of natural resources.

Moreover, this study contributes to all key aspects of the CE and sustainable development. The environmental challenges of material waste generation can be addressed by applying proposed enablers in the construction sector. Second, this reduces the depletion of natural resources by maximizing their utilization. WM methods can significantly limit the amount of construction waste at landfill sites. Therefore, a reduction in waste generation also leads to lower incineration and greenhouse gas emissions. Thus, the carbon footprint of the construction sector can be reduced, thereby making the industry more sustainable. This decrease in waste generation has economic implications as well. WM can save a large number of currency units.

The current research also addresses economic challenges by reducing construction costs through the efficient use of materials. It is found that around three percent (3%) of the project costs can be saved by implementing WM strategies. This will motivate not only clients but also contractors to adopt WM strategies into their projects to increase profit margins. This study makes a major contribution to the initiation of CE and WM cultures. Therefore, the construction industry must improve its awareness of key stakeholders and ensure resource management practices through education, seminars, and regular training programs.

4.5 Summary

This study aimed to provide WM and CE policy guidelines for developing countries, especially Pakistan, where waste generation is a major threat to the environment and material sustainability. This was facilitated by identifying the major enablers as a result of thematic analysis of semi-structured interviews with clients, consultants, contractors, and regulators.

- As a result of thematic analysis, a policy framework was devised, where enablers to promote WM culture awareness mainly categorized into macro levels (national, organizational, and industrial) and micro levels (planning/design, execution, and post-construction). All these enablers had different weights. At the micro level, the use of BIM (5%), considering the least waste generation options (2.3%), and clarification of specifications (4.1%) were identified as major enablers in the planning phase. The execution, collection and segregation of waste (2%) and the reuse of waste (2%) were found to be major strategies. In the post-construction phase, waste either dumped to landfill sites or should sent to recycling plants.

- At the macro level, organizations should develop waste control cultures (5%), hire experienced designers (2.7%), and develop markets for recycled materials (1.1%), whereas awareness programs (11.2%), clauses of WM (3.7%), contents of WM in the curriculum of BS programs (3.5%) and modifications in building codes (3.3%) are significant measures at the industrial level. Governments are required to provide financial assistance (14.6%) in the form of subsidies and ensure collaboration among departments (7.2%) for the implementation of WM strategies.

- Overall, it was found that macro-level enablers have more impact as compared to micro-level enablers. This means that policy must be implemented from the top to obtain required results at the micro level.

So, in this phase of research, significant strategies to overcome the barriers to waste control are devised. Current findings provide a way forward to local stakeholders how to follow waste management practices on construction sites. Findings stress the role of financial incentives, technology, awareness, and cross-sector cooperation in promoting CE adoption. The proposed framework outlines different stakeholders roles to promote WM and CE practices on building projects in construction sector.

Chapter 5

Quantifying the Effectiveness of WM Strategies

5.1 Background

After devising the strategies against the barriers identified in previous two phases of this study, now, it is required to validate this framework on a micro level by choosing a building project as a case study. It is pertinent to mention here that current case study deals with the strategies which occurred at micro level in the framework, because macro level initiatives are required by governments, industries and organizations. The objective of all these macro level efforts are to promote WM practices on construction projects. Therefore, current case study project is employing all those strategies which are suggested in the proposed framework.

5.2 Research Method for Validation of WM and CE Framework

This research was conducted in multiple stages to ensure a comprehensive evaluation of WM strategies as shown in Figure 5.1. The process began with an in-depth review of existing literature to identify effective WM strategies that have been proposed in past studies. Additionally, a recent study conducted within the local construction industry was examined to assess the relevance and practicality of these strategies in the regional context. Based on this background, several construction sites were visited to identify a potential project where WM strategies could be implemented throughout the entire project lifecycle. A suitable case study was selected from Islamabad, the capital city of Pakistan. To discuss proposed WM strategies which could be realistically applied, an interview was conducted with the project manager, during which the feasibility and expected outcomes of various WM approaches were discussed. Once the strategies were finalized, the project was visited regularly throughout its lifecycle including design, construction and post construction phases of project to collect data and ensure that the strategies were being properly implemented. Data collection spanned all phases of the project and included records of materials purchased (inventory data), materials used as documented in IPCs, and detailed logs of which WM strategies were applied during different construction activities. Consistent monitoring and record-keeping enabled accurate tracking of material flows and waste generation. At the completion of the project, the total quantities of waste generated, reused, and sold for recycling were measured. These findings were then compared with data from previous studies completed using traditional construction practices. This comparison allowed the study to quantify the reduction in waste attributable to the implementation of WM strategies, thus providing practical evidence of their effectiveness.

5.2.1 Overview of Selected Case Study Building Project for Validation of WM Strategies

The case study selected for the current research is a commercial building project constructed in the vicinity of Islamabad Capital Territory, Pakistan, as shown in Figure 5.2. The selection was guided by specific criteria to ensure the study's contextual relevance and data accessibility. First, the type of client was considered, in this case, a private commercial contractor willing to provide complete access to technical documentation, site observations, and key personnel for interviews.

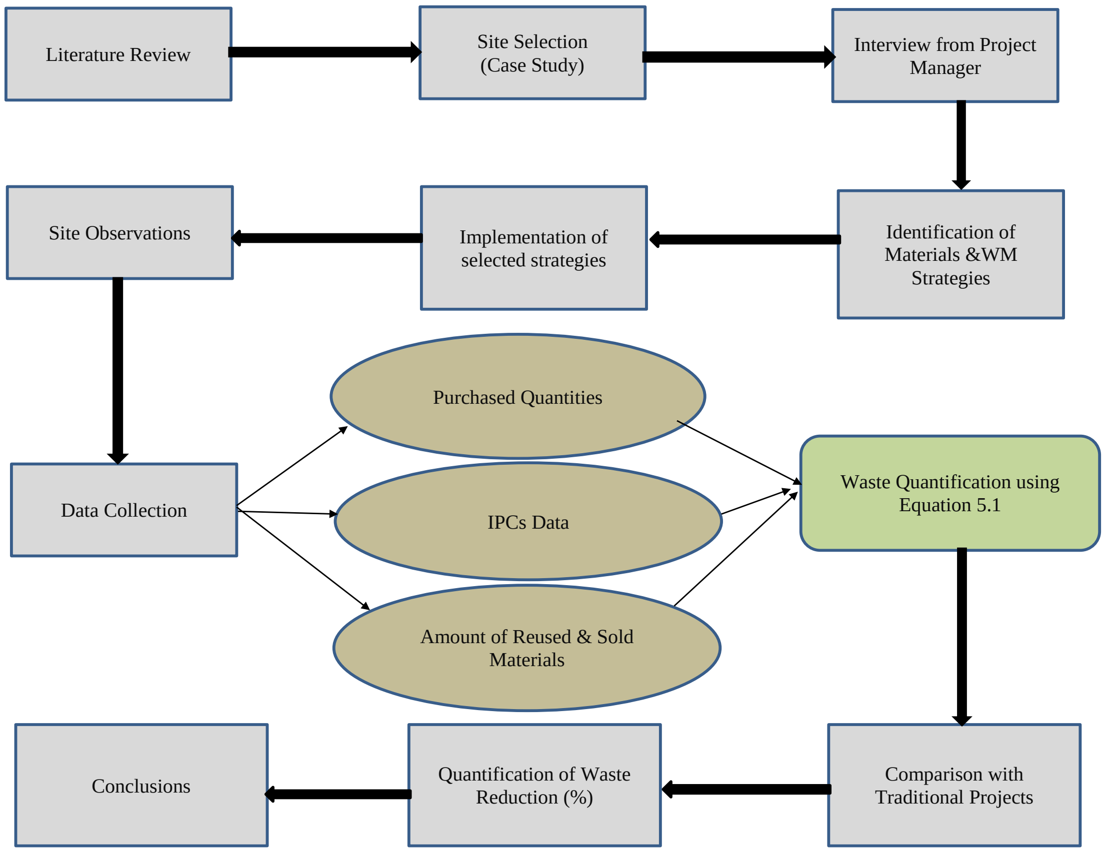

FIGURE 5.1: Flow Chart for Validation of WM Strategies (Phase-3)

Second, the geographic location within the Islamabad Capital Territory was selected to ensure ease of site visits, alignment with local regulatory frameworks, and representation of regional construction practices. Third, the projects construction stage was a determining factor, as it allowed for the direct observation of waste generation patterns and management strategies in real time. The selected building features a reinforced concrete frame structure comprising key construction elements such as concrete, reinforcement steel, bricks, tiles, false ceiling, and glass. The total covered area is approximately 3,150 square feet, with a scheduled completion time of six months and an estimated budget of 156,600 USD. Medium-scale commercial projects of this nature were prioritized because they typically present diverse material usage and complex waste management challenges, making them suitable for detailed investigation. Additional technical and architectural details of the case study are provided in Appendices F.1 to F.4, which include the foundation plan, first-floor plan, roof floor plan, and relevant cross-sections of the building. Similarly, structural details are provided in Appendices F.5 to F.6.

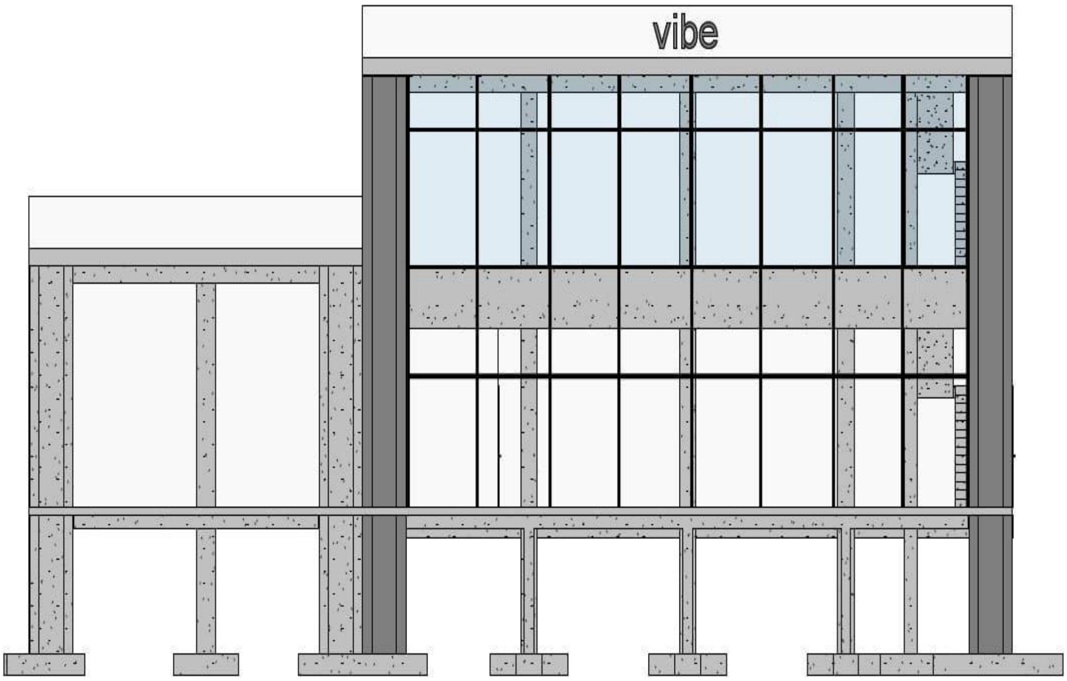

FIGURE 5.2: 3-D Model of Selected Case Study of Building Project

The state of waste generation in Pakistan is particularly alarming, even when compared to other developing countries. According to the Asian Development Bank, approximately 30 million tons of solid waste are generated annually in Pakistan, with 9 million tons originating from the construction sector alone [31]. The report emphasizes the urgent need for the development of WM policy guidelines, as the current WGRs pose serious risks to environmental health and resource sustainability. In response to this issue, a recent study by [191] proposed a set of WM strategies tailored specifically for Pakistan's construction industry, as outlined in Table 5.1 and Figure 4.4 (micro level). However, these strategies have not yet been tested or validated in real-time construction projects, which is crucial to assessing their practical effectiveness. The current case study represents a pioneering initiative in Pakistan, as it integrates multiple WM strategies throughout the entire project lifecycle, in alignment with the recommendations of [191]. However, the implementation of these strategies encountered several challenges. First, identifying a suitable case study proved difficult, as few projects in Pakistan are willing to adopt such WM strategies, given that WM is not yet a priority in the current industry context. In this instance, the adoption was possible primarily because the client was strongly motivated to integrate sustainable practices. Second, the collection of data posed a significant challenge, as the research required data to be gathered in a specific, systematic manner, which was difficult to manage on a busy construction site. Additionally, ensuring the confidentiality of sensitive project data required careful planning and strict adherence to agreed protocols. The real-time application and assessment of these strategies aim not only to quantify their effectiveness but also to provide practical evidence that can inspire broader adoption of WM practices within the industry.

5.2.2 Selected WM Strategies and Building Materials from Developed Framework

In response to the issue of waste generation, a recent study by [191] proposed a set of WM strategies tailored specifically for Pakistan's construction industry, as outlined in Figure 4.4. Previous studies also proposed similar strategies for other construction industries as shown in Table 5.1. However, these strategies have not yet been tested or validated in real-time construction projects. In this study, these strategies have been tested at micro level i.e. a project level, which is crucial to assessing their practical effectiveness. Macro level strategies are out of the scope of this study due to the fact that these strategies are expected from governments and industry stakeholders. Following the selection of the case study, a detailed interview was conducted with the project manager of the selected construction project. The interview lasted approximately one and a half hours and aimed to identify the key materials to which WM strategies would be applied. The criterion of "more than 80% of total project quantities" was based on the BoQ to focus on materials contributing the majority share of volume and weight, ensuring maximum impact of waste minimization with limited monitoring effort. The key materials considered include concrete, plaster, mortar, reinforcement, tiles, bricks, paints, false ceiling, tuff pavers, and glass. Concrete, plaster, and mortar were assessed through their main constituents (cement, sand, aggregates). Tuff pavers and glass were included as their quantities were higher compared to items like electrical and plumbing works, and they also hold strong potential for reuse and recycling within the proposed framework.The detailed implementation of these selected strategies are outlined in the following sections in different phases of a project including design, execution and post construction phases.

TABLE 5.1: WM Strategies Reported for Pakistan's Construction Sector and Other Industries

Sr. No.	Strategy	Other Countries
1	Usage of latest tools such as BIM	[192–194]
2	Least waste design options	[195, 196]
3	Clarity of Specification	[197]
4	Storage for handling of materials	[195, 198]
5	Collection and segregation of waste	[7, 199]
6	On site reuse of waste materials	[97, 200]
7	Recycling of wasted materials	[7, 201]
8	Dumping to designated landfill	[154, 202]

A range of WM strategies were applied across different phases of the project, including the design, execution, and post-construction phases. Table 5.2 lists these strategies in relation to their respective project phases. In the design phase, strategies focused on removing errors and omissions to prevent design modifications and rework in later stages of the project.

Further, prefabrication was considered in design phase as a least waste generating option, which was later adopted in execution phase. During the execution phase, key strategies included prefabrication, designating separate spaces for waste materials, waste collection and sorting, and reusing waste materials for WM practices. In the post-construction phase, due to the absence of on-site recycling, waste materials were sorted and sold to vendors for recycling, ensuring that the principles of the CE-reduce, reuse, and recycle-were applied. This way reduce principle is applied during design phase of project from 3 R's principle.

Table 5.2: Details of WM Strategies Selected for Different Project Phases

Sr. No.	Project Phase	Strategies
1	Planning/Design Phase	Use of modern tools, Least waste design option (Prefabricated Structure and Avoid design modifications)
2	Execution Phase	Material Storage, Waste Handling and sorting, Reuse of materials
3	Post Construction Phase	Sold material to recycling vendor and Dumping of waste at designated landfill

5.2.2.1 Design Phase WM Strategies

The design phase plays a crucial role in the prevention and reduction of waste generation, as waste can be eliminated at its source during this stage. Once the design phase is completed, preventing waste becomes much more challenging, primarily due to rework resulting from poor design decisions. In the current study, Building Information Modelling (BIM) was utilized to integrate the architectural, structural, sewerage, and water supply models, which enabled the identification of clashes and discrepancies in the building design. By addressing these errors at the planning stage, unnecessary rework and associated material waste were avoided, thereby directly promoting WM. Several examples are illustrated in Figure 5.3. For instance, in Figure 5.3a, a clash was detected between a 4-inch diameter sewerage line and plinth beam PB-1. If left unresolved, this would have required on-site demolition and reconstruction, generating concrete and pipe waste. By identifying and correcting this issue in the design phase, waste from rework was entirely prevented. Similarly, in Figure 5.3b, a 1-1/2 inch water supply pipe was shown to pass through column C-1. This would have required core-cutting during execution, leading to waste of concrete and additional labor cost. Early detection and redesign avoided this waste source. The ability to resolve issues lies in the integration of models. Therefore, BIM has shown significant results in WM on building projects.

In Figure 5.3c, a clash between water supply pipes from the pump room and beam RB-3 was observed. Without correction, this error would have necessitated re-routing pipes during construction, resulting in wastage of pipes and fittings. By resolving the clash through BIM, both material and time savings were achieved. Figure 5.3d highlights inconsistency between architectural and structural drawings regarding the placement of additional columns. After clarification with the designer, unnecessary columns were eliminated, preventing the procurement and installation of surplus reinforcement steel and concrete. Likewise, Figure 5.3e shows missing footing details for column C5, which were added in revised drawings, preventing on-site delays, trial-and-error work, and consequent waste. Finally, in Figure 5.3f, the staircase slab was missing from the structural drawings. If not identified early, this would have led to incomplete construction, rework, and waste of shuttering material, concrete, and reinforcement. The issue was corrected during design revisions. Beyond error detection, the project also adopted preventive design strategies. For example, the designer proposed prefabricated glass faade panels instead of site-based cutting. This decision eliminated off-cuts and breakage waste common in on-site glass work. Hence, BIM not only supported clash detection but also facilitated design-based WM strategies, such as specification clarification and promotion of prefabrication.

The above findings demonstrate how BIM translates directly into WM: by eliminating clashes, reducing rework, and enabling design solutions that avoid waste at source. Similar studies have confirmed that nearly one-third of on-site waste originates from designer negligence during the design stage [17, 203], and that advanced tools like BIM can prevent 5-15% of such waste [26, 108]. In this case study, BIM ensured that design-related errors were rectified before execution, thereby preventing avoidable waste generation and promoting efficient material utilization.

5.2.2.2 Execution Phase WM Strategies

The second phase in the project lifecycle is the execution phase, during which physical construction activities are carried out on site and the potential for waste generation is at its peak. As such, strict supervision and the effective implementation of WM strategies are essential during this stage. In the current study, several measures were taken to minimize waste throughout the execution phase as shown in Figure 5.4. One notable strategy was the use of prefabricated glass panels for the building's facade, as illustrated in Figure 5.4a. By employing prefabricated glass, on-site cutting was completely avoided, thereby significantly reducing glass waste. Prefabricated components are typically manufactured by experienced professionals under controlled conditions, which ensures greater precision and minimizes the chances of error. Consequently, the use of such elements reduces the likelihood of material wastage, contributing to more efficient and sustainable construction practices [204]. To ensure minimal onsite glass waste, exact measurements of the glass opening frames were taken, and the fabricator was instructed to supply glass panels cut to the required dimensions. This approach significantly minimized waste during installation. Additionally, materials such as cement, wooden sheets, and steel were carefully stored in a separate building to shield them from weather-related damage, as shown in Figure 5.4b.

Improper storage has been frequently identified as a significant source of construction waste in prior studies [26, 205], so this measure helped mitigate that risk. Efforts to reduce construction waste at the source were further supported by the reuse of materials for secondary purposes. For instance, bricks damaged during masonry work and surplus concrete from the construction of structural elements were not discarded. Instead, brick waste was repurposed as brick ballast, and wasted concrete was crushed and used as aggregate for flooring on both the ground and first floors, as depicted in Figures 5.4c and 5.4d. Approximately 150 Cft of brick ballast and 120 Cft of crushed concrete were reused, amounting to around 5.2% and 6.1% of the total quantities of bricks and concrete respectively, calculated using Equation 2. In a similar vein, leftover steel pieces cut during reinforcement work were reused to fabricate hooks and stirrups for beams and columns. Given the high cost of steel, contractors were particularly motivated to minimize its waste. This initiative led to the reuse of approximately 80 kg of steel, representing about 0.52% of the total steel used, as illustrated in Figure 5.4e.

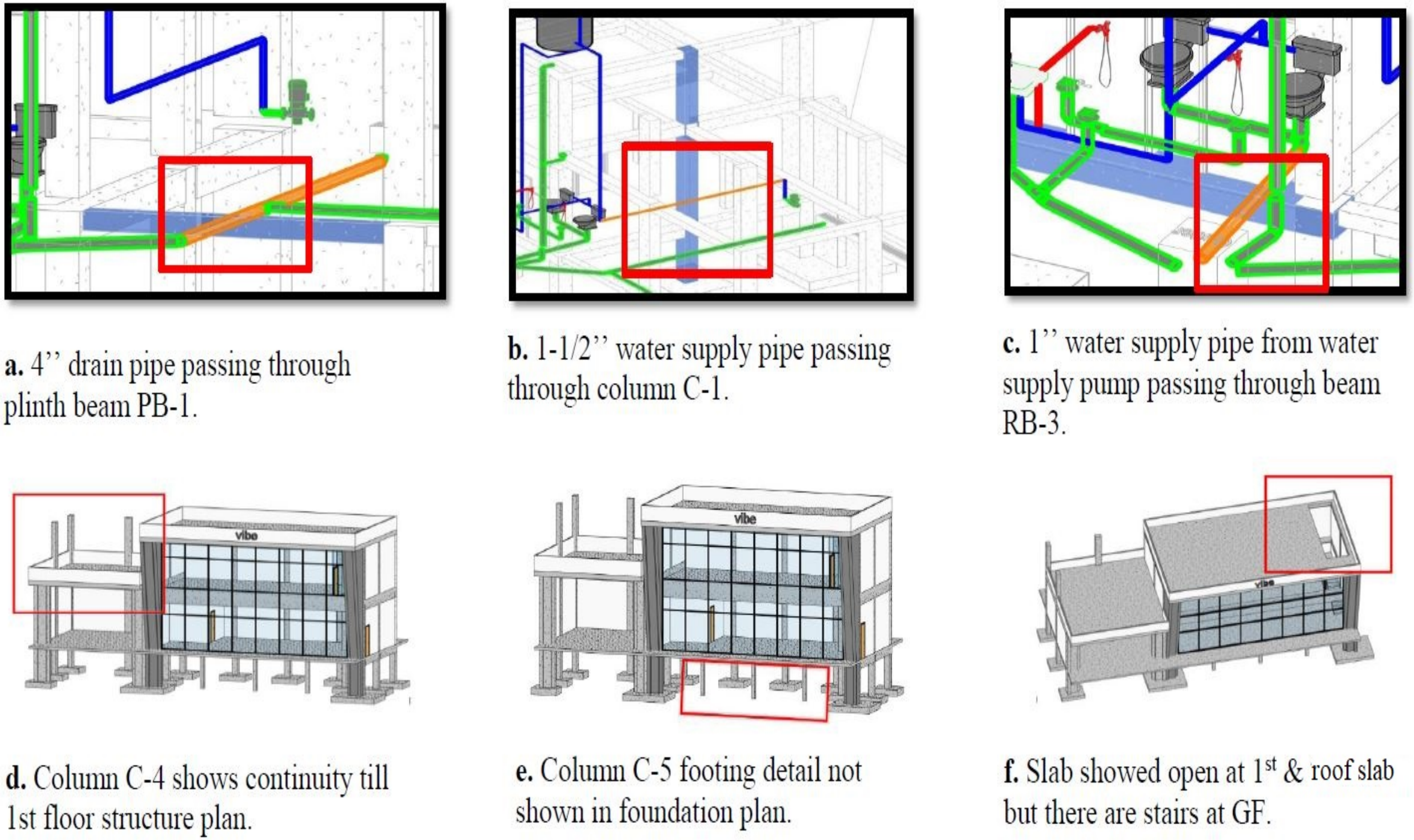

FIGURE 5.3: Clashes, Errors and Omissions Identified from BIM Models for WM Strategies at Design Phase

a. Use of Prefabricated Glass at Facade
b. Storage of Materials
c. Reuse of Brick Blast in Flooring
d. Reuse of Concrete as Filling Material
e. Use of Steel Pieces for Hooks and Stirrups
f. Use of Sand in Pathways at Entrance
g. Surplus Excavated Material
h. Reinforcement Waste

Figure 5.4: Implementation of WM Strategies during Execution and Post Construction Phases of Building Project

As compare to steel, sand is considered very cheap in local industry, therefore, contractors do not bother to minimize its waste. But sand is reused (113 Cft) in pathways as filling material in current case study as presented in Figure 5.4f. It means almost 0.22% of total sand was reused in this process. Similar kind of efforts had also been made in past case study, where demolished material was used for preparation of pathways, landscaping and new roadways [32]. So, all these strategies are implemented to utilize maximum waste as reused material in different activities to promote CE and sustainability cultures in construction sector.

5.2.2.3 Post Construction Phase WM Strategies

In the final phase of the project lifecycle, dealing with the remaining waste that could not be reused was approached with careful consideration. Within the framework of the CE, it is essential to ensure the optimal utilization of resources, which includes recycling material waste and returning it to the market. Although the current project did not carry out on-site recycling during the post-construction phase, waste materials were sold to vendors who specialize in recycling. In this study, two key materials were sold for this purpose, as illustrated in Figures 5.4g and 5.4f.

Firstly, excess soil excavated from the foundation was sold. Since the backfilling process required a smaller volume, approximately 2,000 Cft of surplus soil-equivalent to about 22% of the total excavated volume-was sold to a vendor. This soil was then used for filling another plot located near the construction site, thereby promoting material reuse across different projects. Secondly, about 50 kg of reinforcement waste, which accounts for approximately 0.32% of the total reinforcement used, was sold by weight to another vendor. This vendor would recycle the steel and reintroduce it into the market as recycled material. Similar to this study, another research also focused to optimize the utilization of materials by reusing the demolished materials for construction of different elements in Shenzan city, China [32]. So, current project also tried to optimize the utilization of materials. All three principles of CE i.e. 3 Rs (reduce, reuse and recycling) are being followed to make this project more sustainable.

5.2.3 Analyses on Collected Data

After the selection of materials and corresponding WM strategies, real-time quantitative data were collected through site observations and a review of project documents. This data enabled the quantification of material waste, as well as the amounts of materials that were reused or sold for recycling. Furthermore, the effectiveness of the implemented WM strategies was assessed by comparing the results of the current study with those of traditional construction projects reported in previous literature. The subsequent section provides a detailed explanation of the waste quantification methods employed and the corresponding amounts of material saved as a result of these strategies.

5.2.3.1 Quantification of WGRs for Selected Materials after Implementation of WM Strategies

The next step was to quantify the waste for some important materials. There are several approaches to measuring waste on construction projects. The choice of method relies on construction practices, waste management techniques, and the availability of field data to determine which measurement strategy is most practical. These approaches include waste as percentage of used materials, percent of estimated materials, weight of waste per unit area and volume of waste per unit are. Based on the accuracy and data availability, the percentage of purchased materials was selected for current case study. Since the date were collected in the form of inventory, reused/sold quantities and IPCs. Waste was calculated for each of the materials based on the Equation 5.1. Similar method for waste calculation have been used in number of past studies [57, 206].

To validate the framework data were collected through direct observation and IPCs. Waste was calculated using the following formula:

$$Waste(\%) = [(Mpurchased - Mused - INV]/Mused * 100 \tag{5.1}$$

In Equation 5.1, M purchased is the total purchased quantity of specific material. Mused is the quantity of material which is extracted from IPCs or reused or sold to vendors and INV is the quantity of material which is left out at the completion of project in the store. It is important to mention that reused or sold quantities are also taken into account under the head of Mused because this reused or sold materials would not be treated as waste. Only the amount of materials which would be dumped to landfill sites was treated as waste. Further, (M purchased-INV) gives the quantity of each material which was actually sent to the site for utilization. Subtracting this quantity from Mused gives the amount of material which was wasted on site during execution of specific activity. So, material waste calculated as a result of application of WM strategies.

5.2.3.2 Quantification of Reused Building Materials

Since the current study has employed number of strategies to minimize waste, therefore, amount of waste which was reused was calculated through Equation 5.2. This reused quantity is measured as a percent of total used quantity. Reused quantity of different materials such as brick ballast, concrete, steel and sand were calculated. So, as a result of Equation 5.1 and Equation 5.2, the amount of waste generated and reused were calculated for each of the selected building material.

$$Reused(\%) = [Mreused]/(Mtotalused) * 100 \tag{5.2}$$

5.2.3.3 Quantification of Waste Reduction Rates and Effectiveness of WM Strategies

A comparison was drawn between current case study and conventional project reported in the same country i.e. Pakistan. So, amount of waste generated on case study project and conventional project were compared and waste reduction rates were calculated for each of these materials. The Percent of waste reduction in waste quantifies the effectiveness of WM strategies on a building project.

5.3 Discussion of Results

5.3.1 Findings on the Measured WGRs of Selected Building Materials

As a result of application of WM strategies, WGRs of current study are measured and presented in Table 5.3 and Figure 5.5. Data was taken officially from site as shwon in Appendix-G. It can be observed that sand (4.36%), aggregate (3.76%) and cement (4.15%) are found as most wasteful materials while glass (0.28%), tuff paver (0.57%) and steel (1.25%) were least wasted materials. Further, paint (2.36%), brick (2.26%), false ceiling (2.26%) and tiles (2.05%) are measured as moderate materials in terms of WGRs. So, higher WGRs of cements, sand and aggregate shows that concrete, mortar and plaster works found as the most waste generating as compare to other ones. It is due to the fact that all these activities used manual methods for material preparation and handling, such as concrete was prepared through concrete mixer and then transported through wheel barrows. During the mixing and transportation small quantities of these materials were wasted. Similarly, bricks, tiles and paints were wasted due to the lack of skilled labour in local construction industry. Similarly, lack of skilled labour is a major source of waste generation has also been reported in multiple other studies as well [207–209]. Although implementation of WM strategies reduced significant amount of waste on site but still local construction industry need to work on the development of skilled labour and change of methodologies.

On the other hand glass was brought on site as prefabricated structure, so very less waste was generated and that was also due to improper handling of glass during placing. Tuff pavers were also purchased from supplier as a single material, so very minute quantities of these materials were wasted on site. This the minimum amount of waste which would occur, no matter how many WM strategies are applied, because construction waste can be divided into two categories: natural or unavoidable waste and potential or avoidable waste. Natural waste is the minimum amount of waste generated that is inherent to all types of projects. So, waste of glass (0.28%), tuff paver (0.57%) and steel (1.25%) are natural waste which cannot be avoided by implementing WM strategies. Therefore, local construction industry need to work on development of skilled labour, since this area could not be improved until comprehensive skill development program is initiated.

TABLE 5.3: Results of WGRs (%) Identified as a Result of WM Strategies on Building Project

Sr. No	Materials	Units	Mpurchased	Mused	INV	Waste(%)
1.	Cement	Bags	1645	1569	11	4.15%
2.	Sand	Cft	5700	5442	20	4.36%
3.	Aggregate	Cft	6100	5830	50	3.76%
4.	Steel	Kg	15700	15420	85	1.25%
5.	Paint	Sft	3500	3419	0	2.36%
6.	Glass	Sft	1450	1440	0	0.28%
7.	Brickwork	Cft	2950	2875	10	2.26%
8.	Tuff Pavers	Sft	3000	2983	0	0.57%
9.	Tiles	Sft	2500	2430	20	2.05%
10.	False Ceiling	Sft	2200	2120	32	2.26%

Table 5.4 clearly demonstrates that the adoption of WM strategies in the present case study has resulted in a significant reduction in WGRs for all major construction materials. These improvements are not only substantial within the national context (two studies as reported in Table 5.4 from Pakistan) but also exhibit favorable comparisons with similar data from other developing countries, including Jordan and Indonesia. Notably, Jordan and Indonesia report considerably higher WGRs exceeding those observed in this study by more than 15% and 10%, respectively across all listed materials, highlighting a more pressing need for effective WM interventions in those regions. The high levels of material waste in other developing countries can be attributed to several persistent issues, including limited awareness of WM practices, the absence or inadequate enforcement of regulatory

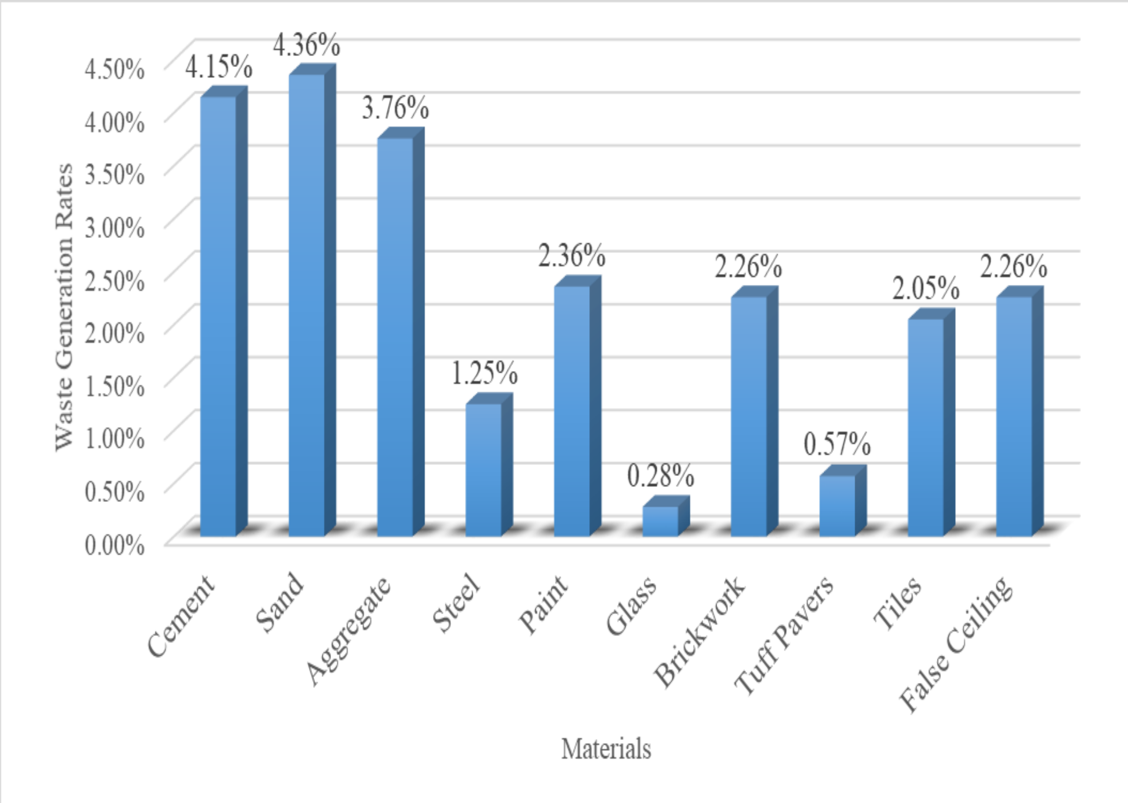

Figure 5.5: Results of WGRs (%) Identified as a Result of WM Strategies on Building Project

frameworks, and poor planning that often results in inaccurate ordering of materials.

Furthermore, factors such as theft, vandalism, and the low cost of materials in certain regions exacerbate inefficiencies and contribute to elevated levels of construction waste. Other reasons of this much WGRs could be availability of these materials at very low prices, under & over ordering of materials and theft & vandalism. When compared to developed countries, the results from the current case study are highly competitive. For instance, concrete waste comprising a mixture of cement, sand, and aggregate amounts to 7.5%, 2.3% , 1.8% and 2 % in Malaysia, China, Australia and South Korea respectively. Similarly, the waste of paint and glass in developed countries is comparable to that observed in the current case study. However, steel waste is notably higher in China (4.4%) and Australia (7.2%). Additionally, the wastage of bricks, tiles, and false ceilings is significantly greater in Malaysia and Australia, respectively, compared to the current study.

Table 5.4: Findings on Comparison of WGRs between Case Study and Other Building Projects

Material	Case Study	[57]	[39]	[210]	[59]	[60]	[61]	[62]	[63]
	Pakistan	Pakistan	Jordon	Indonesia	Pakistan	Malaysia	China	Australia	South Korea
Concrete	-	-	-	-	-	7.5	2.3	1.8	2
Cement	4.2	5.4	18.3	13	-	-	-	-	-
Sand	4.4	28.8	20.9	18	-	-	2	-	-
Aggregate	3.8	12	20.7	-	-	-	-	-	-
Steel	1.3	4.5	16.91	7	5.2	0.9	4.4	7.2	-
Paint	2.4	-	-	-	9.25	1.3	-	-	-
Glass	0.3	-	-	-	-	0.2	-	-	-
Brickwork	2.3	13.7	17	16	10	5.8	-	6.9	3
Tuff Pavers	0.6	-	-	-	-	-	-	-	-
Tiles	2.1	13.5	15.6	11	9.3	2.6	-	3.6	2.5
Ceiling Boards	2.3	13.6	20.70	-	4.3	0.4	-	19.3	-

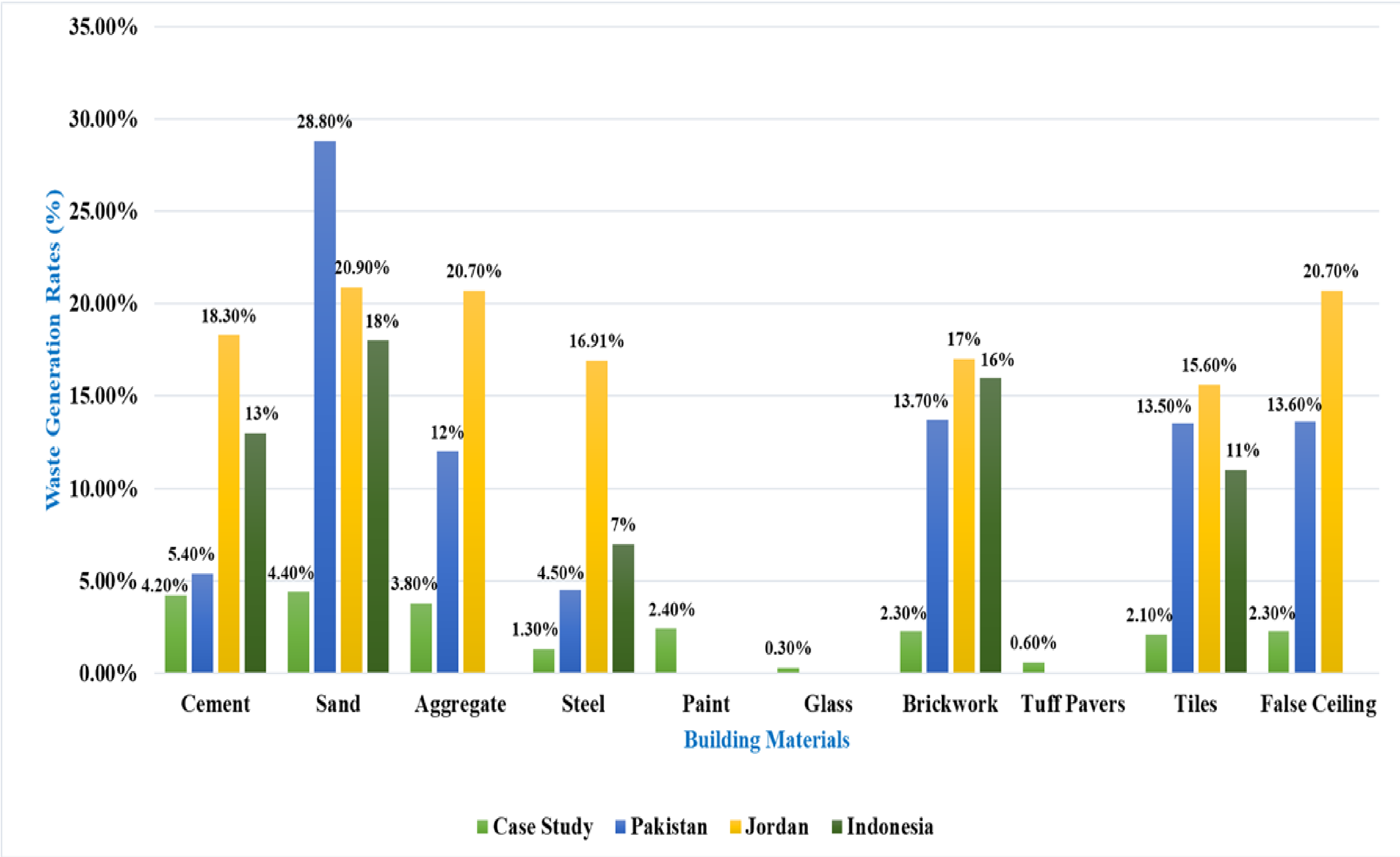

FIGURE 5.6: Comparison of WGRs between Case Study and Developing Countries

Overall, it can be concluded that WGRs for most building materials are higher in developed countries when compared to the current case study as shown in Figure 5.6. While the WGRs for developed countries are markedly lower than those in other developing nations, the current study still records significantly lower WGRs than both developing and developed countries. So, comparing the results of current case study with findings of [57] would provide a very clear picture of effectiveness of WM strategies. Table 5.4 and Figure 5.6 clearly demonstrate that the adoption of WM strategies in the present case study has resulted in a marked reduction in WGRs for all major construction materials when compared to conventional projects in Pakistan. The most significant reductions are observed in sand (24.4%), aggregate (8.2%), brickwork (11.4%), tiles (11.4%), and false ceilings (11.3%). Further, the WGRs of case study is also signficantly lower as compare another study, conducted within construction sector of Pakistan [59]. this difference can be observed in case of steel, paint, brickwork, tiles and false ceiling.

These improvements are not only substantial within the national context but also exhibit favorable comparisons with similar data from other developing countries, including Jordan and Indonesia. Notably, Jordan and Indonesia report considerably higher WGRs exceeding those observed in this study by more than 15% and 10%, respectively-across all examined materials, highlighting a more pressing need for effective WM interventions in those regions. The high levels of material waste in these countries can be attributed to several persistent issues, including limited awareness of WM practices, the absence or inadequate enforcement of regulatory frameworks, and poor planning that often results in inaccurate ordering of materials. Furthermore, factors such as theft, vandalism, and the low cost of materials in certain regions exacerbate inefficiencies and contribute to elevated levels of construction waste [13]. Other reasons of this much WGRs could be availability of these materials at very low prices, under and over ordering of materials and theft and vandalism [57]. In conclusion, it can be asserted that the prevailing conditions of waste generation are generally more problematic across all developing countries; however, there exists significant potential for waste reduction through the implementation of on-site WM strategies. These strategies require minimal investment, yet the resulting reductions in waste are substantial. With relatively modest WM efforts, considerable amounts of waste can be mitigated.

5.3.2 Percent of Reused Quantity of Selected Building Materials

In terms of reuse, multiple building materials are reused on current study during execution phase of project as shown in Figure 5.7. Approximately 150 ft of brick ballast and 120 ft of crushed concrete were reused, amounting to around 5.2% and 6.1% of the total quantities of bricks and concrete respectively, calculated using Equation 5.2. In a similar vein, leftover steel pieces cut during reinforcement work were reused to fabricate hooks and stirrups for beams and columns. Given the high cost of steel, contractors were particularly motivated to minimize its waste. This initiative led to the reuse of approximately 80 kg of steel, representing about 0.52% of the total steel used, as illustrated in Figure 5.4e. As compare to steel, sand is considered very cheap in local industry, therefore, contractors do not bother to minimize its waste [146]. But sand is reused (113 ft3) in pathways as filling material in current case study as presented in Figure 5.4f. It means almost 0.22% of total sand was reused in this process. Similar kind of efforts had also been made in past case study, where demolished material was used for preparation of pathways, landscaping and new roadways [32]. In this study, two key materials were sold for this purpose, as illustrated in Figures 5.4g and 5.4h. Firstly, excess soil excavated from the foundation was sold. Since the backfilling process required a smaller volume, approximately 2,000 ft of surplus soil equivalent to about 22% of the total excavated volume was sold to a vendor. This soil was then used for filling another plot located near the construction site, thereby promoting material reuse across different projects. Secondly, about 50 kg of reinforcement waste, which accounts for approximately 0.32% of the total reinforcement used, was sold by weight to another vendor. This vendor would recycle the steel and reintroduce it into the market as recycled material. Similar to this study, another research also focused to optimize the utilization of materials by reusing the demolished materials for construction of different elements in Shenzan city, China. So, current project also tried to optimize the utilization of materials. All three principles of CE i.e. 3 Rs (reduce, reuse and recycling) are being followed to make this project more sustainable.

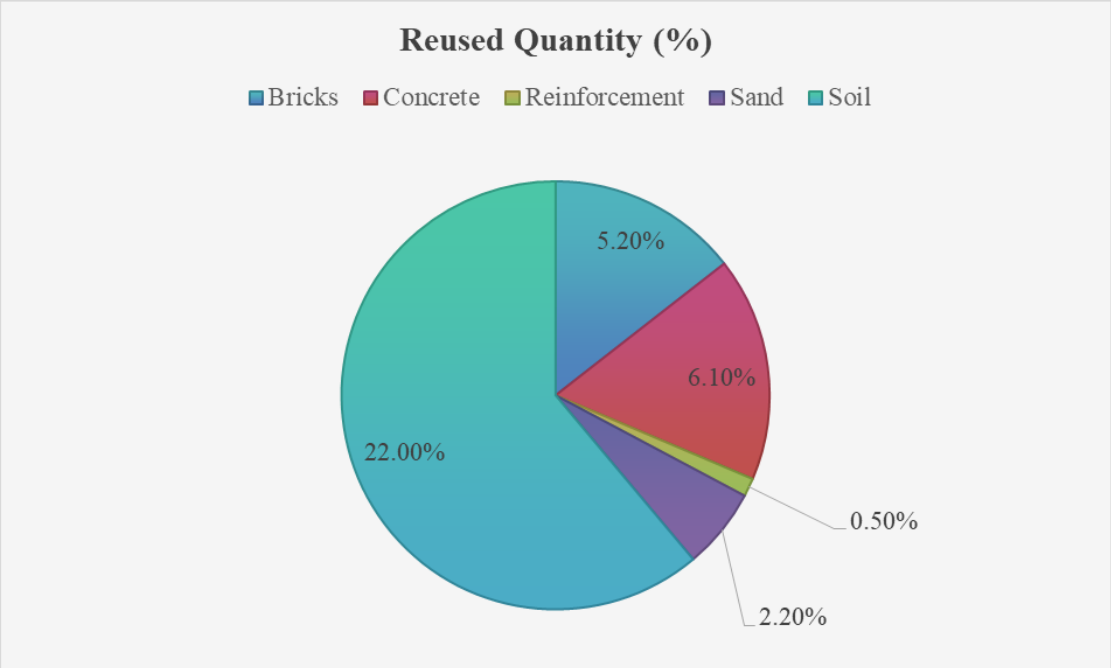

Figure 5.7: Percent of Reused Materials on Case Study Project

5.3.3 Waste Reduction Rates (WRRs) and Effectiveness of WM Strategies

One of the key performance indicators of successful WM implementation is the rate at which waste is reduced across various building materials. As presented in Figure 5.8, among the materials analyzed, sand exhibited the highest WRRs at 85%, followed closely by tiles (84%), brickwork (83%), and false ceiling materials (83%). These figures suggest a high level of efficiency in material handling and reuse practices for non-structural and finishing materials. The elevated reduction rates in these categories may be attributed to advancements in precision cutting, prefabricated construction techniques, and improved site logistics that minimize overuse. Steel and aggregate demonstrated moderate waste reduction rates of 71% and 68%, respectively. These materials are often recycled in large-scale construction management systems [211]. In stark contrast, cement registered a significantly lower WRRs of 22%, indicating a considerable opportunity for improvement. This low figure is due to the fact of unskilled labour in local construction industry. Overall, around 71% waste was reduced on current case study as compare to traditional project in Pakistan.

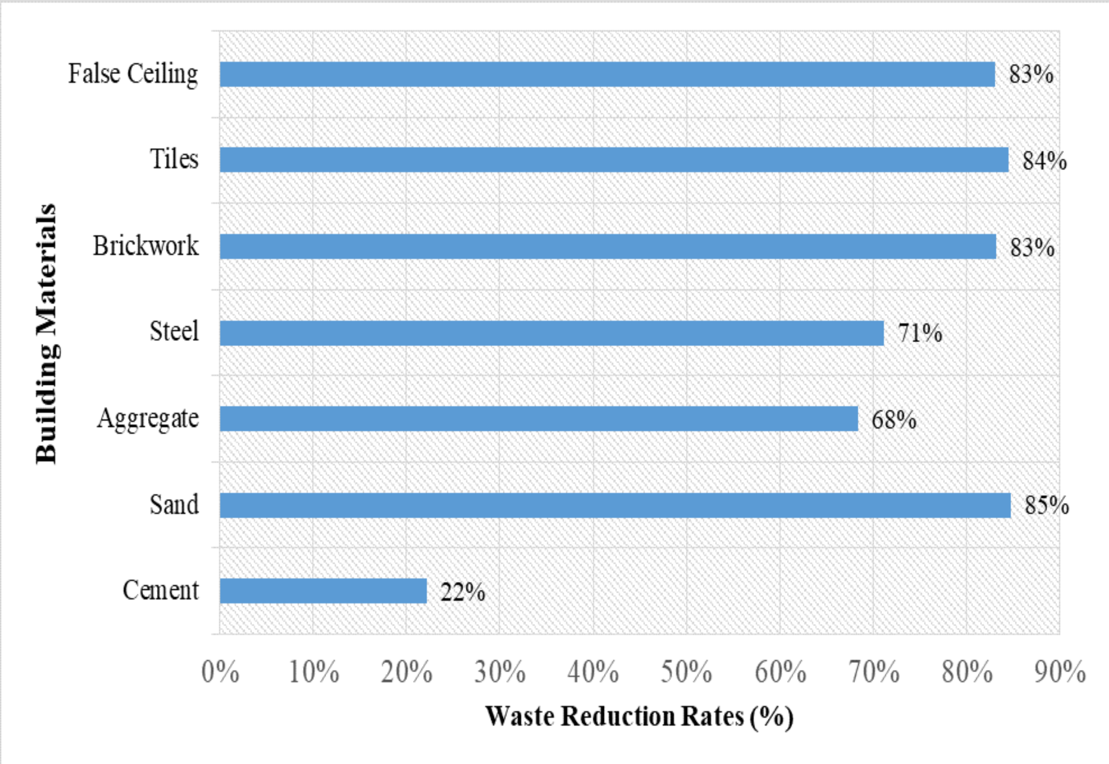

FIGURE 5.8: Waste Reduction Rates (%) for Different Building Materials

5.4 Implications of WM and CE Validation Study

The current research primarily aims to assess the effectiveness of different WM strategies in reducing waste generation in the construction sector, an industry significantly responsible for environmental harm. This study is particularly pertinent to Pakistan, where rapid urbanization and infrastructure progress often outstrip the adoption of sustainable methods. The outcomes of this research provide a vital basis for policymakers, equipping them with practical, evidence-driven tactics to create and enforce regulations tailored to Pakistan's construction sector. As a regulatory body, the Pakistan Engineering Council (PEC) is responsible for overseeing the development, distribution, and enforcement of these policies nationwide. This research can be very useful for PEC to convert the findings into tangible actions by integrating waste management requirements into formal construction protocols. One effective way to ensure this integration is by including WM-specific provisions in standard bidding documents and contract templates. This regulatory integration would compel all contractors, consultants, and project developers-operating at district, provincial, or national levels-to adhere to sustainable waste practices throughout the project lifecycle. From a practical standpoint, the research highlights the necessity of embracing a diverse array of innovative and sustainable strategies. These methods include employing advanced architectural designs that naturally decrease waste, choosing construction techniques that minimize material off-cuts, increasing the use of prefabricated components to cut down on-site waste, and enhancing on-site material storage and handling to avoid spoilage.

Additionally, promoting the reuse of construction materials and establishing effective recycling systems at project completion are essential for realizing CE. As indicated in Table 5.4 of the study, the application of these recommended WM strategies has the potential to lower construction waste by roughly 10% compared to traditional methods. This reduction is advantageous not only for the environment but also economically, as it leads to the preservation of considerable material and financial resources throughout the life of a construction project. Consequently, embracing these strategies could represent a significant advancement toward more sustainable and efficient construction practices in Pakistan. Overall, this research concludes that by implementing WM practices in the construction industry, whether in developing or developed nations, a considerable reduction in waste can be achieved. The proposed measures do not entail significant financial investment, as many of these strategies can be executed without incurring any costs, potentially saving millions in currency by decreasing material wastage. Moreover, this study adds more knowledge into existing literature by providing quantifiable evidence on the effectiveness of various WM strategies. It aims to inspire the local construction sector about WM, as well as encouraging both developing and developed countries to adopt such practices on their construction sites. Consequently, this research significantly contributes to fostering a culture of CE and sustainable development within the construction industry.

5.5 Summary

The current study represents an effort to quantify the effectiveness of WM strategies on a real-time building project to encourage development of sustainable practices. To address this gap, a case study was selected in which WM strategies were implemented throughout the project lifecycle. During the design phase of the project, several errors and omissions were identified by integrating the models through BIM. These errors included clashes among different structural, architectural, sewerage and water supply elements. As a result, these issues were addressed and rectified before the execution phase, thereby preventing the need for rework and ensuring smoother project progression. A range of waste reduction measures, including prefabrication, proper storage of materials, worker incentives, and the reuse of brick ballast, concrete, steel, and sand, were implemented in the current case study. The key findings of this study are as follows:

- WGRs for sand (4.36%), cement (4.15%), and aggregate (3.76%) are found the highest due to manual handling methods. Moderate waste was recorded for paint (2.36%), brick (2.26%), false ceiling (2.26%), and tiles (2.05%), mainly due to limited skilled labor. In contrast, minimal and unavoidable natural waste was noted for glass (0.28%), tuff paver (0.57%), and steel (1.25%). To achieve further waste reduction, the local construction industry must focus on skilled labor development and improved work methodologies

- The project effectively applied the CE principles by reusing and recycling various materials. Reuse efforts included 5.2% of brick ballast, 6.1% of crushed concrete, 0.52% of steel, and 0.22% of sand. Additionally, 22% of excess excavated soil and 0.32% of reinforcement waste were sold for reuse and recycling. These practices highlight a strong commitment to material optimization and sustainability throughout the construction process.

- The WRRs indicate strong performance in managing non-structural materials, with sand (85%), tiles (84%), brickwork (83%), and false ceiling (83%) showing the highest reductions. Moderate WRRs were achieved for steel

(71%) and aggregate (68%), while cement lagged significantly at just 22%, highlighting a critical need for improved handling practices and skilled labor development in the local construction industry.

Overall, the implementation of BIM-based design improvements and waste minimization strategies resulted in approximately 71% reduction in construction waste in the case study project, compared to a traditional project in Pakistan. Further, the WGRs for all listed materials are notably lower than those observed in developing countries and are closely aligned with those found in developed countries.

Chapter 6

Conclusion and Future Recommendations

6.1 Conclusion

Current study is an effort to determine the existing conditions of waste generation and how these higher waste generation rates can be controlled. This is done by identifying the major barriers to waste control, strategies to overcome these barriers and validation of these strategies. At start, barriers to WM on building projects were identified through a detailed literature. Then a frequency analysis was conducted to shortlist the significant factors. Then a questionnaire was formulated and a pilot survey was conducted from some experts to validate the questions asked in the questionnaire. Then fuzzy DEMATEL technique was applied on collected data to identify key barriers to WM. In second phase of research, strategies/enablers against identified barriers were devised for CE culture in local construction industry. For this, semi-structured interviews were conducted. Semi-structured interviews does not only provide the experts to give their opinion on the said issues but also provide free hand to add more information which was originally not included in the interview questionnaire. In last phase of this study, this WM framework was validated partially at micro level on a building project. So, major findings of this study are as follow:

In Phase-1 of current study:

- All key stakeholders including clients, consultants, contractors, and regulators agree on the main barriers to WM and CE practices. These include unclear specifications (B12), lack of rules and regulations (B1), financial challenges (B2), illogical design (B9), poor awareness among stakeholders (B3), and low fines for illegal dumping (B7). Moreover, these barriers are connected to both macro- and micro-level challenges currently faced by the local construction industry on building projects.

- In a comparative analysis of stakeholder perceptions, the contractor-regulator pair demonstrates the highest level of alignment (69%). The client-consultant and client-regulator groups both show moderate agreement (62%). Overall, issues related to regulations (B1) and financial challenges (B2) are the most consistently recognized across all stakeholder groups.

In Phase-2 of this study:

- Thematic analysis led to a policy framework promoting CE culture on building projects in construction sector through enablers at macro (national, organizational, industrial) and micro levels (planning/design, execution, post-construction), each with varying weights. At the micro level, key planning enablers included BIM use (5%), low-waste design options (2.3%), and clear specifications (4.1%). During execution, major strategies were waste collection/segregation (2%) and reuse (2%). Post-construction strategies included landfill disposal (1%) and recycling (1%).

- At the macro level, key organizational actions include fostering a waste control culture (5%), employing experienced designers (2.7%), and promoting recycled material markets (1.1%). At the industrial level, effective measures involve awareness programs (11.2%), WM clauses (3.7%), integrating WM in BS curricula (3.5%), and updating building codes (3.3%). Government roles include providing financial support (14.6%) and facilitating interdepartmental collaboration (7.2%) to implement WM strategies.

- Overall, macro-level enablers (68.2%) have a greater impact than micro-level enablers (18.4%), indicating that effective policy implementation at the top level is essential for achieving results at the micro level.

In Phase-3, it is found:

- During the design phase, integrating the models through BIM revealed several errors, including clashes among different structural, architectural and plumbing elements, missing foundation details, etc. Multiple waste reduction measures, such as prefabrication, proper material storage, worker incentives, and the reuse of brick ballast, concrete, steel, and sand, were implemented in the case study. The results show that 5.2%, 6.1%, 0.52%, and 0.22% of the total quantities of bricks, concrete, steel, and sand, respectively, were successfully reused. In the post-construction phase, around 2000 cubic feet of soil and 0.32% of steel were sold to vendors. The soil was reused for filling a nearby plot, while the steel was recycled and will be used as material in a future project.
- WGRs for sand (4.36%), cement (4.15%), and aggregate (3.76%) are found the highest. In contrast, minimal natural waste was observed for glass (0.28%), tuff paver (0.57%), and steel (1.25%).
- The project effectively applied the CE principles by reusing and recycling various materials. Reuse efforts included 5.2% of brick ballast, 6.1% of crushed concrete, 0.52% of steel, and 0.22% of sand. Further, 22% of excess excavated soil and 0.32% of reinforcement waste were sold for reuse and recycling.
- The WRRs indicate strong performance in managing non-structural materials, with sand (85%), tiles (84%), brickwork (83%), and false ceiling (83%) showing the highest reductions. Moderate WRRs were achieved for steel (71%) and aggregate (68%), while cement lagged significantly at just 22%.
- On average WRR in current study, is approximately 71%.

The study identifies key barriers commonly faced by multistory building projects and explores the challenges that hinder effective WM. These findings support the development of a comprehensive framework aimed at assisting policymakers in regulating and reducing construction waste. By integrating CE principles, the framework promotes sustainability and minimizes the environmental impact of construction activities. A key strength of the research lies in the validation of this proposed framework, which confirms its practical applicability and builds confidence among policymakers, industry professionals, and other stakeholders.

This validation reinforces the frameworks value as a reliable tool for improving WM practices and fostering sustainable construction. The study offers multiple practical benefits, including enhanced material utilization efficiency, reduced project costs, and lower environmental footprints. It also contributes to the formulation of effective policy guidelines for WM and CE, serving as a vital resource for improving environmental regulations and sustainability strategies within the construction sector.

For current study, data were collected from building projects only from twin cities of Pakistan i.e. Rawalpindi and Islamabad. Data were collected for a specific time-period. Developed policy guidelines are proposed based on the opinion of industry stakeholders. Further, proposed framework was validated only at micro/project level, since macro level efforts/measures/strategies are linked to organizations, construction industry and national governments which are beyond the control of authors and this study. The study was conducted in Pakistan using data from local industry experts and building projects; thus, findings may not be fully generalizable to other developing countries as results may vary to some extent for other countries. Furthermore, future studies can focus on expanding the analysis to reflect more explicitly on cost-benefit or return on investment aspects.

6.1.1 Practical Implementation

The proposed WM framework can help policymakers to develop CE culture in the local context as it guides the role of different stakeholders in preventing waste generation in construction projects. In managing construction waste, every stakeholder plays a crucial role in advancing sustainability. The client should set the overall direction by funding waste management and sustainability efforts, allocating resources appropriately, and enforcing waste-related provisions in contracts. They should also encourage collaboration among various departments and implement penalties or rewards based on waste management performance. Consultants should assist both the client and contractor by incorporating waste management strategies into project design, using tools such as BIM to enhance material efficiency. They should promote awareness and ensure adherence to sustainable practices, thereby nurturing a culture of waste control. Contractors are responsible for executing waste management practices at the job site, which includes waste segregation, recycling, and appropriate disposal methods. Regulators should formulate and enforce regulations regarding WM. Collectively, these roles contribute to the effective management of waste and the promotion of sustainability within construction projects. Moreover, this study contributes to all key aspects of the CE and sustainable development. This research is underpinned by an interpretivist philosophical stance, which assumes that reality is socially constructed and best understood through the meanings and perspectives of the individuals involved. In the context of this study, interpretivism provides a suitable foundation for exploring the complex, context-dependent nature of WM and CE practices in the construction sector. This perspective acknowledges that stakeholders' perceptions, experiences, and interactions play a critical role in shaping both barriers and enablers to effective WM. Consequently, the interpretivist approach informed the selection of thematic analysis, enabling a rich understanding of how different actors interpret and respond to WM challenges. This philosophical orientation also guided the design and interpretation of the findings, culminating in the macro-micro level policy framework proposed in this research.

The environmental challenges of material waste generation can be addressed by applying proposed enablers in the construction sector. Second, this reduces the depletion of natural resources by maximizing their utilization. WM methods can significantly limit the amount of construction waste at landfill sites. Therefore, a reduction in waste generation also leads to lower incineration and greenhouse gas emissions. Thus, the carbon footprint of the construction sector can be reduced, thereby making the industry more sustainable. This decrease in waste generation has economic implications as well. WM can save a large number of currency units. The current research also addresses economic challenges by reducing construction costs through the efficient use of materials. It is found that around three percent (3%) of the project costs can be saved by implementing WM strategies.

This will motivate not only clients but also contractors to adopt WM strategies into their projects to increase profit margins. This study significantly contributes to the initiation and development of CE cultures within the construction industry, particularly in developing countries. By highlighting the importance of integrating sustainable practices into construction operations, it underlines the need for heightened awareness among key stakeholders including contractors, developers, government agencies, and local communities. To effectively embed these practices, the construction sector must prioritize resource management through targeted educational initiatives. These can include workshops, seminars, and regular training programs tailored to various stakeholder groups. Such capacity-building efforts not only disseminate knowledge but also equip stakeholders with practical tools for implementation. Ultimately, these combined efforts can enhance the social value of the construction industry in developing regions.

6.1.2 National and Global Impact with Emphasize on SDG

The current study focuses on identifying key enablers for waste control and developing a policy framework for developing countries, especially Pakistan. In practical terms, this study provides decision-makers with concrete strategies to allocate resources efficiently, minimize adoption risks, and encourage collaboration among stakeholders, ultimately increasing the adoption of digital technologies and advancing sustainable construction practices in the context of developing countries. From a theoretical perspective, the results emphasize the need to explore various factors, such as governmental, industrial, organizational, planning, execution, and post-construction phases of a project within theoretical frameworks. This approach allows for future research to more thoroughly understand how different factors interact to influence CE-driven transformation. The significant presence of financial assistance, collaboration among departments, awareness programs, a waste-control culture, the use of the latest tools, and ensuring the reuse of materials onsite highlights the critical role of regional and industry-specific elements. Additionally, the findings of the study highlight the necessity for comprehensive strategies that include financial incentives, capacity development, regulatory changes, and usage of the latest tools, which can be utilized by developing countries aiming to improve their circular practices. The focus on collaboration among multiple stakeholders and the governments role in creating supportive environments further emphasizes approaches that can be applied in contexts beyond Pakistan. By integrating these factors into current construction practices, their relevance to developing nations can be enhanced.

From local to global contexts, the results of the current study have important consequences at the district, provincial, federal, and global scales. Local governments can take advantage by incorporating WM provisions into construction contracts, conducting awareness campaigns, and setting up community landfills and recycling centers. These local initiatives will aid in addressing the micro-level deficiencies identified in the research. At the provincial level, the findings indicate the necessity of updating building regulations, revising engineering and architecture educational programs to incorporate WM practices, and providing financial incentives to promote sustainable construction methods. Provincial governments are also in a position to strengthen collaboration among departments, which is identified as a crucial macro-level enabler. On the federal front, the research highlights the critical need for establishing a comprehensive national waste management strategy, focusing on financial support, interagency collaboration, and technological advancements. A coordinated national strategy would ensure uniformity across provinces and amplify the effects of macro-level initiatives, which were found to have a significantly stronger impact compared to micro-level actions. Lastly, on the global stage, the current study also supports the United Nations Sustainable Development Goals (UN-SDGs), particularly in the area of development of sustainable cities (SDG-11), by minimizing environmental pollution on construction sites by facilitating the responsible consumption of natural resources (SDG-12), i.e., construction materials in current study, and mitigating the impacts of climate change (SDG-13) by curbing the depletion of natural resources.

6.2 Future Recommendations

Future recommendations have been provided in terms of suggestions for stakeholders and future research directions in following sections.

6.2.1 Recommendations for Stakholders

At last, following recommendation have been provided based on the findings of current study:

For Clients:

- Financial Assistance (14.6%): Allocate budget for WM strategies (e.g., recycling units, BIM implementation).
- Long-Term Recycling Plans (3.9%): Incorporate recycling and reuse clauses in project briefs.
- Use of BIM (5.0%) & Least Waste Design Options (2.3%): Support consultants and designers in using digital tools and sustainable materials.
- On-site Reuse (2.0%): Facilitate provisions for temporary storage and reuse of materials. Dumping/Recycling Sites (2.0%): Encourage allocation of space or budget for legal disposal/recycling options.

For Consultants:

- Clarity of Specifications (4.1%): Ensure detailed and accurate material specifications to reduce waste.

- Implementation of Policies (2.3%): Enforce organizational waste policies at the project level.
- Awareness Program (11.2%): Participate in or conduct site training and awareness campaigns.
- Business Development (1.1%): Invest in or collaborate with recycling/reuse businesses.
- Experienced Designers & Staff: Employ skilled labor that can execute low-waste techniques.

For Contractors:

- Collection, Segregation of Waste (2.0%) & On-site Reuse (2.0%): Establish operational mechanisms
- Use of BIM (5.0%): Integrate BIM in design phases for quantity take-offs and material tracking.
- Experienced Designers (2.7%): Promote engagement of skilled professionals familiar with WM practices.
- Waste Control Culture (5.0%): Embed waste minimization as a core design objective.
- Modification in Building Codes (3.3%): Provide feedback to regulators to improve codes based on field data.
- Clauses of Waste Management (3.7%): Add these clauses while preparing contract documents.

For Regulators:

- Heavy Fines (5.5%) & Building Landfill Sites (4.1%): Enforce penalties and provide designated waste zones.

- Collaboration among Departments (7.3%)
- Modification in Building Codes (3.3%) & Content in Curriculum (3.5%)
- Financial Incentives: Provide subsidies or tax relief
- Monitoring: Oversee implementation of recycling units and dumping sites (2.0%).

6.2.2 Future Research

Following future directions are proposed for research in the area of WM:

- Future research should build on this work by investigating advanced recycling methods and their potential to further minimize waste and support sustainable development objectives.
- The current study was conducted in the context of Pakistan, and data were collected from multiple experts from the industry. However, the results may vary to some extent in other developing countries. Therefore, in the future, comparative studies across multiple regions or countries could yield insights into the shared challenges and effective practices for WM in the construction sector globally.
- Another prospective research aspect is the exploration of the impact of emerging technologies, such as BIM, and their incorporation into waste management practices. Future studies might look into how BIM implementation at different phases of a project contributes to minimizing waste generation, improving resource efficiency, and facilitating better decision-making in waste management efforts.
- Future studies can focus on expanding the analysis to reflect more explicitly on cost-benefit or return on investment aspects.

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Appendix A

External Barriers to WM and CE

Sr. No.	Barrier's Name	Details of Barrier	References
1.	Non-availability of rules and regulations	No environmental regulations for waste control	[212],[26] , [165]
2.	Lack of consumer interest in the environment	User motivation to reduce waste of materials	[212]
3.	Lack of qualified professionals in environmental management	Low qualification of employees working in environmental departments	[212]
4.	Lack of legal enforcement	Less implementation of bylaws	[55]
5.	Operating in linear economy	Use and throw away policy	[63]
6.	Finacial Issues	Costly arrangements for waste management techniques	[48]
7.	Low fines for waste disposal	Fines for waste dumping are very low	[107]
8	Poor awareness among stakeholders	Industry preference Issues	[213]

Sr. No.	Barrier's Name	Details of Barrier	References
9	Lack of community attention to CDW impacts	Community commitment to manage waste	[68]
10	Lack of clearly defined national goals, targets, and visions to move toward circular economy	Political leaders preference to keep environment clean	[66]
11	Non-standardized C&D waste reduction reporting	No formal format from waste reduction reporting	[66]
12	Shortage of resources	Non-availability of recycling plants	[214]
13	Consumer confidence on quality of recycled product	Quality of recycled materials is uncertain	[215]
14	Under developed market for reused CDW	Underdeveloped markets for wasted materials	[216]
15	Inadequate information management systems (IMS)	Information management system about availability of waste materials	[212]
16	Poor business case/unconvincing case studies	Uncertainty about business potential of recycled materials	[63]
17	Lack of collaboration among departments	Non-integration among departments to manage waste	[165]
18	Bureaucratic difficulty in applying the legislation	Non-implementation of policies	[217]

Appendix B

List of Internal Barriers to WM

Sr. No.	Barriers	Details	References
1	Lack of modular design	To follow standard options	[65]
2	Lack of use of modern tools	Such as BIM, GPS, RFID	[57]
3	Design not using standard sized materials	Design options and actual design dimensions are different	[26]
4	Illogical design	In structural, architectural and MEP drawings	[108, 218]
5	Lack of innovation in product design	Considering least waste design options	[108, 218]
6	Technical difficulties	Non-availability of recycling equipment, Lack of waste collection mechanisms	[58, 107]
7	Economic incentives	No mechanism for reward and bonus for waste control	[63], [107], [26], [219]
8	Lack of supervision	To observe waste management techniques on site	[55]

Sr. No.	Barrier's Name	Details of Barrier	References
9	Poor behavior of stakeholder	Attitude to save materials	[220]
10	Unclear specifications	Contractual issues	[41]
11	Lack of space for onsite storage	Storage of materials	[26]
12	Lack time needed for material separation	Material separation and sorting times	[26]
13	Use of second-hand materials are not desired	Recycled materials are not used on construction sites	[221]
14	No reuse principles are exploited	Reuse of materials is not encouraged	[214]
15	Clients weak awareness	Clients awareness issues	[107]
16	Lack of contractual requirement for reusing materials	Contractual binding is not available	[26]
17	Competing project priorities	Project priority is not control waste	[26]
18	Poor material storages	Like cement, sand, etc. storage	[222]
19	Under and over ordering issues	To avoid waste during transportation	[13]
20	Non- availability of waste sorting and collection	Waste collection and sorting	[223]
21	Poor workmanship	Unskilled labor	[224]
22	Lack of waste auditing	How much waste is reused and recycled	[225]
23	Insufficient logistics	To deal waste like storage and sorting place and recycling plants	[226]

Appendix C

Summary of External Strategies of WM

Sr. No.	Strategy	Details	References
1	Legislation and policies	Define rules and regulations for CE practices	[227], [96]
2	Education on sustainable development	To promote environmental friendly practices and saving of natural reserves	[26], [97]
3	Financial support for circular economy research	Research projects should be funded	[26], [228]
4	Provide subsidize on CE projects	Subsidize the projects with financial benefits who are following CE methods	[26]
5	Duty and tax relaxation for green practices	Governmental taxes should be relaxed	[26]
6	Preference of stakeholders	Client, consultant and contractor should give it due preferences	[26]

Sr. No.	Strategy	Details	References
7	Collaboration among stakeholders	In-depth teamwork and consultation between project teams	[229], [230]
8	Policies for recycled materials	Recycled materials market should be established	[229], [231]
9	Recycling plants	Government should install recycling plants	[229], [231]
10	Designated public and landfilling areas	For inert and non-inert material separation	[229], [232]

Appendix D

Detailed List of Internal Strategies

Sr. No.	Strategy	Details	References
1	Proper handling	During transportation	[233], [195], [234],
2	Avoid under and over ordering of materials	Order in right quantity	[229]
3	Avoid to purchase low quality materials	Week materials generates more waste	[229]
4	Buy materials with less packaging	To avoid waste	[229]
5	Store material in separate area	To save from weather effects	[233]
6	Waste segregation	Waste separation	[233], [235], [236]
7	Reuse of materials	Use wasted materials for other uses	[233]
8	Safe storage of materials	From theft and vandalism	[199], [195]

Sr. No.	Strategy	Details	References
9	Provide sufficient space for waste handling	To avoid any disturbance on site	[199], [195]
10	Provide bins for storage	To dump waste materials	[199]
11	Identify the activities and materials which can be reused	At planning stage, point out materials and activities which need thorough observation	[199]
12	Waste auditing	Waste monitoring	[233]
13	Making contractors to store materials	Contractors responsibility to store materials	[199]
14	Contractual binding of contractors	Contract agreement	[199], [126]
15	Waste targets	Maximum waste control target	[199], [161]
16	Recycling targets	How much wasted material will be recycled	[233], [161]
17	Use offsite production	Like prefab structures	[233]
18	Use of RFID for materials tracking	Radio frequency identification use for materials tracking	[99]
19	Use of GPS and GIS for landfill designation	To locate dumping sites	[99]

Appendix E

Samples of Questionnaire

Survey Form

Final Questionnaire after Pilot Survey

Title of Research

Development of Policy Framework for Waste Minimization on Building Projects: A Step Towards Circular Economy.

Basic Information			
Name of Project		**Client**	
Consultant		**Contractor**	
Time Duration		**Cost of Project at start**	
Covered Area		**No. of Storey**	
Name of Participant		**Qualification of Participant**	
Experience of Participant		**Organization Type (Consultant, Client, Contractor) & Designation**	

Filled by: **Respondent**/Interviewer (please encircle one).

Please use following rating scale to fill up the given survey form.

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Based on your expertise, if you believe that given barrier has "no effect" on other barrier, please fill "NE" in the box. N/A means not applicable
Similarly, if you believe that given barrier has "medium effect" on other barrier, please fill "ME" in the box.

Question 1: How would you rate the effect of **"Non availability of rules & regulations (Barrier ID: B1)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Effect of Absence of waste control policies at national levels on waste generation.	N/A
B2	Financial issues	Effect of Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material on non-availability of rules and regulations.	
B3	Poor awareness about waste control	Effect of Lack of training & education of stakeholders regarding importance of waste control on non-availability of rules and regulations.	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations on projects	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage, recycling plants and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the generated waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 2: How would you rate the effect of **"Financial issues (Barrier ID: B2)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	N/A
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 3: How would you rate the effect of **"<u>Poor awareness about waste control (Barrier ID: B3)</u>"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels.	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control.	N/A
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field.	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 4: How would you rate the effect of **"Lack of legal enforcement (Barrier ID: B4)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	N/A
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 5: How would you rate the effect of "**Shortage of resources (Barrier ID: B5)**"on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	N/A
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 6: How would you rate the effect of **"Lack of collaboration (Barrier ID: B6)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	N/A
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 7: How would you rate the effect of **"Low fines for illegal waste disposal (Barrier ID: B7)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	N/A
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 8: How would you rate the effect of **"Poor construction practices (Barrier ID: B8)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	N/A
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 9: How would you rate the effect of "**Illogical Design (Barrier ID: B9)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	N/A
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 10: How would you rate the effect of **"Lack of innovation in product design (Barrier ID: B10)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	N/A
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 11: How would you rate the effect of **"Poor behavior of stakeholders (Barrier ID: B11)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	N/A
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 12: How would you rate the effect of "**Unclear specifications (Barrier ID: B12)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	N/A
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	N/A
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 13: How would you rate the effect of "**Lack of use of modern tools (Barrier ID: B13)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	N/A

Survey Form

Title of Research Valid Questionnaire

Development of Policy Framework for Waste Minimization on Building Projects: A Step towards Circular Economy.

Basic Information			
Name of Project	[redacted]	**Client**	
Consultant	[redacted]	**Contractor**	
Time Duration	[redacted]	**Cost of Project at start**	[redacted]
Covered Area		**No. of Storey**	
Name of Participant	[redacted]	**Qualification of Participant**	[redacted]
Experience of Participant	[redacted]	**Organization Type (Consultant, Client, Contractor) & Designation**	

Filled by: Respondent/Interviewer (please encircle one).

Please use following rating scale to fill up the given survey form.

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Based on your expertise, if you believe that given barrier has "no effect" on other barrier, please fill "NE" in the box. N/A means not applicable Similarly, if you believe that given barrier has "medium effect" on other barrier, please fill "ME" in the box.

Question 1: How would you rate the effect of "**Non availability of rules & regulations (Barrier ID: B1)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Effect of Absence of waste control policies at national levels on waste generation.	N/A
B2	Financial issues	Effect of Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material on non-availability of rules and regulations.	VHE
B3	Poor awareness about waste control	Effect of Lack of training & education of stakeholders regarding importance of waste control on non-availability of rules and regulations.	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations on projects	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage, recycling plants and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the generated waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 2: How would you rate the effect of **"Financial issues (Barrier ID: B2)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	N/A
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 3: How would you rate the effect of **"Poor awareness about waste control (Barrier ID: B3)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels.	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control.	N/A
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field.	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 4: How would you rate the effect of "**<u>Lack of legal enforcement (Barrier ID: B4)</u>**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	N/A
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 5: How would you rate the effect of "**Shortage of resources (Barrier ID: B5)**"on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	N/A
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 6: How would you rate the effect of **"Lack of collaboration (Barrier ID: B6)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	N/A
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 7: How would you rate the effect of "**Low fines for illegal waste disposal (Barrier ID: B7)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	N/A
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 8: How would you rate the effect of **"Poor construction practices (Barrier ID: B8)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	HE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	N/A
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 9: How would you rate the effect of "**Illogical Design (Barrier ID: B9)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	N/A
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 10: How would you rate the effect of "**Lack of innovation in product design (Barrier ID: B10)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	N/A
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 11: How would you rate the effect of "**Poor behavior of stakeholders (Barrier ID: B11)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	N/A
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 12: How would you rate the effect of **"Unclear specifications (Barrier ID: B12)"** on ***following barriers*** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	N/A
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	N/A
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 13: How would you rate the effect of "**Lack of use of modern tools (Barrier ID: B13)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	N/A

Survey Form

Excluded due to Incomplete Filled

Title of Research

Development of Policy Framework for Waste Minimization on Building Projects: A Step towards Circular Economy.

Basic Information			
Name of Project		**Client**	PWD.
Consultant		**Contractor**	
Time Duration		**Cost of Project at start**	
Covered Area		**No. of Storey**	
Name of Participant		**Qualification of Participant**	
Experience of Participant		**Organization Type (Consultant, Client, Contractor) & Designation**	

Filled by: **Respondent**/Interviewer (please encircle one).

Please use following rating scale to fill up the given survey form.

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Based on your expertise, if you believe that given barrier has "no effect" on other barrier, please fill "NE" in the box. N/A means not applicable
Similarly, if you believe that given barrier has "medium effect" on other barrier, please fill "ME" in the box.

Question 1: How would you rate the effect of "**Non availability of rules & regulations (Barrier ID: B1)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Effect of Absence of waste control policies at national levels on waste generation.	N/A
B2	Financial issues	Effect of Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material on non-availability of rules and regulations.	HE
B3	Poor awareness about waste control	Effect of Lack of training & education of stakeholders regarding importance of waste control on non-availability of rules and regulations.	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations on projects	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage, recycling plants and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the generated waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	HE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VLE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	NE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 2: How would you rate the effect of **"Financial issues (Barrier ID: B2)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VLE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	N/A
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	NE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	HE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	HE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VLE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

Question 3: How would you rate the effect of "**Poor awareness about waste control (Barrier ID: B3)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels.	HE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants. High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control.	N/A
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field.	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	HE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VLE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VLE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VLE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	NE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 4: How would you rate the effect of **"Lack of legal enforcement (Barrier ID: B4)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	N/A
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	HE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VLE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VLE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VLE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VLE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	HE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

Question 5: How would you rate the effect of "**Shortage of resources (Barrier ID: B5)**"on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	HE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	HE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	N/A
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VLE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VLE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	HE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 6: How would you rate the effect of "**Lack of collaboration (Barrier ID: B6)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	HE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	HE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VLE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	N/A
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VLE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	HE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	HE

Question 7: How would you rate the effect of "**Low fines for illegal waste disposal (Barrier ID: B7)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	N/A
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 8: How would you rate the effect of "**Poor construction practices (Barrier ID: B8)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	N/A
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 9: How would you rate the effect of "**Illogical Design (Barrier ID: B9)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	N/A
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 10: How would you rate the effect of "**Lack of innovation in product design (Barrier ID: B10)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	N/A
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 11: How would you rate the effect of "**Poor behavior of stakeholders (Barrier ID: B11)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	N/A
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 12: How would you rate the effect of "**Unclear specifications (Barrier ID: B12)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	N/A
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	N/A
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	

Question 13: How would you rate the effect of "**Lack of use of modern tools (Barrier ID: B13)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	N/A

Survey Form

Excluded

Discarded due to a Same response in each Question.

Title of Research

Development of Policy Framework for Waste Minimization on Building Projects: A Step towards Circular Economy.

Basic Information			
Name of Project		**Client**	
Consultant		**Contractor**	Allied Contractors.
Time Duration		**Cost of Project at start**	
Covered Area		**No. of Storey**	
Name of Participant		**Qualification of Participant**	
Experience of Participant		**Organization Type (Consultant, Client, Contractor) & Designation**	

Filled by: **Respondent**/Interviewer (please encircle one).

Please use following rating scale to fill up the given survey form.

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Based on your expertise, if you believe that given barrier has "no effect" on other barrier, please fill "NE" in the box. N/A means not applicable
Similarly, if you believe that given barrier has "medium effect" on other barrier, please fill "ME" in the box.

Question 1: How would you rate the effect of **"Non availability of rules & regulations (Barrier ID: B1)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Effect of Absence of waste control policies at national levels on waste generation.	N/A
B2	Financial issues	Effect of Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material on non-availability of rules and regulations.	VHE
B3	Poor awareness about waste control	Effect of Lack of training & education of stakeholders regarding importance of waste control on non-availability of rules and regulations.	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations on projects	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage, recycling plants and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the generated waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 2: How would you rate the effect of <u>**"Financial issues (Barrier ID: B2)"**</u> on **following barriers** in waste generation on building projects?

<u>Rating Scale</u>	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	N/A
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 3: How would you rate the effect of "**Poor awareness about waste control (Barrier ID: B3)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels.	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control.	N/A
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field.	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 4: How would you rate the effect of **"Lack of legal enforcement (Barrier ID: B4)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	N/A
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 5: How would you rate the effect of "**Shortage of resources (Barrier ID: B5)**"**on following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	N/A
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 6: How would you rate the effect of "**Lack of collaboration (Barrier ID: B6)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	N/A
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 7: How would you rate the effect of **"Low fines for illegal waste disposal (Barrier ID: B7)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	N/A
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	VHE
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 8: How would you rate the effect of "**Poor construction practices (Barrier ID: B8)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	VHE
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	VHE
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	VHE
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	VHE
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	VHE
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	VHE
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	VHE
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	N/A
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	VHE
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	VHE
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	VHE
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	VHE
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	VHE

Question 9: How would you rate the effect of "**Illogical Design (Barrier ID: B9)**" **on following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	ME
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	N/A
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

- **Question 10:** How would you rate the effect of **"Lack of innovation in product design (Barrier ID: B10)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	ME
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants. High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	N/A
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

Question 11: How would you rate the effect of "**Poor behavior of stakeholders (Barrier ID: B11)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	ME
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	N/A
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

Question 12: How would you rate the effect of **"Unclear specifications (Barrier ID: B12)"** on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

Barrier ID	Barrier Name	Barrier Details	Rating
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	N/A
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	N/A
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	ME

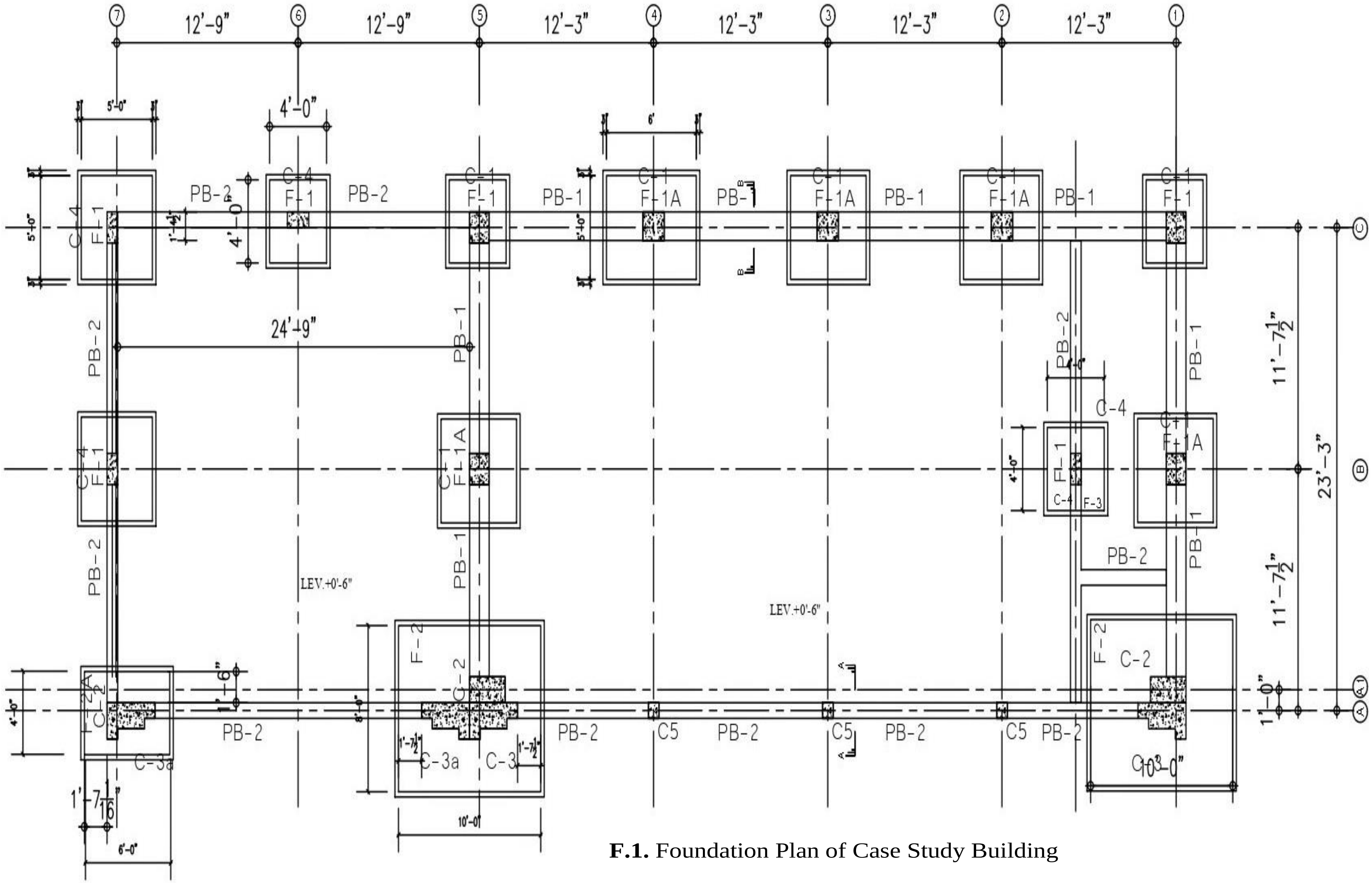
Question 13: How would you rate the effect of "**Lack of use of modern tools (Barrier ID: B13)**" on **following barriers** in waste generation on building projects?

Rating Scale	VHE	HE	ME	VLE	NE
	Very High Effect	**High Effect**	**Medium Effect**	**Very Low Effect**	**No Effect**

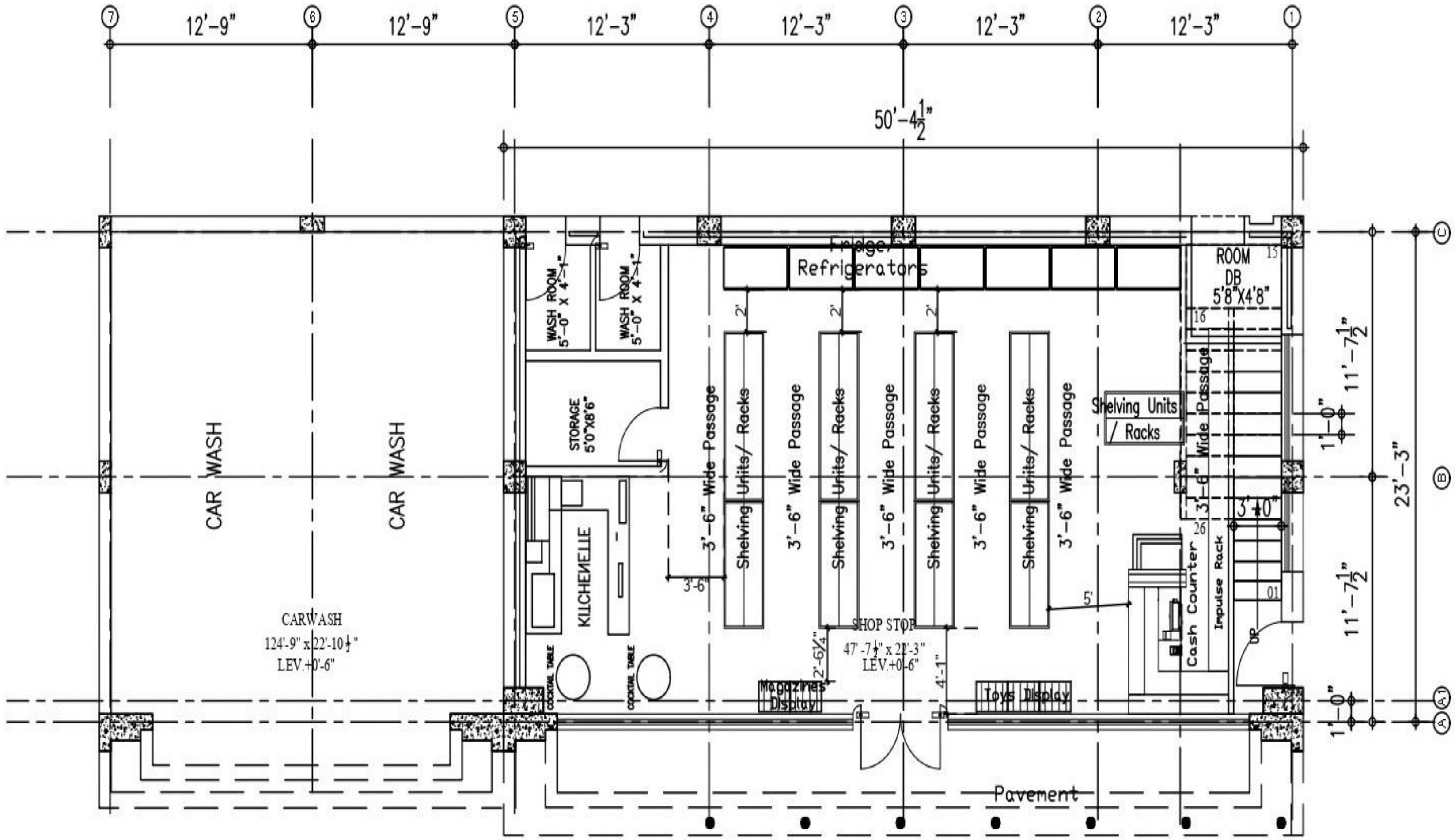
Barrier ID	**Barrier Name**	**Barrier Details**	**Rating**
B1	Non availability of rules & regulations	Absence of waste control policies at national levels	ME
B2	Financial issues	Lack of funds for waste management infrastructure such as recycling plants, High upfront cost for starting a business of recycled material.	ME
B3	Poor awareness about waste control	Lack of training & education of stakeholders regarding importance of waste control	ME
B4	Lack of legal enforcement	Poor implementation of waste control rules and regulations in the field	ME
B5	Shortage of resources	Non-availability of infrastructure i.e. waste sorting, storage and disposal facilities at industrial as well as project levels	ME
B6	Lack of collaboration	Poor communication among departments to deal with the existing waste	ME
B7	Low fines for illegal waste disposal	Fines for illegal waste dumping are very low or non-existent	ME
B8	Poor construction practices	Poor onsite supervision for waste control, inadequate construction methods	ME
B9	Illogical Design	Drafting errors, clashes and discrepancies in drawings due to which rework required	ME
B10	Lack of innovation in product design	No practice of considering alternate design options with less waste generation	ME
B11	Poor behavior of stakeholders	Stakeholders attitude to save materials is very poor due to non-availability of contractual binding	ME
B12	Unclear specifications	Unclear specifications at the time of project initiation, later rework may be required	ME
B13	Lack of use of modern tools	Such as use of BIM, RFID, GPS-GIS for design, supervision and waste handling	N/A

Appendix F

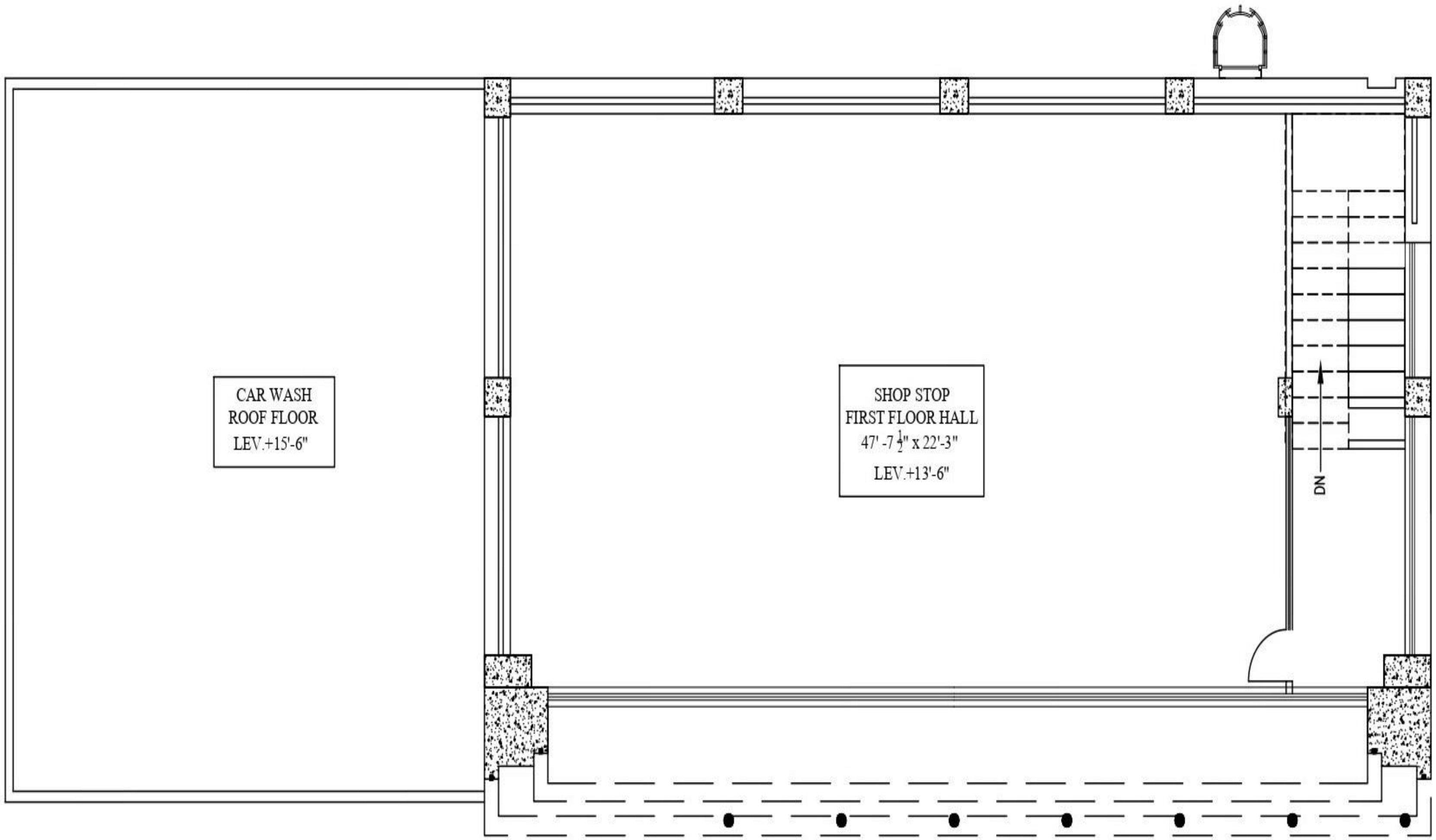
Drawings of Case Study



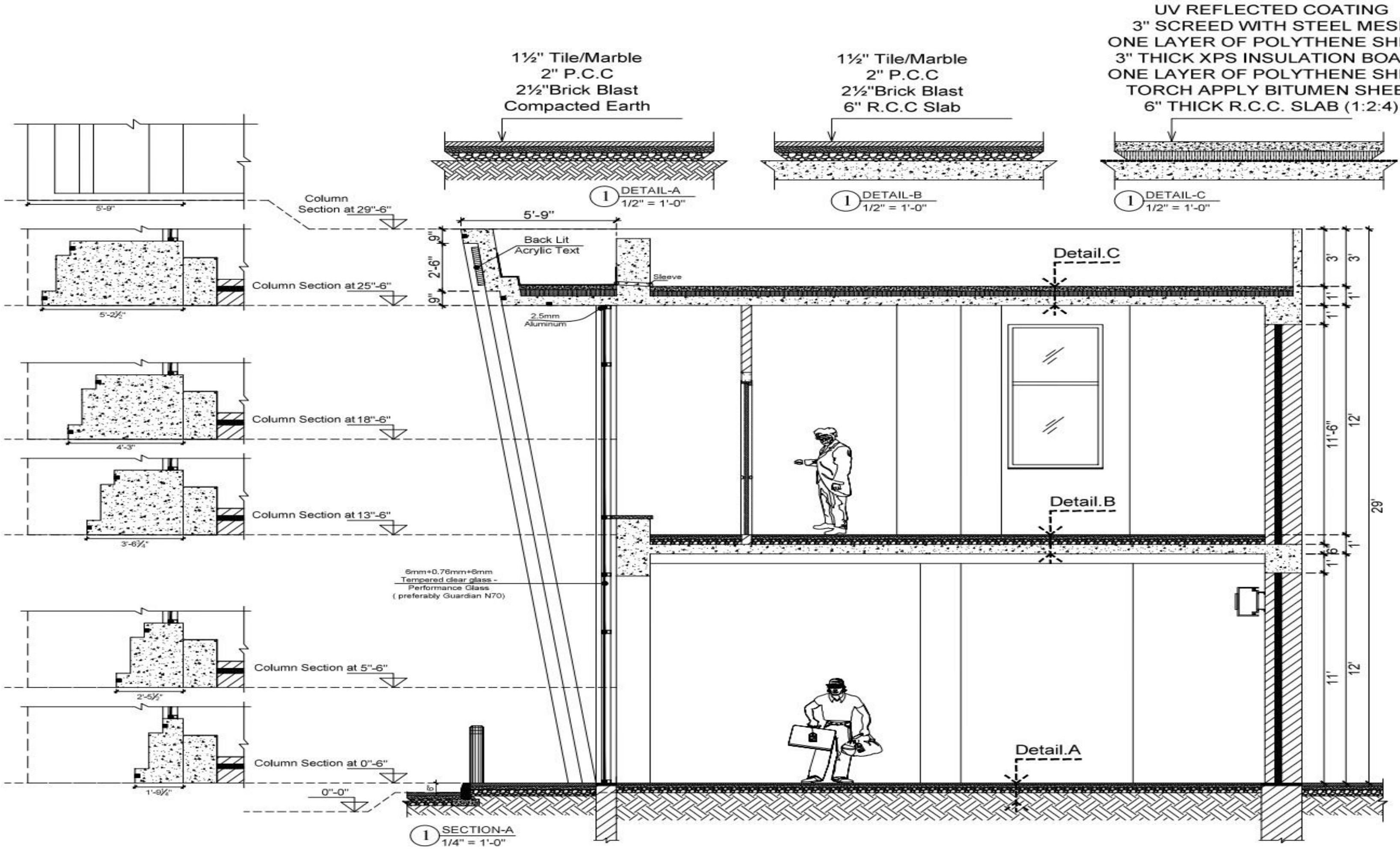
F.1. Foundation Plan of Case Study Building



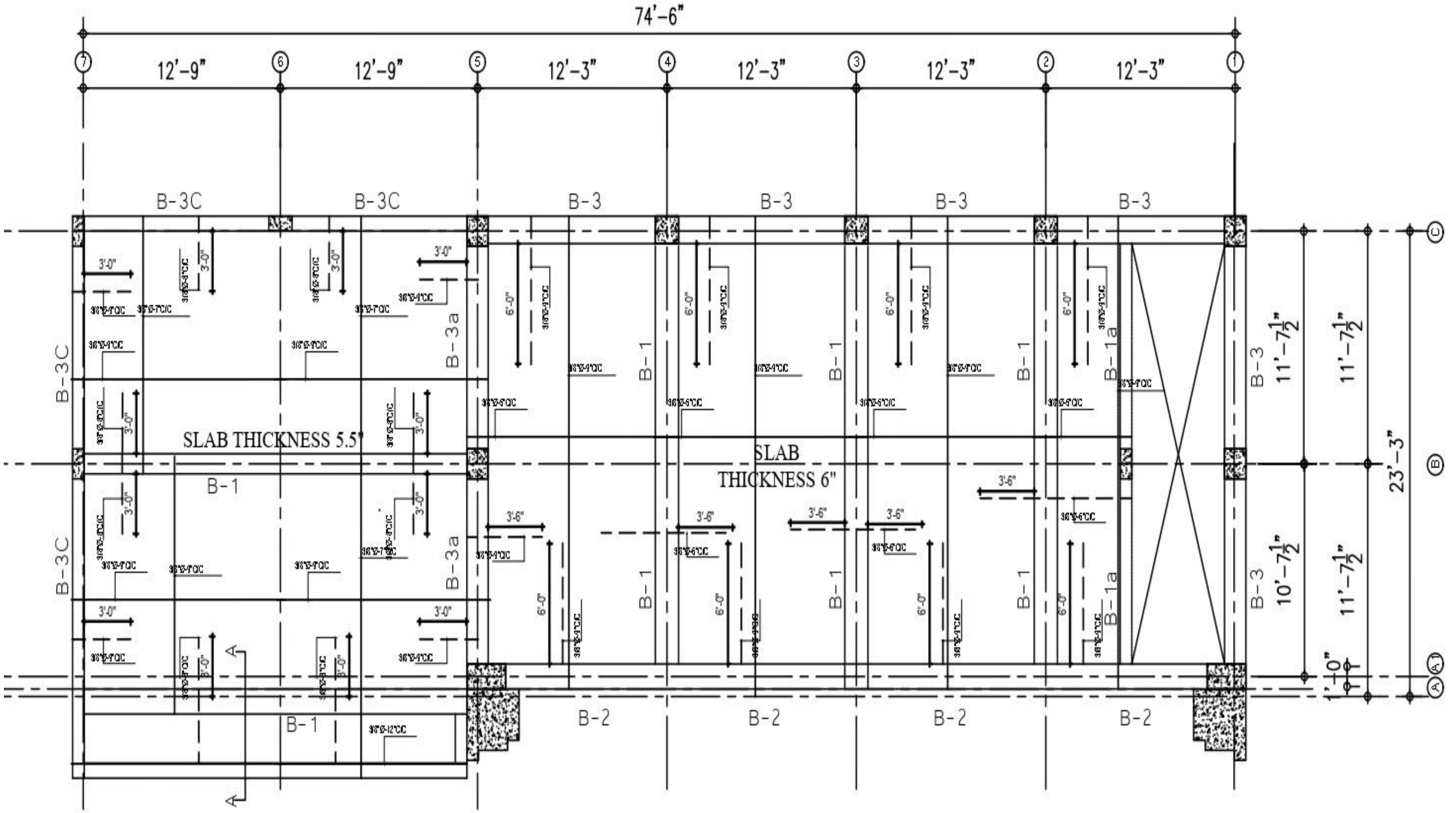
F.2. First Floor Plan of Case Study Building



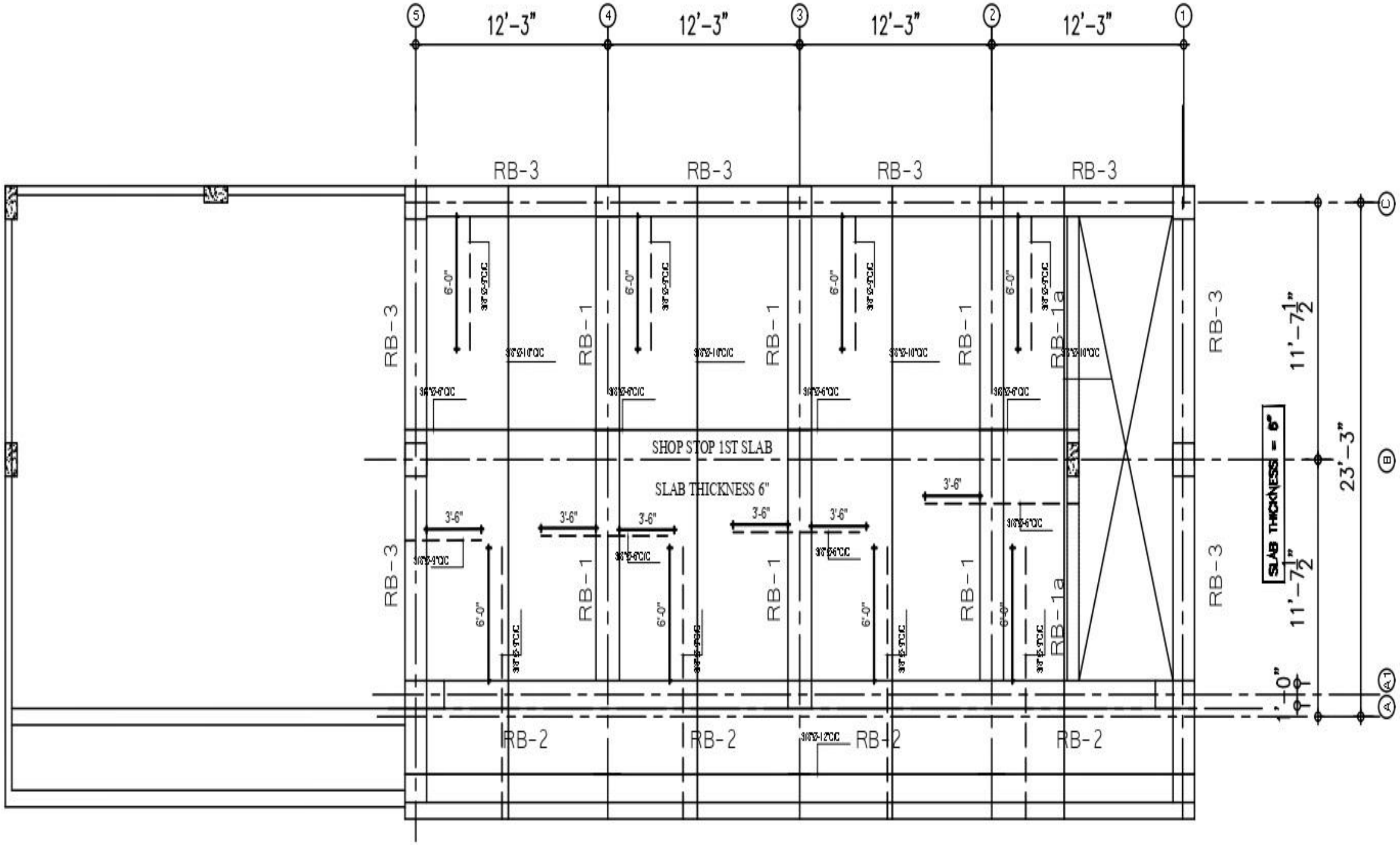
F.3. Roof Plan of Case Study Building



F.4. Cross-Section of Case Study Building



F.5. First Floor Structural Drawings of Case Study Building



F.6. Roof Structural Drawings of Case Study Building

Appendix G

Official Quantities of Case Study

SMART ENGINEERING SERVICES & CONSTRUCTION

To Whom It May Concern

Following is the actual site data which is derived from Interim Payment Certificates (IPCs) and inventory of the project. Data can only be used for research/publication purpose without mentioning the project name by Muhammad Usman Shahid for his PhD research titled "Development of Policy Framework for Waste Minimization on Building Projects: A Step towards Circular Economy." Following materials constitute more than 80% of the project quantities and are the main materials which were used on this project.

Project Name: Construction of Capri Store at PSO station, F-7 Markaz, Islamabad.

Sr. No.	Materials	Units	$M_{purchased}$	M_{used} including reused and sold quantity	Inventory (INV)
1.	Cement	Bags	1645	1569	11
2.	Sand	Cft	57000	54600	20
3.	Aggregate	Cft	6100	5830	50
4.	Steel	Kg	15700	15420	85
5.	Paint	Sft	3500	3419	0
6.	Glass	Sft	1450	1446	0
7.	Brickwork	Cft	2950	2875	10
8.	Tuff Pavers	Sft	3000	2983	0
9.	Tiles	Sft	2500	2430	20
10.	False Ceiling	Sft	2200	2120	32

Regards,

For **THE SESCON (PVT) LTD.**

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Appendix H

Report of Fuzzy DEMATEL Calculations

Project name: Clients-Analysis of Barriers to WM

Date: 8/15/2024 8:15:32 AM

The Steps of Fuzzy DEMATEL Method

Step 1: Generate the fuzzy direct- relation matrix

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

$$z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{1n} & \cdots & 0 \end{bmatrix}$$

The table below indicates the direct relation matrix, which is the same as pairwise comparison matrix of the experts.

The direct relation matrix

Because of the large size of table, download the Excel file to view the full table.

The following table shows the fuzzy scale used in the model.

Fuzzy Scale

Code	Linguistic terms	L	M	U
1	No influence	0	0	0.25
2	Very low influence	0	0.25	0.5
3	Low influence	0.25	0.5	0.75
4	High influence	0.5	0.75	1
5	Very high influence	0.75	1	1

Step 2: Normalize the fuzzy direct-relation matrix

The normalized fuzzy direct-relation matrix can be obtained using the following formula:

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right)$$

where

$$r = \max_{i,j}\left\{\max_i \sum_{j=1}^{n} u_{ij}, \max_j \sum_{i=1}^{n} u_{ij}\right\} \qquad i,j \in \{1,2,3,\dots,n\}$$

The normalized fuzzy direct-relation matrix

. Because of the large size of table, download the Excel file to view the full table

Step 3: Calculate the fuzzy total-relation matrix

In step 3, the fuzzy total-relation matrix can be calculated by the following formula:

$$\tilde{T} = \lim_{k\to+\infty}(\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k)$$

If each element of the fuzzy total-relation matrix is expressed as $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$, it can be calculated as follows:

$$[l''_{ij}] = x_l \times (I - x_l)^{-1}$$
$$[m''_{ij}] = x_m \times (I - x_m)^{-1}$$
$$[u''_{ij}] = x_u \times (I - x_u)^{-1}$$

In other words, the normalized matrix the inverse is first calculated, and then it is subtracted from the matrix I, and finally the normalized matrix is multiplied by the resulting matrix. The following table shows the fuzzy direct-relation matrix.

The fuzzy total-relation matrix

Because of the large size of table, download the Excel file to view the full table.

Step 4: Defuzzify into crisp values

The CFCS method proposed by Opricovic and Tzeng has been used to obtain a crisp value of total-relation matrix. The steps of CFCS method are as follows:

$$l_{ij}^n = \frac{(l_{ij}^t - \min l_{ij}^t)}{\Delta_{min}^{max}}$$
$$m_{ij}^n = \frac{(m_{ij}^t - min\ l_{ij}^t)}{\Delta_{min}^{max}}$$
$$u_{ij}^n = \frac{(u_{ij}^t - min\ l_{ij}^t)}{\Delta_{min}^{max}}$$

So that

$$\Delta_{min}^{max} = \max u_{ij}^{t} - \min l_{ij}^{t}$$

Calculating the upper and lower bounds of normalized values:

$$l_{ij}^{s} = {m_{ij}^{n}}\Big/{(1 + m_{ij}^{n} - l_{ij}^{n})}$$

$$u_{ij}^{s} = {u_{ij}^{n}}\Big/{(1 + u_{ij}^{n} - l_{ij}^{n})}$$

The output of the CFCS algorithm is crisp values.

Calculating total normalized crisp values:

$$x_{ij} = \frac{[l_{ij}^{s}(1 - l_{ij}^{s}) + u_{ij}^{s} \times u_{ij}^{s}]}{[1 - l_{ij}^{s} + u_{ij}^{s}]}$$

The crisp total-relation matrix

Because of the large size of table, download the Excel file to view the full table.

Step 5: set the threshold value

The threshold value must be obtained in order to calculate the internal relations matrix. Accordingly, partial relations are neglected and the network relationship map (NRM) is plotted. Only relations whose values in matrix T is greater than the threshold value are depicted in the NRM. To compute the threshold value for relations, it is sufficient to calculate the average values of the matrix T. After the threshold intensity is determined, all values in matrix T which are smaller than the threshold value are set to zero, that is, the causal relation mentioned above is not considered.

In this study, the threshold value is equal to 0.3250.325

All the values in matrix T which are smaller than 0.3250.325 are set to zero, that is, the causal relation mentioned above is not considered. The model of significant relations is presented in the following table.

The crisp total- relationships matrix by considering the threshold value

Because of the large size of table, download the Excel file to view the full table.

Step 6: Final output and create a causal relation diagram

The next step is to find out the sum of each row and each column of T (in step 4). The sum of rows (D) and columns (R) can be calculated as follows:

$D = \sum_{j=1}^{n} T_{ij}$

$R = \sum_{i=1}^{n} T_{ij}$

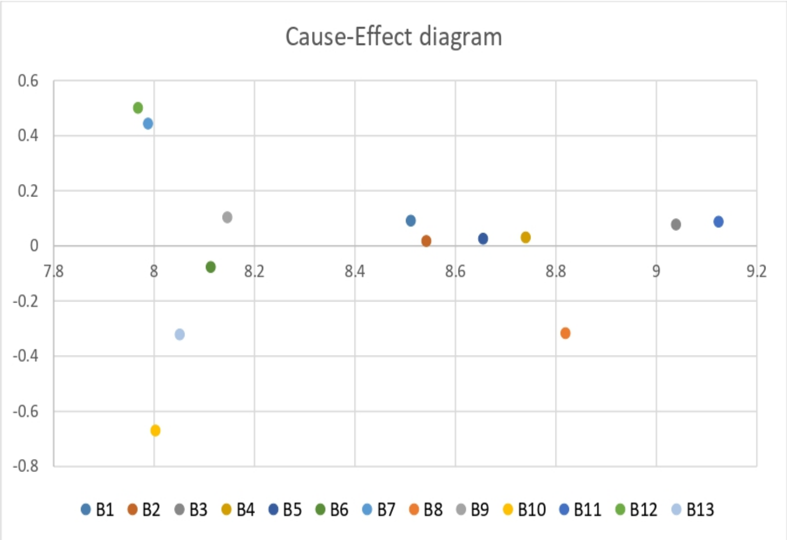
Then, the values of D+R and D-R can be calculated by D and R, where D+R represent the degree of importance of factor i in the entire system and D-R represent net effects that factor *i* contributes to the system.

The table below shows the final output.

The final output

	R	D	D+R	D-R
B1	4.209	4.301	8.511	0.092
B2	4.262	4.28	8.542	0.018
B3	4.481	4.559	9.039	0.078
B4	4.354	4.386	8.74	0.031
B5	4.314	4.341	8.655	0.026
B6	4.094	4.019	8.113	-0.076
B7	3.772	4.216	7.988	0.444
B8	4.567	4.251	8.819	-0.316
B9	4.021	4.125	8.146	0.104
B10	4.337	3.667	8.003	-0.67
B11	4.518	4.606	9.124	0.088
B12	3.733	4.235	7.968	0.501
B13	4.186	3.865	8.051	-0.321

The following figure shows the model of significant relations. This model can be represented as a diagram in which the values of (D+R) are placed on the horizontal axis and the values of (D-R) on the vertical axis. The position and interaction of each factor with a point in the coordinates (D+ R, D-R) are determined by coordinate system.



cause-effect diagram

Step 7: Interpret the results

According to the diagram and table above, each factor can be assessed based on the following aspects:

- Horizontal vector (D + R) represents the degree of importance between each factor plays in the entire system. In other words, (D + R) indicates both factor i's impact on the whole system and other system factors' impact on the factor. in terms of degree of importance, B11 is ranked in first place and B3, B8, B4, B5, B2, B1, B9, B6, B13, B10, B7 and B12, are ranked in the next places.In this study, B1, B2, B3, B4, B5, B7, B9, B11, B12 are considered to be as a causal variable, B6, B8, B10, B13 are regarded as an effect.

- The vertical vector (D-R) represents the degree of a factor's influence on system. In general, the positive value of D-R represents a causal variable, and the negative value of D-R represents an effect. in terms of degree of importance, B11 is ranked in first place and B3, B8, B4, B5, B2, B1, B9, B6, B13, B10, B7 and B12, are ranked in the next places.In this study, B1, B2, B3, B4, B5, B7, B9, B11, B12 are considered to be as a causal variable, B6, B8, B10, B13 are regarded as an effect.