Construction and Demolition Waste Management: A Way Ahead for SME's in Mumbai

Yash V. Raikar

TU Delft Delft University of Technology

Construction and Demolition Waste Management: A Way Ahead for SME's in Mumbai

by

Yash Raikar

to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on

Student number:	5591678	
Graduation Committee:		
Chair:	Prof. Dr. Hans Bakker	TU Delft
First Supervisor:	Assistant Prof. Dr. Tong Wang	TU Delft
Second Supervisor:	Assistant Prof. Dr. Johan Ninan	TU Delft

TU Delft

Preface

Growing up in a family of civil engineers, I have always been fascinated by its concepts and watching how buildings are made in the real world. Their influence peaked my interest and motivated me to pursue a Bachelors in Civil Engineering to become a third generation civil engineer in my family.

I have long believed that construction practices in India often fall short in terms of sustainability. This belief prompted me to pursue a Master's degree in Construction Management at TU Delft, driven by the advancements in sustainable engineering offered by TU Delft and the Netherlands. When it came to picking a topic for my Master Thesis, I wanted to work on something relevant to the industry in India to try and create meaningful change in the industry. Consequently, I chose to focus on the management of construction demolition waste in Mumbai, my hometown.

I would like to thank my TU Delft graduation committee for their continuous support and guidance throughout this journey. To begin with, I would like to thank Dr Tong Wang, my first supervisor, for her constant advice, encouragement and feedback without which this thesis would not have been possible. Next I would like to thank Dr Johan Ninan, my second supervisor, for his advice and for always making time to meet with me and guide me through any obstacles I encountered. Lastly i would like to thank the chair of my committee, Dr Hans Bakker, for being with me since the start and guiding me through the thesis. His help was invaluable in helping me finalise my topic and for encouraging my decision of pursuing a thesis in a foreign industry.

Last but certainly not least, I owe a debt of gratitude to my family and friends for their constant support and encouragement, without which this thesis would not have been possible. A special shout-out goes to my parents, Dr. Vrinda Raikar and Mr. Vikrant Raikar, for their unwavering motivation and encouragement, as well as for providing me with this incredible opportunity. Mom and Dad, this one is for you.

Yash Raikar
Delft, 20th October 2023

Abstract

Mumbai, as a rapidly growing megacity faces considerable challenges with its CDWM endeavours. This research is motivated by the unique context of the city, characterised by its highly fragmented construction industry in critical need of government interventions, to promote effective CDWM due to its fragmented, unorganised and competitive nature. This thesis explores the transitioning of the construction industry in Mumbai towards effective construction and demolition waste management (CDWM) from the perspective of small and medium enterprises (SMEs). It seeks to identify the challenges faced by SME's and propose strategies to enable them to meaningfully contribute to CDWM efforts.

A mixed methods approach was taken, beginning with a literature review to identify barriers and stakeholders involved in CDWM. This was followed by a comprehensive review of international case studies pertaining to Shenzhen, Singapore City and Hanoi to identify international best practices for comparable Asian contexts. Semi-structured interviews with stakeholders from Mumbai's construction industry were conducted to adapt these identified solutions to Mumbai's unique industry fabric. This was followed by the application of the Socio-Technical Systems (STS) theory framework to investigate the interplay of technical and social dimensions within their relevant environment. This leads to societal outcomes in the form of solutions for CDWM in Mumbai, steeped in its specific context using a phase wise approach.

The literature review revealed that the construction industry in India and by extension Mumbai suffers from; insufficient infrastructure, lack of knowledge and technology, lack of governmental incentives for CDWM, mindset problems, lack of enforcement, fragmented nature of the industry, supply chain issues and corruption as barriers towards the adoption of effective CDWM measures. Out of these barriers; the fragmented nature of the industry, lack of enforcement and corruption emerged as the key barriers that serve as stumbling blocks towards the adoption of effective CDWM. Studying international best practices through a case study approach provided solutions that can be divided in to 4 categories, these are; strong governmental interventions, improving monitoring and enforcement, establishment of a thriving recycling market and improvements in infrastructure and technology.

These best practices were aligned to Mumbai's unique context through stakeholder interviews and thematic analysis was conducted using the 4 dimensions of STS analysis as the themes. This allowed for the application of the STS theory framework to Mumbai's construction industry, employing a phase-wise solution due to its suitability to transition projects and the requisite-prerequisite nature of some of the suggested measures. The solution is divided into 3 phases namely; Foundation and Preparatory Measures, Strengthening Implementation and Innovation and lastly Advancing Utilisation and Transition. These measures were suggested with the aim or transitioning Mumbai's construction industry to largely eliminate illegal dumping, improve infrastructure and technology through collaborative research, improve quality of recycled materials, set up a thriving recycling market and introduce technical specifications for their use resulting in establishing material circularity in the industry.That final aim is for landfilling to be restricted purely to soil with all recyclable materials being recycled and processed to improve material circularity and reduce environmental impact of the construction industry in Mumbai.

The research also revealed that SME's operating in Mumbai can be integrated positively into CDWM endeavors by improving the enforcement in the industry, providing incentives against punitive measures and enabling them to incorporate material circularity in projects without significant changes to their operating procedures. This cohesive solution, inclusive of all industry sectors, offers a means for the government to integrate, the historically challenging to organise SME sector into CDWM endeavors in Mumbai.

Nomenclature

Table 1: Abbreviations used in the report

Abbreviation	Description
CDWM	Construction and Demolition Waste Management
SME	Small & Medium Enterprise
STS	Socio-Technical System
GDP	Gross Domestic Product
C&D	Construction & Demolition
CE	Circular Engineering
RCA	Recycled Concrete Aggregates
GOI	Government of India
PMAY-U	Pradhan Mantri Awas Yojana- Urban
PMAY-G	Pradhan Mantri Awas Yojana- Gramin
PMGSY	Pradhan Mantri Gram Sadak Yojana
R&D	Research & Development
GPS	Global Positioning System
KPI	Key Performance Indicator
IRC	Indian Road Congress
MCGM	Municipal Corporation of Greater Mumbai
BMC	Brihanmumbai Municipal Corporation
NMMC	Navi Mumbai Municipal Corporation
BAI	Builders Association of India
CBR	California Bearing Ratio
IIT	Indian Institute of Technology
NIT	National Institute of Technology
UGC	University Grants Commission
GST	Goods & Service Tax
BIS	Bureau of Indian Standards
IS Code	Indian Standard Code
SCADA	Supervisory Control and Data Acquisition
RCC	Reinforced Cement Concrete
RMC	Ready-mix Concrete

Contents

List of Figures

List of Tables

1

Introduction

India being the world's largest democracy, harbours high population densities in all of its major cities. Cities such as Mumbai, Delhi, Chennai, Bangalore, Kolkata etc see a large influx of population who migrate to these cities seeking work and an improvement to their quality of life. In fact, under the Make in India Scheme 2014, the Government of India forecasts that by 2030 over 590 million people will live in major cities in India (Loganathan et al., 2017). This has created a need for the updating and redevelopment of urban cities, along with the creation of new smart cities to create the infrastructure necessary to handle the migration of population from rural to urban India. Furthermore, under the Government of India's rural development scheme titled "Pradhan Mantri Awaas Yojana-Gramin", the government aims to construct 20 million houses across rural areas in India between 2015-2022 (Loganathan et al., 2017). This will result in a planned increase of the built up area from 21 billion sq ft in 2005 to 104 billion sq ft in 2030 (Dadhich et al., 2016). In order to achieve this, the Planning Commission of India, in 2014, committed to spending 10% of India's Gross Domestic Product(GDP) amounting to 32 billion US dollars on infrastructure development by 2017 (Loganathan et al., 2017).

The high demand placed by migration has resulted in the Indian construction industry growing rapidly, exhibiting a year on year growth rate of 10% over the last 10 years as opposed to a world average growth of 5.5% (Dadhich et al., 2016). This has resulted in the Indian construction sector being valued at over 32.6 billion US dollars in January 2022 (Mojumder et al., 2022). As a consequence of the growth of the construction industry, there is expected to be an acute shortage of supply of construction materials in the future.

1.1. Problem Statement

In 2020, construction materials accounted for about 60% of a building's cost in India (Faruqi and Siddiqui, 2020). In 2018, "estimated annual consumption of construction materials in India stood at 750 million tonnes (MT) of sand, 242 MT of limestone, 2 billion tonnes of stone (aggregate), and 350 million m3 of soil" (Faruqi and Siddiqui, 2020). This highlights the huge demand the construction industry places on India's natural resources. However, with resources depleting and river sand mining already outlawed in major Indian jurisdictions, there is expected to be a shortage of construction material. In fact, these material shortages have led to a rise in activities such as, "unlawful material extraction, price inflation and illegal trading" (Sharma et al., 2022) becoming more common in India. Due to these forecasted shortages, there is a real need for the recycling and reuse of construction material in the country.

India is the second largest producer of Construction and Demolition(C&D) waste, producing 1735 kg/m2, resulting in the production of 530 million tonnes of C&D waste in 2014 (Sharma et al., 2022). India has a recycling recovery rate of only 1% with 90% of the C&D waste ending up in landfills (Sharma et al., 2022). A lot of this dumping in landfills is done illegally, which leads to not only a use up of the capacity of the landfill, but also several pollution issues. In certain parts of New Mumbai, protected mangrove forests have been subject to illegal dumping, causing a destruction of their ecology (Assainar, 2022). Furthermore, a recent survey carried out by the Gurgaon Municipal Corporation(MCG)

in the state of Haryana found 314 sites in the city of Gurgaon, where construction and demolition waste was illegally dumped (Chaman, 2022). This leaves the MCG with the task of clearing it away before the monsoon arrives to protect from clogging of drains and waterlogging. In the 2015 Chennai floods, which claimed over 400 lives and displaced 1.8 million people, illegal dumping of C&D debris was found to be one of the main contributors (Ram et al., 2020).

Furthermore, the utilisation of recycled aggregates in India is a “prime concern” (Pavlu et al., 2022). The infrastructure for waste handling and recycling, as it stands, is severely lacking. CDWM rules issued by the Ministry of Environment, Forest and Climate Change published by the Central Pollution and Control Board, suggest the building of recycling plants in all major cities, however, that has not yet been done (Pavlu et al., 2022). In fact, the installed capacity for C&D waste recycling is only 2.5% of the waste generated (Ram et al., 2020). According to the Centre for Science and Environment director general Sunita Narain, “by 2017, 53 cities were expected to set up recycling facilities to recover material from the waste; only 13 cities have done it till 2020” (Somvanshi and Verma, 2020). The replacement of coarse aggregates by recycled concrete aggregates (RCA) has been permitted for use up to 25%, 50%, 100% in reinforced concrete, plain concrete and lean concrete respectively up to a compressive strength of 15 Mega Pascal(MPa). In addition to this, the replacement of fine aggregates by RCA is permitted up to 25%, 50%, 100% in reinforced concrete, plain concrete and lean concrete respectively up to a compressive strength of 25MPa. The use of RCA above 25MPa is not permitted in India (BIS, 2016). Additionally, only the Indian Road Congress mandates the use of RCA in concrete for infrastructure projects (Indian Road Congress, 2017), with the rest of the industry not using RCA. The utilisation of RCA in construction projects is an important prerequisite for promoting greater CDWM as an increase in demand for RCA will promote more recycling and setting up of more recycling infrastructure (Bao and Lu, 2020).

The real estate sector of the Indian construction industry is highly fragmented and competitive (Faruqi and Siddiqui, 2020), leading to higher focus being placed on time and cost targets (Kamma and Jha, 2022). The highly fragmented nature, and the lack of research, specifically to do with Small and Medium Enterprises (SMEs), in this sector, means that the development plans made under the Make in India Scheme (2014), will be difficult to steer towards and achieve reliably. This needs to change if India is to truly drive its economic development in a sustainable way (Mueller, 2006).

1.2. Mumbai Context

Mumbai, titled the “City of Dreams”, is an urban metropolis located on the western coast of India. The city stands as the financial and commercial capital of India, which brings a large influx of aspirants to the city every day in search of work. In 2021, Mumbai had a population of over 21.3 million people with 43% of it made up of migrants (Singh, 2021). This places a huge demand for growth on the city, central to which is the construction industry. With high levels of investment and a rising demand for infrastructure and real estate development, the construction industry in Mumbai has flourished. Constant cycles of development and redevelopment however, have led to the generation of large quantities of construction and demolition waste. In 2015, Mumbai was responsible for the generation of around 2500 tonnes/day of C&D waste (Sekhar et al., 2015). Currently, Mumbai has no available waste recycling plants or avenues to recycle construction waste. Before demolition, all salvageable material is taken out of the building such as tiles, piping, wooden fixtures, aluminium frames etc. This is done due to them having a certain scrap value in the market. Following this, demolition begins and structural steel is also segregated out and sold as scrap. However, the concrete waste mixed with plaster of Paris, gypsum and soil is collected as it is and dumped in landfills situated outside Mumbai, in neighbouring districts, due to lack of space in Mumbai. This poses environmental concerns as well as problems of exhaustion of landfill capacity. In fact, Mumbai being a coastal city leads to all its landfills being in close proximity to the sea. For this reason, Mumbai presents the most severe risk of any Indian city of polluting the ocean due to rainwater runoffs through landfills into the sea (Arora-Desai, 2022). Furthermore, large quantities of waste are illegally dumped to avoid having to haul it long distances to the landfills. This causes traffic obstacles and choking up of drains which leads to frequent flooding in Mumbai during the monsoons (Ram et al., 2020). Additionally, illegal dumping of construction waste has led to the destruction of large areas of mangrove forests.

1.3. Research Scope

This study focuses on enabling the adoption of a more sustainable construction and demolition waste management process in India, in order to transition it towards a more circular construction industry. However, circularity in India is at a very nascent stage. A research conducted by Bao and Lu (2020), highlights the importance of setting up construction and demolition waste management policies and infrastructure in order to harness the increased economic activity of a fast growing nation such as China. Therefore, in order to facilitate the planned economic growth in India, through the implementation of circular principles, it is important to first set up the basic building blocks to enable such a transition. This occurs in the form of enabling effective construction and demolition waste management as seen in case studies such as Shenzhen, China (Bao and Lu, 2020).

Furthermore, bigger construction companies participating in government contracts for infrastructure development, are mandated by the Indian Road Congress to utilise recycled construction material in their projects (Indian Road Congress, 2017). However, smaller companies in the real estate sector have no such obligations (Indian Road Congress, 2017), which allows them to adopt a linear model. Furthermore, the fierce level of competition means that the real estate sector is "primarily driven by cost and time targets with least priority towards waste management" (Vilventhan et al., 2019). For this reason, the research will be done from the perspective of SMEs in the Indian construction industry. Furthermore, Smallbone and Welter (2001) state that SME's in developing industries undergoing economic transformation, are heavily influenced by the external environment in which it operates. This external environment is heavily influenced by the government, where they can enable or constrain the process (Smallbone and Welter, 2001). In developing economies, SME's faces numerous problems such as sensitivity to macro-economic policies, lack of stability of market and differential impact of policies due to size. The government is the chief actor with the ability to help SME's overcome size related disadvantages and market instability (Smallbone and Welter, 2001). Hence, this thesis will focus on how the government can be the driving force behind change and enable SME's to participate in effective CDWM.

1.4. Research Relevance

This thesis is academically relevant as it contributes to research in a largely unexplored domain in literature. Most developing countries in the world have an unorganised construction sector that will have large demands placed on it in order to spearhead economic development. It is important that these industries are studied to ensure that this increase in development is correctly harnessed, to transition the industries towards circular construction practices. All the existing research in the field is less relevant to India, as it has a unique set of challenges towards implementing effective circular construction practices (Sohal et al., 2022) such as; corruption in authorities, archaic regulations, lack of skilled workforce and an abundance of unskilled labour. Therefore, the industry needs to be specifically studied so that a way can be devised to bring about positive changes to construction in India. Most South-East Asian countries will face similar problems to India and this research can serve as a base for driving future research into other countries from that region (Sohal et al., 2022).

1.5. Research Structure

This research follows the following structure. Chapter 2 deals with the theoretical framework selected to guide the research followed by chapter 3 which deals with the research design establishing the objective, research questions and research methodology applied. Chapter 4 contains a review of available literature relevant to the topic, culminating in a list of barriers and actors critical to CDWM in the industry. Chapter 4 concludes with highlighting the gap in available literature that this research aims to bridge. This is followed by chapter 5, where case studies are examined from 3 different cities where attempts to improve CDWM were made and lessons are extracted from there to culminate in a list of solutions. Chapter 6 then goes on to describe the semi-structured interview methodology followed and the reasoning behind participant selection and questionnaire design. This is followed by chapter 7, which deals with the analysis of the data obtained from the semi-structured interviews and the synthesis of the solution. Chapter 8 then contains a discussion of the findings and results obtained along with

recommendations for future research. This is followed by chapter 9, where the research questions are answered and conclusions are formed and presented.

2

Theoretical Background

This section provides a background of the Socio-technical systems theory which was chosen to guide the research into CDWM for Mumbai's construction industry. It provides a background of the Socio-technical systems theory, introduces the framework applied for analysis under this theory and discusses characteristics of systems required for its application. The section concludes with examining the applicability of this theory to the construction industry.

2.1. Socio-Technical Systems Theory (STS theory)

Socio-Technical Systems Theory (STS Theory) creates a framework that allows for investigation into how different components interrelate to create organisational outcomes in its own external environment. The term socio-technical systems, originally coined by Emery and Trist (1960), was "initially developed to describe the complex interactions between humans, machines, and organisational environments leading to successful or unsuccessful organisational performance" (Sohal et al., 2022). This interaction however, is true for most enterprise systems (Baxter and Sommerville, 2011). The STS theory includes three major subsystems; technical, social and environmental.

The technical system includes techniques, tools, procedures, technology and knowledge that organisational employees can use to provide outputs to clients. It aids in creating a structure in which members of an organisation operate (Kull et al., 2013). Technical systems add value to organisations. Supply chain management methods, which are designed to improve performance, are also classified as part of the technical system (Kull et al., 2013). The social system encompasses the people who work within an organisation. It includes personal traits like their "attitudes, beliefs, relations, cultures, norms, politics, behaviours, and emotions"(Kull et al., 2013). It gives an understanding of how relevant actors carry out necessary tasks and provide support for organisational processes. These actors can be employees or other key stakeholders who all take action in achieving an organisation's goals (Sohal et al., 2022). The environmental system is overarching and envelops both the social and technical systems. It defines the relevant environment in which an organisation operates and includes the "relevant governmental, economic, industrial, transportation, and cultural contexts"(Pasmore, 1988).

The STS theory is adaptive and influences its environment. For this reason it is considered an open system and pursuing of strategies, selecting resources and implementation of technology must be done with environmental stressors in mind. STS theory does not deal with the self interaction of the social or technical systems. Instead, it deals with how the social and technical systems interact with each other and the environment to create organisational outcomes (Kull et al., 2013). This leads to the framework in Figure 2.1 suggested by Kull et al. (2013) and modified by Sohal et al. (2022). The proposed framework clearly highlights the interaction of the social and technical systems under the umbrella of the relevant environment leading to organisational outcomes.

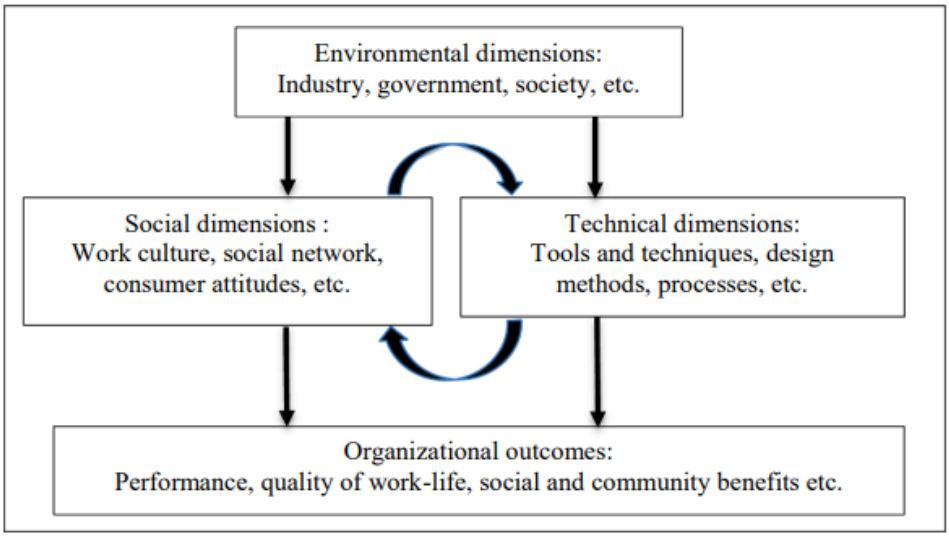

Figure 2.1: STS framework (Kull et al., 2013) (Sohal et al., 2022)

The term socio-technical system can be used to describe a wide variety of complex systems (Baxter and Sommerville, 2011). However, to apply STS theory, the system must qualify as an open system. Badham et al. (2000) suggested five key characteristics that classify a complex system as an open socio-technical system and they are as follows.

- Systems should have interdependent parts.
- Systems should adapt to and pursue goals in external environments.
- Systems have an internal environment comprising separate but interdependent technical and social subsystems.
- Systems have equifinality. In other words, systems goals can be achieved by more than one means. This implies that there are design choices to be made during system development.
- System performance relies on the joint optimisation of the technical and social subsystems. Focusing on one of these systems to the exclusion of the other is likely to lead to degraded system performance and utility.

Based on the aforementioned classification, a study conducted by Sohal et al. (2022) applied STS theory thinking to SME firms operating in India's manufacturing sector and how they can be enabled to adopt circular engineering thinking. Furthermore, Kull et al. (2013) apply STS theory to supplier integration and supply chain management. This suggests that the STS theory is a valuable lens to use when studying CDWM as both circular engineering and supply chain management are key concepts related to CDWM (Schützenhofer et al., 2022). Furthermore, the construction sector of any particular country qualifies as an open system as per the above classification lending to the adoption of STS thinking to analyse and navigate its complex dynamics.

3

Research Design

3.1. Research Objective

The objective of this research is to bridge the gap in the literature and shed more light on the issues and barriers that smaller construction companies in India face towards adopting circular principles such as CDWM. The study also aims to help transition the construction industry in Mumbai towards effective CDWM, by suggesting solutions through the use of STS systems analysis in the form of societal outcomes, that can be used to discourage the adoption of linear economy principles and encourage the industry to adopt certain circular principles. STS theory was initially developed to examine the influence of the interaction of social and technical systems within their relevant environment to generate the desired organisational outcomes. However, as per Pasmore (1988) “whenever there are people, working together in a system with technology, in an environment that provides the resources the system needs, there is the possibility of adapting STS thinking”. This is further underpinned by Kull et al. (2013) when they state that “there would seem, however, to be no reason why socio-technical thinking should not be extended to supply chains, partnerships and other networked ways of working that cross company boundaries”. STS theory has been used as a lens in several management studies, one of them being a study conducted by Sohal et al. (2022) where they studied the adoption of circular engineering (CE) by SME’s operating in India’s manufacturing sector. Since CDWM is an essential component of CE, STS theory becomes an appropriate lens to study how SME’s in India’s construction sector can transition towards the adoption of effective CDWM. However, due to the re-calibrating of the theory to focus on a societal problems rather than being restricted to an organisation, the outcomes section of the framework proposed by (Sohal et al., 2022), can be amended to societal outcomes as seen in Figure 3.1.

Kern and Smith (2008) have described transition projects as “an attempt to complement existing policies with strategic long term transition approach aimed at structural change”. In order to enable transitions, its essential to outline long term goals and develop pathways along which these goals can be realised. Additionally, interviews taken by Kern and Smith (2008) revealed that the transition path in question can be characterised as a “consistent set of actions, fulfilled preconditions and learning experiences that lead to fulfilment of the ambition formulated”. For achieving success in transition projects, it is essential to have a long term transition plan to cause changes in complex societal systems. These have to be supported by short term results in order to harness the momentum they generate towards the desired end state (Kern and Smith, 2008). The complex nature of societal systems requires an approach that remains stable and robust under the influence of the complex dynamics associated with societal changes. For this reason, it is essential that a phase wise approach is taken (Chishti et al., 2023). As changing the CDWM landscape for a city falls under the purview of transition projects, it becomes necessary to device a solution that follows a phase wise approach aimed at creating long term changes, while harnessing existing policies and infrastructure and improve upon it to ensure the transition remains smooth. Furthermore, the fulfilled preconditions Kern and Smith (2008) mention, lends itself to implementing a system where certain steps are pre-requisites to others further steering towards the adoption of a phase wise solution approach.

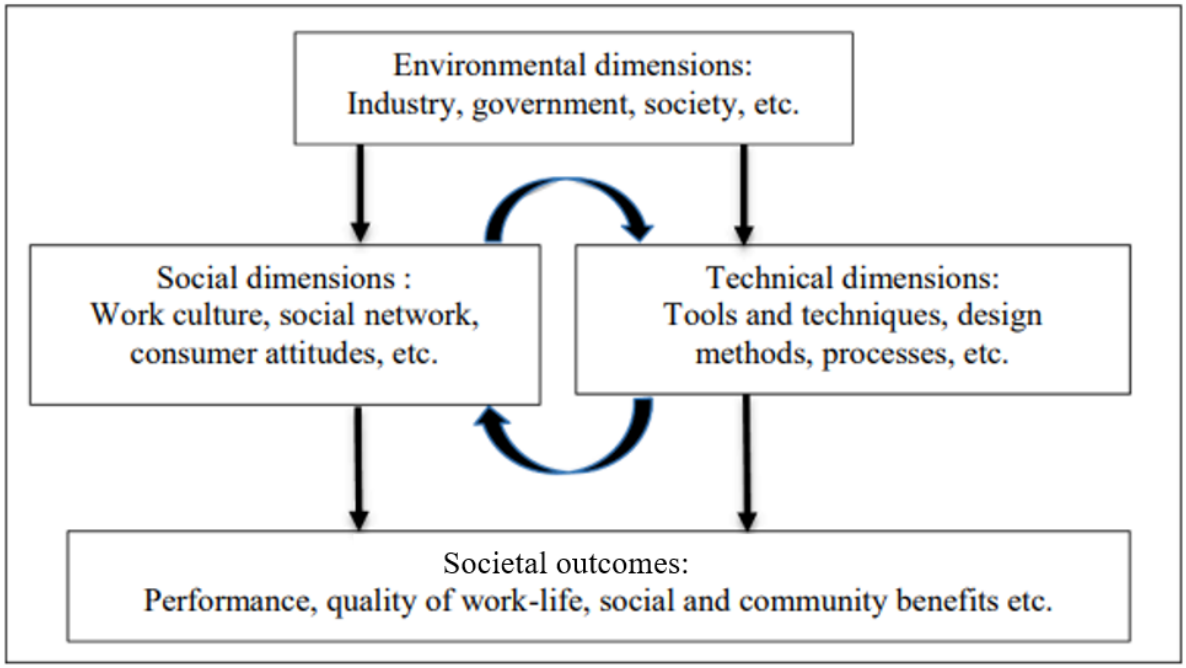

Figure 3.1: STS Framework for Society (Sohal et al., 2022)

Availability of current literature is centred around an investigation of barriers. Therefore, this study aims to generate actionable solutions by investigating the interaction of the social and technical dimensions among each other within the relevant environmental dimension to generate societal outcomes that can create positive long term changes to Mumbai's CDWM landscape.

3.2. Research Questions

The research objectives stated above lead to the formulation of the following research question and sub research questions.

"How can the construction industry in Mumbai transition towards the adoption of effective construction and demolition waste management (CDWM): from the perspective of SME's?"

In order to answer this, the following sub research questions are proposed.

- Q1. What is the current state of CDWM employed by SMEs in Mumbai's construction industry?
- Q2. What are the relevant barriers and actors involved in CDWM in India?
- Q3. What can be learnt about the implementation of CDWM from case studies sharing comparable contexts to Mumbai?
- Q4. How can a multi-stakeholder approach steer the construction in Mumbai towards the adoption of effective CDWM using a phase-wise plan?

3.3. Research and Data Gathering Methodology

This research employs two methods,secondary research through literature study and case studies and primary research through semi-structured interviews with stakeholders in the industry. A comprehensive literature review was conducted to understand the current state of CDWM in India, the barriers and the actors present in the industry. This is aimed at providing answers to sub-research questions 1 and 2. This was followed by case study analysis to generate solutions which would serve as the input for the semi-structured interviews as well as aid in answering sub research question 3. The interview transcripts would be analysed through the lens of the STS theory framework in order to answer sub-research question 4 leading to the answering of the main research questions using the STS theory framework.

Figure 3.2 schematically represent the research design process used. The solid lines represent the chronology of sub questions answered and the dotted lines represent the input of information and data.

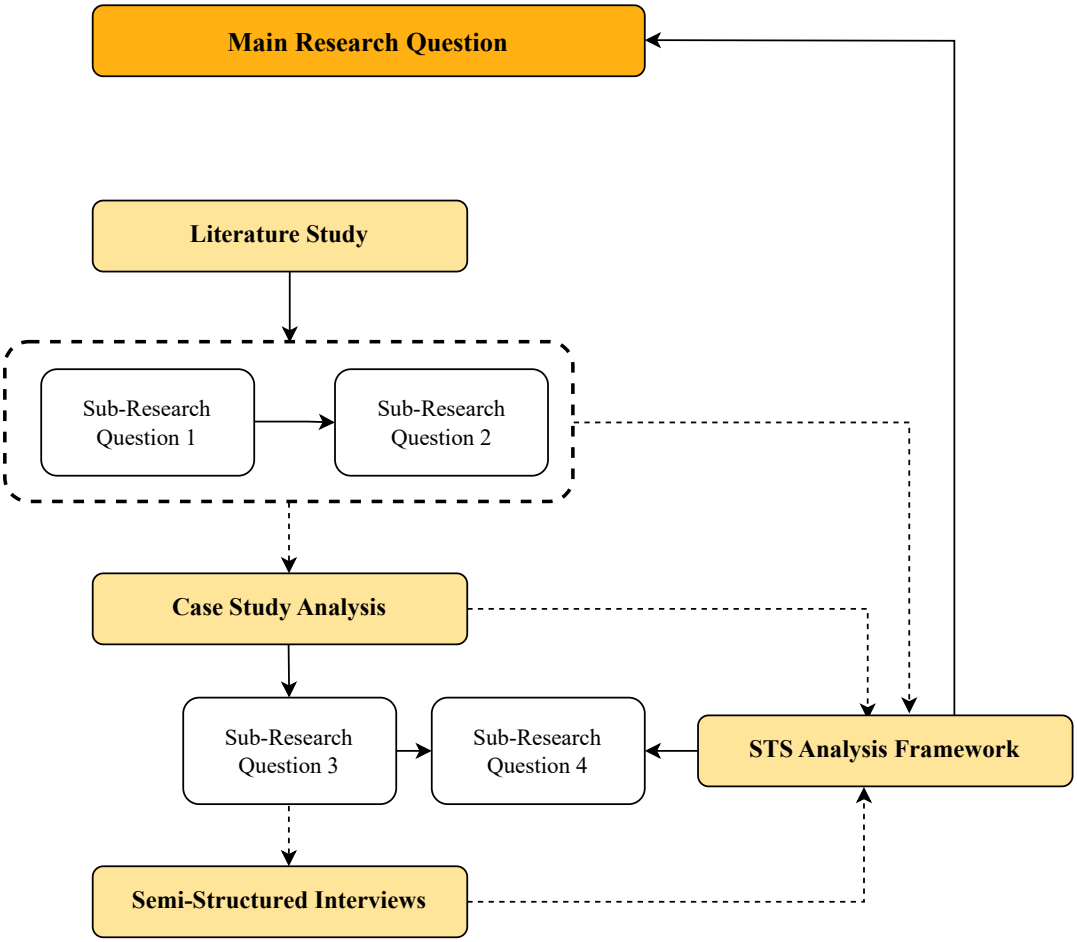

Figure 3.2: Research Methodology

3.3.1. Phase 1: Literature Review

In order to fully understand the importance of effective CDWM, available scientific research will be studied. Articles addressing the Indian industry will be studied, to understand the context of the industry and the problems it harbours. Special attention will be paid to articles about construction and demolition waste management in India; to gauge the level of CDWM currently employed, what are the already identified barriers and who are the key actors present in the industry. The literature review will result in the identification of a list of barriers and a list of actors present in the Indian construction industry along with the current state of CDWM in India allowing for the answering of sub-research questions 1 and 2.

3.3.2. Phase 2: Case Study Analysis

Due to the absence of literature addressing solutions for the problem of C&D waste in India, case studies will be done on examples of other countries in Asia, who have solved or attempted to solve this problem. From these cases, it was desirable to learn what steps are being taken in order to improve CDWM in other countries and how to make these steps work in the Indian context. For this reason, it was decided to look at both successful and unsuccessful examples. Hence, three case studies namely Shenzhen (China), Singapore and Hanoi (Vietnam) were chosen to be studied. Shenzhen and Singapore City are examples of projects where good steps were taken to improve CDWM and with good implementation, that have shown positive results. Hanoi on the other hand, has taken good initiatives to try and solve this problem, however, due to substandard implementation it has not succeeded to the same extent as Shenzhen and Singapore. Furthermore, the construction industry in Vietnam is more similar to the Indian industry, as compared to China and Singapore which would provide valuable lessons to apply to the Indian context. From these case studies, lessons learnt will be extracted and STS theory analysis will be performed on them to understand their implementation in their respective industry and local contexts. These will be used to make a list of solutions as produced and implemented in Shenzhen, Singapore and Hanoi. These identified solutions will serve as the input for the semi-structured interviews. The case study analysis will also serve as the means to answer sub research question 3.

3.3.3. Phase 3: Semi-Structured Interviews

Due to the failure of available literature to appropriately address SMEs in the Indian construction industry, it is necessary to collect primary data. This will be done in the form of semi-structured interviews with industry experts. The list of solutions identified from the case studies, will be geared to and suited to its own industry context. Therefore, there is a need to modify these solutions in order to cater to the construction industry in Mumbai. This will be done through the semi structured interviews. A semi-structured format is chosen to encourage “reciprocity between the interviewer and participant” (Kallio et al., 2016). This format will ensure that the discussion is more or less on topic, but also allows for the participant to talk about or elaborate on specific instances and experiences that will allow for a more comprehensive understanding of the industry. Semi-Structured methodology also allows for the interviewer to ask follow up questions and seek clarifications from the participants and vice-versa. The industry experts will be told about the solutions implemented elsewhere, and discussions will be had with them regarding how these solutions can be applied to the construction industry in Mumbai. They will be asked how they would react if these solutions were implemented in Mumbai, how they would change these solutions and what their opinion is about them.

Participant Selection

Participants will be selected based on their experience levels in order to ensure reliability of information gained. The lack of literature makes the validation of gained information difficult due to which it is essential that collected information is valid and reliable. Experience in the industry leads to a deep understanding of it, making the data collected from experienced personnel more reliable (Tsiga et al., 2016). The interviewed personnel will include site engineers, project developers, structural engineers, demolition contractors and civil engineering professors working at university level with industry experience to also cover a more theoretical angle as opposed to just practical experience. Selecting interview

personnel from the aforementioned roles will help cover most of the critical actors present in the industry apart from the government.

3.3.4. Phase 4: Data Analysis- Thematic Analysis

The interviews will be transcribed and the transcripts will be analysed using thematic analysis. The method chosen is Thematic analysis due to its ability to identify patterns of meaning in datasets and to group them according to their themes. Thematic analysis is especially chosen due to its ability to provide “deep and nuanced insights” (Terry et al., 2017). This will be in done to aid in the generation of solutions for CDWM that will be curated to the Mumbai context through the interview process. The analysis will entail identifying themes by applying codes to the data.

STS theory entails 4 key elements namely Technical system, Social system, Environmental system and Societal outcomes (Kull et al., 2013). Figure 3.1 shows the STS systems theory diagram and what aspects are included in each dimension. These four will serve as the themes chosen for the thematic analysis. This method will allow for an investigation into how the various systems interact with each other, within the relevant environment of the construction industry in Mumbai, and will inform the identification and generation of societal outcomes. These outcomes will be in the form of solutions geared towards the government and will entail how the government can steer the SME’s in the industry towards the adoption of effective CDWM. The purpose of the thematic analysis is to generate solutions that are actionable and apply to the context of Mumbai’s construction industry. The obtained data will then be divided into a phased plan with the STS framework being applied to each of the phases resulting in an understanding of what social, technical and environmental aspects will influence and mould the outcomes for each phase with the societal outcomes forming the solutions recommended for each phase. This will help in the answering on sub research question 4 and the main research question.

3.3.5. Final Deliverable

The final deliverable will be a phase-wise solution that will be devised through discussion with industry stakeholders that fits the context of Mumbai. The solution will be divided into phases with actionable steps that fit with and arise from the interplay of the social technical and environmental dimensions of Mumbai and results in solutions in the form of societal outcomes that need to be applied in each phase to stimulate better CDWM in Mumbai. This will be backed using statements and ideas obtained from and discussed in the interviews.

4

Literature Review

The literature review is divided into 5 sub-sections. The first section introduces the concept of circular economy and its principles. The second section introduces construction and demolition waste management and its importance. This is followed by section 4.3 which discusses the current state of the Indian construction industry, examining the governmental vision, industry make-up, material demand and current state of CDWM in India. This is followed by section 4.4 and 4.5 which address the barriers and actors involved in the industry. Lastly, section 4.5 addresses the research gap identified from literature. The aim of this literature study is to answer sub-research questions 1 and 2 along will allowing for a comprehensive understanding of the problem at hand to aid in the comprehension of solutions.

4.1. Circular Economy

Circular economy presents an economic paradigm that encourages the preservation of natural resources and decoupling the link between economic growth from material exploitation over the entire lifecycle of products or services (Gruis, 2022). It is an attempt to move away from the traditional liner consumption model which follows a take-make-dispose approach. Any system based on consumption as opposed to restorative use of non renewable resources causes significant loss of value and negative effects along the material supply chain (Ellen Macarthur Foundation, 2015). This is especially significant in the construction industry which is responsible for large amounts of material consumption worldwide. As the linear economic model grapples with economic losses, structural waste, price volatility, supply uncertainties, and the degradation of natural systems, it becomes increasingly evident that a shift towards a circular economy is not just desirable but necessary (Ellen Macarthur Foundation, 2015). In essence, “a circular economy is an industrial system that is restorative or regenerative by design” (Ellen Macarthur Foundation, 2015). This allows for value retention along the supply chain.

Circular economy rests on 3 key principles as identified by the Ellen Macarthur Foundation (2015). They are as follows:

Preserve and enhance natural capital

When resources are needed, the circular system chooses the resources and technologies in a way that they use renewable or better performing resources. Furthermore, a circular economy also enhances natural capital by encouraging material flow within the system and creating conditions for its regeneration.

Regenerate Nature

Moving away from a linear economy model towards a circular economy results in the support of natural processes allowing nature to thrive. This can be done by emulating the “zero waste” systems found in nature where nothing is wasted and everything is used for some other purpose till its absorbed back into the cycle allowing for its regeneration.

Optimise resource yields by circulating materials at their highest utility

“This means designing for re-manufacturing, refurbishing, and recycling to keep technical components and materials circulating in and contributing to the economy” (Ellen Macarthur Foundation, 2015). This advocates setting shorter “loops” choosing maintenance where possible to preserve more embedded energy. Materials and products can maintain their circulation through 2 fundamental cycles; the technical cycle and the biological cycle.

- Technical cycle: This involves maintaining and reusing products as it is the most effective way to retain their value. It advocates maintenance, reusing, sharing and resale, repair and refurbishment before ultimately going for recycling in order to prevent loss of the materials value.
- Biological Cycle: It involves biodegradable materials that cannot be reused. They must be circulated back into the economy through biological processes such as composting, digestion of organic materials, regeneration etc.

Before use, it is essential to consider how these products fit into the technical and biological cycles after use. Creation of products combining biological and technical cycles in a way that they cannot be separated must be avoided as it leads to loss of value after use. The technical and biological cycles can be illustrated in a “Butterfly Diagram” shown in Figure 4.1

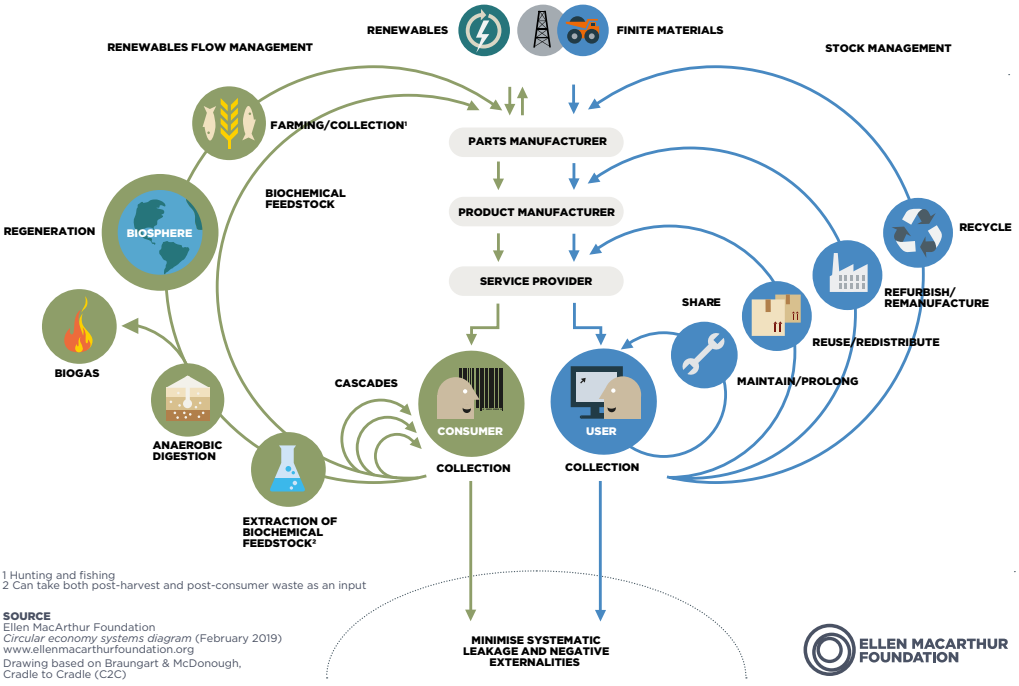

Figure 4.1: Butterfly Diagram (Ellen Macarthur Foundation, 2015)

The term circular economy is often used interchangeably with waste management. While end of life processes such as waste management are essential aspects of circularity, it also includes encouraging value retention along the whole supply chain and life cycle of the product or service (Gruis, 2022). The 4 main strategies for circularity when it comes to material loops are identified by Gruis (2022) and are as follows.

- Narrowing resource loops by refusing the use of products where possible, reducing the use of materials through more efficient manufacturing or efficiency in use.
- Slowing down or elongating resource loops by reuse, repair and re-manufacturing of products.
- Closing the loops by recycling and recovering energy from materials when all the previous options are exhausted, hence, reducing the loss of materials.
- Substitution where applicable encouraging the use of renewable materials where possible.

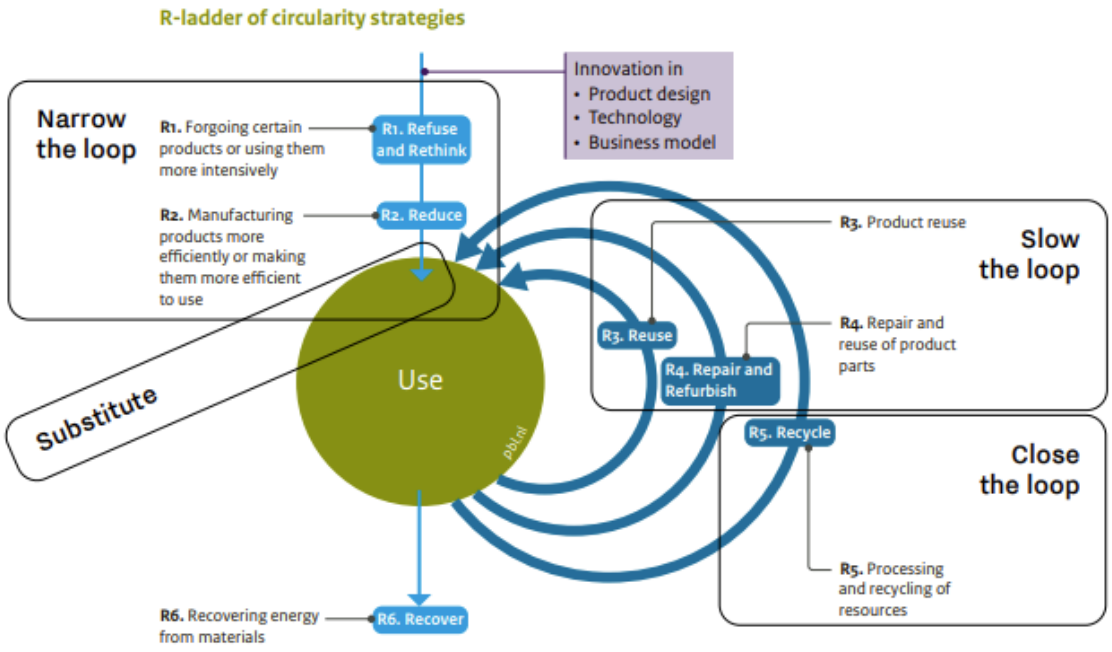

Figure 4.2: Circular Strategies for Material Loops (Gruis, 2022)

4.2. Construction and Demolition Waste Management

The term ‘‘C&D waste’’ is generally used to refer to the ”solid waste generated in the construction sector. More specifically, the term is defined as the waste which arises from construction, renovation and demolition activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation”(Yuan and Shen, 2011). The process of handling the waste generated due to construction, demolition and renovation of buildings and infrastructure is termed as construction and demolition waste management (CDWM). As per the European Union (2018), C&D waste is the largest waste stream in Europe, with it making up one third of all waste. It is made up of materials such as concrete, brick masonry, glass, structural steel, timber, drywall etc. Managing this waste involves activities such as waste separation, salvage and resale, recycling and disposal of the material left behind. CDWM is a massive challenge that faces the world today due to the vast quantum of waste produced(Ragossnig, 2020). Despite this, implementing effective CDWM worldwide is essential for the following reasons.

Environmental Impact: Failure to effectively manage C&D waste causes environmental impact in the form of landfill depletion, consumption of land, resource consumption, resource depletion along with air, noise, soil and water pollution(Prasad et al., 2022). The reuse and recycling of C&D waste impacts the environment positively by recovering valuable materials, adding value to recovered materials, reducing energy consumption, conservation of natural resources and offsetting emission of greenhouse gasses, as the construction industry is responsible for 39% of all greenhouse emissions(Alsheyab, 2022).

Cost Efficiency: Utilising Effective CDWM practices can lead to a reduction in costs associated with waste disposal, transportation and landfilling. Furthermore, it leads to recovery of valuable materials for resale, reuse or recycling which reduces the burden of costs associated with the generation of new materials(Jain, 2012).

Resource Conservation: Sharp rises in construction activities globally, especially in developing nations has lead to strain being placed on natural resources. Implementing effective CDWM can reduce the demand and hence the exploitation of natural resources. This can be done by reusing materials that can be used and recycling or upcycling construction debris. This processed debris can replace virgin materials to a certain extent, leading to conservation of the planets natural resources.

4.3. Current State of the Indian Construction Industry

This section deals with the current state of the construction industry in India first addressing the vision of the government to understand what policies have been enacted and why. Following this, the make up of the industry is highlighted due to its influence of policies and actor behaviours. Lastly, the state of CDWM currently employed in India is explored.

4.3.1. Government Vision

Urban cities in India, such as Mumbai, Delhi, Bangalore, Chennai, Kolkata, etc., are burdened by high population densities and high rates of migration into the cities. By 2030, more than 40% of the population will live in urban India which sees a rise from the 33% in 2014 (gov, 2014). This causes overpopulation problems in the cities. In order to combat this, the Government of India (GOI) has published a number of schemes and policies. These aim at not only increasing the capacity of the urban cities by redevelopment of real estate and infrastructure but also aim to develop rural regions into desirable places to stay and work. Furthermore, the GOI, aims to develop smart cities as migration alternatives. The key policies involved in the same are as follows:-

Smart Cities Mission (2015)

“The objective of the smart city mission is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment through the application of ’Smart’ solutions.” (Ministry of Urban Development, 2015). Through this, the GOI aims to develop 100 cities pan India into smart cities. Smart cities, according to the GOI, is a sustainable, liveable and technologically advanced urban area built with the aim of improving the quality of life of its residents. Under this initiative, the core infrastructure mentioned includes but is not limited to assured water, electricity and sanitation, efficient urban mobility and public transport, affordable housing, health and education services etc. The Smart Cities Mission also encourages the use of sustainable techniques such as smart grids, green buildings etc. A smart cities mission fund was set up in 2015, valued at $27 billion, to be used over the next 5 years.

Pradhan Mantri Awas Yojana-Urban (PMAY-U)(2015)

Under this Scheme the GOI aims to provide affordable housing for the urban poor. Its part of a “Housing for All” mission by the GOI. The government provides financial assistance in the form of housing loan subsidies to eligible beneficiaries for the construction of houses (moh, 2015). The PMAY-U also aims to promote affordable housing through public private partnerships and increase private sector participation in affordable housing projects. The aim is to create 20 million affordable homes for the urban poor (Loganathan et al., 2017). As of 2021, over 10 million homes have been completed and a total investment of $96 billion has been made.

Make in India (2014)

Make in India is an initiative by the GOI to promote the manufacturing sector in India by promoting the manufacture and use of products made in India as well as encouraging foreign investment into manufacturing set ups in India (gov, 2014). For the construction sector in particular, it has resulted in a increase in investment in the manufacturing of raw materials. This has resulted in the availability of better quality of raw materials produced locally. While this initiative has promoted the manufacturing of materials it still fails to sufficiently address the recycling of C&D waste.

Pradhan Mantri Awaas Yojana-Gramin (PMAY-G) (2016)

The PMAY-G is a rural development scheme that aims to target people living below the poverty line in rural areas. Under this scheme, they will be provided with grants to upgrade existing or construct new houses (moh, 2015). This scheme is also part of the “Housing for All” mission. It is aimed towards the upliftment of vulnerable groups and the rural poor by improving the living conditions in rural area.

Pradhan Mantri Gram Sadak Yojana (2000)

The Pradhan Mantri Gram Sadak Yojana (PMGSY) is an initiative launched by the government of India in 2000 to provide connectivity to unconnected rural areas as a part of their poverty reduction strategy (OMMAS, 2023). Through this initiative, the GOI aims to set high technical standards and policy development at the State level to ensure sustainable management of rural roads in achieved. The aim is for all rural areas with over 500 inhabitants and all rural areas in mountains with over 250 people to have access to all weather roads (OMMAS, 2023). As of 2023, about 167,000 rural habitations are eligible for this initiative and involved the construction of around 371,000 km of roads and upgrade another 368,000 km of village roads which do not qualify as all weather road due to their susceptibility to being damaged during the Indian monsoon (OMMAS, 2023).

The above mentioned schemes are the major initiatives by the GOI towards investment in the construction sector. This has resulted in the Indian construction industry growing rapidly exhibiting a year on year growth rate of 10% over the last 10 years as opposed to a world average growth of 5.5% (Dadhich et al., 2016). The high level of migration as well as the aforementioned initiatives have led to the Indian construction industry being valued at 10% of India’s Gross Domestic Product (GDP) (Loganathan et al., 2017). As per the World Bank, India’s GDP from 2021 stands at $ 3.18 trillion. This would put the construction industry at a valuation of $ 318 billion (wor, 2021).

4.3.2. Industry Make Up

As per (Faruqi & Siddiqui, 2020) the development of infrastructure such as roads, highways, flyovers, facilities etc account for about 50% of the Indian construction industry. This is dominated by bigger companies usually competing for government tenders. While there exists some research on the implementation of construction and demolition waste management and the application of recycled materials in the Indian construction industry, it is mainly restricted to the infrastructure sector. The other 50% comprising of the real estate sector(commercial and residential construction) is largely dominated by small to medium enterprises(SME). This sector is highly fragmented (Faruqi & Siddiqui, 2020), cluttered, unorganised and fiercely competitive as seen in Figure 4.3. As per (Kamma & Jha, 2022) the real estate sector includes residential and commercial complexes and is expected to reach a market size of $ 1 trillion by 2030. Furthermore, there is a distinct lack of available research focusing specifically on this sector. Development in the real estate sector is necessary in order to spearhead economic development.

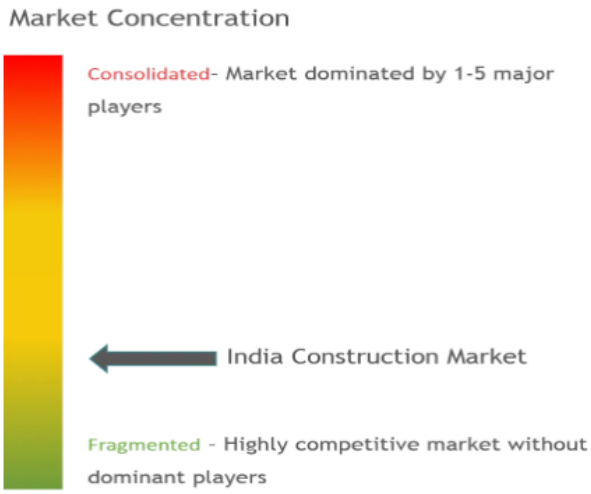

Figure 4.3: Market Make-up for the Indian Construction Industry (Mordor Intelligence, 2022)

4.3.3. Current State of CDWM in India

The different types of C&D waste generated in India include concrete waste, brick masonry and tiles, wood, steel from reinforcement, piping and roofing, plastic waste, glass, asphalt and soil and rock from excavation. India is the second largest producer of Construction and Demolition(C&D) waste, producing 1735 kg/m2, resulting in the production of 530 million tonnes of C&D waste in 2014 (Sharma et al., 2022). However, all the data available about C&D waste generation is estimates made by authors based on the method they used. Infact, the India Road Congress, in its report titled “Guidelines for use of construction and demolition waste in road sector”, claims that “no authenticated data is available about quantum of C&D waste generation in India” (Indian Road Congress, 2017). Ram and Kalidindi (2017) used the waste generation rates in Chennai to quantify the C&D waste generated in the city of Chennai. They arrived at the figure of “1.4 million tonnes, which amounts to 175kgcapita-year-1”. An estimation using permit data conducted by Kamma and Jha (2022) found that “the obtained kgcapita-year−1 values ranged between 65 kgcapita-year−1 in 2017 and 239.2 kgcapita-year−1 in 2019” in the city of Hyderabad.

During demolition, all salvageable materials such as steel, timber, plastics, pipes etc are salvaged and sold as scrap to collectors who will reuse or recycle them. This ties in with the Indian culture of not wanting to waste anything that can be monetised as suggested by Sohal et al. (2022). The remaining C&D waste is made up of concrete rubble and soil mixed with gypsum and plaster. The most popular way of dealing with this C&D waste in India is through dumping in landfills. Infact, India has a recycling recovery rate of only 1% with 90% of the C&D waste ending up in landfills (Sharma et al.,

2022). The remaining 9% is made up of illegal dumping. Illegal dumping not only uses up of the capacity of the landfill when done in a landfill, but also causes several pollution issues when done outside of landfills. In certain parts of New Mumbai, protected mangrove forests have been subject to illegal dumping causing a destruction of their ecology (Assainar, 2022). Furthermore, a recent survey carried out by the Gurgaon Municipal Corporation(MCG) in the state of Haryana found 314 sites in the city of Gurgaon where construction and demolition waste was illegally dumped (Chaman, 2022). This leaves the MCG with the task of clearing it away before the monsoon arrives to protect from clogging of drains and waterlogging. In the 2015 Chennai floods, which claimed over 400 lives and displaced 1.8 million people, illegal dumping of C&D debris was found to be one of the main contributors (Ram et al., 2020).

Only 13 out of the 53 required cities in India have already set up debris recycling plants putting India's installed capacity for C&D waste recycling at just 2.5% of waste generation (Ram et al., 2020). This highlights that not only does India produce a large quantity of C&D waste, its available infrastructure for its recycling is severely lacking. This streams from both an ignorance by construction professionals towards the importance of CDWM but also from a lack of enforcement from the central government on the rules they create for the setting up of infrastructure. This also reflects in the State governments lethargy and unwillingness to comply with regulations. Furthermore, the estimations made by various Governmental Agencies vary from each other to a large degree and are observed to be significantly lower than other developing countries showing a serious understatement by the government regarding the quantum of C&D waste produced and a serious underestimation about the challenges it brings.

4.4. Barriers Faced for Effective CDWM

Effective CDWM is crucial for effective resource recovery and sustainable development. As described above, the current scenario of CDWM in India continues to be a major challenge. For the industry to grow in a sustainable way, it is imperative that the current situation is improved. The barriers present in the industry affecting the setting up of effective CDWM in India were found from literature and are described below.

Infrastructure

India generates large quantities of C&D waste as described above, however, there is a distinct lack of infrastructure and resources for the effective handling of this waste. Sharma et al. (2022) cites the lack of infrastructure as one of the key barriers towards the effective implementation of CDWM . Currently many construction sites in India lack proper sorting infrastructure along with lacking proper waste disposal strategies. This leads to all the concrete waste being dumped in landfills. The lack of infrastructure also severely hinders the resources recovery further underpinning the reliance of the growing construction industry on virgin materials leading to depletion of resources. The GOI is aware of this problem and while efforts have been made towards its mitigation, it has been largely unsuccessful. India's resources recovery rate stands at 2.5% of its waste generation rate (Ram and Kalidindi, 2017) and only 13 out of the 53 cities mandated to setup recycling plants have done so as of 2020 (Somvanshi and Verma, 2020). Furthermore, the government focus is largely on bigger cities when it comes to waste management. Smaller towns, while having a significant contribution to waste management, are not required to set up recycling plants (Sharma et al., 2022). The GOI needs to adopt a more holistic approach towards the development of infrastructure and work together with state governments to ensure an improvement in the available infrastructure.

Lack of Knowledge and Technology

The lack of knowledge about the importance of effective CDWM is prevalent in the industry. Sharma et al. (2022), Devaki and Jayanthi (2014), Mojumder et al. (2022), Faruqi and Siddiqui (2020) all cite the lack of knowledge among stakeholders as a key area of concern. This extends to not only a lack of knowledge about the importance of CDWM, but also a lack of knowledge about best practices for waste management. Furthermore, Sharma et al. (2022), Sawhney et al. (2014), Loganathan et al.

(2017), cite the lack of technical knowledge and skills as a key barrier. This further extends to a lack of skilled manpower that exists in the industry with knowledge of state of the art methods and processes. Lack of technical expertise along with the unavailability of advanced technologies for waste sorting, processing and recycling severely handicaps the waste management potential of India. This knowledge and technology gap poses a significant hurdle for the industry.

Govt Support (Incentives)

The lack of incentivisation for the private sector to adopt effective CDWM has been stated as a major barrier by Sharma et al. (2022), Sawhney et al. (2014) and Liu et al. (2021). While the GOI has implemented regulations to improve CDWM, the lack of enforcement and incentivisation leads to non-conformation of the private sector with the established rules. Due to the Goods and Services Tax (GST) being applicable on recycled materials in India, they are taxed at 18% making their use more expensive as compared to virgin materials Sharma et al. (2022). Furthermore, a lack of coordination among government bodies has led to an inefficient approach towards CDWM. Liu et al. (2021) suggest financial incentivisation in the form of tax breaks or subsidisation to boost private sector participation in CDWM to boost resource recovery.

Mindset Problem

The mindset of the actors involved is a major barrier towards the effective utilisation of CDWM. The lack of willingness of users to adhere to the established CDWM rules is cited by Sharma et al. (2022) and Mojumder et al. (2022) as an important barrier that needs to be mitigated. Furthermore, insufficient governance and low fines have left stakeholders with low accountability which leads to non conformity towards CDWM rules with each stakeholder blaming another for the state of CDWM in India (Sharma et al., 2022), (Sawhney et al., 2014). Lastly the Indian industry tends to have senior actors who exhibit a reluctance to change their ways of working and adopting new methods as the old methods have served them well (Devaki and Jayanthi, 2014). This is further exasperated by the fact that the industry lacks entry and exit barriers allowing people with no technical knowledge and a lack of understanding of the importance of CDWM to carry out projects (Loganathan et al., 2017). Furthermore, there is an absence of a responsible waste management culture in the industry further hindering actor participation in effective CDWM (Mojumder et al., 2022).

Lack of Enforcement

Although the GOI has established various rules for the collection, sorting and processing of construction waste, their enforcement is often lax. In many cases, construction waste is dumped illegally and indiscriminately causing severe pollution problems such as destruction of protected mangroves (Assainar, 2022) and choking of drainage infrastructure causing floods (Ram et al., 2020). Sawhney et al. (2014), Loganathan et al. (2017) and Mojumder et al. (2022) state that the lack of enforcement and inadequate governance is one of the major barriers towards the implementation of effective CDWM while Sharma et al. (2022) and Mojumder et al. (2022) state that the negligible criminal action prescribed against offenders, leads to negligent or ignorant behaviour by the involved actors. Furthermore, Faruqi and Siddiqui (2020) and Liu et al. (2021) state that the lack of a mature regulatory environment in the sector contributes to the non-conformity of industry players to existing rules. Due to the lack of enthusiasm from the industry actors to implement new techniques for CDWM, a binding and stringent regulatory environment is necessary to enforce the laws and ensure conformity with strict monetary consequences for non-compliance.

Fragmentation

The industry is highly fragmented with a number of SME's operating in the real estate sector. This leads to intense competition in the sector making projects incredibly time and cost sensitive. This puts high importance on the final deliverable leading to cutting of corners in other aspects such as waste management in order to remain competitive in the market (Mojumder et al., 2022). The competitiveness and immature regulatory environment also leads to a lack of trust between actors, which prevents the formation of a responsible waste management culture in the industry (Loganathan et al., 2017). The fragmentation also makes it difficult to establish uniform regulations in the industry, further exasperating problems of unethical behaviour (Sawhney et al., 2014). As per Liu et al. (2021), there is a need for the establishment of a platform for the sharing of knowledge and development of skills, however, this level of cooperation if difficult to achieve due to the lack of trust and competitiveness in the industry. Lastly, the GOI also has a fragmented approach towards its waste management, choosing to focus mainly on cities, exhibiting a lack of focus on Indian towns who are also a significant contributor to C&D waste (Sharma et al., 2022).

Supply Chain Issues

The supply chain in India for the collection, transportation and disposal of construction waste is immature and disorganised (Devaki and Jayanthi, 2014). Due to this, the supply chain is fragmented with a number of intermediaries involved which leads to delays and higher costs making the system inefficient. This also attracts the involvement of the informal sector of workers who lack technical knowledge to effectively manage construction waste (Sharma et al., 2022), (Sawhney et al., 2014). The lack of an established supply chain also makes it difficult to adequately quantify the waste generation in the country which leaves the available policies insufficient to handle the quantum of waste produced (Faruqi and Siddiqui, 2020). Furthermore, the fragmented and informal supply chain also leads to unethical behaviours such as cartelisation which raises costs. The cartel behaviour, coupled by the fragmented nature and low governance, leads to the sale of rejected materials elsewhere and a general lack of consistency in the industry that hinders participation by other actors due to a lack of trust (Loganathan et al., 2017). Establishing a well managed and strictly governed supply chain is essential to drive forward effective CDWM in India.

Corruption

Corruption has been stated by Sawhney et al. (2014) as one of the key barriers faced by the Indian industry. This corruption increases the problems arising from the lack of correct mindset of stakeholder and lax enforcement. Officials often take bribes from stakeholders who are flouting rules and turn the other way. This allows for illegal disposal and the adoption of substandard techniques. The corruption in government officials also retards the adoption of better practices of waste management, as it reduces the opportunities for those in power to make extra money through bribes. The lack of enforcement due to the corruption also allows for the formation of cartels and lets them operate unregulated, which allows them to manipulate the market as they see fit, further leading to inefficiencies and a lack of trust in the market (Loganathan et al., 2017). The transparency and accountability needs to be improved to galvanise the industry towards adoption of good CDWM practices.

4.5. Actors Involved in CDWM in India

Effective CDWM requires the active participation of various actors to ensure its success (Andersson and Buser, 2022). This ranges from governmental agencies, developers etc. Each actors plays a critical role in their own way and cooperation is needed to ensure successful CDWM. The synergy of involved actors is essential to ensuring that C&D waste is collected, transported, sorted, processed and disposed in a sustainable way. It is essential to understand the actors involved and the roles they play to tackle the issue of ineffective CDWM in India. The following are the actors involved:-

Government Agencies

These agencies are responsible for regulating and promoting CDWM in India. The key governmental bodies involved are Ministry of Environment, Forest and Climate Change, the Central Pollution Control Board, State Pollution Control Boards, Municipal Corporations, Indian Road Congress and the National Highway Authority of India. They have the responsibility of developing regulations for CDWM along with the issuing of permits and licences (Central Pollution Control Board, 2017). In addition to this, the governmental bodies are responsible for monitoring and ensuring compliance with the rules along with spreading awareness about the importance of effective CDWM (Central Pollution Control Board, 2017).

Developers

These are project runners and are responsible for managing it. They can either be the project owners or can be running a project for a third party client. They are responsible for ensuring that the C&D waste produced on their projects is properly managed and disposed off in a responsible way. They need to ensure adherence to the guidelines published by the governmental bodies regarding CDWM. Furthermore, they should strive to minimise waste generation on sites (Agrawal and Iyer, 2020). They are the key decision makers in the projects, therefore it is important that they encourage sustainable practices. However, due to a lack of entry barriers, developers are sometimes individuals who lack technical knowledge. They hire engineers to provide the technical knowledge choosing to deal more with the financial side of the project. This lack of technical knowledge, coupled with the intense competition in the sector leads to an underestimation of the importance of effective CDWM, choosing instead to prioritise time and cost targets (Kamma and Jha, 2022).

Site Engineers

Site Engineers are the site supervisors and project managers. They are responsible for ensuring that the waste generated on site is handled as per the government regulations. Furthermore, they are responsible for coordinating various stakeholders such as contractors, sub-contractors and waste handlers. They need to ensure that waste management guidelines are followed by instructing and educating the workers on site about the appropriate method to handle waste (Agrawal and Iyer, 2020). In cases where the developer lacks technical knowledge, they also responsible for technical decisions and should ensure that waste management is not ignored. They must have knowledge about the different types of waste their project will create and how to dispose of it. By managing on site C&D waste effectively, site engineers can control environmental impact of the project and safeguard the workers under them.

Client

In cases where the developer does not own the project, the client is the owner. It is their job to set up the objectives and goals of the project. The client has the power to specifically demand that CDWM is done appropriately through the project. The client should ensure that a part of the budget is set aside for implementing effective CDWM in their projects (Sezer, 2017). However, the clients often are not aware of the importance of effective CDWM or choose to prioritise time and cost which leaves no consideration for CDWM, promoting developers to ignore CDWM, in order to reduce costs and increase profits (Sezer, 2017). It is essential that the client and developer work together and discuss to ensure CDWM is involved in the project planning and that the appropriate resources are set aside.

Consultants

These include architects and structural engineers who are involved during the design and construction phase of the project. The architects are responsible for the calculation of waste generation when submitting permits to the Municipal Corporations (Agrawal and Iyer, 2020). Furthermore, they can incorporate waste management techniques in their designs (Sezer, 2017) along with advising developers regarding the importance of and the different techniques they can adopt for waste management. Additionally, during the design phase, design for demolition can be incorporated so that towards the end of

the buildings lifecycle, demolition and material recovery is seamless (Osmani et al., 2008). In addition to this, structural engineers can incorporate recycled aggregates and steel in the member design taking all the necessary precautions and design amendments to facilitate the use of recycled aggregates.

Customers

The customers are the end users in the industry that will utilise the completed structure. As things stand, in India, customers usually prioritise cost. They want to pay as little as possible for the final product with less focus on the sustainability aspect (Kamma and Jha, 2022). The customers play a vital role in the creation of a responsible waste management culture which will encourage industry players to adopt effective CDWM (Sezer, 2017). Customers can demand that the development is carried out sustainably and choose to do business with developers who have a proven track record of responsible waste management. While this will result in an increase in the price they will have to pay for the final structure, a shift in mentality is required, where sustainability is given precedence over price. However, with the general consumer this is difficult to achieve without governmental aid.

Contractors and Sub-Contractors

The contractors and subcontractors are responsible for executing construction work and generate large quantities of waste. They need to ensure that the generated waste is appropriately collected, segregated and delivered to waste management facilities (Agrawal and Iyer, 2020). They must also make sure that their workers are appropriately trained in responsible waste management and ensure that they adhere to the training through supervision. They must also ensure that all the relevant construction and demolition waste management laws established by the government are adhered to and followed (Agrawal and Iyer, 2020). Finally, contractors and subcontractors can contribute by taking an initiative to reduce waste generation during construction to reduce the quantum of waste that needs to be managed.

Waste Recyclers

Waste recyclers are responsible for setting up the infrastructure necessary for waste recycling as well as collecting, segregating and transporting construction waste to be recycled. Their main directive is to segregate the waste and identify the materials that can be recycled or reused (Agrawal and Iyer, 2020). The rest of the waste should be sent to landfills and disposed of responsibly. Their role is essential towards reducing the quantity of waste ending up in landfills and boosting material recovery. They can also provide technical expertise to other actors involved as the low level of technical knowledge present in the industry is a significant barrier (Sharma et al., 2022). The waste recyclers need significant support from the government to not only ensure their endeavours are profitable, so that more people are incentivised to participate, but also in setting up the entire infrastructure and supply chain to ensure that maximum C&D waste goes through the correct process to boost nationwide material recovery.

Demolition Contractors

Demolition contractors are actors specialising in the demolition aspect. They are responsible for the safe demolition of structures, sorting the waste and ensuring proper disposal. They must ensure adherence to the established rules and regulations for CDWM (Agrawal and Iyer, 2020). They must also ensure that their workers are well trained in the latest demolition technologies. Currently, demolition contractors, on demolition, sort the waste and recover materials of resale value such as steel, tiles, fittings and wood to sell on for their profits. The rest of the waste consisting mainly of concrete and soil is then transported to landfills and dumped in its entirety. This places a strain on the infrastructure as noted by Kamma and Jha (2022) where they found that the C&D waste generated in Hyderabad between 2017 to 2020 would require 41 ha to dump considering a 6m height of filling if nothing was to be reused or recycled. This highlights that huge strain placed on landfills in India where due to the high population density, land is better served for living and commercial spaces. Using up such large parcels of land purely for landfilling is not a sustainable way forward and the onus falls on demolition contractors to participate in recycling. They will need government support however, to account for the

increased costs of sorting concrete waste and sending it to recycling centres in the form of financial incentives.

Academics

This includes researchers and professors who deal with the more theoretical and academic side of engineering. They have the responsibility of conducting research on novel methods of conducting CDWM sustainably. They can find new methods and practices and share these with industry stakeholders to improve the state of CDWM in India. They can also advocate the importance of effective CDWM to policy makers and provide a push towards the establishment of better policies (Blaisi, 2019). However, most importantly, they are responsible for the education and moulding of the next generation of industry members and must imprint upon them the seriousness of the problem and stress the importance of effective CDWM to ensure the next generation does not suffer from the lack of awareness and indifferent attitude towards CDWM that is prevalent in the industry today. Finally, academics can also work as consultants in order to help set up appropriate infrastructure by carrying out research to determine the actual quantum of C&D waste generated in India as this is key information that is required but not readily available in the industry.

4.6. Research Gap

There exists a plethora of research on Construction and Demolition waste management and its correct implementation. There are several case studies exhibiting successful waste management applied in projects. However, these studies are chiefly focused on Europe, the USA, Australia and China. Considerably less research exists about countries in South East Asia. For the purpose of this study, the Indian construction industry was chosen, as the current scenario in the industry, dealing with construction and demolition waste management is severely lacking and needs to be improved in order to bolster and support India's rapidly growing economy. Furthermore, the author is familiar with the industry and has connection there that can aid in the research. Scientific literature agrees that one of the chief issues faced by the industry is its fragmented nature (Loganathan et al., 2017), literature study revealed that there is no research done that specifically addresses the SMEs of the industry. Only one paper was found which refers to small to medium enterprises by (Mojumder et al., 2022). However, out of the 45 companies studied in that paper, only 4 were classed as small companies. Furthermore, they excluded companies with annual turnover of under INR 100 crores ($12 million) (Mojumder et al., 2022). A significant proportion of the small companies in India operate under this threshold. Therein lies the research gap where 50% of the construction industry(Faruqi and Siddiqui, 2020) in one of the world's fastest growing economies is missing from available literature. The planned investment by the Government of India in the construction industry, makes it imperative that the industry is researched. Furthermore, while some research does exist regarding barriers for CDWM in India, there is a distinct lack of solutions that have been proposed to target the industry. Therefore this thesis aims to bridge the gap by suggesting actionable solutions for SME's to implement in order to improve the level of CDWM in India.

5

Case Study

5.1. Introduction

Case study approach is a qualitative research method that involves an in-depth and detailed study of a subject and its context (Arya, 2021). This approach can capture the complexities of a problem under study without generalising it and can compare different cases to identify the factors that explain the similarity and differences in different cases (Arya, 2021). This allows for the identification of key factors that caused differing results allowing for insights into particular actions that contribute to the improvement of CDWM in those countries based on evidence from cases.

The objective of the case studies is to identify solutions implemented in other countries in Asia where the particular contexts can be comparable to Mumbai in certain aspects. Since the success and failure of solutions depends heavily on the specific contexts it was decided to select 3 case studies to gain various perspectives. Lessons learnt from the successes and failures of the efforts will be extracted and compared among each other keeping in mind their contexts. A brief STS analysis will be conducted for each case as a means to better understand the applied measures within their own context. The efforts of the governments to create an environment conducive to CDWM will be studied along with how the technical and social dimensions interact with each other within this environment to create societal outcomes. Keeping this in mind, a set of solutions as implemented in their respective cities will be generated. These extracted solutions will then serve as the basis for the semi-structured interviews to be carried out as well as assisting in answering sub research question 3.

5.1.1. Selection Criteria

The cities were selected for the case study with the condition that they had to have made efforts to improve CDWM starting from a low base, as that is the condition Mumbai finds itself in right now. Furthermore, to ensure the contexts are relatively comparable, developing nations in Asia were chosen for the case study as opposed to Europe, Australia or the United States. Furthermore, 2 examples were taken of successful implementations in order to maximise solution identification and 1 case study was taken where while efforts were made but the outcomes were substandard to obtain insights into pitfalls. The chosen case studies and the reasoning behind their selection can be found in Table 5.1.

Nr.	City	Country	Reasoning
1	Shenzhen	China	China is included along with India as one of the BRICS countries, which denotes rapidly developing economies putting the two in comparable economic brackets
2	Singapore City	Singapore	Singapore City has some similar challenges as Mumbai, namely high population density and lack of land availability
3	Hanoi	Vietnam	Vietnam has a governmental system that is more comparable to India than China and Singapore. Additionally, Hanoi suffers from similar issues as Mumbai such as high population density, illegal dumping, and lack of sophisticated technology

Table 5.1: Case Study Selection

5.2. Shenzhen Case Study

Construction and demolition waste management is a key challenge for fast growing economies where economic growth "induces massive construction without the capacity to manage the associated waste" (Bao and Lu, 2020). There is often a conflict in these countries between economic expansion and environmental degradation. One such example is from Shenzhen, China, which has seen large economic growth in the last few decades compelling it "to rapidly develop an effective C&D waste circular economy from a low base" (Bao and Lu, 2020). In 2018, China had a waste reuse and recycling rate of only 5% (Huang et al., 2018) signifying the need for significant advancements in this sector. The underlying barrier to adopting effective C&D waste management is economic viability (Bao and Lu, 2020). The C&D waste recycling industry was only viable when supported by governmental subsidies. This is not sustainable in the long run which created a need for the development of a complete waste recycling system and infrastructure in China (Bao and Lu, 2020).

Shenzhen, established in 1980 as a Special Economic Zone (SEZ), is one of the 4 tier 1 cities in China after Beijing, Shanghai and Guangzhou. To support this meteoric growth, Shenzhen has seen large scale construction activities that have led to the generation of a large quantity of waste. In 2019 Shenzhen was seeing an average annual construction waste generation of 100 million m3 (Bao and Lu, 2020). To deal with this waste Shenzhen has developed a sophisticated and well-functioning construction waste recycling system without impacting economic development. In 2020, there were 42 officially registered waste recycling enterprises in Shenzhen and most importantly this was achieved while sustaining economic growth with a 6.7% increase in GDP (Bao and Lu, 2020). In the following sections, the author will explore the lessons learnt from Shenzhen.

5.2.1. Lessons Learnt

There are 4 key lessons that can be learnt from the C&D waste recycling infrastructure and market set up in Shenzhen that can be used as a starting point for studies in CDWM in other developing countries. They are identified by (Bao and Lu, 2020) and are as follows:-

Implementing strong governmental interventions

As a result of a severe landslide in landfills in 2015, the government outlawed all landfills in the city except one, that was kept open but only accepted renovation waste. This sent out a strong message to the industry that landfilling was no longer an option, necessitating them to utilise recycling as the method to dispose of their C&D waste. Infact, showing sufficient waste disposal capacity was established as a pre-requisite to obtaining a building permit. Furthermore, in January 2020 the government released a C&D waste discharge quota which establishes the amount of C&D waste that is allowed to be transported out of a site depending on the type of project. This mandated project developers to engage with the C&D waste recycling industry. Non-compliance with these rules incurred a heavy

economic penalty that was described by industry stakeholders as considerably high and almost intolerable. This really incentivised adherence to the established rules.

To support these policies, the government also incentivised recycled products. The incentivisation policies included payments for every piece of recycled product created that differs with type, size and quality. For example, for every recycled brick produced by a recycler, the government pays the company 1 Chinese Yuan (CNY)($0.14). Furthermore, as per stakeholders, over 80% of the recycled products produced by one of the biggest recycling companies is utilised by the government in governmental projects. This allows recycling companies to be economically viable by creating a thriving market for recycled goods. Good performance by recycled products in government projects is also subject to cash grants amounting to 1-2 million CNY($14,000-28,000) depending on the situation.

Due to this new system, project developers are heavily dependent on waste recyclers to process waste on site in their mobile units. Any delays here are catastrophic for the project developers, which has lead the government to place fines of 10,000 CNY ($1400) per day of delay on the recycling companies, incentivising them to deliver timely performance. This clearly shows the “carrot” and “stick” approach that the government of Shenzhen has taken, rewarding good performance while penalising non-compliance or delays.

Developing a thriving C&D waste recycling market

In addition to the incentives and penalties imposed, the government had to facilitate it by creating a thriving market for recycled products. The government has outlawed the quarrying of river sand and stone in the Guangdong region. This has caused a significant increase in the price of virgin material causing recycled material to be 10-30% cheaper than their virgin counterparts, giving them a competitive advantage (Bao and Lu, 2020). Furthermore, waste recycling companies in Shenzhen have set up a staged charging scheme for waste collection, that depends on the composition of the received waste. This encourages stakeholders to conduct on site sorting, which results in the companies receiving better quality waste, which results in the development of good quality recycled products. This charge also constitutes an important part of the revenue for waste recyclers.

Transportation costs are high for recycled products. To combat this, the recycling companies in Shenzhen use an interesting system where tenders are adjusted depending on the availability of projects around a certain demolition project. The company surveys surrounding projects and estimates the demand for recycled materials from them. If the demand is high, they charge the demolition project developers a lower service fee and vice versa. This ensures that the combination of the two sources of income allows the companies to remain profitable. This highlights how “government led and market driven interventions work together to expand the market space” (Bao and Lu, 2020) making it possible for all involved in the industry to make healthy profit margins, in turn bolstering the circular economy.

Introducing advanced recycling technologies

The recycling technology used in Shenzhen consists of two types, the on-site/portable technology and the off-site/stationary technology. This creates a buffer and allows more flexibility for the recycling companies. On-site technology is used due to the lower cost, lower transportation costs, less dust and noise pollution due to on-site operations. However, this has low capacity and needs to be backed up by off-site setups. Furthermore, the government of Shenzhen has mandated the use of a certain type of vehicle for recycling that is covered and GPS enabled. This protects the C&D waste, as well as increasing safety due to preventing overloading of the vehicles. Furthermore, the GPS feature prevents illegal dumping. These vehicles have been heavily subsided by the Shenzhen government allowing for C&D waste recycling companies to gain access to them. This is done by the government to help all companies to upgrade their current vehicles to the government approved ones, with the government paying for the difference.

Furthermore, the government has encouraged R&D by promoting the combined research between recycling companies and local universities. This has resulted in each company having their own patented

products which allows for price flexibility in the market. One of the stakeholders working in a large recycling firm stated that due to this initiative their company currently has over 30 patents filed for recycled products. The patents are counted by the government as a "key performance indicator for the allocation of subsidies", which promotes research in the domain of recycling technology, improving the range and quality of recycled products available in the market.

Enacting responsive institutional arrangements

The Housing and Construction Bureau (HCB) has set up a "bilateral binding mechanism between recycling and demolition companies" (Bao and Lu, 2020). It is called the "Measures for the Management of House Demolition Projects in Shenzhen", which mandates that for any demolition project with floor area above 500m2, a demolition company and a recycling company must join together and approach the HCB for the tender. The companies must launch a joint bid, ensuring that proper care is taken of waste handling. The recycling companies provide expertise and supervision to the demolishing company to ensure maximum quality of the demolition waste, leading to good quality of recycled products. Undesirable material like furniture, pipelines and red brick slag are eliminated as they impact quality of recycled products produced (Bao and Lu, 2020). This not only ensures that the recycled products entering the market are of good quality, but also helps maintain profitability of the recycling companies by providing them with revenue as service fees.

5.2.2. STS Analysis for Shenzhen

Viewing the efforts made in Shenzhen through the STS theory lens, allows for the understanding of how government driven initiatives when manged right, can lead to rapid progress in CDWM in a city. Due to low resource recovery rates and high rates of development, the government of Shenzhen decided to create a system where C&D waste recycling markets can thrive. From the environmental dimension perspective, the HCB was set up to oversee the CDWM and a carrot and stick approach was chosen where good performance is rewarded and poor performance is met with heavy monetary consequences. Furthermore, the government aimed to create an environment where the market for recycled construction materials can thrive. In order to facilitate this, they outlawed sand and stone mining in the Guangdong region. This drove up the price of virgin materials. Additionally, the decision to outlaw landfilling was made once the required infrastructure was set up. This allowed for the creation of an environment where the government could steer the interaction of the technical and social dimensions in order to produce desirable outcomes. It is important to note that the authoritative nature of the government in Shenzhen was an enabling factor allowing for a rapid transformation of the CDWM process followed. In the following paragraph we will examine how the technical and social dimensions interact within the environment set up by the government of Shenzhen.

Over 42 waste recycling companies were set up through encouraging participation using incentives. Furthermore, establishing waste discharge quotas meant that now developers were forced to conduct on site sorting. This forced them to work with recycling companies, which presented revenue streams to those companies. The government's efforts to promote research in this field also lead to the creation of on-site recycling set ups that allowed the developers to adhere to the waste discharge quotas. The waste leaving the site would then be taken to the off-site setup due to the limited capacity of the on-site setup. Furthermore, for larger projects, the government set up a bilateral binding mechanism where demolition companies and recycling companies need to approach the HCB for tenders together. This further allowed for recycling companies to establish additional revenue streams. The government also mandated that all trucks that transport debris, will have to be fitted with GPS and covered. They provided monetary aid to demolition contractors to acquire these special vehicles to combat illegal dumping. Lastly, the research and development incentivised by the government lead to each company having a roster of patented products to their name, allowing for the creation of a market where the actors can enjoy flexibility of price.

As a result of their efforts, Shenzhen improved its resource recovery dramatically while sustaining economic growth. The outlawing of landfills, price flexibility enjoyed and guarantees of revenue streams made recycling a lucrative business encouraging participation. The R&D carried out also led to the creation of better quality recycled products being available in the market. Lastly, using GPS tracking allowed for a severe reduction in illegal dumping. Figure 5.1 shows the STS theory framework applied to Hanoi's CDWN.

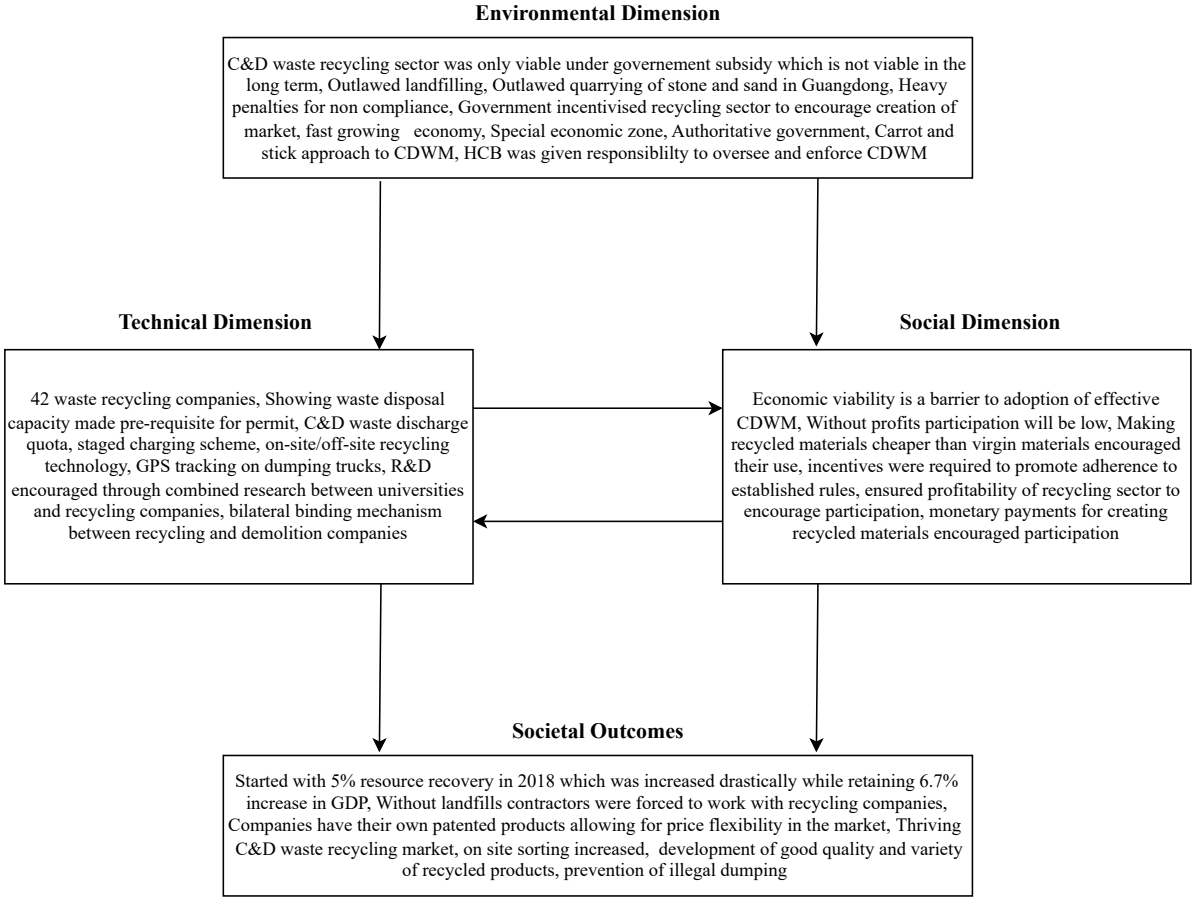

Figure 5.1: STS framework for Shenzhen

5.3. Singapore City Case Study

Singapore is a small island-state located in South-East Asia. Despite the small landmass, Singapore has the 37th largest GDP in the world and the 7th largest ecological footprint (Carriere et al., 2020). Singapore, recognised as South-East Asia's most modern city in terms of construction, could "offer valuable insights in the design and implementation of CE policies for high-density and rapidly expanding cities" (Carriere et al., 2020). The Singapore construction industry, like many others from that region, suffer from a typical set of problems. The industry is highly fragmented, with no entry barriers, leading to family owned companies entering the industry, who focus mainly on profitability which prevents the building of a good waste management culture. This lack of entry barriers also makes the industry highly fragmented and volatile, making it highly sensitive to economic changes (Dulaimi and Caroline, 2001). Furthermore, the industry is filled with SME's and the general profit margin in the industry is low (Hwang et al., 2021). This is typical of construction industries that are fragmented and intensely competitive. Additionally, the industry is led by senior management who still employ traditional methods of contracting and working, despite the Singapore governments push to adopt early contractor involvement, collaborative contracting and integrated digital delivery. This hinders the adoption of new technology (Hwang et al., 2021). A study conducted by Hwang and Yeo (2011), revealed that out of 66 industry stakeholders interviewed to understand their attitude towards waste management, 26 of them ranked cost saving as the most important consideration while 22 chose profit maximisation. This shows that the industry is more focused on how waste management can lead to cost reduction and increase in profits, rather than recognising its environmental benefits. According to Hwang and Yeo (2011) the benefits and criticality of waste management goes unrecognised among the majority of stakeholders in the construction industry.

Due to its small size, Singapore suffers from space congestion making landfilling difficult leading to the government finding other avenues to deal with construction waste. The government tries to encourage waste minimisation, waste recycling and uses an innovative method called Waste to Energy (WTE) in order to reduce the load of landfills. WTE involves incinerating the construction waste to generate ash, heat and flue gas. The heat generated during this process is used to generate steam to produce electricity. "The recovered energy is mainly used to operate the waste-to-energy plant, and the extra electricity is then sold to the electricity institutions. As a result, the revenue from the sale of energy becomes a major income to the plants" (Li et al., 2015). There are 5 operational WTE plants in Singapore which are Ulu Pandan (1,600 tons/day), Tuas (2,000 tons/day), Senoko (2,400 tons/day) and Tuas South (3,000 tons/day) (Li et al., 2015). The ash, which is a by-product of the process, is dumped into the Semakau Landfill situated off the coast of Singapore. It is carried there by tugboats and the change from dumping construction waste to dumping ash resulted in the extension of the life span of the landfill from 20-30 years to 35-40 years (Li et al., 2015). This process does result in air pollution due to ash and flue gas, however, it is viewed as an intermediary measure which creates less environmental damage and achieves environmental sustainability (Li et al., 2015).

5.3.1. Lessons Learnt

The 4 key lessons that can be learnt from the implementation of CDWM in Singapore are as follows:

Strong governmental interventions

The Government of Singapore has imposed stringent rules and regulation for CDWM under the ISO 14000 EMS. This has been done in order to improve the performance of environmental construction in the country (Nagapan et al., 2012). The National Environmental Agency (NEA) is tasked with its enforcement and they have implemented heavy fines for non-conformation including issuing stop work orders (Nagapan et al., 2012), (Hwang and Yeo, 2011). This dissuades non-compliance with Yin et al. (2018) suggesting regulatory compliance as a major driver for the adoption of effective CDWM in Singapore. Furthermore, Singapore's regulatory landscape encourages compliance as stakeholders are aware of the penalties and know that they will be enforced. Furthermore, the government has increased

disposal costs and reduced the number of landfills making waste management a necessary endeavour. In addition to this, the main operational landfill of Semakau, is offshore and only accessible by boat making illegal dumping in landfills challenging.

Developing recycling infrastructure and market

The government implemented the Construction and Demolition Waste Management and Recycling Framework (CDWMRF)"in 2006 which mandates handling of construction waste. This stipulates that project developers need to submit a waste management plan before commencement of a project. It also requires the participation of licensed waste collectors to collect and transport C&D waste from site (Nagapan et al., 2012). This creates opportunities for waste collectors to earn money, hence promoting participation in the industry. Furthermore, the NEA has also set up recycling facilities that turn the waste into non-structural concrete products, causing the resource recovery rate to rise from 85% in 2001 to 99% in 2012 (Li et al., 2015). The government also utilises recycled goods in government projects and incentivises their use in the private sector creating a thriving market for recycled products. In addition to this, the Government of Singapore, encourages participation in the recycling sector through public-private partnerships and monetary incentives such as grants, tax rebates and research funding (Li et al., 2015)

Promoting advanced technologies, education and research

"The Singapore government has identified the promotion of adopting advanced technologies as one of the key pillars to transforming the Singapore construction industry" (Hwang et al., 2021). Under this, the government promotes adoption through providing incentives to help companies, especially SME's, gain access to these technologies. As part of their efforts, the government has found that training, development of standards, incentives and partnerships can help SME's implement building technologies such as BIM etc. (Hwang et al., 2021). The government aims to provide incentives to encourage adoption of smart technologies along the entire supply chain for C&D waste (Hwang et al., 2021). The government is also making efforts to digitise the industry. "through a construction industry transformation map (CITM)" (Hwang et al., 2021). This is aimed at creating a shared platform to establish standards, raise competencies, develop an ecosystem and digitally transform the industry. In addition, the Building and Construction Authority (BCA) and the Construction Industry Training Institute (CITI) hold workshops and seminars that workers of all construction companies are mandated to attend in order to raise competence levels across the industry (Dulaimi and Caroline, 2001). The government also uses a process named Waste to Energy (WTE) where waste is disposed into incinerators and the combustion releases energy that is used to run the incinerator and the excess is sold. The resulting ash is disposed into landfills but occupies less area compared to the original waste matter.

Emphasis on waste reduction

Due to a small land area coupled with high population density, Singapore does not have land to spare for landfilling. Hence, the government has placed a keen focus on waste reduction to reduce the use of land (Nagapan et al., 2012). This not only reduces the amount of construction waste that has to be processed but also leads to an increase in the life of the landfills (Li et al., 2015). Furthermore, the BCA awards the Green Mark Certification to projects run with sustainable building practices such as design for disassembly and use of recycled materials. This directly leads to a reduction in construction waste as companies are keen to obtain the Green Mark Certification in order to boost their marketability and reputation (Yin et al., 2018). Furthermore, BCA focuses on training industry workers on resource efficiency in order to minimise wastage. The WTE program is also geared towards reducing the amount of waste going to landfills, with the incineration providing both a reduction in volume and generation of useful energy.

5.3.2. STS Analysis for Singapore

Singapore City having a relatively small land are coupled with high development meant that landfilling of C&D waste was not a viable solution due to space constraints. For this reason the Government has strived to create a waste management system which can counter its lack of space. Singapore's construction industry is highly fragmented and filled with SME's and family businesses. However, Singapore has an authoritative government and a strict regulatory landscape which allows them to better enforce CDWM laws that they set up compared to developing countries in which governments wield less power. In order to oversee CDWM, the NEA was tasked with it is enforcement. Additionally the government chose to focus on waste reduction and technology in order to counter the waste disposal problem that low land area brings. In the following paragraph, we will examine how the technical and social dimensions interact within the environment set up by the government of Singapore.

The government imposed stringent regulations under ISO 14000EMS to govern the industry. Waste disposal plans were made into a pre-requisite for permits. Additionally, to fix the issue of space, they reduced the landfills keeping only offshore landfills operational. Furthermore, dumping costs were increased to further discourage landfilling. Instead of landfilling, construction waste could now go to recycling companies or the "Waste to Energy" plants that were set up. Furthermore, waste collection agencies were licensed and mandated to participate in demolition projects ensuring that waste disposal is taken care of. However, the fragmented nature of the industry filled with SMEs and family businesses caused the industry to have a very keen focus on cost and profit maximisation as opposed to waste management. Monetary benefits were offered to counter this along with holding seminars and workshops to increase awareness and develop the relevant skills among workers to minimise waste on site. The "Waste to Energy" plants ensured the total quantity of waste that need to be landfilled in minimised and useful energy is generated as a result of its incineration. Furthermore, SMEs were aided in the adoption of new technologies to aid in waste minimisation and reduce quantum of waste generated in Singapore. Lastly, the existing landfills were kept offshore to make illegal dumping very difficult ensuring that the waste passes through the desired channels.

As a result of these efforts, load on landfills was severely reduced extending their lives. Furthermore, strict regulations and monitoring considerably reduced illegal dumping especially as it was much harder to do it after the landfills were all moved offshore. This resulted in a rise in resource recovery rate from 85% in 2001 to 99% in 2012. Due to public private partnerships established and incentives provided participation in the recycling industry was increased as it became a profitable endeavour. Figure 5.2 shows the STS theory framework applied to Hanoi's CDWN.

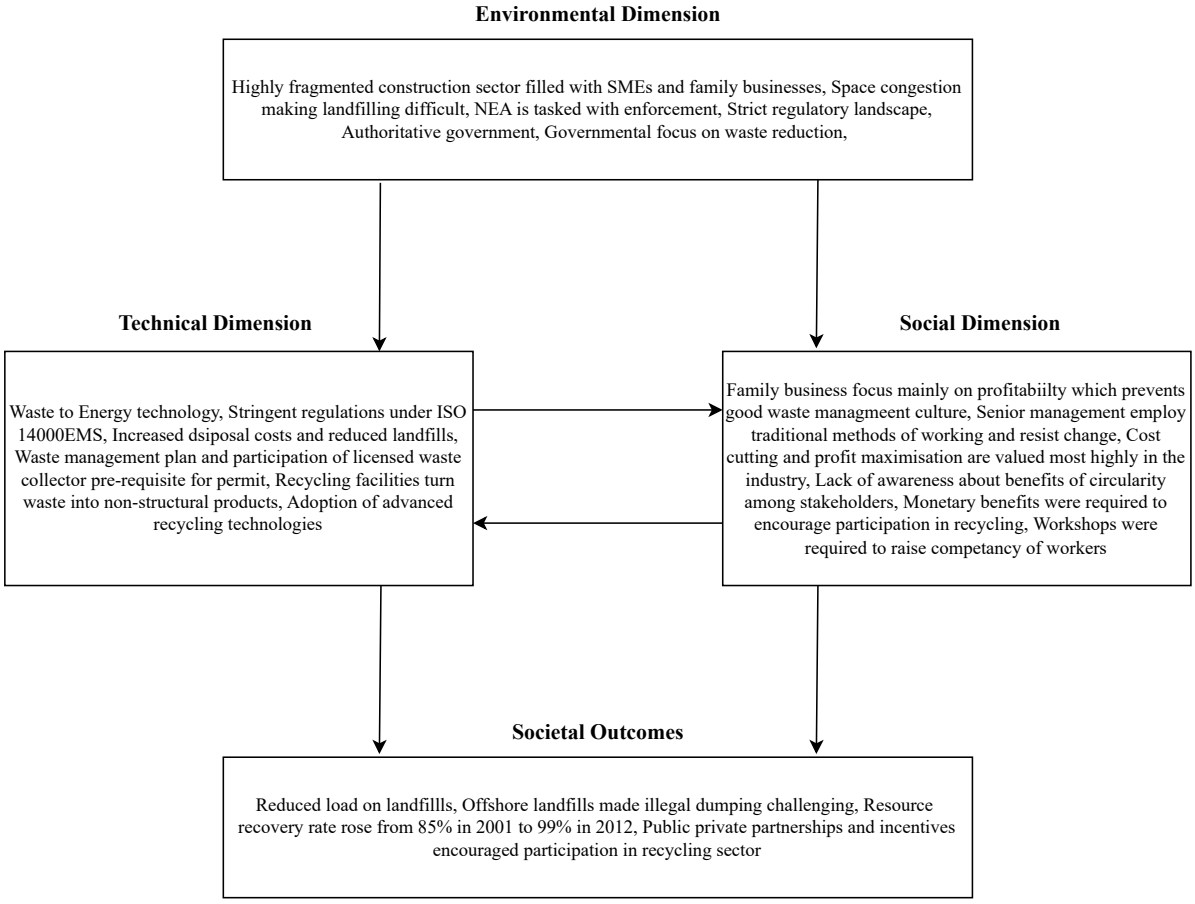

Figure 5.2: STS framework for Singapore

5.4. Hanoi Case Study

Hanoi is the densely populated capital city of Vietnam. Being a developing city, it experiences significant construction and demolition activities. This gives rise to large quantities of C&D waste. In fact, Hanoi has a daily C&D waste generation of about 3000 tonnes (Tuan et al., 2018). The government of Hanoi, in its attempt to manage this waste, has taken on a number of measures. The Ministry of Construction (MOC) was given the responsibility to manage CDWM and put in place a number of laws and regulations to manage the waste. A system for reporting C&D waste was set up where "construction companies, treatment companies, and landfill sites report CDW management plans and treatment data to relevant agencies. Furthermore, the Department of Construction (DOC) is to develop and manage a database on CDW management in the provinces/cities and report to the Ministry of Construction annually" (Tuan et al., 2018). However, it was noted that the responsible stakeholders faced many problems with this due to lack of experience and technical skills.

Current method of disposal for waste in Hanoi is landfilling. However, this is restricted by its limited capacity causing widespread illegal dumping in and around Hanoi. This has caused transportation obstacles, accidents, poisoning of groundwater and blockages of canals leading to flooding under heavy rainfall. Despite legislative efforts and national strategies from the government, detailed technical guidelines and standard are not available for the recycling of construction and demolition debris as well as for the use of recycled aggregate. Due to this, the recycled material sector is not fully regulated discouraging participation. This coupled with the tendency to focus more on time and cost parameters (Kim et al., 2020), has lead to the creating of a blasé attitude towards CDWM in Hanoi.

In order to improve their waste management potential, the government of Vietnam has been working with Japan since 2018 under the project titled "Establishment of Environmentally Sound Management of Construction and Demolition Waste and Its Wise Utilization for Environmental Pollution Control and for New Recycled Construction Materials in Vietnam" (Tuan et al., 2018). This project aims to improve the recycling of C&D waste in Vietnam by establishing the necessary guidelines for environmentally sound CDWM, to develop quality standards for recycled materials, to develop new technologies utilising recycled products and to develop a business model designed to promote C&D waste recycling in the country. Along with this, green certification schemes were launched such as US Green Building Council's LEED system, and Vietnam's LOTUS system. The government hoped that these schemes would result in an improvement of the attitude towards CDWM in Hanoi. However, with economic viability as a key barrier the uptake of these schemes has been slower than desired (Lockrey et al., 2016).

5.4.1. Lessons Learnt

The 4 key lessons that can be learnt from the Hanoi case study are as follows.

Strengthening Regulations

The Hanoi case shows strengthening regulations regarding CDWM as an important step. Over the last two decades, the government of Vietnam has implemented several new rules and policies to govern CDWM. In 2007, the MOC was given "the prime responsibility for organising the elaboration of regional, inter-provincial or inter-municipal solid waste management planning" (Tuan et al., 2018). The main collection actor is the governmental agency Urban Environmental Company (URENCO). The law mandates that the construction contractors are responsible for CDWM, including collecting and treating the waste appropriately. They are also responsible for transporting it to suitable site for disposal. However, this work is often contracted to specific companies dealing with waste management. The government has implemented a comprehensive legal framework for environmental protection that includes guidelines for the management and disposal of construction waste, supported by a variety of national policies. These include "National Strategy on Environmental Protection up to the year 2010 and Vision to 2020" and the "National Strategy for Integrated Management of Solid Waste up to 2025

and Vision towards 2050" (Tuan et al., 2018). Construction companies have to submit waste management plans before the start of construction to obtain permits (Lockrey et al., 2016). There has also been given importance to research and development in the Law of Environmental protection (2014) which encourages stakeholders to conduct research into new technology and apply it towards the disposal and recycling of waste in an environmentally friendly manner. Furthermore, the government aims to increase the recycling rate upto 30% by 2020 (Lockrey et al., 2016). To aid in this, levies are applied to trucks entering landfills to discourage dumping of waste. However, this can lead to demolition companies avoiding official landfills and dumping the waste illegally. Construction waste falls under general waste according to the Vietnamese Government, which means that no licences are required for handling it. This lack of entry barrier, encourages the participation of the informal waste management sector which further exasperates the problems of illegal dumping. Despite the rules and national strategies, detailed rules for recycling and CDWM are not fully available in Vietnam. Furthermore, guidelines for the use of recycled materials have not been fully implemented and regulated which hinder their adoption (Hoang et al., 2020). In addition to this, "at most demolition sites, only marketable materials are sorted. Hazardous materials are not separated at sources but dumped illegally together with other C&D waste" (Tuan et al., 2018). Rules need to be implemented that govern the quantity and type of construction waste that leaves the site. Therefore, it is clear that even though Vietnam has made progress in setting up the regulatory framework, more work is needed for its enforcement and amendments are required in places as the current laws have been described by Kim et al. (2020) as "unclear and inefficient".

Monitoring and Enforcement

As we can see above, the government has implemented several policies and directives to improve the state of CDWM in Vietnam. However, without effective implementation and enforcement, the regulations hold little value. As per Hoang et al. (2020), Hanoi requires stricter supervision and enforcement by the government at local and central level so that CDWM related policies are rendered effective. The government has implemented laws against illegal dumping of construction and demolition waste, however, it is still rampant in the country. Illegal dumping is done either due to an exhaustion of landfill capacity, or a hesitation to pay the levy for trucks entering the landfill. URENCO experts noted that while waiving away the levy would crack down on illegal dumping to a certain extent, it will result in the landfill capacity being used up very quickly and leave no incentive for demolition contractors to segregate waste at site (Lockrey et al., 2016). The link between authorities and industry(URENCO and private players) is weak. There is a need to improve monitoring and enforcement by improving the financial and legislative autonomy of URENCO (Lockrey et al., 2016). The current situation leads developers to only really care about the paper work for waste management being in order and not about actually implementing it in practice. In fact, "with a high level of consensus, demolition contractors in Hanoi agreed that regulations must be implemented so that C&D waste is managed and recycled properly" (Nghiem et al., 2020). The case from Hanoi clearly shows that while setting up laws and regulations for CDWM is an important first step, it achieves little if those laws are not suitably enforced. There is consensus among industry and practitioners that there is a necessity for better enforcement and a stronger authority to URENCO to oversee the enforcement.

Incentivisation

The public attitude and awareness towards CDWM in Vietnam is limited. Therefore there is a need to create an enthusiasm in the industry to promote effective CDWM. This can be done by providing incentives for showing effective performance in CDWM. The lack of incentives was stated as a key barrier towards the adoption of effective CDWM by Lockrey et al. (2016), Kim et al. (2020) and Ling and Nguyen (2013). Lockrey et al. (2016) stated that, on site sorting in Hanoi is at a very low level and can be significantly boosted by providing incentivisation to workers. Furthermore, enforcing waste management contractually and inserting penalty clauses can incentivise subcontractors to pay attention to waste management (Ling and Nguyen, 2013). In addition to penalties, rewards can also be used to incentivise good waste management practices. Through an interview with a project manager, Ling and Nguyen (2013) found that "incentives and penalties are not implemented despite their important roles in waste management". They believed that positive incentives are better than penalties, however,

due to waste management and minimisation being unpopular in Vietnam, penalties are still required to force stakeholders to pay attention to waste management. He went on to suggest, since Vietnamese workers are not well aware of the importance of CDWM, they will only practice it if incentivised by it affecting their job security negatively. Therefore, we can see that the lack of awareness and an increased focus on cost and time targets (Kim et al., 2020), means that incentivising the actors in the industry would be an important step towards achieving effective CDWM.

Infrastructure

In order to improve the level of CDWM in Vietnam, it is essential that the infrastructure available is upto the mark required. However, around 40-56% of the daily generated C&D waste is brought to landfills. Out of the remaining waste, the marketable materials are salvaged and sold while the rest is dumped illegally (Tuan et al., 2018). At most sites only the marketable materials are sorted. Hazardous materials along with the rest of the waste is dumped indiscriminately due to the costs associated and the lack of treatment facilities. In fact until 2000, Hanoi did not have a planned dumping site. Now there are several that have been assigned for that purpose, but they get filled up very quickly (Nghiem et al., 2020). According to the guidelines, the demolition contractors are to dispose C&D waste at landfills specified by the authorities. However, these fill up rather fast which makes it necessary for the demolition contractors to maintain a network of information to identify other uses for the C&D waste such as dumping them in private ponds that need to be filled or in abandoned paddy fields. If they cannot find these, they resort to illegally dumping the waste (Nghiem et al., 2020). Furthermore, the infrastructure for formal recycling is severely limited with only one trial plant in operation that processes 40 tonnes of concrete a day. The burden of recycling falls on the informal sector comprising of the villages around Hanoi but their capacity is limited and there is an absence of quality control.

5.4.2. STS Analysis for Hanoi

Hanoi is a densely populated developing city which suffers from widespread illegal dumping and low levels of resource recovery. In order to combat this, the government has made some efforts to set up the environment in order to improve its state of CDWM. The government handed over the management of CDWM to the MOC which tasked the DOC to develop and manage a database on CDWM. URENCO was tasked as the main collection actor. However, the lack of financial and regulatory autonomy meant that this was an inefficient system, with these bodies retaining little power to truly enforce laws. Furthermore, as per the government, C&D waste is included in general waste meaning separate laws for its handling do not exist, further making it difficult to enforce strict monitoring. Lastly, the recycled material sector is not fully regulated which causes it to have inconsistencies of quality and price inflation. In the following paragraph we will examine how the technical and social dimensions interact within the environment set up by the government of Hanoi.

The government of Hanoi set up a system for reporting C&D waste and waste management plans were made a pre-requisite for building permits. Furthermore, the construction contractors were made responsible for the C&D waste management. However, the lack of enforcement and poor attitude towards CDWM meant that project developers only care about ensuring that all the paperwork is in order, electing to ignore following up on the established CDWM process. Landfilling is the main form of waste disposal in Hanoi. However, due to limited landfill capacity and levies imposed on trucks, contractors often choose to divert their waste to other locations to dump their waste illegally to avoid levies. This is accentuated by the lack of sufficient landfill capacity and the lack of sufficient infrastructure to receive C&D waste for recycling. Furthermore, Hanoi does not require waste handlers to be licensed prompting the involvement of the informal sector which is difficult to monitor and lacks quality control. Lastly, there is a tendency for project developers in Hanoi to focus primarily on time and cost targets which leaves CDWM to be a secondary concern especially due to a lack of incentives being available to promote CDWM.

As a result of this, illegal dumping in Hanoi causes transportation obstacles, accidents and canal blockages that can lead to flooding. Furthermore, failure to establish economic viability has meant that CDWM schemes have been very slow in their uptake. Additionally, lack of autonomy of regulatory bodies further hinders the effectiveness of monitoring and enforcement on the construction industry. Lastly however, through its partnership with Japan, the government of Hanoi aims to raise its recycling rate up to 30% by 2020. Figure 5.3 shows the STS theory framework applied to Hanoi's CDWM.

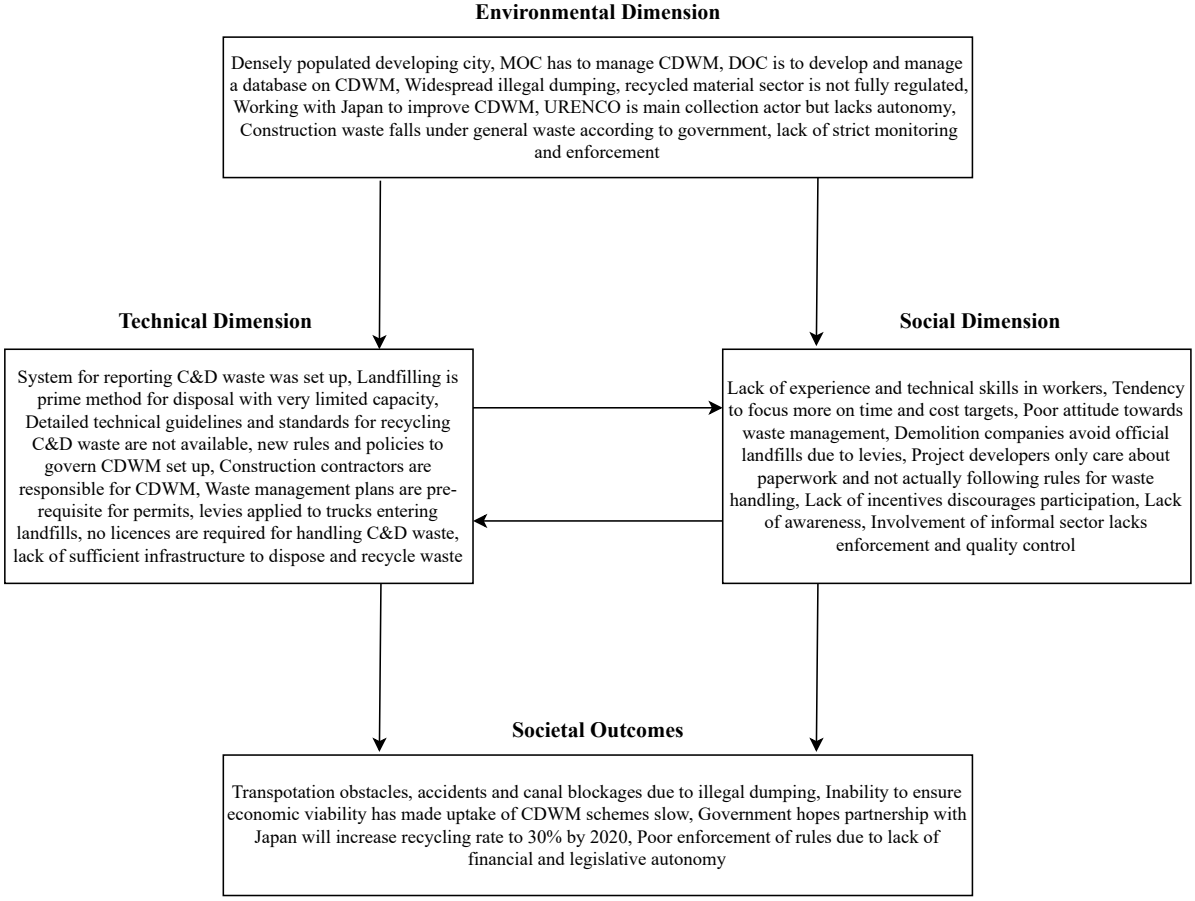

Figure 5.3: STS framework for Hanoi

5.5. Solutions from Case Studies

In order to extract solutions, it is necessary to compare initiatives taken in all the cases with each other, to study in what way were they similar and where the point of differences were. This allows for the identification of key factors which contributed to successes and also allows for identification of factors that were missing, which contributed to failure. In order to translate the lessons learnt into solutions, 4 different categories of solutions as implemented in their respective cases were identified. The first category is improve regulations and this deals with all new rules and regulations that were implemented to control landfilling, CDWM rules for permits etc. The second category is improve recycling market which deals with initiatives taken to stimulate the growth of construction material recycling and their usage to create a demand for the materials, which incentivises their production. The third category is the improvement of enforcement of rules. This deals with all policies and initiatives aimed towards ensuring that rules and regulations are followed, such as monitoring agencies and penalties. The final category of solutions is improving infrastructure and technology. Sufficient infrastructure to deal with the construction waste is the backbone of CDWM and improvements in technology can prove to be a driving force in improving CDWM. As observed from the case studies both the examples of successful CDWM projects from Shenzhen and Singapore had aspects of all four categories working together to improve CDWM suggesting that an actionable solution for solving CDWM should be a synthesis of all four solution categories.

5.5.1. Improve Regulations

In order to truly drive an industry towards effective CDWM, it is necessary to implement regulations to steer the industry to adopt the right practices (Jain, 2012). In the past, construction industries, especially in Asia have been predominantly driven by time and cost targets. In order to galvanise such an industry to adopt effective CDWM it is necessary to implement appropriate regulations. This can be seen in both Shenzhen and Singapore where strong governmental interventions were a key driving force behind the improvement to CDWM (Bao and Lu, 2020)(Hwang and Yeo, 2011). Both Shenzhen and Singapore made it less desirable to use landfills by outlawing landfills in Shenzhen except for renovation, and increasing dumping charges in Singapore. This makes it a necessity for the project developers to explore alternate avenues for waste disposal. Furthermore all 3 cities also made exhibiting sufficient waste disposal capacity as a pre-requisite for building permits. This is essential as this way, waste disposal is paid attention to in the design stages of the project. Furthermore, it also allows governments to estimate the quantity of waste generated which is difficult to do otherwise and essential from the perspective of policy making. Shenzhen and Singapore also mandated allowing only licensed waste collectors to participate in onsite waste collection. Hanoi implemented no such rule which meant that there is no entry barrier for waste collection, making it difficult to guarantee quality of work. In Shenzhen and Singapore, the government also put limits on how much waste can leave the sites hence incentivising on site processing and sorting. This however, was not implemented in Hanoi due to lack of space and technology on site. Therefore, as we can see above, Shenzhen and Singapore's success stems from a combination of discouraging landfilling, ensuring competency through licences and encouraging a reduction in waste leaving the site. Hanoi on the other hand, failed to establish entry barriers and lacked regulations governing onsite processing. This can however be attributed to a difference in the type of governments with China and Singapore where the government has greater power to pass and regulate laws due to their authoritative nature as opposed to Hanoi.

From the above text we can conclude that the following strategies are essential to improving the state of waste management in the construction industry.

- Discouraging the use of landfills either by outlawing them or by increasing disposal fees.
- Encouraging consideration to waste management early in the project life cycle by making it a requirement for permits.
- Ensuring competence in the industry by adding an entry barrier for waste handling.

5.5.2. Improve Monitoring and Enforcement

In order for implemented rules to be effective, they need to be enforced effectively. This involves increasing the level of monitoring in order to catch rule offenders and having a strong legal backing in order to penalise them. The effect of strong monitoring and enforcement can be seen in both Shenzhen and Singapore where various methods were used for it. Both Shenzhen and Singapore implemented heavy economic penalties for offenders discouraging rule breaking. Additionally, both Singapore and Hanoi has set up regulatory bodies in order to oversee the monitoring and enforcement of rules in construction. The NEA in Singapore, has the power to issue heavy fines and stop orders for offenders which heavily encourages adherence to rules. The transparent judicial system in Singapore ensures that any rule breaking is discouraged (Nagapan et al., 2012). Hanoi has also set up a body with a similar objective in URENCO. However, UERNCO lacks financial and legislative autonomy preventing it from being effective in its duty due to having very limited power (Lockrey et al., 2016). Therefore, it is essential that any judicial body set up to oversee CDWM needs to have some degree of autonomy to carry out its function effectively. Furthermore, in order to improve monitoring and crack down on the illegal dumping, Shenzhen has mandated that only a certain type of covered and GPS enabled vehicle can participate in hauling construction waste. This eliminated the possibility of illegal dumping as it can now be tracked and the offender will be fined severely. It is important to note here that the governments of China and Singapore have an authoritative regulatory system and the government wields greater powers making enforcement easier. Vietnam on the other hand, is harder to monitor due to the fragmented nature of the industry and the government wielding less power. However, with better policies and stronger power to legislative authorities, these problems can be mitigated to an extent and will have to be kept in mind when implementing them for India which has a system of government that is comparable to Vietnam rather than to China and Singapore.

From the above text we can conclude that the following strategies are effective in improving the state of monitoring and enforcement in an industry.

- Heavy economic penalties and stop work orders to discourage rule breaking.
- Financially and legislatively autonomous body to carry out monitoring and enforcement.
- Vehicular tracking as an effective counter measure to illegal dumping.

5.5.3. Stimulate Market for Recycled Products

Even if a country improves regulations and their enforcement, the large quantities of construction material that gets recycled needs a market for their consumption. Without this, private sector participation in recycling will be minimal due to no way to make profits from this endeavour. In order to facilitate this, the government needs to create a thriving market for recycled products. A C&D waste recycling industry that is only viable when supported by government subsidies is not sustainable in the long run which creates a need for the development of a complete waste recycling system and infrastructure (Bao & Lu, 2020). Furthermore, creating a market for recycled products, allows for their utilisation and creates demand for more waste to be recycled rather than landfilled. In order to facilitate this in Shenzhen, the Chinese government took a number of steps. They made royalty payments to recycling companies per recycled product made. Furthermore, they set up a staged charging scheme based on the available market in order to ensure profitability for the recycling company. Furthermore, both Singapore and Shenzhen have mandated the use of recycled construction material in infrastructure projects creating a large market. Shenzhen government even gives large cash grants to recycling companies for good performance of their materials during government projects. In addition to this, Shenzhen incentivised use of recycled materials in private projects by outlawing sand and stone mining driving up the price of virgin materials, making recycled materials more economical. Similarly, Singapore also incentivised the use of recycled materials in the private sector by providing cash grants and tax rebates for their use. On the other hand, Hanoi did not take any particular efforts in this aspect. While there exists an informal recycling sector around Hanoi, it is very limited and the government has no policies incentivising the use of recycled products. This creates a lack of incentive for companies to enter the recycling business, which contributes to Hanoi failing to appropriately address the CDWM problems, with landfilling still the

most popular method of disposal.

From the above text we can conclude that in order to foster and stimulate a thriving market for recycled products the following strategies have proved to be effective.

- Monetary incentives for production of recycled construction materials.
- Monetary incentives such as tax rebates or grants to stimulate usage in private sector.
- Utilisation of recycled products in government projects.
- Discouraging the use of virgin materials by making recycled materials cheaper.

5.5.4. Improve Infrastructure and Technology

In order to implement effective CDWM practices, it is essential for a country to have the required level of infrastructure to handle the quantum of waste produced. Having sufficient infrastructure and technology are the building blocks on which policies and practices can be laid in order to create an effective waste management system. In the absence of the required infrastructure, project developers are forced to landfill waste or worse, dump it illegally. In Shenzhen, before outlawing the use of landfills, the Chinese government helped set up recycling stations to handle the waste that will be diverted from landfills. Furthermore, they implemented new technology in the form of their onsite and offsite recycling technology which aids in adherence to their waste discharge quota rules. In Singapore, landfilling was restricted to landfills situated on islands off the mainland. However, before implementing it, Singapore implemented their Waste to Energy systems that incinerate waste and take it to landfills by tug boats. Even Vietnam set up landfills around Hanoi during their construction boom in order to handle the C&D waste. However, they have failed to set up the required levels of recycling infrastructure which has affected their ability to make regulations to handle the large amounts of landfilling and illegal dumping that occurs. Due to landfilling being the only option and their capacities filling up fast, demolition contractors often find fields and ponds that need to be levelled as a means of disposing C&D waste. This problem could be alleviated to a large extent if the appropriate infrastructure for recycling was set up to reduce the load on landfills and take away the necessity to find alternate locations to dump waste. We can see that in both cases of successful implementation, the government prioritised the setting up of infrastructure before regulation changes in order to ensure there was low resistance for the adoption of new regulations. However, in this case, it is also necessary to note that while infrastructure was set up to minimise resistance, the authoritative nature of the governments of China and Singapore made it easier to ensure laws were implemented with minimal resistance.

Another aspect of this is encouraging research and development of new technologies in material recycling to promote development in the sector. Both the governments in Shenzhen and Singapore encourage collaboration between universities and recycling companies to promote research in this sector. Shenzhen uses patents filed as a KPI for grants benefiting the university and companies while Singapore provides financial incentives to companies to collaborate with universities which brings them funding. Furthermore, Singapore also encourages the adoption of new technologies by incentivising their adoption and providing aid to SME's in particular to adopt these technologies.

From the above text we can conclude that

- Developing sufficient infrastructure before passing laws for CDWM is essential.
- Setting up recycling infrastructure is essential as landfilling is no longer suitable as the only method of construction waste disposal.
- Encourage collaborative research between universities and industry.

6

Semi-Structured Interviews

The main aim of the interviews is to explore the adaptations of solutions identified from the case studies of Shenzhen, Singapore and Hanoi to Mumbai's unique context. Due to differences between the studied cities and Mumbai in terms of; population size, style of governance, availability of technology, social and cultural norms and level of competition in the industry, it is necessary to explore each solutions application to Mumbai's context. In order to achieve this, discussions will be held with stakeholders working in the industry. Their knowledge of the industry and experience will be used to cater solutions to Mumbai and lead to new solutions via discussion.

Due to all the interview participants being from India, the interviews will be held online through the Microsoft Teams platform. The interviews will be recorded and transcribed and their contents will undergo thematic analysis. The themes for the analysis will be based on the 4 aspects of Socio-Technical Systems Theory namely Environmental Dimension, Social Dimension, Technical Dimension and Societal Outcomes (Sohal et al., 2022). This is done to aid in the STS analysis for the generation of solutions in the form of the societal outcomes.

6.1. Participant Selection

The selection of participants will be done on the basis of their experience and role occupied in the industry. The participants will be chosen such that as many relevant stakeholders are covered as possible. The criteria for selection will be 15+ years of experience to ensure reliability of information gathered as that has been listed as one of the critical success factors for the construction industry by Tsiga et al. (2016). The names of the participants will be kept confidential. Table 6.1 will provide relevant information about participants and the reasons for their selection.

Participant	Experience	Reason for Selection
Participant 1	33 years	Project Developer with experience running residential and commercial construction projects in Mumbai.
Participant 2	35+ years	Structural Consultant and Restoration Expert. Great knowledge of the industry with experience in a variety of projects. Provides a technical perspective.
Participant 3	50+ years	Project developer with a large amount of experience in a variety of residential and commercial projects. Worked closely with and has a wealth of knowledge about working with regional governing bodies
Participant 4	28 years	Site Engineer with a wealth of experience in running demolition projects with knowledge of process and outcomes of demolition projects
Participant 5	35+ years	Professor of Civil Engineering with a wealth of industry experience in projects both regional and international. Provides a combination of theoretical and industry experience.
Participant 6	35+ years	Professor of Civil Engineering with industry experience more specifically consulting on government housing projects. Keen understanding of government perspective.

Table 6.1: Participant Selection Reasoning

6.2. Questions Design

The interview will be conducted using the semi-structured format. The questions were kept intentionally open ended where it was possible to encourage elaboration and simulate a natural discussion. The interviews began with an explanation of the topic at hand to ensure an understanding of the topic among both parties to allow for a relevant and fruitful discussion. A rigid structure was not followed in the interview to allow for an open discussion to flow to aid in idea generation. Viewing the questions through the STS lens, the objective was to identify the technical, social, environmental dimensions and societal outcomes through discussion. The questions can be classified into the dimensions as demonstrated below. Most of the questions were classed under the technical and environmental dimension as these dimensions were the ones information was most needed for. Their applicability to the social dimension came forward through discussion organically, hence, it was decided to not force in questions for the social dimension. Within the STS theory analysis, the technical and social dimensions interact with each other within their relevant environmental dimension to yield societal outcomes. The objective was to arrive at ideal societal outcomes through discussions of the other dimensions with the industry practitioners hence no questions were formed directly pertaining to the societal dimension.

The first part of the discussion revolves around gauging the level of infrastructure, its utilisation and efforts that must be made for the same. The next part follows addressing regulations and their enforcement examining their suitability or need for change. The third part deals with the recycling market in Mumbai, followed by a discussion about how research can be promoted through collaboration at a governmental and university level. Finally, the questionnaire concludes with an investigation into gauging the level of involvement of the government in CDWM.

The final part of the interview is reserved for an unstructured discussion regarding any ideas the participant might have for improvement of CDWM in Mumbai. This allows for an exploration of solutions not restricted by idea obtained from other nations and allows for the generation of fresh ideas. Furthermore, this part of the interview will also involve discussing with the interviewee the chronology of the measures discussed above. They will be asked about their opinions what measures need to be implemented in what order and what measures would have necessary pre-requisites for their implementation in order to gain an understanding of how to structure the solution into a phase-wise approach.

Each interview will last approximately 45 minutes. This allows for open-ended questions to result in fruitful discussions and allows for enough time to build rapport with the interviewees to avoid discomfort or evasion compromising the authenticity and reliability of the interview.

6.2.1. Questions

Technical Dimension

1. Can you describe the current waste management practices at construction sites you've worked on in Mumbai?
   (a) What are the major challenges in this process?
   (b) What aspects need improving?
2. Are there any specific waste segregation practices employed on site?
3. According to the Make in India initiative, any city with population above 1 lakh (100000) is mandated to have a construction waste recycling plant. What is your opinion about the level of infrastructure in Mumbai for recycling concrete waste.
   (a) What needs to change here?
   (b) How can developers and demolition contractors be incentivised to use these plants as opposed to landfills or illegal dumping?
   (c) Should the demolition contractor or developer be paid by the plant for bringing the materials or would the absence of landfill charges be a fair compensation?
   (d) Singapore and Shenzhen increased charges for dumping in landfills to deter their use and exhaustion of their capacity. Would this be necessary to implement in Mumbai?
4. Shenzhen established waste discharge quotas that govern how much waste leaves the site. This promotes waste reduction as well and promotes more comprehensive on site sorting. Would something similar work in Mumbai?
5. If they produce less than the quota they could be sold as credits the way manufacturing companies sell carbon credits incentivising waste reduction. Would this be an effective incentive to reduce waste on site?
6. Both Shenzhen and Singapore strived to improve the market for recycled products as a means to promote greater recycling and solve their C&D waste problem. What is your opinion about the quality of recycled material available in the market in Mumbai?
   (a) Is sufficient quantity available?
   (b) Currently only the Indian Road congress(IRC) mandates the use to recycled aggregates for road base in infrastructure projects. How can use of recycled materials be encouraged in private sector projects?
   (c) As it stands recycled materials cost 10-15% more than virgin materials. What can be done here to encourage their use by private sector?
7. Shenzhen used number of patents for recycling technology or products as a key performance indicator(KPI) for grants to encourage research between private companies and universities. Can this be implemented in India or is there another way to encourage research in waste management in India?

Social Dimension

1. Who needs to set up recycling infrastructure. Will it be purely governmental or can private sector be incentivised to participate in this sector through tax benefits?
2. What are the key skills and knowledge a worker needs on site to aid in waste reduction and to improve handling of waste?
    (a) Will workers need better training to improve this process?
    (b) Are there any form of certification workers are required to have to participate in waste management?
    (c) What is the level of awareness among site labour regarding the importance of proper waste management?
3. How can stakeholders, including the government, contractors, and workers, collaborate to improve waste management in the construction sector?
4. If it was mandated that recycled materials should be used on site, in what capacity would it change a site engineer and site labours jobs. Would additional training be required?

Environmental Dimension

1. Shenzhen, Singapore and Hanoi have mandated showing sufficient waste disposal capacity. While for the last few years MCGM also requires calculation of generated waste and assurances of capacity from landfill owners. In your opinion, what is the level of enforcement on this. Is this monitored in anyway or just treated as a formality?
    (a) In what way can this monitoring be improved by MCGM and NMMC?
    (b) Should this task remain under the MCGM or should an independent body be set up that deals exclusively with construction waste for its effective enforcement as done in Shenzhen and Singapore?
    (c) cTo prevent illegal dumping Shenzhen mandated trucks to be fitted with GPS. Should this be made a prerequisite for obtaining C&D permission in Mumbai. Who should carry out the monitoring?
        i. How will corruption be dealt with here?
2. CIDCO regularly landfills large plots of land. Should they be made to take up a larger responsibility and be mandated to use soil and concrete rubble from construction sites as landfill material?
3. How would you rate the involvement of the government at the present in CDWM?
    (a) Is there a need for them to take a more active role and involve themselves past the permit stage?
    (b) In what capacity should they get involved?
    (c) In what way would the collaboration of government and private sector be implemented?

7

Data Analysis and Results

This section deals with the analysis of the data obtained from the semi-structured interviews. Thematic Analysis is conducted with the themes corresponding to the 4 dimensions of the STS theory framework namely; Technical Dimensions, Social Dimensions, Environmental Dimension and Societal Outcomes. Following this, STS theory framework will be used to form societal outcomes serving as solutions for the CDWM problem in Mumbai. This will aid in answering sub-research question 4 along with the answer for the main research question.

Before starting the data analysis and solution formulation, it is essential to first understand what aspects of CDWM will be included as part of each dimension of STS theory. This will form the basis of the thematic analysis and will dictate what aspects of CDWM are included within the technical, social and environmental dimensions. The following list has been curated based on descriptions of the relevant dimensions of STS theory as described by Sohal et al. (2022), Pasmore (1988) and Baxter and Sommerville (2011).

Technical Dimension

- How to deal with the process of change towards effective CDWM.
- Waste handling technologies which includes the technical side of waste handling encompassing the technologies used for transportation, recycling, disposal, etc.
- The level of infrastructure available and required for landfilling, waste handling, recycling, etc and aspects such as their capacity, availability and accessibility.
- Data management systems which includes the role of technology in data collection, monitoring, and reporting related to waste management.
- Technical standards and regulations that govern C&D waste management in Mumbai.
- Research and Innovation into now technologies, processes and regulations for CDWM in Mumbai.
- The structure within which organisations must operate (Sohal et al., 2022).

Social Dimension

- Provides an understanding of how participants or actors in SME organisations carry out the necessary tasks and provide support towards implementing effective CDWM.
- Aspects that lend themselves to promoting incorrect CDWM in Mumbai.

- Aspects such as attitudes, beliefs, cultures and norms that influence actor engagement and participation.
- Actors can range from immediate employees to influential key stakeholders, all of who are responsible in collectively taking actions in achieving the societal goal of effective CDWM.

Environmental Dimension

- This envelopes the socio-technical aspects and includes government, industry and society.
- Government industry collaboration measures to promote effective CDWM.
- Level of transparency and accountability within the regulatory environment.
- Enforcement measures which includes both measures currently being applied and measures suggested by interviewees.
- Governmental waste management planning.
- Incentivisation schemes and policies offered and required from the government.
- Laws and regulations applied by the government for environmental protection.

Themes and Codes

In order to analyse the data obtained from the semi-structured interviews, a mixed approach involving both deductive and inductive coding was employed. Deductive approach was taken to set the 4 main themes under which codes would be established. These themes were predetermined and arose from the 4 dimensions of STS theory analysis. In order to identify the codes to group under the themes, inductive coding was employed. Codes were chosen based on the dataset such that they emerged naturally from the data. Figure 7.1 shown below illustrates the themes and their respective codes.

Environmental Dimension	Social Dimension	Environmental Dimension	Societal Outcomes
Tracking	Rise in Costs	Government Enforcement	Effective Implementation
Recycling Plant/ Infrastructure	Loopholes/Bribes	Government utilisation	Infrastructure
Debris Utilisation	Reasons for Illegal Activities	Enforcement agency	Laws\Regulations
Construction Permit	Incentives	Laws	Enforcement
CDWM Regulations	Nuiscance to Residents	Corruption	Utilisation of debris/ Recycled aggregates
Transportation	Willingness of Stakeholders	Political Will	Recycling Market
IS Code	Lack of Trust	Fragmentation/Competition	Reduction in Illegal Dumping
Research/Recycling Technology			Updated IS Code

Figure 7.1: Themes and Codes for Thematic Analysis

7.1. Phase 1: Foundation and preparatory Measures

7.1.1. Agency Inception and Establishment

Technical Dimension	Current C&D waste permissions are good, enforcement is necessary. MCGM monitors solid waste management and has SCADA so it can be used for CDWM as well
Social Dimension	Enforcement is required to promote following rules over the typical drive to save costs and dump. Corruption of officers aids in illegal dumping. Business of dumping is lucrative. Bribe culture. Nuisance to residents
Environmental Dimension	Corruption of MCGM. Over competition in industry (fragmentation). MCGM has power to govern process enforced by Supreme Court of India.
Societal Outcomes	Body is set up to oversee CDWM. Trucks fitted with GPS.

Table 7.1: Agency Inception and Establishment

The first step of phase 1 needs to be to set up a body to oversee the Construction and Demolition waste management process. According to interviewee 1, the CND permission process is already being implemented but there is no agency to check whether the rules are being followed. The Municipal Corporation of Greater Mumbai (MCGM or BMC) currently treats C&D waste as part of municipal solid waste. However, the quantum of C&D waste generated is enough reason for it to be dealt with separately and would need a new body to be set up to oversee its implementation.

Technical Dimension

The current process to obtain C&D permit has been in implementation for the last 5 years and is quite effective. It involves having to submit to MCGM the quantity of debris and soil that will be generated, along with a certificate from the landfill owner that they have sufficient capacity to accept the debris. This is insured against a bank guarantee of Rs 5 lakhs (USD 6,200) which would be forfeit in case of rule breaking. This is further secured against a challan (government receipt) issued in the name of the contractor. The truck will only be unloaded at the landfilling site upon furnishing of the ETP number (unique code) on the challan. On paper, this process is effective and can be carried on if effective monitoring and enforcement is implemented. For this reason it is necessary to set up a body which deals with the enforcement of CDWM laws.

Social Dimension

As per interviewee 3, in Mumbai, illegal dumping steams primarily from the transportation costs associated with landfills situated far from the densely populated parts of the city. The drive to save on project cost is ingrained in the Indian culture and further augmented by the high levels of competition brought on by the fragmentation of the industry. This promotes contractors to dump C&D waste in marshes and low lying land at night, illegally. Furthermore, there is a bribe culture where rule breakers can get away with illegal dumping by paying bribes if caught as stated by all six interviewees. This is augmented by the unscrupulous nature of a lot of the government officers involved.

Additionally, for smaller works such as construction and renovation waste it is sometimes dumped in the city itself, causing nuisance to the residents of Mumbai. This has gotten so bad that the matter reached the Supreme Court of India.

The dumping of construction waste is also ignored due to the lucrative nature of the operation. Every year, large tenders are furnished for cleaning the Mithi River and the various nallas (external storm water drains) around Mumbai, which are common sites for the dumping of debris. This allows for

officials to skim from the top, earning large sums of money and has been described as a racket by interviewee 2. Interviewees 1,2 and 3 all state that there is a need for more scrupulous officers and a separate body to oversee the implementation in order to counteract the systemic corruption in the industry.

Environmental Dimension

Currently all of Mumbai's CDWM falls under the solid waste management department of the MCGM. They have the resources and the expertise required to carry out the monitoring of CDWM in Mumbai. All six interviewees suggested that the MCGM should be the agency tasked with monitoring with interviewees 1,2,5 and 6 suggesting setting up a separate body for CDWM within the MCGM. However, MCGM historically has been a corrupt organisation which would raise questions about their suitability to manage C&D waste. However, as per interviewee 3, despite the corruption, MCGM is run systematically as opposed to other governmental agencies in Mumbai, making them the suitable choice for setting up a body for CDWM. Additionally, the MCGM has been tasked by the Supreme Court of India to set up the process for waste disposal to curb illegal dumping making them the best candidate for its management.

The construction industry of Mumbai is highly fragmented and intensely competitive. This leads to a very keen attention to the cost of projects to remain competitive, especially from the fragmented part of the industry populated mainly by SME's. This ultimately leads to illegal dumping to save on transportation and landfilling costs.

Interaction of Socio-Technical System within its environment

Even though the permit process for waste management on paper looks suitable, the unscrupulousness of certain contractors and officials coupled with a bribe culture, has lead to rampant illegal dumping across the city. This is further augmented by the "over competitiveness of the industry"(interviewee 2), leading to more people dumping illegally to save costs. All interviewees agree that in order to enforce the process set out by the Supreme Court, a separate body dealing exclusively with CDWM is necessary. The solid waste management body of MCGM currently uses GPS enabled trucks to monitor transfer of solid waste. A similar system has been suggested for C&D waste. This has been seen to be effective in Shenzhen (Bao and Lu, 2020) and would need to be implemented in Mumbai.

Societal Outcomes

A separate body would be set up by the MCGM with the purview of managing the CDWM for Mumbai. Additionally, to aid in the enforcement of rules, all trucks carrying C&D debris will be fitted with GPS trackers.

7.1.2. Stakeholder Dialogue and Collaboration

Technical Dimension	Site segregation is necessary. Some sites are too small for segregation. Carrot, stick and sermon approach.
Social Dimension	Contractor Lobby will resist new regulations due to lucrative nature of the illegal dumping operation. Lack of incentives to segregate.
Environmental Dimension	Contractor Lobby controls MCGM. River cleaning operation and slum building racket.
Societal Outcomes	Incentives, fines and regulations. Increase in awareness

Table 7.2: Stakeholder Dialogue and Collaboration

The second stage of the first phase will have to comprise of discussions between the key stakeholder involved in order to furnish new regulations, incentives and punitive measures. This would involve the Builders Association of India (BAI), the MCGM, the Contractor Lobby and delegates from the Ministry of Environment as suggested by interviewees 5 and 6.

Technical Dimension

Interviewees 2,4,5,6 mention the importance of on site segregation to be implemented in Mumbai. However, interviewee 1, a project developer running a SME, rejects the notion saying “on site segregation is not possible as the sites are very small in Mumbai”. Interviewee 1 also went on to say it “would be physically impossible” on smaller sites due to space constraints. This highlights the difference in influence regulations would have on different stakeholders depending on the size of the business, creating a need for discussions to be held leading to an acceptable compromise for all relevant stakeholders. Interviewee 2 also states the importance on implementing a “carrot and stick approach” suggesting a combination of incentives and penalties for effective enforcement.

Social Dimension

Interviewee 5 states that the money of the “contractors lobby controls the BMC(MCGM)”. They would not allow regulation to be passed which they disagree with. Furthermore, the operation of illegal dumping is lucrative to certain contractors and the government officials involved, with an interviewee calling it a “racket”. This makes it necessary for discussions to be held so that a compromise is reached in order to curb illegal dumping by set up incentives as a counter income to illegal dumping. Furthermore, as per interviewee 1, the lack of incentives also make on site segregation an endeavour that is not worth the time and money it needs. Furthermore, this can be a great opportunity to stress to the industry professionals about the importance of effective CDWM, raising awareness in the industry.

Environmental Dimension

The systemic corruption in the industry has lead to a situation where the MCGM is to a certain extent under the control of the contractors lobby. This has lead to an entire “racket” where debris is dumped in the Mithi river and nallas (open water drains) for the purpose of large cleaning contracts and into marshy lands to construct housing in Mumbai.

Interaction of Socio-Technical System within its environment

Due to the fact that regulations impact different stakeholders differently and the power the wealth of the contractor lobby exerts on MCGM, it would be ineffective to implement regulations without offering a mutually beneficial situation. For this reason, MCGM needs to offer a set of incentives against a set of punitive measures to encourage their acceptance in the industry. This would need to be a compromise that is reached through discussion between representatives of the key actors to ensure all their interests are safeguarded. The BAI will safeguard the interests of the builders and developers while the contractors lobby will safeguard the contractors. The Ministry of Environment will safeguard environmental concerns and repercussions of CDWM. The MCGM is tasked with safeguarding the interests of their residents and to ensure the problem of CDWM is appropriately handled. All the aforementioned stakeholders have a responsibility to ensure that CDWM is carried out effectively for the future of the industry, hence, it is suitable to hold a platform such as this where ideas, problems and regulations for implementing CDWM in Mumbai can be appropriately discussed. The environmental body can also conduct seminars as a part of this stage raising levels of awareness among industry professionals about the importance of effective CDWM. This culminates in the carrot, stick and sermons approach suggested.

Societal Outcome

The discussions should yield a set of regulations for the enforcement of CDWM. On site segregation should be mandated for sites above a certain size. In addition to this, different rates should be charged for sorted and unsorted waste at recycling plants and landfills as derived from the staged charging scheme implemented in Shenzhen, to incentivise on site sorting in SME's where sites are too small to mandate on site sorting. This would make on site sorting optional in sites below a certain threshold in terms of size, but the higher rate offered for sorted debris will be a good incentive for sorting if possible for the SME's. This puts the responsibility of conducting sorting onto the SME's running smaller sites with the superior rates offered serving as an incentive if it is logistically possible for them to sort. This stage also aims to increase the levels of awareness in the industry regarding the importance of CDWM.

7.1.3. Maximising Current Infrastructure

Technical Dimension	2 plants nearing completion. Capacity below required levels. Private sector must have avenues to earn. PMGSY road base on CBR value. Upcycling debris as a replacement for Murum and Rubble. Precast elements(paver blocks)
Social Dimension	Anything with scrap value is sorted out. Concrete does not have scrap value. Official avenue to dump will reduce illegal dumping. Waste dumping creating nuisance. More plants will be problematic for citizens.
Environmental Dimension	Business of dumping is lucrative, counter income is necessary. Exorbitant land cost. Tax incentive policy. Purchase guarantees by govt.
Societal Outcomes	2 plants for C&D waste recycling. Regulations for debris utilisation. Building blocks for recycling market. Concrete getting scrap value will reduce dumping.

Table 7.3: Maximising Current Infrastructure

The third stage of the first phase involves deciding how to effectively maximise the current infrastructure for waste management in Mumbai.

Technical Dimension

Currently, as per the Make in India (2014) initiative by the GOI, 2 plants are under construction in Mumbai on the outskirts of the city. The plant situated at Gorai will handle the waste generated in the Western suburbs of Mumbai, while the plant at Shilphata will handle the waste generated in the eastern suburbs. The plants will have a combined capacity of 1200 tonnes/day which has been described as inadequate and in "nascent stage" by interviewee 6. These plants, while being built by the government, have been awarded to 2 private sector companies to manage and operate and will focus on turning C&D waste into precast paver blocks.

Interviewee 2 suggests that due to the costs associated with crushing and processing of construction debris, upcycling of debris should be explored. The replacement of murum and rubble with upcycled debris have been suggested by interviewees 2 and 6. Furthermore, the selection of aggregates for road base is done on the basis of California Bearing Ratio(CBR) test. This can be an appropriate use for recycled waste for infrastructure projects as suggested by interviewee 6, a structural engineer.

Social Dimension

Both interviewee 1 and 3 have stated that any part of the waste that has scrap value is sorted out and sold. This corresponds with literature where Sohal et al. (2022) states that there is a culture in India about not wasting anything that can be monetised. Concrete is dumped as it has no scrap value. Furthermore, interviewee 1 suggests that if there was places where contractors can dump concrete waste and get paid for it, no one will indulge in the illegal activity of dumping. Furthermore, recycled products are viewed as inferior causing a distrust of them in the industry.

Interviewee 3 stated that recycling plants in the city will cause pollution problems and be a nuisance for the residents. This restricts how close to the main city the plants can be situated. This is seem with both the current plants under construction being situated on the outskirts of Mumbai.

Environmental Dimension

Currently, the land cost in Mumbai is exorbitant which makes it such that private sector companies need government assistance to operate profitably in recycling. In addition to this, due to the lucrative nature of dumping, a counter income has to be provided to appropriately arrest illegal dumping activities. Furthermore, in order to be truly profitable, the recycling sector would also need guarantees of business from the government in the form of purchase guarantees as seen in Shenzhen and Singapore. However, the capacity of the 2 plants are not sufficient for the quantum of waste Mumbai produces, hence, landfilling would still have to be kept as an option with MCGM deciding at the time of permit granting if the final destination will be the recycling plants or a landfill.

Interaction of Socio-Technical System within its environment

The 1200 tonnes/ day capacity of the plants is not enough to deal with the entire quantum of waste generated in Mumbai. Additionally, the demolition works in Mumbai are expected to grown as suggested by interviewee 3 guaranteeing the generation of more debris in the future. However, interviewee 6 stresses on the importance of first maximising the current infrastructure. This has to be done first to establish a market in Mumbai for recycled products so that the trust builds in the industry. Furthermore, setting up a plant big enough to handle Mumbai's C&D waste anywhere near the city will cause large nuisance to residents. Instead, first the State Government should help stimulate a recycling market by utilising recycled aggregates as road base in the Pradhan Mantri Gram Sadak Yojana (PMGSY)(Prime Minister Rural Road Scheme). Road base applications are based on CBR value and that parameter can be easily tested by recyclers to ensure aggregates are of the required quality. Furthermore, the partial replacement of murum and rubble with upcycled debris in walkways and embankments in the city will not only lead to a utilisation of debris, but also prevent the cutting of hillocks to gain material as suggested by interviewee 2. Additionally, MCGM has pledged rates of Rs 1400 ($17)/ tonne of concrete waste to incentivise delivery of waste to the plants. This is a great incentive as the transportation would cost anywhere between Rs 300-500 ($3.6-6) per tonne (interviewee 1), ensuring that segregating concrete waste becomes a profitable endeavour, encouraging participation of SME's in C&D waste management endeavours.

Societal Outcomes

This stage aims to contribute by finalising the setting up, operations and services offered by the 2 recycling plants. Additionally, regulations should be put in mandating the utilisation of recycled aggregates in road base for PMGSY projects in the villages near Mumbai, as well as base material for walkways and embankments in the city. This aims to create a reduction in landfill load and illegal dumping due to alternate lucrative avenue for dumping concrete waste.

7.1.4. Research and Development Initiative

Technical Dimension	Current recycling process leads to recycled aggregates being more expensive. Requirement of improved technology. IIT's and NIT's have required infrastructure. Upcycling is a valuable tool. Institutes can include CDWM in civil engineering syllabus.
Social Dimension	Price will have to be comparable to promote use. Promote professors to push topics(grants are available). Recycled and upcycled debris is viewed as inferior. Lack of regulations for use. Lack of awareness among students.
Environmental Dimension	UGC and Ministry of Human resources need to push. Make in India Initiative can involve tech companies. Joint research with Bureau of Indian Standards.
Societal Outcomes	Better understanding for use case of upcycled debris. Improvement in recycling technology. Updated IS code. Increase in awareness about importance of CDWM.

Table 7.4: Research and Development Initiative

The fourth stage of the first phase involves creating regulations and technical instructions to aid in the utilisation of upcycled C&D debris culminating in an updated Indian Standards Code (IS Code). It also aims to drive research in recycling technology to reduce cost of recycled aggregates and yield superior quality of recycled materials.

Technical Dimension

Currently the GOI imposes the Goods and Services Tax (GST) on recycled aggregates. Furthermore, the technology as of now is at an early stage as described by interviewee 5 which makes it inefficient and it suffers from economies of scale. The combination of this makes recycled aggregates more expensive than virgin materials. There is a need to improve the technology through research in this sector. Currently, the Indian Institute of Technology (IIT) and the National institute of Technology (NIT) are the 2 premier technical universities in India with campuses all through out the country. They have the infrastructure and the technical expertise to carry out research in this field. Furthermore, research is required for more uses of upcycled debris, which these institutions are best placed to carry out. Additionally, the Indian Standard (IS) code is outdated and needs to be amended for the application of upcycled debris to construction projects. Furthermore, civil engineering syllabus at the bachelor level in Mumbai does not include CDWM. According to interviewee 5 and 6, it is important that the syllabus be amended.

Social Dimension

Interviewee 2 and 6 have expressed concern that unless the price of recycled aggregates are brought down to make them comparable to virgin materials, their acceptance in the industry would suffer. Additionally, there needs to be a drive from professors at the IIT and the NIT to push research in this sector. There is a lack of awareness among students about the importance of CDWM further hindering research in this domain.

The Indian market traditionally views recycled and upcycled materials as inferior to virgin materials. This will hamper their acceptance and efforts are needed to build confidence in the industry towards the use of these materials.

Environmental Dimension

Under the University Grants Commission (UGC) and the Ministry of Human Resources grants are available for research into construction waste management. Over the past few years, research in these universities about CDWM has grown considerably. Furthermore, under the Make in India initiative by the GOI, they hope to stimulate the manufacturing sector of India. Under this initiative, they can push for combined research and development between recycling companies and these educational institutions. Furthermore, the Bureau of Indian Standards should collaborate with universities to update the IS code to deal with the upcycling of debris.

Interaction of Socio-Technical System within its environment

In order to bring down the price of recycled materials so they can compete with virgin materials, a streamlining of the recycling process and an improvement in technology is needed. Here, the onus is on the IITs and the NITs to carry out research in this sector with recycling companies. Furthermore, research into utilisation of upcycled debris is necessary to increase the use cases for the material, due to the lower cost of producing it, as compared to recycled aggregates. Additionally, GST on recycled aggregates must be removed in order to bring down the price, allowing them to compete with virgin materials.

Furthermore, there is a need to amend and update the IS code, as publishing tested regulations for the use of upcycled materials in construction would help build confidence about their use in projects among stakeholders. This can be achieved through collaborative efforts of the Bureau of Indian Standards with educational institutions. The educational institutes must also include CDWM in the Bachelors of Civil Engineering syllabus, to build awareness and knowledge in future professionals and to encourage more research in this field.

Societal Outcomes

The outcomes from this phase will result in a number of use cases for upcycled debris for use in the construction industry. Furthermore, it will also result in a superior recycling process in an effort to improve quality of recycled material as well as reduce the cost to produce them. Most importantly, this stage will result in the furnishing of an updated IS code which details use cases for upcycled debris as well as application of recycled aggregates for road base in infrastructure projects based on its CBR value. It will also yield an increase in awareness about CDWM among future professionals.

7.1.5. Summary and STS Framework

The objective of phase one is to put in place the building blocks required to drive changes in the CDWM landscape of Mumbai. All 6 interviewees have stated the current permit process to be sufficient and only lacking enforcement. This creates a requirement to set up a body to oversee the enforcement of the process. Due to possessing the technology and the expertise, MCGM is chosen as the governmental institution under whom the enforcement body must be set up. Phase 1 also discusses fitting all debris transit trucks with GPS trackers by the advent of phase 2, in order to aid in enforcement. After a body is set up, the next step is holding discussion panels between the builders association, the contractor lobby, environmental bodies and MCGM to ensure a set of regulations, punitive actions and incentives are devised to help encourage participation in CDWM. The regulations discussed must involve setting up rules for on site sorting on bigger construction sites and offering different rates for sorted and unsorted debris in order to incentivise sorting as done in Shenzhen (Bao and Lu, 2020). MCGM is currently building 2 debris recycling plants in Mumbai as per the Make in India (2014) initiative. While the capacities of these plants are not sufficient for the quantum of C&D debris Mumbai generates, it is required to first maximise their utility before improving the infrastructure. This can be done by generating regulations governing the use of upcycled debris and mandating the use of and developing regulations for the use of recycled debris as a road base using CBR value. Finally, phase 1 drives research in developing use cases for upcycled debris and the development of superior recycling

technology to allow for the generation of superior quality recycled aggregates at lower prices. The phase concludes with an amendment to the IS code, enabling the use of recycled debris as road base for infrastructure projects, enabling private sector actors to take initiative and start utilising debris in their project. With these building blocks in place, efforts can then be made towards starting the implementation of CDWM in the industry.

Figure 7.2 shows the STS System theory diagram showcasing the technical and social dimensions operating within its relevant environmental dimensions leading the societal outcomes proposed for phase 1.

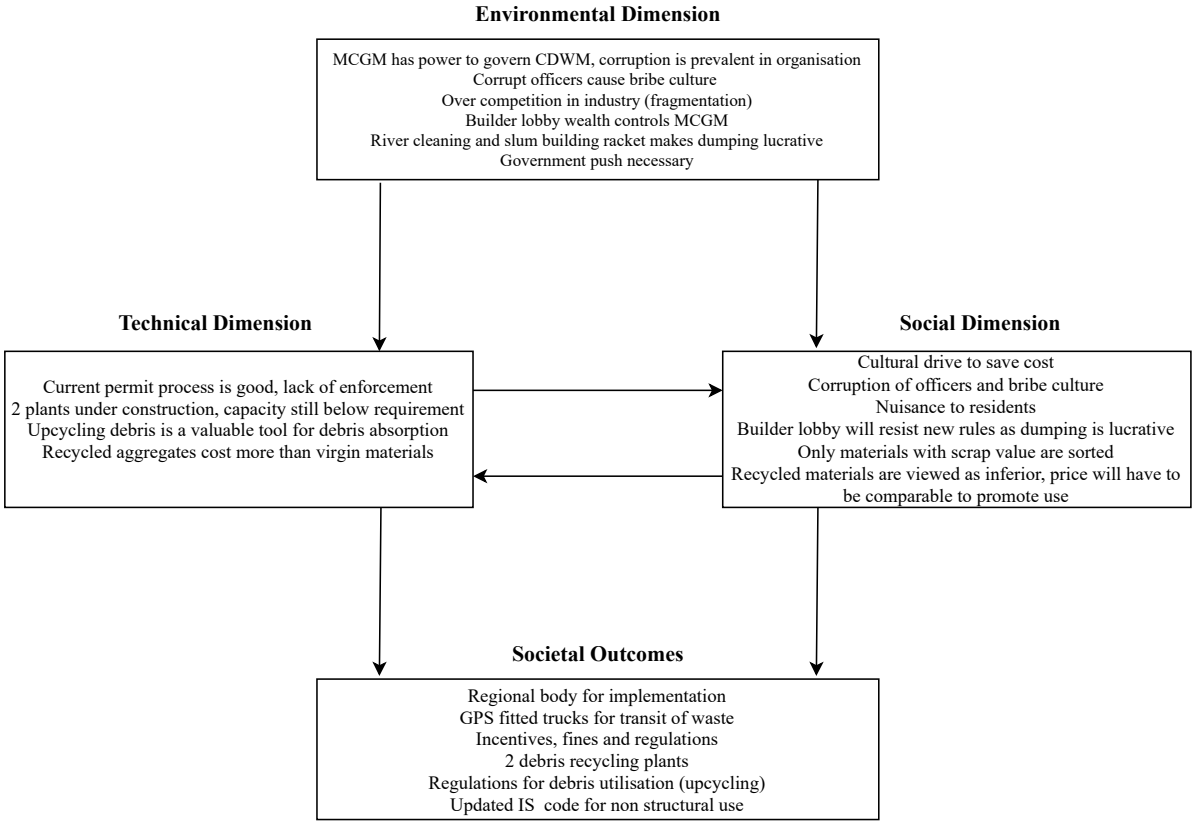

Figure 7.2: STS Theory Diagram- Phase 1

7.2. Phase 2: Strengthening Implementation and Innovation

7.2.1. Rigorous Enforcement Strategies

Technical Dimension	GPS tracking is used for MSW and sand royalty, can be extended to C&D waste. SCADA system is already implemented, GPS can be made pre-requisite.
Social Dimension	Marginal rise in costs must be absorbed for environment sake. Counters bribe culture.
Environmental Dimension	MCGM can take over monitoring. Implement severe penalties.
Societal Outcomes	Severe reduction in illegal dumping. Reduction in environmental challenges.

Table 7.5: Rigorous Enforcement Strategies

The first stage of phase two involves curbing the problem of illegal dumping in Mumbai. As previously highlighted, the permit process is extensive and just needs to be enforced appropriately. For that reason, this stage focuses on how enforcement of CDWM laws regarding illegal dumping can be improved.

Technical Dimension

With the permit process in Mumbai being appropriate, the problem of illegal dumping starts after the truck is loaded and sent to the landfill. GPS tracking emerged as one of the premium solutions to this in Shenzhen, China. When asked about its implementation in Mumbai, all interviewees were for it with interviewee 1 stating “GPS tracking is a must, without it implementation cannot be done”. Additionally, as per interviewee 5, MCGM already carriers out the monitoring for solid waste in Mumbai. They employ Supervisory Control and Data Acquisition (SCADA) which is a software to monitor and analyse real time data for processes. This is used to monitor the transit of solid waste as the trucks are fitted with GPS sensors. Implementing SCADA would require GPS sensors on trucks hauling C&D debris to be a pre-requisite for the permit process.

Social Dimension

In order to properly carry out monitoring, interviewee 2 has asked that more scrupulous officers are appointed by the MCGM. However, the prevalent bribe culture makes this an unreliable method to enforce laws. The presence of GPS tracking might deter illegal dumping due to the threat of getting caught being much higher.

Environmental Dimension

MCGM, despite its tendency to be corrupt, is best placed to carry out the monitoring and enforcement for CDWM. They possess the technology and the technical skills required for this. Hence, the monitoring should be placed with the department set up in phase 1. Additionally, the fines which stand at Rs 25000 (USD 300) per truck while not unsubstantial, need to be increased so that the consequences of getting caught by the GPS system would be dire.

Interaction of Socio-Technical System within its environment

The advent of GPS tracking will counter the bribe culture, as according to interviewee 1, having the GPS data allows for perpetrators to be apprehended even after dumping has occurred. Furthermore, the fact that any officer of the department will have access to the data creates a situation where in order to get away with illegal dumping, contractors might have to bribe multiple people which would make it unsustainable for them. Furthermore, increased fines would make the prospect of getting caught and fined a big hindrance to illegal dumping, as contractors will be keen to avoid an increase in costs as

a result of this. This will be very effective on the fragmented SME part of the industry as the fines will have proportionately a bigger impact on project costs for SMEs. This would allow for rule enforcement on a section of the industry that has historically been difficult to monitor and enforce rules upon. Lastly, while fitting GPS sensors on trucks could contribute to a small increase in costs, the onus is on the contractors to enable this change making back their money by selling the debris to the plants.

Societal Outcomes

The consequence of implementing GPS tracking under MCGM supervision would be a notable reduction in illegal dumping with interviewee 1 stating that, ”while these measures might not prevent 100% of illegal dumping, it would result in around a 90% decrease”. The reduction in illegal dumping would also reduce a number of environmental challenges faced in Mumbai such as the pollution of Mithi River and nallas, waste dumped in civilian areas and the destruction of mangroves due to illegal dumping.

7.2.2. Implementation of Non-Structural Application

Technical Dimension	Amending the IS code to allow non structural use of upcycled debris. C&D debris can be used as road base in infrastructure projects.
Social Dimension	Lack of confidence in products. Lack of costs associated with recycling.
Environmental Dimension	PMGSY can be biggest customer.
Societal Outcomes	Utilisation of debris. Purchase guarantees by govt to recyclers. Growth of market for recycled and upcycled products. Preservation of natural resources.

Table 7.6: Implementation of Non-Structural Application

The second stage of phase 2 involves implementing non structural use of recycled and upcycled C&D debris. The prerequisite for this is the amendment of the IS code, to allow non structural application, as described in phase 1. With the quantity of debris available in India, the potential for their reuse is immense.

Technical Dimension

Upon amending the IS code to allow for the use of upcycled debris in various cases, technical instructions for their use will aid in their utilisation (interviewee 5). Furthermore, as suggested by interviewee 6, upcycled debris or recycled aggregates can be very suitable for road base materials, if their CBR value is assured by manufacturers. Processing plant can provide materials with technical data sheets, guaranteeing sufficient CBR value to aid acceptance.

Social Dimension

There is a tendency to view recycled or processed waste as inferior in India distrusting their quality. The same is true for the construction industry of Mumbai. It is necessary for the utilisation of upcycled debris first in government projects, to help build a confidence in the private sector. Furthermore, upcycling debris is a cheaper process compared to recycling as stated by interviewee 2. This would be highly desirable for the recycling plants as it will result in a reduction of their costs. Incentivising the use of upcycled debris, in place of rubble, in the private sector needs to be done due to a general lack of willingness in the industry. This can be done by making using upcycled debris cheaper compared to rubble through providing incentives to the plants to allow them to sell them for cheaper to compete with the price of virgin materials. Additionally, the Ministry of Environment can provide green building certification to projects utilising recycled or upcycled materials which serves as a marketing tool for the developers.

Environmental Dimension

The Pradhan Mantri Gram Sadak Yojana (PMGSY) is a large undertaking by the Indian government to build roads to improve the inter connectivity of villages, as well as to improve their connectivity to neighbouring towns and cities. Under this initiative, a large number of roads will be built. As per interviewee 6, a structural engineer, these village roads are expected to carry much lower loads compared to city roads and would be the ideal place to absorb construction waste. Furthermore, according to interviewee 1, murum can be partially replaced with upcycled rubble in the base for walkways, embankments and even city roads if sufficient quality is assured.

Interaction of Socio-Technical System within its environment

Amending the IS code will help generate some confidence in the professionals of the industry regarding the use of these materials in their projects. Furthermore, their utilisation in infrastructure projects such as the PMGSY, will further help counter the lack of trust in the industry regarding recycled material. Additionally, mandating their use in PMGSY will also provide a business for the recycling plants, ensuring a revenue stream for them to stimulate the growth of the recycling market. Additionally, the large quantities required for the PMGSY would make them the biggest customer for these recycling companies. Infact, these plants can be given purchase guarantees by the government to ensure a revenue stream for them. Contractors participating in government projects must take the initiative to incorporate upcycled debris in their projects, not just to boost the recycling market, but also to reduce the demand for natural murum and rubble. Furthermore, incentivising plants to make upcycled debris cheaper than virgin materials will encourage their use in private sector projects, further boosting the recycling market. This will also help change the narrative of inferiority that currently exists against recycled materials. Incentivising the plants through subsidies or tax breaks is essential until economy of scale challenges that the plants face will reduce with time and growth of business, at which point subsidies can be scaled back.

Societal Outcomes

Encouraging non structural use of these materials as described above will provide a productive avenue for the absorption of C&D waste, which in turn would reduce the reliance on virgin materials and reduce the pressure on their stocks. Purchase guarantees provided to recyclers would encourage interest in the industry due to guaranteed revenue streams. Furthermore, it would help stimulate a market for recycled products to grow in the country, reducing the reliance these endeavours have on government subsidies as it would provide revenue streams for the recycling plants.

7.2.3. Improvement to Infrastructure

Technical Dimension	Insufficient capacity of current infrastructure. Waste generation expected to rise. Transportation by trucks very costly over long distance.
Social Dimension	Residents will object to the noise and air pollution. Gainful employment in rural areas.
Environmental Dimension	Mumbai already has a train tracks leading out of the city. Mines in Mumbai have run out.
Societal Outcomes	Larger plant with sufficient capacity for current and future waste generation.

Table 7.7: Improvement to Infrastructure

The third stage in phase two involves the planning of additional infrastructure for C&D debris recycling, as the two plants currently under construction are not sufficient. This stage proposes the setting up of

a new plant, including where it can be built and how debris and recycled material can be moved from Mumbai to the plant and vice versa.

Technical Dimension

All 6 interviewees agree that the level of infrastructure in Mumbai for C&D waste handling is insufficient. In addition, interviewee 3 and 6 also state that due to the rise in redevelopment projects in Mumbai, the quantity of C&D waste is expected to rise. This creates a need for the additional infrastructure.

Interviewee 4 also stated that during the monsoon seasons, it is becoming increasingly difficult to get aggregates for concreting in Mumbai, due to the long transit they have to go through. This creates a need to source aggregates from locations closer to Mumbai. Additionally, the long transit by trucks is very expensive.

Social Dimension

Interviewee 3 states that setting up a plant of the size required will cause tremendous nuisance to the residents. Due to this, a plant of this size will have to be constructed away from Mumbai and the surrounding urban areas of Thane and Navi Mumbai. The plant will have to be placed in rural areas with significantly lower population densities.

Rural areas in India are plagued with lack of gainful employment which leads to Mumbai's migration problem in the first place. Setting up a plant in those areas and providing training to the locals will provide gainful employment, preventing the need for them to migrate to bigger cities in search of work.

Environmental Dimension

Land cost in Mumbai is very expensive, due to which it makes more sense to situate a large plant outside of Mumbai. This is backed by both interviewee 3 and 5. Additionally, Mumbai is very well connected by its train system with the tracks already in place that connect the entire city. Furthermore, according to interviewee 5, all the mines for aggregates in and around Mumbai have exhausted their capacity, apart from one which is also nearing its end. It has necessitated long transits for aggregates which are both expensive and time consuming.

Interaction of Socio-Technical System within its environment

The only solution to the rising amount of C&D waste is building a large plant which will have to be away from the city due to space and pollution concerns. Furthermore, building a plant far away raises costs of transit heavily. This can be tackled by making use of Mumbai's railway system. Interviewee 3 suggested setting up of 4 or 5 collection centres near railway tracks, where contractors can come drop their C&D waste. This can then be loaded up into a goods train and transported out of the city at lower costs than transits using trucks.

Furthermore, as per interviewee 3, training rural area residents to work in a concrete recycling plant will not be very difficult and the employment generated by this will lead to rural development and reduce the need for them to leave their homes and migrate to big cities.

The same train that takes C&D waste from Mumbai can be used to bring back recycled concrete materials back to Mumbai on the return journey. This will also improve access to aggregates especially in monsoon where obtaining aggregates becomes difficult and will reduce the costs associated with long transits. Furthermore, SME's in Mumbai are plagued with time and cost delays in construction projects. Guaranteeing availability of aggregates from sources closer to Mumbai will greatly benefit them. Furthermore, multiple collection points across the city will further cut down how far SME's need to transfer waste, further reducing their costs and helping them be a contributing part of the CDWM process.

Societal Outcomes

A large concrete waste recycling plant should be set up away from Mumbai, connected by the rail system with collection depots set up connected to the rail head. This will also lead to a reduction in consumption of virgin materials, as recycled materials will become easier to obtain without the long transit charges. Lastly, it will lead to skill development and employment generation in rural areas.

7.2.4. Advancement in Research and Standardisation

Technical Dimension	Need standardisation for structural use. For high grades of concrete high quality aggregates are necessary. IS Code lacks any standardisation.
Social Dimension	Lack of trust in the industry for recycled products.
Environmental Dimension	Dwindling natural resources. BIS does not allow use of recycled aggregates above M25 concrete.
Societal Outcomes	New IS code detailing grades of recycled aggregates and details for their use in RCC works.

Table 7.8: Advancement in Research and Standardisation

The fourth stage in phase 2 deals with driving research into standardisation of recycled aggregates and the generation of technical specification for their use in structural applications. Availability of good quality recycled aggregates is a pre-requisite to drive research into their application and standardisation.

Technical Dimension

Interviewee 6 stated that in order to use recycled aggregates for RCC, there will need to be standardisation introduced where aggregates are categorised into different grades based on their physical and chemical properties. The properties of the aggregates are important at higher grades of concrete. Hence, there would be a need for manufacturers to provide information about the aggregates necessitating standardisation.

Currently, the IS 456, the code for reinforced concrete, does not allow recycled aggregates in higher grades of RCC, allowing its use freely only in lean concrete.

Social Dimension

Recycled materials are viewed as inferior in the Indian market. Their use is restricted to lower grade with interviewee 3 highlighting the poor condition of roads in Mumbai stating using recycled materials would just make it worse. There is a need to build trust in the professionals regarding the qualities of recycled materials.

Environmental Dimension

Bureau of Indian Standards restricts the use of recycled aggregates to concrete under M25 strength. Today in Mumbai, most construction uses grades higher than that. There is a need to expand their use case to truly lead to their utilisation beyond lean concrete. Furthermore, the dwindling natural resources in and around Mumbai for natural aggregates, creates a real need to ease that burden and establish alternate sources for aggregates.

Interaction of Socio-Technical System within its environment

Creating a new IS code or amending IS 456 to allow for the use of recycled aggregates above M25 in RCC applications, will not only increase their use cases but their inclusion in the IS Code will also help build confidence in the industry professionals regarding their use(interviewee 5). In order to use them in higher grades of concrete, the recycled aggregates will need to be standardised to ensure the required technical quality is available. Therefore, first the BIS will have to drive research to standardise the recycled aggregates with interviewee 6 suggesting assigning grades to them. This can then correspondingly be used in the IS code to permit usage in higher grades of concrete based on their technical properties. This research can be done in collaboration with universities, utilising their talent pool and facilities. Furthermore, greater utilisation of recycled aggregates will also reduce the demand on natural aggregates which are becoming scarce.

Societal Outcomes

Grading scheme for recycled aggregates based on their technical qualities will be established. New IS code or an amendment to IS 456 to be published detailing the use of recycled aggregates in higher grades of concrete for RCC applications. Reduction in demand for scarce virgin materials will also be observed.

7.2.5. Summary and STS Framework

Following the building blocks being established in phase one, phase two begins the implementation of the measures suggested to improve CDWM in Mumbai. The first step is the curbing of illegal dumping by effectively enforcing the permit process already in place in Mumbai. Phase one sets up the prerequisite for this, with MCGM mandating the fitting of GPS trackers on trucks hauling C&D debris. Making GPS trackers on trucks a requirement, and monitoring the transit using SCADA software already in use for MSW by the MCGM, will result in a severe reduction of illegal dumping of C&D debris in Mumbai. The presence of data regarding the transit also helps counter the bribe culture prevalent in the industry. The next step involves implementing the use of recycled and upcycled debris for non structural application. The absorption of debris is an essential part of CDWM and the amended IS code from phase 1 is a prerequisite for the utilisation in phase 2. Based on their CBR value, recycled and upcycled debris can be easily used as material for road base construction, especially on smaller roads outside big cities. The PMGSY aims to interconnect villages with roads near big cities. Furthermore, recycled or upcycled debris can also be used for walkways, embankments etc in big cities like Mumbai itself. Regulations must be established mandating the use of recycled and upcycled aggregates in these projects. Apart from regulations, project managers and contractors working in these projects have a responsibility to endeavor to utilise these materials in their projects. Due to the scale of the undertaking, PMGSY could be the biggest customer for the absorption of debris. This would also create a market for recycled construction material, allowing companies to operate in this sector without an over reliance on government subsidies due to established revenue streams. Due to the available infrastructure being insufficient, there is a need to set up a bigger plant to cater to current and future C&D waste generation needs. Exorbitant land costs, high population densities and the nuisance it will create for the residents mandates that the plant must be set up away from Mumbai in less densely populated areas. To avoid the heavy transit fees that this would accrue, the already established local train system of Mumbai can be utilised for transit. Collection depots can be set up near the rail heads at various location through Mumbai. These can be loaded onto a train and transferred to a plant situated a long distance out of Mumbai. This would allow for a big plant to be set up, which would not have been possible in the city due to space constraints and the nuisance it would create for residents, and leads to the development of skills and gainful employment in rural areas around the plant. The plant must be set up and operational by the time phase 2 concludes. With phase 2 implementing non structural use of debris, there is a need to carry that forwards and extend it to structural use. IS code currently restricts structural usage of recycled aggregates up to M25 concrete. Standardisation of aggregates is necessary to enable the development of an IS code to allow partial replacement of virgin aggregates with recycled aggregates in higher grades of reinforced concrete. For that reason, phase 2 includes

carrying out research on aggregates to introduce standardisation and concludes with the development of an IS code or an amendment to IS 456 to allow structural use of recycled materials beginning in phase 3.

Figure 7.3 shows the STS System theory diagram showcasing the technical and social dimensions operating within its relevant environmental dimensions leading the societal outcomes proposed for phase 2.

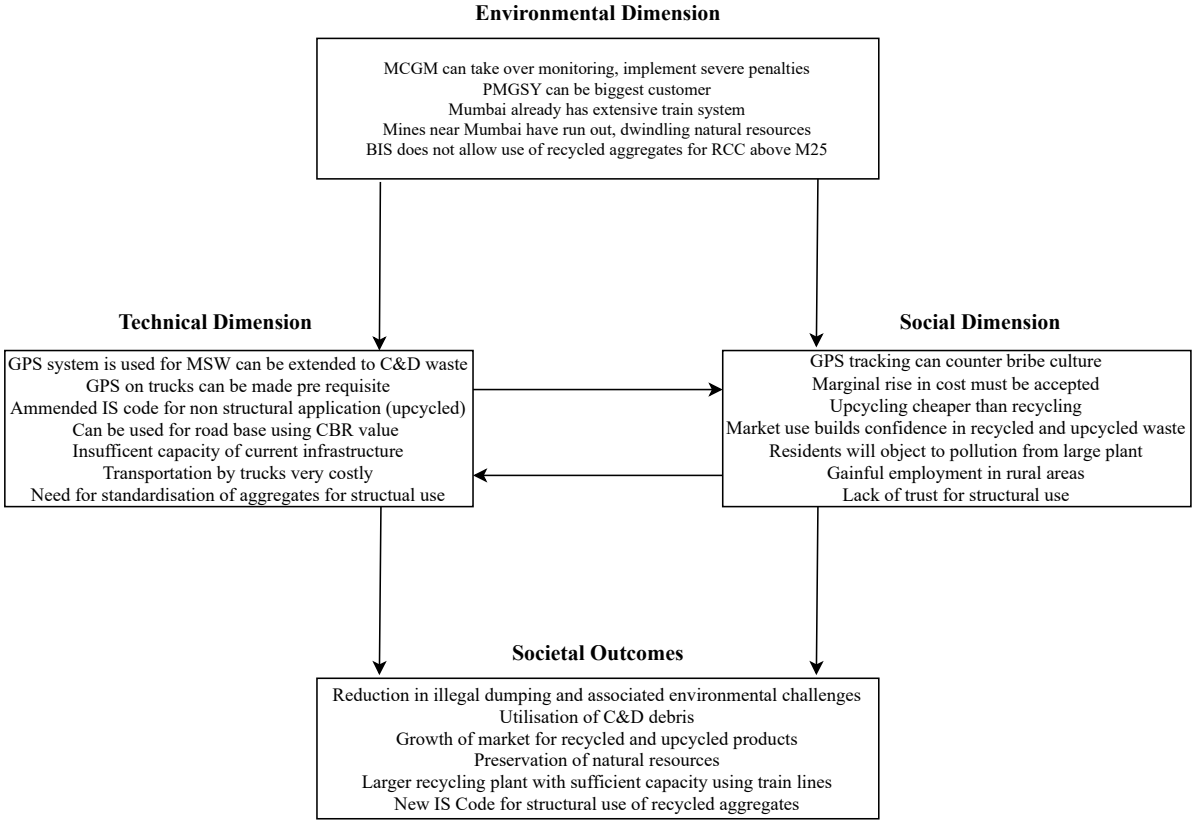

Figure 7.3: STS Theory Diagram- Phase 3

7.3. Phase 3: Advancing Utilisation and Transitioning

7.3.1. Implementing Structural Use of Recycled Aggregates

Technical Dimension	Construction in Mumbai uses RMC. RMC plants have better quality control.
Social Dimension	Without government mandate very few will utilise recycled aggregates. Lack of awareness of the importance.
Environmental Dimension	Government mandate for utilisation of recycled aggregates in projects.
Societal Outcomes	Structural use for recycled aggregates. Reduction in demand for virgin materials. Stimulation of recycling market.

Table 7.9: Implementing Structural Use of Recycled Aggregates

The first part of phase 3 involves implementing structural use of recycled aggregates. The prerequisite for this is the standardisation of recycled aggregates and the generation of an updated IS code as described in phase 2. Due to the prevalence of RMC in construction in Mumbai, the potential for the utilisation of recycled aggregates is immense.

Technical Dimension

According to interviewee 1, most of the construction today in Mumbai uses concrete from Ready-mix Concrete (RMC) plants. These RMC plants conduct their batching operations in a controlled setting, allowing for far superior quality control than on site. For this reason, RMC plants would be well placed to utilise recycled aggregates in their concrete, as long as standards for the aggregates are available ensuring their quality. Interviewee 6 highlighted the importance of ensuring the quality of aggregate, to enable its use in higher grades of structural concrete. However, initially the recycled aggregates will be more expensive compared to virgin materials.

Social Dimension

Professionals working in the civil engineering industry in Mumbai have shown the ability to adapt to the use of alternate materials. Fly ash was mandated as a partial replacement for cement and the industry has adapted to it. However, to guarantee their use, using recycled aggregates as a partial replacement for virgin materials needs to be mandated. Interviewee 4 says that the ”government needs to mandate partial replacement of aggregates with recycled ones, otherwise very few people will use them”. Interviewee 6 also highlighted that there is a lack of awareness about the importance of utilising recycled aggregates in the industry.

Environmental Dimension

Currently there are no mandates for the utilisation of recycled aggregates in the private sector. With an updated IS code allowing structural use and standardisation for the recycled aggregates, their use in projects must be mandated. Furthermore, with bigger recycling infrastructure being setup, recycled aggregates will be available in the market in required quantities.

Interaction of Socio-Technical System within its environment

With updated regulations and standardisation, construction professionals will be more likely to accept the use of recycled products in their projects (interviewee 5). This should be further harnessed by mandating their use in projects, especially through RMC applications, due to them possessing superior quality control. As per interviewee 4, certain percentage replacement of aggregates with recycled aggregates must be mandated in the industry to truly drive their use. However, it will be some time

before the economy of scale challenges as well as the streamlining of the production process will occur. Therefore to begin with, recycled materials will be more expensive then virgin materials. Therefore, the government must provide incentives to compensate that difference in costs until a time that recycled materials can be offered at comparable prices to virgin materials. These incentives should be provided to the manufacturing plants. They should be such that it allows these plants to sell recycled material at comparable prices to virgin materials profitably. This would ensure that RMC plants and private sites will at most see just marginal increase in costs from the use of recycled aggregates.

Societal Outcomes

The aim here is to ensure the use of recycled aggregates in all projects to not only encourage their utilisation but also reduce the load on natural resources. With government aid in terms of regulations and incentives, the recycling market can really thrive in Mumbai especially as rampant redevelopment not only brings demand for aggregates but also large amounts of C&D waste to produce more aggregates.

7.3.2. Phasing Out Landfilling (Soil Disposal Only)

Technical Dimension	Permit process dictates where waste goes.
Social Dimension	Lot of time landfilling is done illegally.
Environmental Dimension	Landfilling of construction debris is harmful to the environment. Government regulations are required.
Societal Outcomes	Outlawing of landfills except for soil. Mitigating harmful effects of landfilling construction debris.

Table 7.10: Phasing Out Landfilling

The last stage involves the phasing out of landfilling after alternate avenues to dump C&D debris have been set up. The landfills should only be reserved for soil dumping as other materials cause environmental challenges.

Technical Dimension

The current permit process applied in Mumbai involves the MCGM dictating where the waste will be dumped. Upon setting up the 2 recycling plants in Mumbai and a bigger one outside Mumbai, MCGM can now divert all waste to those plants. This eliminates the need for sending C&D waste to landfills.

Social Dimension

Landfilling is often done illegally in Mumbai as per interviewee 3. This not only causes ecological damage but can also be a nuisance to the residents. Mandating delivery to recycling plants and offering incentives for the delivery as planned by MCGM will eliminate landfilling and reduce the nuisance dumping brings to residents.

Environmental Dimension

A policy push is required so that landfilling is only restricted to soil. As per interviewee 2, using construction rubble as landfill has a “long term effect on the rain water recharging into earth and will change the nature of the area in the future”. Restricting landfilling to just soil, would mitigate this issue and conserve landfill areas in the long term.

Interaction of Socio-Technical System within its environment

With the permit process applied, it will be very easy to dictate where the waste ends up and eliminate landfilling through this. The addition of GPS tracking can further be used to ensure C&D waste is not landfilled but taken for recycling. This will prevent contamination of soil and damage to rain water recharging (interviewee 2). Furthermore, this also prevents loss of material that can be utilised again, as now all debris will be redirected to recycling plants. Restricting only soil to landfills will not alter the rain water recharging, which will reduce resident nuisance as flooding during monsoons will be reduced. Here, landfill owners have to take up the responsibility of ensuring only soil is allowed into the landfills in line with mandates.

Societal Outcomes

Landfilling of construction and demolition waste will be outlawed. This will help conserve raw material for recycling and prevent the harmful effects landfilling of debris brings.

7.3.3. Summary and STS Framework

Following phase 2 implementing non structural use of recycled and upcycled aggregates, there is a need to extend their use in structural reinforced concrete. For this to occur, the standardisation of aggregates and the amendment to IS 456 are important prerequisites set up in phase 2. Due to the popularity of RMC based construction in Mumbai, RMC plants must be mandated to partially replace virgin materials with recycled aggregates. RMC plants batch concrete in a controlled environment possessing superior quality control making them the prime candidate to utilise recycled aggregates. Due to economy of scale concerns and inefficiencies in the production process stated by interviewee 5, recycled aggregates are initially expected to be more expensive than virgin materials. Until such a time that the price can be brought down to be comparable to virgin materials, the government should subsidise the recycling plants so they can provide recycled materials to RMC plants and private parties at rates comparable to virgin materials. Lastly, once alternate avenues for debris disposal such as the two plants in Mumbai and a bigger one outside Mumbai are established, landfilling of C&D waste must be outlawed in Mumbai. The permit process must be used to route transit of waste to one of these plants and landfilling must only be reserved for soil as landfilling C&D waste causes environmental challenges and loss of material.

Figure 7.4 shows the STS System theory diagram showcasing the technical and social dimensions operating within its relevant environmental dimensions leading the societal outcomes proposed for phase 3.

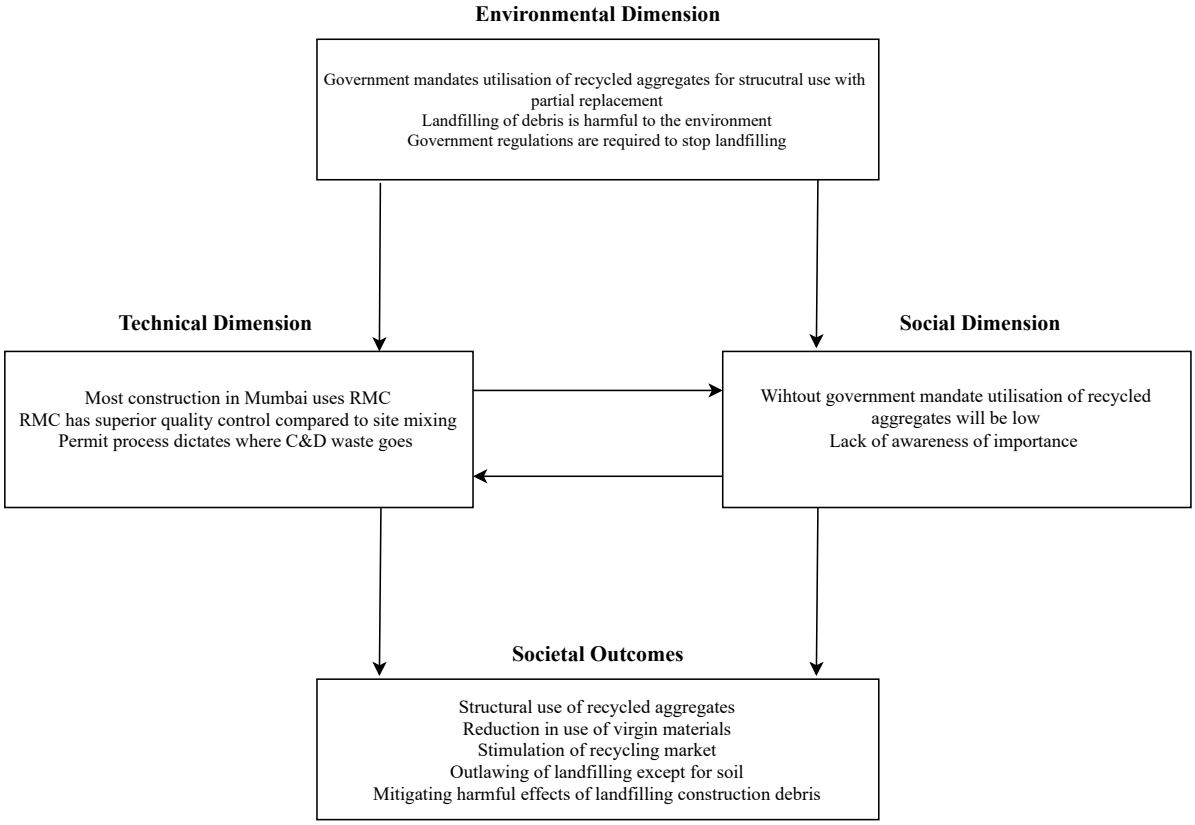

Figure 7.4: STS Theory Diagram- Phase 3

7.4. Phase Wise Solution

The societal outcomes described are actionable steps that the Government of India must take in order to improve the CDWM situation in Mumbai. The government has to drive the process as according to Smallbone and Welter (2001), in developing economies, SME's are heavily influenced by the external environment they operate in. Since the government holds power to mould the external environment that the SME's operate in, the onus lies on them to spearhead positive changes in the sector to enable a sustainable CDWM process. While the government has to spearhead the phase wise process described, The responsibility is not entirely on them with. Other actors in the industry must contribute by adhering to the new regulations and participating constructively in planned initiatives.

The technical, social and environmental dimensions were generated through interviews with actors working in SME's in the industry, along with academics to provide a theoretical base. The culmination of societal outcomes aims at improving CDWM practices in Mumbai in a way SME's will be able to participate in and contribute constructively to Mumbai's CDWM. The solution proposed is divided into phases facilitating the formulation of actionable steps to address specific problems in the CDWM landscape. Applying prerequisites for different stages, the phased approach presents a blueprint for effective implementation of CDWM in Mumbai. The phased approach takes the form of Figure 7.5 with the phases and their corresponding stages shown.

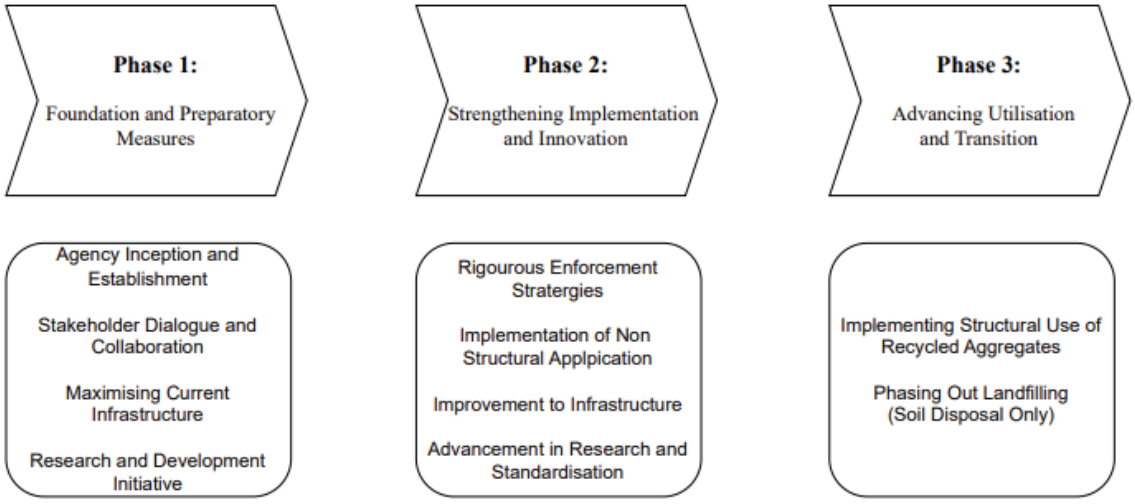

Figure 7.5: Phase-wise solution

8

Discussion

8.1. SME perspective

Revisiting the motivation behind this research, it was to explore how the construction industry in Mumbai could be transitioned to adopt effective CDWM and how SME's from the city can contribute effectively to the CDWM process. To understand this, it is necessary to first understand the specific challenges SME's in Mumbai face when implementing effective CDWM.

Through the semi structured interviews conducted with actors working in SME's in Mumbai, various issues they faced were revealed. For starters, the fragmentation in the industry means that SME's are always in intense competition with one another. This severely restricts any opportunity to implement principles to improve CDWM that would result in an increase in operational costs. It was revealed that this sector of the industry operates on low margins and any increases in cost will result in an increase in what they have to charge consumers. This results in them losing customers to other developers who might be offering cheaper options, in line with findings by Hwang et al. (2021) who state that SME's often operate with tight margins. The presence of "over-competition"(interviewee 2) in the industry means that customers will always have other options meaning they have to be very conscious of how much they charge customers.

Another issue that plagues SME's is the disproportional impact of regulations and fines on them due to size related concerns. Fines implemented in the industry have a relatively smaller impact on the overall project costs for bigger companies, due to the size of the investment and project. On the other hand, these fines can have large impacts on SME's due to their projects requiring smaller investments. However, these fines are necessary in the industry to ensure adherence to rules. Where the government can help SME's however, is the disproportional impact of regulations. Regulations regarding mandating on site sorting will not be very challenging for larger companies with access to superior technology and bigger construction sites. SME's however, can not afford access to the same level of technology, prompting most of the site work to be carried out by manual labour. Additionally, smaller construction sites prevent SME's from being able to allot sections of their sites for sorting or processing waste, giving rise to logistical issues when implementing on site sorting. Interviewee 1, an owner of an SME involved in building development stated multiple times how, most sites in Mumbai run by smaller companies are far too small to enable on site sorting. Mandating onsite sorting in some capacity is essential to improve the CDWM process. However, this mandate will make it very difficult for SME's to operate profitably in the industry. For that reason, on site sorting must be mandated but only for construction sites above a certain size to counteract the disproportional impact this would have on SMEs.

SME's in Mumbai also often suffer from a lack of awareness about the importance of CDWM. This is underpinned by a research conducted by Hwang and Yeo (2011) where waste management was ranked significantly lower than cost saving and profit maximisation by interviewees working in SME's for the Singaporean industry. This lack of awareness prevents the building of a responsible waste management culture. The lack of awareness is made worse with the lack of technical knowledge among site labours. Labours working on sites in Mumbai often lack formal education and training. This results in a lack of knowledge and awareness making them have an indifferent attitude towards waste management.

One of the key revelations from the interviews was that, SME actors are unwilling to make changes to their operating procedures without government interventions. Although these actors acknowledged the potential benefits of measures such as utilising recycled aggregates, they expressed a reluctance to adopt such practices without explicit governmental mandates. This reduces the chances of SME actors taking initiatives of their own accord and puts the onus on the government to implement desirable actions. This stems from cost sensitivity and being set in their ways of working. For this reason, any intervention that is required in the SME sector of the construction industry needs to come from the government, otherwise currently established practices will continue. This needs to change for holistic development and building awareness in the industry aims to promote participation in CDWM endeavors from SME's.

These findings about the SME perspective and reliance on the government concur with available literature. A study conducted by Smallbone and Welter (2001) address how SME's in a changing economic landscape are vulnerable to disproportional impact of regulations and market sensitivity and how government is the actor with the power to steer this sector to truly harness their strengths to enable effective economic development.

8.2. Reflection on Methodology

Case Studies

The purpose of the case study approach was to extract valuable insights and lessons learnt regarding efforts taken to improve CDWM starting from a low base. The ultimate aim of this was to furnish a list of solutions that arise from points of common ground and differences in the selected cases. These solutions served as the basis for the semi-structured interviews. This section provides a reflection of the case study methodology employed and highlights its effectiveness and limitations in achieving the objectives of this research.

The selection of the cases was a crucial first step in this methodology. Countries were chosen where their cities would have comparable contexts to Mumbai to boost the applicability of the solutions to Mumbai's context. Furthermore, case studies from more developed countries such as those in Europe, USA and Australia were avoided as the solutions implemented there might be too technologically advanced for the Indian construction industry in the present. For that reason, 3 cases were chosen namely Shenzhen (China), Singapore City (Singapore) and Hanoi (Vietnam). Each of these cases offered different perspectives and varying level of success allowing for the formulation of solutions from a larger range of perspectives.

The methodology involved first conducting a through literature study to collect information about CDWM efforts in the aforementioned cases. This was followed by extracting lessons learnt from the success and failures of the cases. These cases then underwent STS analysis to provide an understanding about how technical and governmental endeavours were affected by social dimensions such as norms, values, attitudes etc. This was done as it would later aid in the modification of the solutions to Mumbai's context.

The case study analysis yielded a wealth of lessons learnt. It was evident that successful CDWM initiatives in different cases shared some common elements. Through the analysis it was revealed that the successful CDWM endeavours contained the following elements; improving regulations to encourage desired practices and discourage undesirable practices, improving monitoring and enforcement to ensure that established rules are followed and offenders have ramifications, stimulating a market for recycled products in order to encourage participation in CDWM and boost material recovery while reducing reliance on subsides and finally improving the level of infrastructure and technology available to ensure sufficient capacity to treat all the waste generated and the technology required to process this waste is available.

While the case study approach proved instrumental in providing valuable insights and solutions, it is necessary to acknowledge its limitations. Case studies sometimes provide a frame of a specific point in time which can lead to them not capturing the dynamic nature of CDWM practices. Furthermore, biases from both the researcher and the original authors of the literature might impact that solutions that are extracted. Furthermore, with a case study approach of this nature, sometimes access to key information might be missing that can affect the data analysis. Lastly, had time permitted, more examples of cases would have been chosen for the case studies as opposed to just 3 to gain a wider range of solutions in a greater variety of contexts.

Semi-Structured Interviews

Building on the lessons learnt from case studies, this research sought to adapt the proposed solutions to the unique context of Mumbai's construction industry. To achieve this, semi-structured interviews were conducted with industry stakeholders. Interviewees were selected to ensure as many stakeholders key to CDWM as possible will be interviewed and their perspectives considered. All stakeholders selected worked in SME organisations to ensure their needs and perspectives are represented in line with the objectives of the research. Apart from this, 2 civil engineering professors were also chosen as they had ample industry experience and could provide a more theoretical and technical angle to the data gathered. This section provides an in-depth reflection on the process of tailoring solutions, highlighting key findings and insights obtained through these interviews.

The solutions identified from the case studies were discussed with industry stakeholders, keeping in mind the context of the proposed solution as well as Mumbai, in order to ensure that the solution is applicable and relevant. The collected data was analysed using thematic analysis with the main themes corresponding to the 4 dimensions of STS theory framework namely; technical dimension, social dimension, environmental dimension and societal outcomes. This was done to ensure seamless data analysis and solution generation in the next step.

Through these interviews, a wealth of context specific information was gained. Interviewees provided valuable perspectives on the feasibility, practicality and potential challenges associated with the proposed solutions from the case studies. This allowed for the solutions to be tailored to Mumbai's specific context. Some of the key takeaways from the interviews were as follows. A recurring theme observed from the interviews was the recognition of the pivotal role the government will have to play in shaping the CDWM landscape of Mumbai. The interviewees emphasised the need for effective regulatory frameworks, incentives and better enforcement measures to be implemented to drive change in Mumbai's CDWM. This validates the significance of government involvement and aligns with findings from the case studies and from literature. Furthermore, stakeholders interviewed were skeptical about the practicality of implementing advanced measures of circular engineering such as pre-cast construction and design for deconstruction. The affordability of pre-cast construction was brought up and it was the general consensus that the level of technology in Mumbai, is not developed enough to implement pre-cast construction on a large scale. Furthermore, stakeholders had a negative attitude towards design for deconstruction, exhibiting a reluctance to reuse elements from old buildings as they will deteriorate with time. This validates the decision made to ignore case studies from more developed countries, as their practicality in Mumbai is questionable. Another key takeaway from the interviews was the scale and impact of the corruption in the industry. While literature does site corruption as a major barrier in

Mumbai's construction industry, the scale of it, as understood from the interviews is larger. While factors such as bribing to escape penalties for rule breaking are consistent with literature, the interviews revealed the presence of river cleaning rackets in the industry and the level of power the wealth of the contractor lobby exerts on MCGM. Dumping of debris is intentionally allowed into the Mithi River and nallas in order to justify large tenders for their cleaning. This allows officials to line their pockets and lets contractors accept these large tenders. This level of corruption is systemic in the industry and will be very difficult to mitigate.

The interviews were invaluable in gaining insights and to modify solutions to fit Mumbai's complex dynamics. In spite of that, it is necessary to recognise its limitations. While the diversity of the stakeholders contributed to a variety of perspectives, it can also lead to clashing viewpoints and requirements that need to be resolved. Furthermore, data collected from the interviews can often be subjected to biases that the interviewee holds and can be subject to a "someone else will fix it" line of thinking. Another limitation is the scope of the study. As the study focused on the SME perspective, the actors chosen were all working in SME's. However to gather a more complete understanding on the industry and the measures necessary to improve CDWM the perspective of stakeholders from bigger enterprises would have also been valuable. However, due to restriction of scope and time the interview process was restricted to stakeholders from SME's. Moreover, due to the criticality of the government as an actor, it was desirable to interview a representative from the MCGM. However, it was not possible to obtain an interview with an officer who would speak candidly about issues such as corruption, slum and river rackets etc. For this reason, government representatives were not interviewed to ensure collected data remains as authentic as possible.

STS Framework Application

STS theory was used as the analytical framework in order to unravel the interplay of technical and social dimensions within its relevant environmental dimension. This led to the generation of societal outcomes which serve as solutions for the CDWM problems in Mumbai. The interviews taken before, produced insights into how the economic and technical factors of CDWM within the city such as waste disposal technologies and procedures, regulatory frameworks and waste sorting interacted with the social aspects such as norms, attitudes and perceptions. This section provides a reflection on the STS theory analysis applied to the data from the interviews.

One of the key takeaway from this analysis was the importance of economic viability for any measure proposed. In Mumbai, economic viability was seen to be the foremost consideration. This is in line with research conducted by Vilventhan et al. (2019) where they cited cost as the most important parameter in Indian projects. For this reason, any new rule or measure that the government poses needs to be made economically viable to encourage its adoption. This is especially necessary for recycled construction material as economy of scale challenges and the presence of Goods & Service Tax (GST) would ensure they are more expensive compared to virgin materials. Encouraging their adoption needs subsidising by the government until economy of scale challenges are solved and GST is removed. Moreover, the analysis also highlighted the poor ingrained attitude in the industry towards recycled materials. There were reservation regarding if it will even be possible to produce recycled aggregates of good enough quality to be used in structural works and there was skepticism regarding their application for main roads in Mumbai. This stems from ingrained values and from the lack of exposure to good quality recycled materials. A lot of work is necessary in this aspect to build a trust among industry players regarding the quality, viability and potential of recycled materials.

The application of STS theory framework proved to be pivotal in connecting theoretical understanding to practical action. Dissecting the interplay of technical and social dimensions within their relevant environment resulted in the generation of nuanced societal outcomes geared to Mumbai's dynamic CDWM environment. However, it is necessary to investigate the limitation of this methodology. The first limitation stems from the nature of the research. Due to its qualitative nature, the research can be prone to subconscious biases stemming from the researcher or the interviewees. Furthermore, the inherent complexities in Mumbai's construction industry can lead to an oversimplification of certain aspects for the purpose of the analysis. The most notable aspect of this is corruption. The problem of

corruption has been simplified to a certain extent for the purpose of solution generation, however, in reality, the corruption is deeply ingrained in the fabric of the industry and rooting it out would require long term efforts beyond the scope of this study.

8.3. Solution

8.3.1. Practicality of Proposed Solution

In order to address the intricate challenges associates with CDWM in Mumbai, the creation of a phased plan emerges as a strategically significant approach. The problems of waste management in Mumbai are multifaceted and need a comprehensive strategy that takes into consideration the interplay of technical, social and environmental factors. Adopting a phased plan is necessary in order to systematically tackle the complexities by breaking down the problem in manageable stages. This approach will not only address immediate problems but also sets up a logical sequence for long term improvements to Mumbai's CDWM process. This allows for the navigation of the complex dynamics associated with CDWM such as stakeholder interests, resource scarcity, outdated regulatory frameworks, etc. Additionally, using a phased approach ties in well with the STS theory approach which includes examining the interplay of social and technical dimensions within their environment to create societal outcomes. This alignment will ensure that the emerging solutions embody a holistic approach to CDWM. Furthermore, a phased plan not only presents a structured road map that provides specific interventions but also acknowledges that certain steps are pre-requisites for the successful implementation of subsequent actions. This ensures that the proposed solutions are not only isolated steps but form a cohesive, adaptable and interdependent framework that aims to promote sustainable and holistic waste management. Lastly, implementing all the required measures simultaneously can potentially encounter resistance from industry actors who are set in their ways of working. The phased plan allows this resistance to be addressed by demonstrating incremental improvements in each phase and allowing for gradual adjustment to new practices, thereby enhancing the likelihood of successful adoption of the measures. This ties in well with research conducted by Kern and Smith (2008) and Chishti et al. (2023) advocating the use of a phased approach when faced with transition projects.

8.3.2. Reflection on Solution

The following section delves into the phase wise solution designed to address the CDWM problem that Mumbai faces. The phased approach is tailored to Mumbai's dynamic waste management landscape and offers a systematic road map dividing the challenges into feasible segments which promote cohesive progress towards sustainable societal outcomes. Each of the phases are designed to examine the interaction of technical and social dimensions within their relevant environment, within their relevant phase to provide effective C&D waste management solutions for Mumbai. Applying a phased approach, presents the overarching narrative of gradual transformation of the CDWM process in Mumbai that this thesis aims to accomplish.

Phase 1: Foundation and Preparatory Measures

Phase 1 aims to implement the building blocks that are necessary to introduce improvements to the CDWM process in Mumbai. Without first setting up a strong foundation, implementation of measures would be haphazard. This section reflects upon phase 1 of the proposed solution.

The first step of phase 1 titled as "Agency Inception and Establishment"emerged from the analysis as a need to set up a body to oversee the implementation of CDWM in Mumbai. This is in agreement with existing literature as assigning civil bodies to oversee implementation were important first steps in

Shenzhen, Singapore and Hanoi. Discussions with industry stakeholders revealed that MCGM would be the most suitable body to oversee the implementation despite its corruption issues. This was unexpected as a history of corruption in MCGM makes them undesirable candidates to oversee CDWM. However, since corruption is ingrained in most governmental bodies MCGM was chosen for its tendency to operate in a systematic way. Furthermore, setting up an entirely new governmental organisation creates many regulatory issues that would not occur if MCGM was kept as the body responsible for implementation. MCGM currently considers C&D waste to be a part of MSW. However, the quantum of C&D waste generated in Mumbai means there is a need to set up a separate body within the MCGM to oversee its implementation. Hiring of more scrupulous officers has been suggested as a measure to counter corruption, however, this is difficult to implement in practice due to the intangible definition of a more scrupulous officer. Lastly, MCGM uses GPS enabled trucks to transport municipal sewage and the same technology needs to be extended to CDWM. This agrees with literature as GPS tracking emerged as a premier solution to curbing illegal dumping in Shenzhen, China.

The next stage involves holding discussion rounds between the newly set up body and representatives of the key stakeholders in the industry. Due to a poor attitude towards waste management, discussions are necessary to increase awareness and to establish policies such that the key stakeholders are incentivised to participate in effective CDWM. This is especially important here to reduce the tendency to form river cleaning rackets in Mumbai. Offering contractors incentives to correctly dump C&D waste will result in them being less likely to be involved in the river cleaning racket. However, due to the benefits that corrupt officers get from this and the sheer size of the river cleaning contracts, this will be very difficult to eradicate just through incentives. The only solution for this according to interviewees is more ethical officers. This is however difficult to implement in real life and dumping of C&D waste in the Mithi river will persist albeit to a smaller scale if enough contractors are satisfied with the incentivisation schemes. For this reason, it is essential that the key stakeholders have representatives present for the discussions so they can be consulted on the nature of incentives required. The aim of this stage is to furnish a list of regulations, incentives and punitive measures following the carrot, stick and sermon policy suggested by interviewee 2 where incentives are offered against a set on punitive actions. These punitive actions have to be large enough to truly impact project costs as that is the most important parameter for construction projects in Mumbai. Furthermore, it is important to include the representatives of the major stakeholder to examine how each stakeholder will contribute to CDWM in Mumbai.

MCGM is currently in the process of building 2 construction debris recycling plants on the outskirts of Mumbai. While their capacity is inadequate for the quantum of waste produced, stage 3 involves maximising their utility for the following reasons. The presence of debris recycling plants in densely populated cities like Mumbai presents a tremendous nuisance to residents of the city. For this reason the Supreme Court of India will block any attempts to build a debris recycling plant within the main city. Furthermore, exorbitant land costs dictate that the plants can only be built on the outskirts of the city. Interviewee 2 advocates for the utilisation of sorted construction debris as a road base material and as a replacement for murum and rubble. This not only reduces costs associated with producing the material but provides a significant avenue for the absorption of debris. The government aims to handover the plants on completion to private sector parties for operations. This is in line with existing literature as recycling industries run entirely on government expenses is not sustainable in the long run (Bao and Lu, 2020). However, due to the lack of a recycling market available, the government needs to provide purchase guarantees to these companies for a certain quantity of their products to utilise in infrastructure projects. Their use in infrastructure projects first is recommended due to the effect it will have on the private sector to build trust. Building trust in the private sector towards recycled or upcycled waste products will help create a thriving recycling market in the long run. The government also plans on paying contractors for each tonne of debris they bring, which not only offsets transportation costs but also provides a good incentive to avoid landfilling.

The last stage of phase 1 involves increasing research and development efforts regarding CDWM. Combined research between educational institutes and industry, will result in a greater awareness regarding the importance of CDWM among future professionals. The onus should be on the educational institutions and the recycling plant runners to conduct research into recycling technology. Additionally,

researching additional use cases for upcycled debris will boost material recovery. There is a need to update the IS code to allow for this. This is essential not only from a legal standpoint, but the inclusion of upcycled debris in the IS code will help build confidence in industry members regarding their applications. Bureau of Indian Standards must take responsibility for this and update the code through research with technical universities. Without building this confidence, offering upcycled debris at prices cheaper than murum and rubble would still be met with apprehension due to an inherent distrust of ”waste” in the industry. Furnishing updated technical regulations and building trust through use in infrastructure projects are important steps in the right direction for ultimately establishing a thriving market for recycled and upcycled products.

Phase 2: Strengthening Implementation and Innovation

Following the building blocks being established in phase 1, phase 2 aims to begin the implementation of CDWM in Mumbai. This involves strengthening enforcement, implementing non structural use of recycled or upcycled debris, improvements to infrastructure and advancing research. The following text reflects on the measures implemented in phase 2.

The first stage of Phase 2 involves curbing of illegal dumping in the city, as it is one of the biggest issues plaguing the industry. However, corruption here plays a huge role as it is the means employed to get away with illegally dumping waste. While incentives offered for bringing debris to the recycling plants will offset this to some extent, the corruption of the officers and wealth of the contractor lobby will ensure that incentives, among themselves, are not enough. Using GPS tracking in conjunction with SCADA will circumvent this to some extent. The chief reason for this is that GPS data can be accessed by any officer at any time. This means that offenders can be apprehended even after dumping has already occurred. This reduces the chances on contractors getting away with dumping. This coupled with increased fines should deter undesirable behaviour to a certain extent. Furthermore, it brings up a situation where contractors might have to bribe several officers to get away with illegal dumping which is not sustainable to them. While it is worth acknowledging that this will not completely stop the problems of illegal dumping and corruption in the industry, it is one of the best methods to significantly reduce them.

Stage 2 of the second phase is centered around implementing non structural use of recycled and upcycled debris. With an amended IS code to enable and guide this implementation, this holds tremendous potential for debris absorption and reduction in demand for natural materials. Due to village roads carrying lower loads, this debris can be utilised in road base construction based on their CBR value. Basing their use on recognised technical parameters boosts confidence in their use in the industry, further improving the attitude towards recycled and upcycled debris. It was decided to first mandate non structural use, as structural use requires superior quality of aggregates, which are not reliably available in the market. Their use must be mandated in infrastructure projects inside and around Mumbai. This not only provides business to the recycling companies, making it a profitable endeavour, but is also an important step in establishing a thriving recycling market that can eventually function without government subsidies.

As previously discussed, the infrastructure for waste processing in Mumbai is inadequate. This creates a need to build additional infrastructure if Mumbai is to ever truly move away from the landfilling model it currently employs. However, previous discussions have highlighted that situating the new plant inside Mumbai is fraught with issues such as resident nuisance, exorbitant land value etc. However, building a plant far outside Mumbai in the less densely populated rural areas incurs very high transportation charges for transporting material to and from the plant. An interesting solution for this emerged through discussion with the stakeholders that involves making use of Mumbai’s well established local train systems. This takes away the expensive transits as now debris can be dropped off at collection centres based near the rail lines, to be taken by train to the new plant to be set up, and the same train can bring back recycled materials with it. This system allows a large plant to be set up away from the city, that will have sufficient capacity for current and projected future needs. Furthermore, an added benefit of this will result in job creation for people living in rural areas, providing gainful employment and reducing

the need to migrate to Mumbai for jobs, which further reduces the load on Mumbai's infrastructure. The aim here is for the construction of the plant to be completed by the time phase 2 concludes.

The final stage in phase 2 includes advancing research to enable structural use of recycled aggregates. When it comes to structural use, trust from industry stakeholders is far bigger consideration compared to non-structural use. For that reason, non structural use was prioritised. In order to enable structural use, a serious overhauling of IS 456 is required as presently it does not allow structural use above 25 MPa. However, in order to enable this, the standardisation of the aggregates is important. Introducing standardisation of recycled aggregates will contribute well to building trust due to the presence of technical data sheets for the aggregates and will enable their structural use through an updated IS code. This stage aims to set up the pre-requisites for mandating structural use through establishing standardisation of aggregates and amendments to IS 456. Through this, the government will be in a place to harness the improving attitudes towards recycled and upcycled materials from previous efforts. This would allow them to establish a thriving market for recycled products and enable structural use starting in phase 3.

Phase 3: Advancing Utilisation and Transitioning

Following phase 2 strengthening enforcement, implementing non structural use of debris, improving infrastructure and advancing research and innovation, phase 3 aims to conclude the phased plan. Due to the previously laid steps, phase 3 then focuses on implementing structural use of recycled aggregates and phasing out landfilling.

Phase 2 included introducing standardisation in recycled aggregates and an updated IS code to allow structural use of recycled aggregates for higher grades of concrete. These were a pre-requisite for implementing structural use of recycled aggregates in Mumbai. Partial replacement of natural aggregates with recycled aggregates in concrete, complicates the procedure of concreting and calls for the need for higher levels of quality control, therefore, it was decided that mandating it for use through site mixing would be inefficient and raise objection from stakeholders. Furthermore, the new or updated IS code for recycled aggregates may require the mix-design procedure to get altered slightly, making implementing site batching and mixing difficult as site workers will need new training for it to work. This would be especially problematic for the SMEs as appointing more skilled labour comes with its associated increase in costs. However, according to interviewee 1, most of the construction in Mumbai today happens through the use of concrete from RMC plants. This provides the ideal avenue for enforcing partial replacement of natural aggregates with recycled aggregates. Batching and mixing at a RMC plant take place in a controlled environment. This allows for far superior quality control and would be well suited to absorb recycled materials. However, until all the economy of scale concerns and inefficiencies in the recycling process are ironed out, recycled aggregates will me more expensive than natural materials. This would seriously hamper the adoption of recycled materials and mandating their use in RMC plants will cause them to lose business to site mixing. However, this can be addressed by the regional government by subsidising the 3 recycling plants in a way that allows them to sell recycled aggregates at the same price as natural materials. This would mean RMC plants will only see a marginal rise in costs and allows for utilisation of recycled aggregates in the industry.

Mumbai has a large daily requirement of concrete and this would be an excellent avenue to absorb recycled debris. Furthermore, with the constant development-redevelopment cycles in Mumbai, this business is only likely to grow. This would make the recycling industry thrive, as they can sell large quantities of recycled and upcycled construction materials to RMC plants and the government for infrastructure projects. Offering pre-mixed concrete with recycled aggregates and mandating their use in the industry, without adding significantly to the cost to the developer, will result in relatively easy integration of the private sector and SME's in the recycling market. This would eventually allow for the 3 plants to become self sufficient allowing the government to scale back on the subsidies.

The last step of the phased plan is to outlaw landfilling. Once the capacity of the plants to accept C&D waste has been raised to the required levels, landfilling of C&D debris should be outlawed. Landfilling of debris not only causes a loss of usable material but also damages the water absorption capacity of the land and can poison the groundwater. Additionally, landfilling requires large parcels of land and in a city like Mumbai, with extremely high population density, it is highly desirable to not allot large parcels of land for landfilling. Therefore, C&D debris should be restricted to only the recycling plants and the permit process along with the GPS tracking can aid in that. Some landfills should still be kept operational but should be restricted to only accepting soil as that does not damage the environment.

The final end state envisioned for the industry is as follows. The permit process will dictate which recycling plant or collection depot the debris will go to and GPS tracking will be used to ensure that it is followed. This will result in a serious decrease in illegal dumping in the city. The incentives offered by the plants for delivery will ensure this is a lucrative avenue for SME's, prompting their adherence to established rules. The recycling plants will produce upcycled debris and recycled aggregates and other materials such as paver blocks for sale in the industry. The sale of material through these government approved plants will offset the problem of cartelisation, ensuring material is available at the right prices and of the right quality. The research and development done before will not only ensure that technical regulations are available governing their use but also that good quality of material is available in the industry. Overtime, the recycling plants will solve problems related to economies of scale and inefficiencies as their businesses grow, which would bring down their production cost, allowing the government to scale back subsidies in an effort to make the recycling market self sufficient with the government only participating as a customer for infrastructure projects. The sustained use of recycled aggregates in projects by the private sector, availability of technical specification guaranteeing their suitability and their use in governmental projects will eventually result in bringing down the stigma regarding recycled material and lead to their acceptance in the industry. This is especially important for SME's as that part of the sector has higher aversion to recycled material and is harder to govern necessitating their acceptance of recycled aggregates as a viable alternative to natural materials. Lastly, the outlawing of landfilling will further reduce loss of valuable materials and reduce the environmental impact of the construction industry. Through the above discussed method, the author hopes that the construction industry in Mumbai can be transformed in a way to reduce their ecological footprint. Through the participation and contribution of the government sector, the private sector and SME's the construction industry in Mumbai can be put on the right path to contributing to the economic growth in Mumbai in a relatively sustainable way.

8.4. Contribution to Literature

Mumbai stands out as a significant generator of C&D waste in India, generating more C&D Waste compared to any other city (Aggarwal, 2019). However, it is largely omitted from literature. Therefore, a notable contribution of this thesis is that it addresses this gap and adds to the existing literature regarding barriers for CDWM in India. Moreover, it contributes through the generation of knowledge regarding solutions for CDWM problems in Mumbai. Currently available literature is centered around identification of barriers, whereas this research aims to broaden the discourse by proposing actionable solutions. Additionally, the STS theory analysis conducted showcases how cultures and attitudes in developing countries can impact their industries and serves as a foundational framework that can guide research regarding the impact of cultures, attitudes and norms on industries.

This thesis also adds knowledge regarding the problems SME's face in the construction industry and how they can be enabled to effectively contribute to CDWM. This has been largely unexplored in India and one of the objectives of this research was to bridge that gap. Importantly, this research has implications beyond India due to many developing countries worldwide possessing unorganised construction sectors. Understanding the unique needs of these sectors is necessary to harness their potential for economic development and would be of interest to the governments of these nations.

CDWM is currently at a nascent stage in many developing countries, where conventional linear economy principles often prevail, with time and cost targets often dominating the industry. Through this research, the author aims to establish a foundation for further investigation into CDWM for developing countries, with the aim of discouraging the persistence of linear economy principles. This, in turn, can contribute to sustainable waste management practices in line with global environmental goals.

8.5. Research Limitations

While this study offers valuable contributions, it is imperative to acknowledge that it is not without limitations. The following section addresses these limitations which encompass the contextual specificity of the findings, challenges in accessing candid perspectives from government officials and potential biases inherent to qualitative research.

This research is catered to the construction industry in Mumbai and completely geared to its unique context. Implementing the proposed solutions to any other city would require considerable modifications to align with the distinct characteristics and challenges of that new context. Additionally, Mumbai being the financial capital of India is different from most other cities in developing countries in terms of availability of governmental and private sector funds. For that reason, some solutions suggested in this research would be difficult to replicate elsewhere due to a lack of financial resources.

Moreover, while this research presents a phased plan that will have to be run by the MCGM with active participation from other stakeholders, providing solutions for improving CDWM and enabling SME participation, it was desired to gain the perspective of government officers on the solutions presented in an effort to validate them. However, unfortunately, it was not possible to interview a government officer who would speak candidly on issues such as corruption and river cleaning and slum building rackets that exist in the country. For that reason, MCGM officers were not interviewed to ensure authenticity and reliability of information gained. This does however, impact the applicability of the solution and it would ideally be presented to ethical and transparent government officers in the future to enhance its credibility.

Lastly, due to the qualitative and exploratory nature of the research, the findings are based on perceptions and interpretations. There is a possibility of subconscious biases introduced by both the interviewees and the researchers. Additionally, the STS theory analysis and solution generation is based on the researchers interpretation of the gathered data and has the potential to contain biases the researcher might harbour.

In conclusion, this research undeniably offer valuable solutions for improving the state of CDWM and enabling SME participation in developing cities. However, the aforementioned shortcomings highlight the need for continued efforts in research and validation to achieve a more complete understanding of CDWM problems in developing countries and fortify the reliability of the solutions offered.

9

Conclusion

This research aimed to explore how the construction industry in Mumbai can transition towards the adoption of effective CDWM. Additionally, the research also aimed at investigating how SME's can be enabled to participate in and effectively contribute to CDWM in Mumbai. Results from this research suggest a phase-wise implementation plan in order to transition the industry. The plan adopts an inclusive approach suggesting measures to improve CDWM not only by improving the regulations, infrastructure, processes and technologies but also considering the unique set of challenges that SME's face. This results in the solution considering measures that allow for SME's participation without affecting them greatly in terms of their cost targets. The research was steered through the main research question, "How can the construction industry in Mumbai transition towards the adoption of effective construction and demolition waste management (CDWM): from the perspective of SME's?".

To answer this, a literature review was conducted followed by a study of cases in Asia with comparable contexts to Mumbai where CDWM efforts were made. This was then followed up with semi-structured interviews with stakeholders working for SME's involved in CDWM in Mumbai. Thematic analysis was conducted on the interview findings to decipher them followed by the application of STS theory framework in order to generate solutions.

To answers the main research question, sub-research questions were curated to aid in the research. The answers to these sub-research questions are essential to understand before the main research question can be answered. Each chapter of this report contains insights and works towards answering these research questions. The findings from each chapter are consolidated in the following section in order to answer the research questions.

SQ1: What is the current state of CDWM employed by SMEs in Mumbai's construction industry?

Mumbai has the highest daily rate of C&D debris generation in all of India, however, no reliable data is available regarding the actual quantity. The current CDWM process in Mumbai begins with the issuing of a permit for waste management. This permit is issued by the MCGM and requires the developer to furnish the quantities of waste to be created and a letter from the landfill owner that they can absorb that quantity of waste. Construction or demolition work can only begin once the permit has been issued. This permit is insured against a bank guarantee of $ 6200 which would be forfeit if the developer fails to dump the waste at the designated landfill.

Following the granting of the permit, demolition work begins and it involves the sorting out of all materials that have salvage value associated with them (Sohal et al., 2022). This includes most of the materials such as timber, steel, plastics, fittings. pipings etc. The remaining waste is chiefly a mixture of concrete waste and soil and this is supposed to be dumped in landfills. The lack of recycling infrastructure in the city also lends itself to landfilling being the only official destination for C&D debris. However, due to landfills being located on the outskirts of the city, dumping is often done illegally at night in locations

closer to the site to avoid the long transit charges associated with hauling the waste to the landfill. This creates nuisance to residents, environmental pollution such as destruction of mangroves and a loss of material leading to the consumption of more virgin materials in future projects. Furthermore, the long standing bribe culture allows for agreements to be made between landfill owners and contractors to furnish the challan to ensure the bank guarantee is not forfeit.

Furthermore, the prevalent culture present in the industry does not lend itself to the creation of a responsible waste management culture. Due to the lack of a salvage value associated with concrete, it is usually dumped illegally or into landfills. Additionally, there is a tendency in the Indian market to view recycled materials as inferior further hindering their adoption in the country. Lastly, the drive to save costs is inherently present in the Indian culture which further hampers the adoption of effective CDWM principles that will result in an increase in costs. In conclusion, the current process is suitable on paper up to the permit stage, however, a lack of enforcement means that beyond this stage, the industry is largely unregulated and results in illegal dumping, poor material recovery and environmental destruction.

SQ2: What are the relevant barriers and actors involved in CDWM in India?

In order to understand why the adoption of effective CDWM has suffered in India, and by extension Mumbai, it is necessary to understand what barriers are present in the industry. The adoption of effective CDWM has been slow due to a number of barriers such as; low levels of infrastructure; lack of knowledge, technology and awareness, lack of governmental support, mindset issues stemming from cultural factors, lack of effective enforcement, fragmentation in the industry, supply chain issues and corruption from officials.

The fragmentation and lack of governmental support lead to the creation of an industry that is intensely competitive, which leads to time and cost being the main concern for any civil engineering project especially in the real estate sector that is dominated by SMEs (Kamma and Jha, 2022). Concerns regarding waste management are usually secondary or they are not paid attention to. Furthermore, the corruption in the industry among government officials has led to the creation of a bribe culture which promotes rules breaking among industry actors. This is further augmented by a lack of effective enforcement of CDWM rules which makes it easy to get away with flaunting rules. This is further exasperated by a lack of knowledge and awareness about the importance of CDWM and a lack of incentives for participation. These factors lend themselves to create an industry where intense competition necessitates the prioritising of time and cost parameters, especially among SMEs, in order to survive and remain competitive in the industry. All other factors that lead to an increase in costs are assigned low priority, with the industry finding loopholes around aspects such as effective CDWM which is enabled by the lack of enforcement and bribe culture (interviewee 3).

The supply chain for C&D debris, virgin materials and recycled materials are largely unregulated due to the lack of enforcement which introduces unnecessary inefficiencies and most importantly cartelisation. This cartelisation leads to inflated prices for materials and the sale of poor quality materials that would have otherwise been rejected. Finally, the lack of sufficient infrastructure for waste management also means that even stakeholders keen to recycle their debris are often left with no avenue to do so, forcing them to opt for landfilling.

The aforementioned barriers all lend themselves to destabilising the industry and prevent the adoption of effective CDWM. Through this research, it was revealed that, out of all these barriers the fragmentation of the industry, the lack of enforcement and corruption have the greatest impact on the industry. The fragmentation, especially in the SME sector, creates an intensely competitive environment necessitating a keen focus on time and cost. Due to the fragmentation, stakeholders often do not have the luxury of pursuing more sustainable methods if they are to remain competitive in the industry. It also makes that sector notoriously difficult to monitor and govern due to the sheer number of enterprises present. Furthermore, the lack of enforcement not only makes existing rules and regulations ineffectual but also enables industry stakeholders to operate in ways which allow them to cut time and cost whilst disregarding regulations. Finally, the most significant barrier to the industry is the systemic corruption

that is prevalent in the industry. Corruption can cause any rule, regulation and enforcement method to be disregarded and allows offenders to escape punitive measures by lining the pockets of officials. While better enforcement methods can, to a certain extent, circumvent the problem of corruption, it can not be completely eradicated from the industry. Hiring honest and scrupulous officers is a way to counter corruption, however, it is extremely unreliable as it is very challenging to guarantee the honesty of an officer. Digitising the entire supply chain and CDWM process has emerged as a valid counter measure to battling corruption in more developed countries, however, the Indian construction industry is not placed to adopt significant technological advents in the near future(interviewee 5).

In addition to the barriers, it is necessary to understand what actors are involved in the CDWM process in India. The chief actors involved are the government, developers and contractors. The government are responsible for regulating, monitoring and promoting CDWM in India. Additionally they are also responsible for setting up the infrastructure required for waste processing and recycling. They are responsible for setting CDWM goals at the national level and to ensure that their jurisdictions operate towards these goals at the regional and municipal level. They are heavily involved in setting up the environment that the industry operates in, however, within the actual CDWM process they are absent past the permit stage. There is a real desire from industry stakeholder for the government to involve themselves further beyond just the permit stage to ensure CDWM is improved in India.

Project developers are the project owners and the people who run the project. They supply the money and retain maximum control of the project. They are responsible for ensuring that CDWM is effectively enforced on their site and strive to minimise the waste generated. They are responsible for taking decisions and would need to be enabled to incorporate effective CDWM in their projects without greatly impacting project cost and time parameters. The last key actor is the contractor. Depending on the type of project they can either be a general construction contractor or a specialised demolition contractor. Smaller projects will opt for the same construction contractor involved to carry out demolitions while larger projects will opt for specialisation in these aspects. The contractors are responsible for carrying out the demolition in a safe and sustainable way along with sorting out material with any salvage value. Furthermore, once the trucks with debris leaves the construction site, the developer is unaware of what happens to it. The onus is on the contractors to ensure the waste reaches the allotted landfills. In order to save costs, contractors will often dump the waste illegally. Furthermore, large contracting companies will dump debris into rivers in order to justify a large tender before the monsoons hit. This racket involves both the contractor lobby and corrupt government officials (Interviewee 2).

Apart from these 3 key actors, various actors directly and indirectly are stakeholders in CDWM in India. Site engineers are responsible for supervision on site and should aim to minimise waste produced on site. The client has decision making powers and should choose to work with developers and contractors they know to be reliable to ensure the correct CDWM process is followed. Consultants make up the architects and structural engineers. They are responsible for calculating the quantity of debris to be generated for the permits and design the structure safely to ensure using recycled materials concrete can be done without increasing risk of failure of structural members. The customers are the ones who buy the structures of the developers and hold soft power to ensure CDWM processes are followed by choosing to do business with developers with a history of honest operations. This is however rarely considered, as a customers first priority is a reduction in the cost they have to pay. Waste-recyclers are the companies who will run the recycling plants and they aim to produce good quality recycled and upcycled materials to sell in the industry. They need government support for the foreseeable future due to economy of scale concerns and due to inefficiencies in the currently available technology. The last actor relevant to CDWM are the academics and their responsibility is conducting research into superior technologies and processes, Furthermore, they are responsible for the education of the future engineers who will enter the industry and have a responsibility to ensure they understand the criticality of CDWM.

While the government, contractors and developers play a larger role in the CDWM process in India, all actors contribute in their own way and are all necessary to improve CDWM in India.

SQ3: What can be learnt about the implementation of CDWM from case studies sharing comparable contexts to Mumbai?

In light of the gap in existing literature regarding solutions for CDWM within Mumbai's construction industry, this study aimed to draw inspiration from comparable contexts in Asia. Specifically, Shenzhen, Singapore City and Hanoi were chosen as case studies offering valuable lessons and insights from their own CDWM endeavours. The methodology extended beyond a mere transfer of solutions as it sought to ensure seamless integration of these solutions into Mumbai's industry fabric. Stakeholder interviews were employed, engaging stakeholders involved in Mumbai's CDWM. This served as a way to adapt international best practices to Mumbai's unique context through the experience and knowledge of industry stakeholders. The culmination of this methodology yielded a curated set of solutions categorised into 4 categories. The following section delves into these solutions that were extracted from the case studies.

The first solution category deals with **improving regulations through strong governmental interventions**. As per the STS theory framework, the interaction of the technical dimension and social dimensions will only be effective if the environment within which the industry operates is conducive to enabling this interaction. The government has the responsibility to create an environment that enables effective CDWM and that can be done through improving regulations and policies. The first important solution that emerged, was necessitating showing waste generation estimates and sufficient waste disposal capacity as a pre-requisite for the permit process. This not only forces industry members to consider waste management early in the project life cycle but also helps create estimates for C&D waste generation rates. Additionally, discouraging landfilling also emerged as a vital step with Shenzhen and Singapore outlawing it and increasing disposal charges respectively. This is necessary to force contractors and developers to explore alternate avenues for waste disposal. However, here it is essential to consider the governmental context for these regions. In case of autocratically governed regions such as Shenzhen and Singapore, swift enforcement was possible. Conversely, in Mumbai and Hanoi, implementing a ban on landfilling can further increase illegal dumping due to the absence of a fully integrated waste management infrastructure. Furthermore, both Shenzhen and Singapore ensured competence in the CDWM supply chain by introducing licences for waste handling. However, in cities like Hanoi and Mumbai where a significant portion of the labour lack formal education and training, implementing licensing measures can be a potential disruptor to local employment dynamics.

The second solution category that emerged was **improving monitoring and enforcement**. Implementing new regulations and policies will be largely ineffective without proper enforcement. In fact, a significant contributor to Shenzhen and Singapore's success stems from employing effective monitoring and enforcement. Conversely, the lack of effective enforcement in Hanoi and Mumbai is a core contributor to CDWM problems, a phenomenon underscored in existing literature as well. Notably, studies by Nagapan et al. (2012) and Lockrey et al. (2016) underscore the pivotal role of enforcement in Singapore's success and Hanoi's struggles, respectively. Enforcement measures have included implementing severe penalties to encourage rule adherence. Additionally, implementing a body with legislative autonomy emerged as an essential solution in Shenzhen and Singapore. In fact, the lack of autonomy of URENCO has been cited by Lockrey et al. (2016) as a key reason for failure of enforcement in Hanoi. Furthermore, Shenzhen implemented GPS tracking of trucks carrying debris to crack down on illegal dumping. This has emerged as the most effective counter measure to illegal dumping and one of the key reasons for the success of CDWM in Shenzhen. While the autocratic governments of Shenzhen and Singapore will find enforcement easier, cities like Hanoi and Mumbai can still improve enforcement through measures such as establishing autonomous bodies, GPS tracking and implementing heavy economic penalties and stop work orders for rule offenders.

A key measure to improve CDWM emerged as the **establishment of a thriving recycling market**. This is essential as a market reliant entirely on governmental subsidies has been stated to be unsustainable in the long run by Bao and Lu (2020). This was achieved in Shenzhen and Singapore by offering monetary incentives to promote production and utilisation in the private sector. Furthermore, Shenzhen and Singapore implemented the use of recycled materials in government projects to ensure that recycling companies had avenues to sell their products in the market. Lastly, Shenzhen also en-

courages research between universities and recycling companies in order to increase the variety of recycled materials in the market encouraging price flexibility. The setting up of such a market was not possible in Hanoi due to a lack of sufficient recycling capacity, suggesting improved infrastructure to be a pre-requisite for this measure. This is fortified by the fact that in Mumbai, the municipality is prioritising the setting up of required infrastructure with 2 plants already under construction.

The last solution category that emerged from the case studies was the **improvement of technology and infrastructure**. As discussed above, setting up the required infrastructure is key before regulations for CDWM are passed. This is seen with both Shenzhen and Singapore implementing recycling centers and Waste to Energy plants before restricting landfilling. This strategic sequencing of actions highlights the pivotal role of infrastructure development as the foundation upon which sustainable CDWM practices can be built. Additionally, both cities encouraged combined research between industry and universities in a bid to improve the technology available. This is a key measure as it harnesses the research potential of universities and guides it in directions desirable for improving CDWM. Improving infrastructure is essential, as landfilling is no longer sustainable as the only means of waste disposal today. Similar mechanisms should be employed in Mumbai to improve technology and infrastructure as Hanoi's failure to do so was a key contributor to their failure to cut out illegal dumping and boost material circularity in the industry.

In summation, the four distinct solution categories explored above converge to form a holistic blueprint for advancing CDWM practices. Embracing these solutions will not only address immediate challenges but also lay the foundation for a sustainable future for the industry.

SQ4: How can a multi stakeholder approach steer the construction in Mumbai towards the adoption of effective CDWM using a phase-wise plan?

The government is one of the key stakeholders involved in CDWM in Mumbai. They are the one with the power to mould the environment to make it conducive to effective CDWM. This puts the onus onto them to steer the transition of Mumbai's construction industry towards employing effective CDWM. This is in line with existing literature, as Smallbone and Welter (2001) underpin the importance of the government in spearheading changes within SME dominated sectors. However, not all of the responsibility falls only on the government. Enabling effective transition projects requires active participation of all relevant stakeholders as highlighted in a study by Boyle (2021). For that reason, even though the government will have to drive the phase-wise plan described above, it requires the cooperation and active participation of all relevant stakeholders. For that reason, a multi-stakeholder approach is necessary where all stakeholders contribute to the process where required in order to enable Mumbai's construction industry to transition towards effective CDWM.

To begin with, the regional government needs to create an environment where CDWM efforts are enabled and their monitoring and enforcement is possible. For that reason, it is essential that they set up a body tasked with overseeing CDWM under the MCGM. Currently MCGM is only heavily involved in CDWM up to the permit stage. However, all 6 interviewees have expressed the need for the government to involve themselves past the permit stage and as per interviewee 2, they should "take up the position of enforcers of the law". However, due to the varying range of interest of stakeholders and the disproportionate impact policies have on SME's, it is necessary that the laws and regulations that frame the environment that CDWM occurs in have to be created through discussion between the relevant stakeholders. Here, the onus lies on all major stakeholders such as the government, developers, contractors, academics, etc to put forward their expertise and perspectives in order to develop a set of regulations that can be implemented to improve CDWM in Mumbai. Furthermore, this stage involves raising awareness regarding the importance and the benefits of CDWM to industry stakeholders. This will ensure that the interests of all stakeholder groups are considered and the environment is set in a way that the MCGM can employ enforcement through a carrot, stick and sermons approach where incentives are offered against a set of punitive actions to steer the industry towards adopting desired practices.

MCGM is already in the process of setting up 2 recycling plants in Mumbai and they should endeavour to maximise their utility before considering extending the infrastructure. Due to the recycling technology being in the nascent stage, quality of recycled aggregates is still unreliable. Educational institutions such as the IIT's and NIT's and recycling companies need to conduct collaborative research in order to improve the technology available for recycling. Next, the state government needs to take the responsibility to inaugurate the setting up of a recycling market by using upcycled debris in government projects. Due to the general lack of trust in the market towards recycled products, the government needs to employ curling policies, which involve removing stumbling blocks in order to allow the recycling market to flourish. This will be through encouraging research to improve technology, make technical specifications available, incentivise sale of debris to recycling plants, incentivise plants to allow them to sell recycled materials at prices comparable to virgin materials and use recycled or upcycled materials in government projects. Additionally, the Bureau of Indian Standards needs to endeavour to introduce standardisation of recycled aggregates and update existing IS codes in order to allow their structural use in the private sector.

Additionally, as suggested above, the government needs to take up the mantel of enforcers of law. This is necessary to ensure established regulations are followed and is critical to reducing illegal dumping that is currently rampant in Mumbai. This can be achieved by mandating GPS trackers on all truck carrying C&D debris and using it in conjunction with SCADA to ensure debris is taken to the allotted recycling facility. This should be paired with high fines to make the consequences of being caught dire, to promote rule adherence from the industry. While this will eliminate a large portion of illegal dumping, it is not a reliable way to eliminate river dumping rackets that exist in Mumbai. These stem from corruption and would need resident and environmental bodies to maintain vigilance and file complaints against the offenders in order to discourage the forming and functioning of these rackets.

Once the current infrastructure is maximised, the regional government needs to take responsibility for creating more infrastructure for current and future needs. However, MCGM is tasked with safeguarding the interest of local residents. Therefore, they must set up the plant out of Mumbai closer to rural areas accessible by rail. Once this is complete, MCGM needs to mandate the use of recycled aggregates in RMC plants to truly boost the recycling market and increase levels of material recovery. Due to economy of scale concern, at the beginning MCGM needs to take the responsibility of providing grants and subsidies to support this market. However, once these challenges have been ironed out, they can scale back the subsides and allow the market to thrive off its own volition. Furthermore, at this stage, developers can take more of an initiative and utilise recycled materials in their projects beyond government mandates to help create a self sufficient market.

Once this is achieved, MCGM should outlaw landfilling, restricting it to only allow soil which would prevent material loss and pollution associated with landfilling. It is recommended that the government follows a phase wise approach as discussed previously due to the requisite/pre-requisite relationship of certain stages and since it is conducive to transition projects as described by Chishti et al. (2023). In essence, the governments multifaceted role involves policy formulation, enforcement, infrastructure development and market nurturing. Their increased involvement, as suggested by all 6 interviewees, is essential towards creating an environment that is conducive to effective CDWM and allows other stakeholders to take required actions economically.

Answering the main research question

The answering of the sub-research questions was essential to the formulation of the answer to the main research question. Investigating the current CDWM process, the actors and barriers involved, solutions applied in comparable case studies and how stakeholder driven interventions can transition the industry towards effective CDWM; enables us to answer how SME's can be enabled and empowered to participate in and contribute effectively to the new transitioned industry that the solution proposes. This allows for the main research question **"How can the construction industry in Mumbai transition towards the adoption of effective construction and demolition waste management (CDWM): from the perspective of SME's?** to be answered.

SME's are prone to being affected disproportionately by CDWM regulations. This is one of the key reasons that discussions are suggested as part of phase 1. This should allow for regulations to be set in a way that allows SME's to operate constructively as a part of the CDWM process, without affecting their ability to operate in the industry profitably. The chief concern here is mandating on site sorting, which is not feasible or logistically possible on some of the smaller sites that SME's operate. For that reason, regulations have been suggested that mandate onsite sorting only on sites above a certain area. Furthermore, it has been suggested to offer superior rates at the recycling plants for sorted debris. This allows SME's operating on smaller sites to conduct sorting if possible to acquire better rates for their debris without the burden of a mandate on them. Additionally, the recycling plants offering $17 per tonne of debris against a transportation cost of $ 3.6-6 per tonne incentivises SME's to ensure their debris reaches the plant and is not dumped illegally.

One of the major concerns with the SME sector is the fragmentation and the lack of organisation of the sector. This makes it very challenging to monitor the sector and by extension crack down on illegal dumping. The GPS tracking solution that has been suggested goes a long way towards eliminating illegal dumping in the SME sector. Automated tracking using SCADA enables the SME sector of the industry to be regulated, which means that SME's will be positively contributing to CDWM by ensuring their debris reaches the plants in order to prevent being fined. Furthermore, raising awareness about the importance of CDWM should serve to deter illegal dumping to an extent. This highlights the carrot, stick and sermons approach that the government must take in order to ensure SME's contribute positively by offering incentives for desirable actions against punitive measures as suggested by interviewee 2. This is in line with existing literature as Ling and Nguyen (2013) have suggested offering incentives and punitive measures both towards SME's in Hanoi's construction industry.

Additionally, including SMEs in promoting material circularity in the industry is a challenging proposition. SME's are often family businesses who hold traditional ways of working and are often resistant to change. Furthermore, the construction industry as a whole, but most prominently the SME's, possess a mindset that leads them to view recycled materials as waste and distrust their use in their projects. The proposed solutions suggests building trust in the sector by creating technical regulations and promoting their use in the government sector. However, mandating their use on sites as it is will be met with resistance from SME's. Their labour often lack the knowledge and training to incorporate recycled aggregates and providing additional training not only takes away from site work time but also adds to costs. The proposed solution offers a counter measure to this by mandating partial replacement of aggregates with recycled aggregates in RMC plants. Most of the construction in Mumbai, including SME's, utilise RMC to carry out concreting on their sites. Boosting material circularity with this method ensures that SME's do not need to make significant changes to their operating procedures, allowing for seamless integration of recycled aggregates in SME run construction projects.

In summation, SME's operating in Mumbai can be positively integrated into CDWM endeavours by improving enforcement, providing incentives against punitive measures and enabling them to incorporate material circularity with minimal changes to their operating procedures. Implementing these measures means that SME's will be capable of and empowered to contribute positively to CDWM whilst still maintaining profitability and remain competitive in a highly fragmented and competitive industry.

9.1. Future Work

While this thesis has focused on presenting practical and actionable solutions for CDWM in Mumbai, several avenues for future research exist that can enhance the depth and applicability of the proposed solutions. They are as follows:

1. **Real Life Application and Impact Assessment:** According to the researcher, a crucial next step involves the implementation and testing of the proposed solutions in a real life situation in the construction industry of Mumbai. This will provide valuable insights into the actual impact and feasibility of the solutions allowing for their optimisation as required.
2. **Quantitative Analysis:** To gain a more comprehensive understanding of the proposed solutions, future research should focus on quantitative studies to assess the financial implications and economic viability of these solutions. This can help quantify the potential cost savings and economic benefits and capital outlay necessary, to truly understand the viability of the proposed solution.
3. **Corruption:** Corruption remains a complex and perennial issue in Mumbai's construction industry. Future research should delve deeper into understanding its true extent to shed light on its hidden dimensions and its tangible effects, to provide a nuanced understanding for designing effective anti corruption strategies.
4. **Government Validation:** Collaboration with trustworthy and transparent government officials is paramount in enriching the authenticity of the proposed solutions. Future research should prioritise engaging with government officers who can offer their insights, thereby ensuring a more holistic understanding of the industry and the government's perspective on it.

These future research directions will not only refine and validate the solutions presented in this thesis but also contribute to a more comprehensive and nuanced understanding of the challenges and opportunities for Construction and Demolition Waste Management in Mumbai.

Bibliography

Construction, 2014. URL https://www.makeinindia.com/sector/construction.

Pradhan mantri awas yojana – urban, 2015. URL https://pmay-urban.gov.in/about.

Gdp (current us$) - india, 2021. URL https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=IN.

M. Aggarwal. Mumbai and delhi generate most solid waste among metro cities, October 15 2019. URL https://thewire.in/environment/indias-megacities-mumbai-and-delhi-sitting-on-a-pile-of-waste. The Wire.

U. Agrawal and A. Iyer. *Sustainable Construction and Demolition Waste Management: Training Manual*. National Institute of Urban Affairs, Ministry of Housing and Urban Affairs, 2020.

M. A. T. Alsheyab. Recycling of construction and demolition waste and its impact on climate change and sustainable development. *Int. J. Environ. Sci. Technol.*, 19:2129–2138, 2022. doi: 10.1007/s13762-021-03217-1. URL https://doi.org/10.1007/s13762-021-03217-1.

R. Andersson and M. Buser. From waste to resource management? construction and demolition waste management through the lens of institutional work. *Construction management and economics*, 40 (6):477–496, 2022.

P. Arora-Desai. Mumbai's leaky landfills pose 'severe' risk of plastic pollution. *Hindustan Times*, October 16 2022. URL https://www.hindustantimes.com/cities/mumbai-news/mumbais-leaky-landfills-pose-severe-risk-of-plastic-pollution-101665942939800.html.

P. Arya. Case study methodology of qualitative research: Key attributes and navigating the conundrums in its application. *Sociological Bulletin: Indian Sociological Society*, pages 94–110, 2021.

R. Assainar. Mangrove cell to register case on illegal debris dumping in mangroves in kharghar, June 24 2022. URL https://www.hindustantimes.com/cities/mumbai-news/mangrove-cell-to-register-case-on-illegal-debris.dumping-in-mangroves-in-kharghar-101656077242636.html.

R. Badham, C. Clegg, and T. Wall. Socio-technical theory. *Handbook of Ergonomics. New York, NY: John Wiley*, 2000.

Z. Bao and W. Lu. Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from shenzhen, china. *Science of the Total Environment*, 724:138264, 2020.

G. Baxter and I. Sommerville. Socio-technical systems: From design methods to systems engineering. *Interacting with computers*, 23(1):4–17, 2011.

BIS. BIS: 383-2016; Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. Technical report, New Delhi, India, 2016.

N. I. Blaisi. Construction and demolition waste management in saudi arabia: Current practice and roadmap for sustainable management. *Journal of cleaner production*, 221:167–175, 2019.

E. Boyle. *A multi-stakeholder approach to the socio-technical transition to a low-carbon society*. PhD thesis, University College Cork, 2021.

S. Carriere, R. W. Rodriguez, P. Pey, F. Pomponi, and S. Ramakrishna. Circular cities: the case of singapore. *Built Environment Project and Asset Management*, 10(4):491–507, 2020.

Central Pollution Control Board. Guidelines on environmental management of construction demolition (c d) wastes. Technical report, 2017. URL https://cpcb.nic.in/openpdffile.php?id=TGF0ZXN0RmlsZS8xNTlfMTQ5NTQ0NjM5N19tZWRpYXBob3RvMTkyLnBkZg.

V. Chaman. Illegal dumping of building waste at 314 spots: Survey, January 28 2022. URL https://timesofindia.indiatimes.com/city/gurgaon/illegal-dumping-of-bldg-waste-at-314-spots-survey/articleshow/92506753.cms.

M. Z. Chishti, A. Sinha, U. Zaman, and U. Shahzad. Exploring the dynamic connectedness among energy transition and its drivers: understanding the moderating role of global geopolitical risk. *Energy Economics*, 119:106570, 2023.

D. N. Dadhich, M. Bishnoi, P. Arya, P. Saini, and M. Manda. Investigation of construction waste- a case study of jaipur city. *INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) NCACE*, 4(23), 2016.

M. P. Devaki and R. Jayanthi. Barriers to implementation of lean principles in the indian construction industry. *International Journal of Engineering Research & Technology (IJERT)*, 3(5), 2014.

M. F. Dulaimi and T. Caroline. The principles and applications of lean construction in singapore. In *9th International Group for Lean Construction*, 2001.

Ellen Macarthur Foundation. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. EU: Ellen Macarthur Foundation, 2015. URL https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition.

F. E. Emery and E. L. Trist. Socio-technical systems. *Management science, models and techniques*, 2:83–97, 1960.

European Union. Construction and demolition waste, 2018. URL https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en.

M. Z. Faruqi and F. Z. Siddiqui. A mini review of construction and demolition waste management in india. *Waste Management & Research*, 38(7):708–716, 2020.

P. Gruis. Circular economy: Constructing a sustainable future, May 2022. URL https://circulareconomy.europa.eu/platform/sites/default/files/nl-branding-circular-buildings.-f.pdf.

N. H. Hoang, T. Ishigaki, R. Kubota, T. K. Tong, T. T. Nguyen, H. G. Nguyen, and K. Kawamoto. Waste generation, composition, and handling in building-related construction and demolition in hanoi, vietnam. *Waste Management*, 117:32–41, 2020.

B. Huang, X. Wang, H. Kua, Y. Geng, R. Bleischwitz, and J. Ren. Construction and demolition waste management in china through the 3r principle. *Resources, Conservation & Recycling*, 129:36–44, 2018.

B.-G. Hwang and Z. B. Yeo. Perception on benefits of construction waste management in the singapore construction industry. *Engineering, Construction and Architectural Management*, 18(4):394–406, 2011.

B.-G. Hwang, J. Ngo, and J. Z. Teo. Challenges and strategies for the adoption of smart technologies in the construction industry: The case of singapore. *American Society of Civil Engineers*, 2021.

Indian Road Congress. Guidelines for use of construction and demolition waste in road sector. Technical report, New Delhi, 2017.

M. Jain. Economic aspects of construction waste materials in terms of cost savings – a case of indian construction industry. *International Journal of Scientific and Research Publications*, 2, 2012.

H. Kallio, A.-M. Pietilä, M. Johnson, and M. Kangasniemi. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, 72(12):2954–2965, 2016.

R. C. Kamma and K. N. Jha. Quantifying building construction and demolition waste using permit data. *Journal of Construction Engineering and Management*, 2022. © ASCE, ISSN 0733-9364.

F. Kern and A. Smith. Restructuring energy systems for sustainability? energy transition policy in the netherlands. *Energy policy*, 36(11):4093–4103, 2008.

S. Y. Kim, M. V. Nguyen, and V. T. Luu. A performance evaluation framework for construction and demolition waste management: stakeholder perspectives. *Engineering, Construction and Architectural Management*, 27(10):3189–3213, 2020.

T. J. Kull, S. C. Ellis, and R. Narasimhan. Reducing behavioral constraints to supplier integration: A socio-technical systems perspective. *J Supply Chain Manag*, 49:64–86, 2013. doi: 10.1111/jscm.12002. URL https://doi.org/10.1111/jscm.12002.

R. Y. Li, S. Fong, and H. M. Chan. Scholars' comments and criticisms on construction and municipal solid waste management in hong kong and singapore from 2000 to present: A review of digital information online. In *Construction Safety and Waste Management An Economic Analysis*, pages 31–46. Springer International Publishing, Hong Kong, 2015.

F. Y. Ling and D. S. Nguyen. Strategies for construction waste management in ho chi minh city, vietnam. *Built Environment Project and Asset Management*, 3(1):141–156, 2013.

J. Liu, P. Wu, Y. Jiang, and X. Wang. Explore potential barriers of applying circular economy in construction and demolition waste recycling. *Journal of Cleaner Production*, 326:129400, 2021.

S. Lockrey, H. Nguyen, E. Crossin, and K. Verghese. Recycling the construction and demolition waste in vietnam: opportunities and challenges in practice. *Journal of Cleaner Production*, 133:757–766, 2016.

S. Loganathan, P. Srinath, M. Kumaraswamy, S. Kalidindi, and K. Varghese. Identifying and addressing critical issues in the indian construction industry: Perspectives of large building construction clients. *Journal of Construction in Developing Countries*, 22(Supp. 1):121–144, 2017.

Ministry of Urban Development. *Smart Cities: Mission Statement & Guidelines*. Government of India, New Delhi, 2015.

A. Mojumder, A. Singh, A. Kumar, and Y. Liu. Mitigating the barriers to green procurement adoption: An exploratory study of the indian construction industry. *Journal of Cleaner Production*, 372:133505, 2022.

P. Mueller. Exploring the knowledge filter: How entrepreneurship and university–industry relationships drive economic growth. *Research Policy*, 35(10):1499–1508, 2006. ISSN 0048-7333. doi: 10.1016/j.respol.2006.09.023. URL https://www.sciencedirect.com/science/article/pii/S0048733306001600.

S. Nagapan, I. A. Rahman, A. Asmi, A. H. Memon, and I. Latif. Issues on construction waste: The need for sustainable waste management. In *IEEE Colloquium on Humanities, Science & Engineering Research (CHUSER 2012)*, 2012.

H. Nghiem, Q. M. Phan, K. Kawamoto, K. Ngo, H. Nguyen, T. Nguyen, and M. Kawasaki. An investigation of the generation and management of an investigation of the generation and management of. *Detritus Multidisciplinary Journal for Waste Researces & Residues*, 12:135–149, 2020.

OMMAS. Pmgsy, 2023. URL https://omms.nic.in/.

M. Osmani, J. Glass, and A. D. Price. Architects' perspectives on construction waste reduction by design. *Waste management*, 28(7):1147–1158, 2008.

A. W. Pasmore. *Designing Effective Organizations: The Sociotechnical Systems Perspective*. Wiley & Sons, New York, 1988.

T. Pavlu, N. V. Khanapur, K. Foˇrtová, D. Mariaková, B. Tripathi, T. Chandra, and P. Hájek. Design of performance-based concrete using sand reclaimed from construction and demolition waste–comparative study of czechia and india. *Materials*, 15:7873, 2022.

D. Prasad, B. Singh, and S. K. Suman. Utilization of recycled concrete aggregate in bituminous mixtures: A comprehensive review. *Construction and Building Materials*, 326:126859, 2022. ISSN 0950-0618. doi: 10.1016/j.conbuildmat.2022.126859. URL https://www.sciencedirect.com/science/article/pii/S0950061822005451.

A. M. Ragossnig. Construction and demolition waste – major challenges ahead! *Waste Management & Research*, 38(4):345–346, 2020. doi: 10.1177/0734242X20910309.

V. Ram and S. N. Kalidindi. Estimation of construction and demolition waste using waste generation rates in chennai, india. *Waste Management & Research*, 35(6):610–617, 2017.

V. G. Ram, K. C. Kishore, and S. N. Kalidindi. Environmental benefits of construction and demolition debris recycling: Evidence from an indian case study using life cycle assessment. *Journal of Cleaner Production*, 255, 2020.

A. Sawhney, R. Agnihotri, and V. K. Paul. Grand challenges for the indian construction industry. *Built Environment Project and Asset Management*, 4(4):317–334, 2014.

S. Schützenhofer, I. Kovacic, H. Rechberger, and S. Mack. Improvement of environmental sustainability and circular economy through construction waste management for material reuse. *Sustainability*, 14 (17):11087, 2022.

A. Sekhar, D. Varsha, K. Nagrath, and V. Rathi. *Resource Efficiency in the Indian Construction Sector: Market Evaluation of the Use of Secondary Raw Materials from Construction and Demolition Waste*. 2015.

A. A. Sezer. Factors influencing building refurbishment site managers' waste management efforts. *Journal of Facilities Management*, 15(4):318–334, 2017.

N. Sharma, P. P. Kalbar, and M. Salman. Global review of circular economy and life cycle thinking in building demolition waste management: A way ahead for india. *Building and Environment*, page 109413, 2022.

D. P. Singh. *Migration and Occupation in Mumbai: Issues and Implications*. Tata Institute of Social Sciences, Mumbai, 2021.

D. Smallbone and F. Welter. The role of government in sme development in transition economies. *International Small Business Journal*, 19(4):63–77, 2001. doi: 10.1177/0266242601194004.

A. Sohal, A. A. Nand, P. Goyal, and A. Bhattacharya. Developing a circular economy: An examination of sme's role in india. *Journal of Business Research*, 142:435–447, 2022. ISSN 0148-2963. doi: 10.1016/j.jbusres.2021.12.072. URL https://www.sciencedirect.com/science/article/pii/S014829632100984X.

A. Somvanshi and A. Verma. *Another Brick off the Wall: Improving Construction and Demolition Waste Management in Indian Cities*. Centre for Science and Environment, New Delhi, 2020.

G. Terry, N. Hayfield, V. Clarke, and V. Braun. *Thematic Analysis*, volume 2, pages 17–37. 2017.

Z. Tsiga, M. Emes, and A. Smith. Critical success factors for the construction industry. *PM World Journal*, 5(8):1–12, 2016.

N. V. Tuan, T. T. Kien, D. T. Huyen, T. T. Nga, N. H. Giang, N. T. Dung, and K. Kawamoto. Current status of construction and demolition waste management in vietnam: Challenges and opportunities. *International Journal of GEOMATE*, 15(52):23–29, 2018.

A. Vilventhan, V. G. Ram, and S. Sugumaran. Value stream mapping for identification and assessment of material waste in construction: A case study. *Waste Management & Research*, 37(8):815–825, 2019.

B. C. Yin, R. Laing, M. Leon, and L. Mabon. An evaluation of sustainable construction perceptions and practices in singapore. *Sustainable Cities and Society*, 39:613–620, 2018.

H. Yuan and L. Shen. Trend of the research on construction and demolition waste management. *Waste Management*, 31(4):670–679, 2011. ISSN 0956-053X. doi: 10.1016/j.wasman.2010.10.030. URL https://www.sciencedirect.com/science/article/pii/S0956053X1000588X.

A

Appendix

The key quotes and takeaways from the interviews have been listed below.

A.1. Interviewee 1

Interviewee 1
Yeah, in Mumbai nowadays they have started C&D permission, that is you have to have a permission where you can dump your debris generated or your soil generated or whatever is generated. Architect and engineer have to calculate how much waste will be generated and for that waste we have to get a certificate from the landfill owner that he will allow us to dump that much waste there and accordingly we have to submit papers in the MCGM and then they give us permission and then only it is allowed to do excavation or whatever. And in fact for commencement certificate also that is required.

Yash Raikar
And do they monitor if the debris actually went to that area or is it just a prerequisite and then later it doesn't really make a difference?

Interviewee 1
Hmm, I don't think they have a system to monitor that.

Yash Raikar
Do you think a system where later you could get a certificate signed by the owner that this much waste was actually dumped at the landfill and wasn't dumped wherever?

Interviewee 1
No. Yeah, but that see that can be managed, right?

Interviewee 1
Because all these places are far off from Mumbai, like Bhiwandi or Taloja or Ulva, which are 40 to 50 kilometres away. So the transportation cost is very heavy. So generally they only take permission from there and then dump the debris somewhere else.

Yash Raikar
Would a GPS system like that work, or are there too many demolition contractors?

Interviewee 1
Hmm. Definitely, definitely that, that that should work because, see nowadays dumpers do various activities, but if something like this? Should be done so that this system can be effectively implemented. Definitely the cost of the demolition and transportation will increase, but that is I think that is the only

solution for solving this problem of dumping.

Yash Raikar
Would you as a developer be OK with that cost increase in your projects if it ensured that proper care was taken with construction waste?

Interviewee 1
If if we want to care for the environment, we have to accept it in our project cost. I don't think it will matter that much because that may not be 0.1% or oh point 0.2% of the project cost the difference in the transportation cost, but the effective environment effective the environment will be much more than the this thing to then definitely we should do it.

Interviewee 1
Whatever salvageable material is there, like steel, wood, aluminium and formwork? Whatever this thing is there they.
They remove 100%, which has a some scrap value.

Interviewee 1
When they are disposing off at certain places they have to bribe some people

Interviewee 1
No one will want to dump the material illegally if there is a easier, simpler way of giving the material to a recyclable plant and disposing of the concrete. So if that is there then government should promote that that industry and make some plants so that people can dump there.

Interviewee 1
Concrete doesn't have any scrap value, that is, that's why it is disposed off.

Interviewee 1
I have one point actually.

Yash Raikar
Yeah.

Interviewee 1
Bridges and some construction activity. Bigger, bigger, big landfills and area. Why not use debris? They always do it with murum. That is soil.

Yash Raikar
Right.

Interviewee 1
Why don't they use some? Construction material to fill up that portion. If you get good quality then roads also you can use this.

Yash Raikar
You're saying it's not being implemented everywhere?

Interviewee 1
See generally in Mumbai, the plots are very small, so that concrete lumps, which can that those can be used as a rubble, but we don't have that much space available on site to keep store those rubble. And then after the excavation, use it for the soling and all these things though. The problem is we have to dispose it off and then get the new one.

Interviewee 1
And then NMMC also some as that permission. But it so this was it's only a formality that you should

have a permission but there is no implementation agency for that whether it is disposed of properly to that particular place or something like that that is not there.

Yash Raikar
You think an agency like this needs to be set up, which oversees and enforces the laws when it comes to waste management.

Interviewee 1
There should be. Ohh, but under GPS tracking system and all these things will help to implement that. There can be a different agency from municipality only that keep fixing GPS trackers to all the vehicles and all these things that will help track the vehicle whether that vehicle is going there because we have too whilst applying for CND permission we have to give vehicle numbers to BMC.

Interviewee 1
See what CND permission is there,there if we take that permission but there is no implementing agency to check if it is being followed or not. The BMC should start a this thing with which trucks having GPS system. Then they can implement

Interviewee 1
Most of the construction in Mumbai is done with RMC and in RMC the Quality control is much better than on sites, so we can definitely instruct them and ask them to use recycled material.

Interviewee 1
They do. The fines are very high, but generally it is managed because it is generally done at night when nobody can find out, or if it is caught then they just wiggle out by paying some bribe.

Interviewee 1
I don't think any other this way other than GPS tracking. At this moment, GPS tracking is a must and unless GPS tracking is in first, this implementation cannot be done. Dumping cannot be avoided.

Interviewee 1
At this stage since there is no recycle plant recycling plant nearby to, we don't have any. Even if we are interested, we cannot do anything. We have to dump it when it is there.

Interviewee 1
No, but at least night, but at least you can have a data with GPS. You can have a data that this truck is leaving from this site and whether it has reached that site that that that data can be checked anytime afterwards also. And if we get more honest officers than nothing like it.

Yash Raikar
Right, right.

Interviewee 1
Hmmm. There can there can be some implementing some vigilance agency. Those who can, those who will check and see. But with corruption it will be there. But much will be reduced in that the illegal dumping. I can't say it will avoid 100% but definitely 90% of these things we can reduce by these things.

Interviewee 1
There should be some implementing agencies, whether BMC or some private agency or whatever it is, but there should be some agency which will monitor the GPS and basically the construction, recycling units, construction, debris recycling unit that is a merged and if BMC government does it. Nothing like it.

Yash Raikar
So do you think that segregation should happen on site or do you think that's something happens at the recycling plant?

Interviewee 1
On site, on site it is not possible. On site it is not possible at all because the sites are very small so we can't. The biggest, biggest sites also it's very difficult to segregate and all these things because there is no incentive to segregate on site.

Yash Raikar
Right. So if rules were implemented for segregating out bricks in concrete, you wouldn't be for it as a developer.

Interviewee 1
No, no, its because it doesn't make any sense because here the sites are small, small, so it is not physically possible to do that.

Yash Raikar
Right. So for the last part of the interview. Theory says that. Umm a phase wise approach is best for transition projects. Do you agree with this? What problems do you think needs to be solved first?

Interviewee 1
Yes 100%. If many new things are done at once it will create confusion, yeah. For starting, for starting I think first BMC needs to make a body for implementation. That body can then take care of everything. So. They can only decide regulations weather it is with discussion or not whatever it is.

Yash Raikar
Right. And what about GPS tracking? When should that be implemented.

Interviewee 1
See before that you need the body which will monitor the GPS. Only then all these things can be done. First step, first step has to be setting up the body. Then they can only handle like GPS on trucks. One thing I would like to add. Last step should be that you ban landfills. But this can only be done at the end otherwise if you don't leave option they. They will dump illegally only.

Yash Raikar
Right. When in your opinion, can we start utilising debris and recycled aggregates?

Interviewee 1
There are many things that need to be done before we can do that. First all those things like setting correct rules, research and whatever needs to be done. Then only we can be able to utilise debris properly.

Yash Raikar
Right. So considering a phase wise approach the first phase should have setting up the body and all and taking care of all the prerequisite?

Interviewee 1
Yes. That is. That is what I think should be done.

A.2. Interviewee 2

Yash Raikar
The thing that I want to ask was about the level of infrastructure currently available in Mumbai for recycling construction waste. Are you aware of any recycling plants that are operational or any such industry in Mumbai?

Interviewee 2
There is supposed to be a recycling plant, but it's not fully operational because the construction is going on. And the plant capacity is way below the waste that is generated because entire Mumbai is being reconstructed from the older structures. So every time you pull down the structure, there is huge amount of debris that is generated. The old roads are being reconstructed in the concrete so as soon as you remove the top couple of layers of the road you generate huge amount of debris. So I believe what we have currently is substantially under what is needed.

Interviewee 2
And incentivise so if you use a carrot and stick both then I think it will be. successful.

Interviewee 2
Or there are rivers in Mumbai you know, every year there are thousand, thousands of crores of contract being given for cleaning of them. From where is this debris coming? It's a very open secret that, you know, it's illegal dumping is going on, but who you see there are Cctv's all across. So must be it's a big racket that, you know, the cops also know about. The corporation officers they work with unscrupulous contractors. The debris is not automatically jumping out of the truck and getting into the river. So someone is dumping it there.

Interviewee 2
Extensive R&D is the only option. I personally believe extensive R&D if it is done and as you rightly said by economies of scale if you're able to bring the cost of production down or the overheads of the companies who are making that comes down and the cost per unit of course aggregate comes down or fine aggregate comes down only then people are going to use it, otherwise it will. It will be at the mercy of some people, those who want to really show that they are so careful about the world and the future and things like that. Only they will keep using it and it will become a very small quantum of area where this is being used.

Interviewee 2
So these kind of areas, it can be easily used. So if you're talking of a retaining wall, it can be used because retaining wall, if it is not RC retaining wall you know then you don't you just require a strong base there and then whether it's earth or concrete or any other material, it doesn't matter really if you're using rubble soling, rubble wall instead of rubble wall. You can use this. So it's a dual advantage that you are not using rubble which is a natural produce. So you are cutting less number of hillocks and mountains. And 2nd is you are using the debris. So these kind of usages will have to be worked out. People think of using only one usage of because the debris first. If you try to break it into smaller pieces and this and that it's a very expensive process, time consuming and then so nobody wants to go to that level. You know it's extra energy inputs are very expensive so we should also try to use debris as it is with some minimum processing.

Interviewee 2
Construction rubble should not be used as land-fill. This will have a long-term effect on the rain water re-charging into mother earth & will change the nature of the area in future.

Yash Raikar
Right. So how can people be encouraged to use debris

Interviewee 2
It will have to be that way. It's money driven here. Monetarily people will have to benefit by using the

debris.

Yash Raikar
Ohh, The thing is, the Indian industry is so fragmented and so cluttered with so many people that becomes a very strong game of cost and time. Who can manage the time and the cost of the project best and any value you can cut money you have to to survive in in the Indian industry that's not so necessary true here in Europe where there's less number of companies.

Interviewee 2
Absolutely. That also is a very good point because you have. Maybe we have over competition in anything. that's also the possibility.

Yash Raikar
So do you think. The answer for that is a new agency who oversees all of this, because the current agencies aren't working.

Interviewee 2
Yes. Probably within BMC itself because I cant think who else will be able to do this because it's a big task you know.

Yash Raikar
Right. Not just the rivers I was reading a couple of news articles about the mangrove forests in Kharghar being decimated with construction debris.

Interviewee 2
That's it. Really, absolutely. And then they they purposely do that, create land and create hutments on it. This also is a big racket and a big industry.

Interviewee 2
So, its important that it needs to be segregated and sent in different trucks.

Yash Raikar
So basically the main main problem is the enforcement aspect, where the government needs to do a better job of enforcing the rules because a lot of the rules are already in place, but they're just not being enforced.

Interviewee 2
Yes. Absolutely. Absolutely. They're not being enforced. Maybe solution for this is getting more scrupulous officers who will enforce but how will you guarantee that about an officer because today most things you get away with by paying some type of bribe.

Yash Raikar
Ok so for the last part id like to ask you what your opinion is on a phase wise approach to this. Like do you think the government needs to employ an approach where implement all the things we discussed in phases.

Interviewee 2
See the thing is. So much is needed to be done that its impossible to do it at once. You cant make so many changes at one time it will all be here and there.

Yash Raikar
Right. And certain things will have to be prerequisites to others right.

Interviewee 2
Absolutely. Absolutely. So I think they will have to do it in different stages.

Yash Raikar
Right. Right. So what do you think should be part of phase one.

Interviewee 2
See first thing that has to be done is set up a body. Yes the government will have to first set up a body like we discussed and then other things can happen. And yes research can also start. Infact it will can take time to set up a body and all. Research can start before that itself.

Yash Raikar
Right. Right. What's the point of waiting. Ok and if the landfilling of debris has to be banned. When do you think that can be done?

Interviewee 2
See for that we need to give contractors somewhere else to dump first. Only. Only if that option is there then you can ban landfills. Otherwise if you corner them like this. They will surely dump it illegally.

Yash Raikar
Right so when do you think well be in a place to consistently utilise recycled aggregates in Mumbai.

Interviewee 2
See it is very difficult for me to give you a time frame. Many things there are not yet solved and will take time. What I can say is that while research happens for recycled debris why don't we start utilising debris as it is. For that only some regulations are needed. We can, we can definitely start with that first.

A.3. Interviewee 3

Interviewee 3
There is no infrastructure in Mumbai to recycle concrete waste or any waste. They are simply dumping the waste out of construction in some place. authorised or unauthorised. There is no facility to process the waste right now.

Interviewee 3
Nowadays only use for debris is they are dumping in some ground to fill the low lying areas or in marshland and that that is mostly done in illegal way. Mumbai waste is dumped in New Mumbai at different places for which local residents also object.

Interviewee 3
Similarly is recycling plants are located anywhere in the city it would create a lot of dust that will be a problem for local residents and they will object to it. Mumbai, the land value is exorbitant. So I'm doubtful whether this is possible unless government gives land free of charge or subsidised rates to such plants.

Interviewee 3
These landfill contractors, they are mostly in illegal business.

Yash Raikar
Is it just something that's on paper or is it something that's actually being enforced by the government?

Interviewee 3
No. Not being enforced. In fact, when we get approval of any plans, we are supposed to give as per Supreme Court judgement. This matter was referred to Supreme Court. Supreme Court has given a judgement that in any construction work. You should not get CC (commencement certificate) unless the landfill site is identified. And we are supposed to give bank guarantee of the specified amount depending on type of construction maybe 5 lakh 6 lakh and get bank guarantee will be encashed, if you do not follow all guidelines. But of course there are some some lacunas, some anti social elements to take the stuff from the up to all the permissions and instead of dumping the debris to far off places they dumped somewhere near Mumbai where they get to work for landfilling or plinth filling etcetera.

Interviewee 3
That number will be taken from this side to this side and they are supposed to check up. On paper all checks are mentioned. But sometimes these fellows find some loopholes and dump it in the surrounding areas. I think we cannot help it as they will just bribe and get away.

Yash Raikar
So do you think implementing GPS like this in Mumbai would be effective? Because as you say, the trucks are all you have to be told from the start, so it wouldn't be very difficult for them to check if the truck has GPS.

Interviewee 3
Yes. That would be very effective.

Yash Raikar
But in such a situation, if it's say a part of the BMC, now BMC historically is very notorious with corruption. So in such cases, how can corruption be prevented then?

Interviewee 3
See that is with every department. I would not say which department is not corrupt, but if you take it BMC, I think it's more systematic than other departments, so BMC they can have some, you know, some section, ward, office, etcetera. They can monitor it and if it is going to be as you said with the

GPS it can be much better.

Interviewee 3
Unless there is some incentive. People will not participate.

Interviewee 3
Mumbai rent and land cost is horrible and if you have to purchase land and far off places then transport will be exorbitant. Actually that is a big big reason that people dump debris here and there.

Yash Raikar
Right, right. So there has to be a trade off between distance and population, so it has to be far enough that it it's not in a densely populated area, but also close enough that transportation doesn't become a big issue.

Interviewee 3
That's the main problem . Otherwise many issues are solved. With the price of disel and stuff transport cost is, is exorbitant. It's the main problem.

Interviewee 3
This type of materials should be used for not main roads but pathways and all.

Yash Raikar
Right.

Interviewee 3
But that is only some part of it. But India as, you know, the roads made by using good materials are in very shabby conditions. So if you use recycled materials. You can imagine what will be the status of the roads.

Interviewee 3
And it (debris generation) is going to increase because in Mumbai earlier old buildings were very old. Those buildings they're going for redevelopment and so that construction waste is increasing. Ill give one suggestion that can be transported by railway wagons.

Yash Raikar
OK.

Interviewee 3
To far off places. 50 60 70 kilometres away. There you can process it. There land cost will be less. Then one can process it in Large Quantity. See in Mumbai everywhere you have got the railway track. so you can transport everything by railway wagon to far off places maybe 70-80 kilometres away from Mumbai. Set up an unit there. There you can sort out everything so waste will come from all over Mumbai at 4 or 5 places. Some central side some on western side(2 of the most prominent railway lines in Mumbai). And we can process it there in large quantity.

Yash Raikar
Right. So how do you rate the government's current involvement in construction demolition waste management? Are they involved enough or do you think that they need to take more initiatives?

Interviewee 3
Only involvement is in the permit because of the passed resolution by Supreme Court that that is only because somebody has filed suit to Supreme Court, we could have passed a resolution. There is no other involvement of government other than these rules and there needs to be more. I feel if you recommend that government should take all this all day, every set, every place should be collected at one location. So maybe 70 kilometres from Mumbai with the land rate is less.

Yash Raikar
Right. And if these plants were, say, set up in an obscure area that's far outside Mumbai, you would also contribute to a lot of gainful employment in those areas. For the locals there.

Interviewee 3
Yes that is important

Yash Raikar
So they would have to be trained right. There would be training for workers, but that that can be managed.

Interviewee 3
Anybody can be trained. See even the man who comes to Mumbai city from village. Even village man, if you just training for one week he will be fully trained and it can create jobs.

Yash Raikar
Right. Ok uh what is your opinion of a phase wise solution. Like implementing things in phases. Do you think that is better or everything should be done together.

Interviewee 3
If you. If you do everything together how it will work? No. No. It will have to be done systematically step by step.

Yash Raikar
Right. And what do you think needs to be done first?

Interviewee 3
What I will suggest is first decide who will control the process. Whether it is a new body or whatever. They have to be ready only then remaining things can be done.

Yash Raikar
Right so first the body should be set up?

Interviewee 3
Yes I think that will be best. Then after that. After that you can look at regulations.

Yash Raikar
Right. What about mandating use of recycled materials. When can that be done.

Interviewee 3
See. There are many challenges that for that to be done. First you will have to do research and all to improve quality. Also you have to give code for that also.

Yash Raikar
Right right. So you're saying there are pre requisites to solve.

Interviewee 3
Yes. That is also why it would be better to do it in stages.

A.4. Interviewee 4

Yash Raikar
So, can you describe the current practices for waste management, especially construction and demolition waste management that are used at sites today in Mumbai.

Interviewee 4
See basically at the time of excavation we had to get the permission from collector office Okay, they will be issuing chalan books and then that we had to issue the expert excavation contractor and there is a mechanism called ETP slips with my mobile number and the contractors mobile number, they will issue an ETP number with that ETP number only and the challan only they will be able to unload the excavated soil okay. So, that is the as far as the excavation soil is concerned. So, at the designated locations they will unload the soil and the verification will be the total excavated quantity and number of trips that will be automatically generated from the app. So, from that app based on this ETP number they will verify whether the unloaded quantity and the expected quantity are matching or not. So process is there and it is being used but no one see where it goes.

Yash Raikar
What do you think is the level of infrastructure that Mumbai has right now.

Interviewee 4
I haven't seen this entirely in Mumbai

Interviewee 4
The government has to impose at least 30% of the gravel should be there from the waste, manage waste, crushed waste material, something like that has to be done and then BIS and then other codes have already given some outlines for utilization of those material 30% of total volume of this thing you can use 20 to 30% of this material isn't something they are already given the guidelines, but in reality, nobody use that thing, but strictly the government will ask like, what they're saying what they're disposing of the material and reconciling the material like this , they have to strictly do that, in concrete also, basically, this crushing thing can be maximum be utilized in the concrete. if they will impose strict laws then definitely it can be done.

Interviewee 4
Yeah, that's exactly what I'm saying. If the government will impose that at least 30 To 50 to 40% of concrete has to be borne by these things, then obviously, the market price will come

Interviewee 4
Because right now, metal (Indian term for course aggregates) today, we are facing metal problem from the surrounding mines to enter into Mumbai due to rains.

Yash Raikar
Construction debris that gets dumped into say the mangroves in Kharghar, in Navi Mumbai it happens a lot right

Interviewee 4
It happens a lot because there are a lot of open spaces are there but in Mumbai there is no space to dump so they take over there and dump at night. If they are caught they will simply pay it off.

Yash Raikar
Speaking of technology, do you think prefab construction can be used on large scale here?

Interviewee 4
See that is still very costly here so only it find use in infrastructure. For regular use I don't think its possible. Maybe someday it will be but its difficult to use now.

Interviewee 4
Definitely IS code has to be change and cooperate on other things, but lean concrete there, there may not be any problem

Interviewee 4
their to take more active role for taking more I took them definitely there will be a having manpower, additional manpower controlling all those things. Otherwise, they will control.

Interviewee 4
No, no, definitely it will work, if you will, GPS tracker is there and maybe we can definitely they will, they will try

Yash Raikar
and who should do this tracking should it be under the BMC itself

Interviewee 4
only BMC. Only ultimately they have the power to govern the thing, because they are providing the vacant sites for dumping making it as dumping yards and they are proposing and they are looking except for monitoring, they are doing everything that monitoring has to be done.

Yash Raikar
Right. So the last thing I want to discuss is if taking a phased approach will be suitable. So what I mean by that is government does it step by step to improve CDWM.

Interviewee 4
That will be good. We will have to do it like that. We will have to otherwise there will be confusion. You follow.

Yash Raikar
Right. And what do you think should be the first step.

Interviewee 4
First thing is that government, they will have to formulate some kind of rules and guidelines. Once the necessary mandates are there we can go forward with everything else. With that some development can also be done. I think that will be best.

Yash Raikar
What kind of development are you talking about?

Interviewee 4
Technology. If technology and research can be improved then nothing like it.

Yash Raikar
Right. Research is necessary if we are to use debris properly in Mumbai. We need to improve technology and codes both.

Interviewee 4
Yes. Yes. Exactly. Regulations research all these things are the base level. Once you have that solved you can do many number of things. Like for concreting, for concreting unless IS code changes we cannot replace metal with partial replacement. All these things will have to be taken care of first.

A.5. Interviewee 5

Yash Raikar
What is your opinion about the level of infrastructure in Mumbai regarding the same?

Interviewee 5
This is just the beginning. We are yet not ready with the infrastructure

Yash Raikar
So how do you think this monitoring can be improved by BMC.

Interviewee 5
Well, now. See the legislation is already there. Legislation is already there, but. They require maybe more manpower is required to check whether the implementation also is there because it is important. That can be done by maybe appointing a third party agency.

Interviewee 5
And so what I think is it is possible for mcgm also to do it on those basis then they can do it for debris also. Then again, it is going to add to the cost. But it will make it inconvenient to bribe and escape like they are doing right now, you know.

Interviewee 5
They have a separate cell, cell is there and that monitoring is done by that solid waste management department. They have installed SCADA devices like SCADA have been installed. And they are monitoring, so if they can monitor the solid waste handling, they can monitor this also. It's only the question of willingness. On their part and maybe extra manpower will be required and they need to separate construction waste management from solid waste.

Interviewee 5
Let us face it, I mean the contractor lobby controls the BMC.

Interviewee 5
See in Mumbai today everything is still on paper in the industry. This kind of high level technology will meet tremendous resistance because people will struggle to understand, you know. So this kind of thing is still far away for Indian industry.

Interviewee 5
Yeah, but yes, it's a good idea to mandate the RMC plans to. Start the usage of recycled aggregates. I mean they could be the biggest customer.

Interviewee 5
But of course, yes, the time available and the level of focus in syllabus(CDWM in Btech courses) is quite low.

Yash Raikar
So right now, how would you rate the involvement of the government in CWM in Mumbai? Are they involved as much as they should be or should they be involved more past just the permit stage?

Interviewee 5
They should. They should involve get involved more.

Yash Raikar
In what capacity?

Interviewee 5
They should get involved more and yeah, it's basically. Legislation has to be there. Proper legislation

has to be there. Ohh proper in the sense I in the beginning I said that legislation is already there, but something that level has to go up level of legislation and they should create some more facilities. They should also make sure people follow the legislation.

Yash Raikar
Right. So in what way can we improve the collaboration between the government sector and the private sector when it comes to construction waste management?

Interviewee 5
Organisations, the builders organisations, the Builders Association of India or similar organisations and the environmental groups, they have to together take this up with the government.

Interviewee 5
There are no quarries left in it in Mumbai or maybe very few queries near Ghatkopar and Vikhroli. But otherwise there are no quarries in Mumbai. Everything comes from outside.

Yash Raikar
So what can be done here? Is it just a problem of economy of scale or is there inefficiencies in the production process?

Interviewee 5
Both. You know. Right now this is this technology has not yet matured, you know. So I will say that it's a combination of both. When the technology matures both of these things can be handled. Of course the production process. Like I mentioned, the technology has not matured, so we are talking about crushers, but there could be some other processes which need to be invented, some chemical process or maybe something else. That is required. So you need innovation for that.

Interviewee 5
Ohh, and that trust. I mean if you formulate such kind of standards(standardisation of recycled aggregates) then automatically it will help building the trust as well.

Yash Raikar
One last thing I wanted to discuss with you was using a phase wise approach. Do you think the government will have to put in all the measure step by step or all at once?

Interviewee 5
Definitely. Definitely they will have to do it step by step. Yash Raikar Right. So what do you think needs to be the first step.

Interviewee 5
See the thing is MCGM still doesn't consider construction waste separate from MSW. I think. I think first they will have to separate it and create separate regulations for it.

Yash Raikar
Right so you thing first step is for them to set up a new body to deal with CDWM and introduce better rules?

Interviewee 5
Yes that should be done first. They can see what regulations all that is necessary and the body has to be there right.

Yash Raikar
Right. And what about recycled aggregates. When can we start using them regularly in the industry.

Interviewee 5
See research is already going on. Maybe we need some more research before that can be possible.

But certainly, certainly it can be done just some efforts are required.

Yash Raikar
Right. And what about landfilling. When can that be banned.

Interviewee 5
See I don't think that can be done. At least not now. That much capacity isn't there for recycling that we can ban landfills. Maybe after the recycling capacity is increased they can think about it but as of now it is unlikely that they can ban landfilling. Because think about it. Where will contractors dump waste. They have to have some place to do it right.

Yash Raikar
So they'll have to first improve infrastructure only then this can be done.

Interviewee 5
Yes. This can only be done much later. And even later I don't think its correct to completely ban it. I think for soil you can still use landfills. Infact it will be better for soil.

A.6. Interviewee 6

Interviewee 6
Uh, I think infrastructure for recycling in, in and around Mumbai is not what that make in India set up want to establish. I think it is just in the nascent state right now. There is little more time, maybe required to take an initiative and maybe the awareness about the recycling is still not as good as it should be.

Interviewee 6
Ohh I think for that government should take little more in incentive and initiative

Interviewee 6
Ohh, you cannot mandate it for the private sector right away, but. Ohh, those are into the infrastructure business for them. Some mandate can be prepared. For example the Prime minister's Gramme Sadak Yojana.

Yash Raikar
Yeah.

Interviewee 6
Right, so far that the recycle aggregates can be easily used. Ohh I as there is a scarcity of the aggregates, those recycled aggregates, if they can be used easily, that will definitely help for the environment as well as the cost of the road construction also.

Yash Raikar
Right. Right.

Interviewee 6
And because the Prime Minister, Graam Sadak Yojana they, are connecting the roads from the small villages to the state highways and from the state highways to the National highways. OK, so from the village to the state highways, if the intensity of the vehicle load will be not as high as required for the National Highway or the state highway. So we can definitely think of using the recycled at least recycle aggregates for that. That's what I feel.

Interviewee 6
Yeah. Ohh I think for that the quality of the recycled aggregate plays important role because right now the Indian Standard code might be having some apprehension about the quality of the recycled aggregate. So if we can recycle the aggregate at a reasonable price.

Yash Raikar
Right.

Interviewee 6
And then provide that aggregate. Then maybe a assurance about the quality of that recycled aggregate the main point in this case maybe that the bond between concrete or the cement and the aggregate that plays the important role and even for the infrastructure project like roads. Now the quality of the grade of the concrete required is minimum grade is M40.

Yash Raikar
Right.

Interviewee 6
So are you are we in a position to use those recycled aggregate and make the mix for M40 and above is the question?

Yash Raikar
Right.

Interviewee 6
So if that quality is assured, then Indian IS code may not have any apprehension of using the recycled aggregate. The first thing is the quality of the aggregate recycled aggregate and therefore what I say is that first standardise them then it can easily be part of code.

Yash Raikar
So we kind of need to bring in some form of standardisation for the aggregates basically.

Interviewee 6
Yeah, yeah. If you have some grades then adoption will be much much easier.

Interviewee 6
Sorting of the waste and rescaling, reusing if it is done at the site and if that is made mandatory by the BMC in Mumbai. Then. But somebody should take an initiative for. Imposing the importance of recycling.

Yash Raikar
what in your opinion is the level of monitoring on this? Is this just on paper or do they actually implement it and check whether the waste is reaching the designated site or is it being dumped along the way somewhere?

Interviewee 6
Hmm. See process is there. No issue with that. But how to keep that control? Because people will bribe if they are caught. It is difficult task.

Yash Raikar
Right. So for this control, what they did in Shenzhen, in China is they mandated that any truck carrying construction debris has to be GPS enabled. So then you know, if you find debris dumped somewhere, you can then track which truck went through there.

Interviewee 6
Ohh.

Yash Raikar
Is this something that can realistically be put in?

Interviewee 6
Ohh. Excellent suggestion, excellent solution, excellent solution.

Yash Raikar
And then who should do this tracking?

Interviewee 6
BMC has to do the tracking, no? Who else will do tracking but BMC. So environmental Engineering department from the BMC. If they could set up some cell of this for this particular cause.

Interviewee 6
The environmental engineering bodies in India, if they will pressurise BMC for waste management of the debris from the Demolition Project, maybe that will work out like nowadays that solid waste management segregating the waste at the source itself has become a big initiative and to a great extent.

Yash Raikar
So do you think we need to establish a platform where say, the BMC environmental groups, the Builders

union, they sort of get together and you know? Ohh, there should be some sort of discussion because the BMC can't just go along putting on regulations cause if the cause at the end of the day the Builders Guild money controls the BMC so you know BMC can't put in regulations that are gonna damage the builders. So there needs to be a solution that is that comes apart where everyone benefits. So this level of collaboration do you think is possible in Mumbai?

Interviewee 6
Yes. Yeah. Yes, it should start at the local level like the ALM which are started for the segregation of the waste. That there should be no dumping on the road.

Yash Raikar
What's your opinion about the level of technology we have available today in Mumbai for, you know on site processing for recycling all of this, what is the level of technology? Is it too up to par or is there work that needs to be done there?

Interviewee 6
Lot of work needs to be done.

Interviewee 6
Still, the engineers which are providing solution if they are made aware then definitely it will be used.

Yash Raikar
So awareness needs to be increased at the industry level as well, like where people working in the industry, workshops or seminars or stuff like that.

Interviewee 6
Yes, yes. Yes, yes, yes, yes, 101%. And those who are working into this business of recycling, they should give the assurance from their side what kind of material they will be provided and if they could give with the academic support that using this recycled material the the concrete of so and so grade will be will be produced and the cost benefit analysis because ultimately the solution provider.

Interviewee 6
Still, the engineers which are providing solution if they are made aware then definitely it will be used.

Yash Raikar
So awareness needs to be increased at the industry level as well, like where people working in the industry, workshops or seminars or stuff like that.

Interviewee 6
Yes, yes. Yes, yes, yes, yes, 101%. And those who are working into this business of recycling, they should give the assurance from their side what kind of material they will be provided and if they could give with the academic support that using this recycled material the the concrete of so and so grade will be will be produced and the cost benefit analysis because ultimately the solution provider.

Interviewee 6
Because right now we have just on the spur of the moment, whatever I have thought, whatever I I know about the subject I have given, but I think the Prime Minister Gramm Sadak Yojana.

Yash Raikar
Yeah.

Interviewee 6
is across the India.

Yash Raikar
And that, that, that they could become the biggest customers for recycled aggregates.

Interviewee 6
Yes, only thing I you should be able to get a certain CBR value.

Yash Raikar
Right. So we need to 1st maximise the current infrastructure and get the market rolling, which will in turn also help the market grow in the future because once the ball gets rolling.

Interviewee 6
Yes exactly. We should first see what is the market available with the available quality.

Yash Raikar
So the last thing I would like to discuss with you is. Is if you think if a phased approach will be best for the industry. Like should all solutions be done as and when or should they follow a phased plan.

Interviewee 6
See. I definitely feel that. That whatever is done it has to be step by step. Like we discussed before. For aggregate use we have number of steps that need to be done. Standardisation and whatnot so I think step by step only will be best.

Yash Raikar
Right. Right. And what do you think should be first then.

Interviewee 6
I think first infrastructure they should take care of. All infrastructure from plant to body. Without that how they will do. The infrastructure first we need to maximise. And body should also be there, no?

Yash Raikar
Right. So first step should have regulatory body and infrastructure?

Interviewee 6
Yes. Absolutely.

Yash Raikar
Right and what about utilisation of recycled materials in projects. When can that be done.

Interviewee 6
That we discussed before no that standardisation and Is code all these things are needed. Some research is needed only then we can use them.

Yash Raikar
Right. Right. And what about GPS tracking and better enforcement. When should that be started.

Interviewee 6
That can be started immediately after the infrastructure is set. Everything they need for this type of tracking they have to set up and then they can start.