APPLICABILITY OF ZERO WASTE CONCEPT TO THE SRI LANKAN CONSTRUCTION INDUSTRY

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Declaration

"I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Further, I acknowledge the intellectual contribution of my research supervisors Dr. (Mrs) K.G.A.S.Waidyasekara, and Mrs. B.H.Mallawaarachchi for the successful completion of this research thesis. I affirm that I will not make any publication from this research without the names of my research supervisors as contributing authors unless otherwise I have obtained written consent from my research supervisors.

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Dr.K.G.A.S.Waidyasekara

Abstract

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The construction industry, being the largest industry, it generates massive quantities of Construction and Demolition waste (CDW). Generation of CDW leads to issues related to environmental pollution, adverse health issues, economic issues, social issues, and undesirable landfill creations. Strategies such as the 3R concept (Reduce, Reuse, Recycle), and waste hierarchy are followed in the construction industry for CDW management. Although such strategies are applied to manage the CDW, CDW management is still in a primary stage. In order to eliminate CDW, the Zero waste concept emerged as a potential solution. Although, Construction Waste Management (COWAM) project is available for manage CDW in Sri Lanka, there is a lack of studies to manage C&D waste management. Thus, this study focuses on elimination of CDW from construction industry by applying zero waste concept.

To achieve the ultimate aim of the study, comprehensive literature survey was carried out by referring to the existing findings on CDW definitions, origins and causes for CDW generation, composition of CDW, impacts of CDW, strategies, enablers, barriers and zero waste concept. Further, qualitative research approach was followed and eight case studies were used to collect data. Semi structured interviews, document review and observations were carried out in the selected eight case studies. To analyse the collected data, cross case analysis was followed.

Through the case study findings, composition of CDW, origins and causes of CDW, current CDW management procedure, strategies, enablers, barriers and suggestion to apply zero waste concept in the Sri Lankan context were identified. Finally, all the collected data was harmonized into one place and a framework was developed to apply zero waste concept in the Sri Lankan construction industry.

Key words: Applicability, Barriers, Construction and Demolition waste (CDW), Enablers, Suggestions, Zero Waste

Dedication

To my beloved parents

and brother…

Acknowledgement

The correct guidance and follow-ups should be there to be successful in doing any kind of task. This dissertation would not be possible without the guidance and dedication of numerous respectable individuals. I take this opportunity to convey my gratitude to all of them.

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Abbreviation

BIM	Building Information Modelling
CDW	Construction and Demolition Waste
CIDA	Construction Industry Development Authority
CWS	Construction Waste Sorting
EMS	Environmental Management System
EPR	Extended Producer Responsibility
EU	European Union
IS	Industrial Symbiosis
LCA	Life Cycle Assessment
MT	Million Tons
MSW	Municipal Solid Waste
SW	Solid Waste
WM	Waste Management
ZW	Zero Waste

CHAPTER ONE

1.0.INTRODUCTION

1.1 Background

In the construction industry, due to improper consumption of large amount of natural resources, an enormous increase of construction and demolition waste(CDW) has taken place (Kulatunga, Amaratunga, Haigh, & Rameezdeen, 2006). Yuan (2012) said that throughout the world irresistible amount of solid construction waste caused through building activities, renovation, and demolition activities. The construction industry faces difficulties in reducing the waste that gets generated through the construction activities (Banihashemi, Tabadkani, & Hosseini, 2018). In the life cycle of buildings, waste is generated in the construction, demolition and restoration phases of structures (Lu et al., 2011; Wang, Yuan, Kang, & Lu, 2010). Waste in general is defined as a byproduct of material that is generated as a result of industrial and human activities and which has no residual value (Teo & Loosemore, 2001).

Waste arising from the construction, repair, maintenance and demolition of buildings, structures and roadways is defined as CDW (Ghosh & Ghosh, 2016). Moreover, Hsiao et al. (2002) explained CDW as waste materials generated through construction, repair, renovation, addition, rebuilding and demolition of legal and illegal construction activities. When considering the CDW composition, it consists of concrete, tile, asbestos, aluminium, cement, heavy metals, steel and timber (Esin & Cosgun, 2007; Wang, Kang, & Tam, 2008). In addition to that, Yeheyis et al.(2013) have elaborated that, CDW consists of wood products, asphalt, drywall, concrete, masonry and in significant quantities of metals, plastics, earth, gravels, paper and cardboard.

In Australia, 20-30% of CDW gets landfilled (Craven , Okraglik , & Eilenberg , 1994). In Hong Kong, during 2005, out of the 21.5 million tons of construction waste, 11% were landfilled and 89% were used in public filling areas (Jaillon, Poon, & Chiang, 2009). Llatas (2011) stated that 35% of CDW ended up in landfills, open waste dumping areas and in unsuitable places or in unsuitable sites. Further, in many landfills around the world, 10-30% of SW are from CDW (Wang et al., 2010). As per Wang et al. (2008), out of the generated CDW, concrete waste generation is higher and it is nearly 80% to 90% due to the concrete demolition, plastering flow, excess ordering, and template leakage. Mhaske, Darade, and Khare, (2017) said that CDW contributes negative impacts for cost, time, environment and to the productivity of the country.

As per Osmani (2012), CDW gets originated as a result of poor information in design, frequent changes in the design, long project duration, and due to the communication issues in construction and design team. Further, Jaillon et al. (2009) stated that as a result of clients' design changes and requirement changes, huge amount of waste gets generated. In addition to that, Li , Tam, Zuo, and Zhu, (2015) found 33% of the wasted materials are due to designer's failures. Moreover, CDW gets generated due to contractor's lack of interest, lack of knowledge in the designing stage, use of poor quality products, and poor material handling (Kofoworola & Gheewala, 2009). Furthermore, Magalhaes et al. (2017) explained that, construction planning, designing decisions also lead to the generation of CDW.

Improper management of CDW leads to adverse environmental impacts and also to the health issues of the human beings (Sapuay, 2016). Coelho and Brito (2012) mentioned that, CDW creates damage to the ecological environment, consume land resource, and leads to soil and water pollution. When CDW management takes place in a proper manner, adverse environmental impacts, undesirable landfill site creation, and health risk related to construction waste get reduced (Lingard, Graham, & Smithers, 2000).

Tan and Khoo (2006) explained Waste Management (WM) as collection, sorting, recovery, recycling of materials through biological treatments, thermal treatments, and landfill. Moreover, attention is given to CDW recycling in order to gain an economic value and also to divert waste from landfills (Kofoworola & Gheewala, 2009). Similarly, Li et al. (2015) stated that construction waste generation can be reduced in both designing and construction by dimension coordination, use of prefabrication components, use of standard dimensions and units, detail designing, by avoiding design modification and by avoiding the use of low waste technologies. According to Wang , Li, and Tam, (2015), to reduce the adverse effect of construction waste on human health and sustainable development, 3R principle is used to manage the construction waste. Further, Osmani , Glass, and Price (2008) emphasized that considering the impacts of CDW in the long run, there is a persuasive need to control the waste. Moreover, Osmani (2012) said that involvement and commitment of the stake holders to reduce waste generation at source and efficient waste managemnt strategies can lead the industry to achieve zero waste taregt.

According to Curran and Williams (2012), zero waste (ZW) is defined as a whole system approach that removes waste from the source and also from each and every point in the supply chain. ZW concept motivates optimum recycling and resource recovery, sustainable production and consumption, and restricts mass incineration and landfilling (Zaman, 2015). Furthermore, Connett (2006) said that ZW concept binds community and industry together. Recently in the construction industry, with the understanding of the benefits of waste minimization in cost as well as through the protection of the environment, focus is given for the CDW management (Osmani, 2012). With the implementation of ZW concept, natural resource optimum usage and reduction in environmental issues can be achieved (Zaman, 2014). Moreover, Osmani (2012) has said that for the construction industry, ZW achievement is a highly challenging target. The author has further explained that, to achieve ZW target in the construction industry, waste reduction at source and material and component reuse and recycle can be carried out. When the construction industry focusses on waste minimisation, construction material flow through a closed loop system to preserve natural resources and to reduce waste landfilling (Akinade, et al., 2018).

To implement ZW concept, Eco design, Life Cycle Assessment (LCA), Industrial Symbiosis(IS), Closed loop supply chain management, innovative technology, Product stewardship(EPR/IPR), and Environmental Management System (EMS) are considered as the key stratergies (Bhamra, 2004; Curran & Williams 2012). Further, Peng, Scorpio, and Kibert (1997) stated that to achieve sustainable construction, waste hierarchy can be followed in the construction industry. Eco design can be defined as, starting from the origin of the product thinking about the whole life cycle and environmental impact reduction throughout the product life (Vallet, et al., 2015). Moreover, reverse and forward supply chains together form closed-loop supply chains (Krikke et al., 2004). Furthermore, supply chain of the construction industry can be discussed under four roles as, supply chain impacts on on-site activities, focus on the supply chain and cost reduction in inventory, logistic and lead-time, focus on activity transferring from site to former stages in the supply chain and finally in the management integration, supply chain and site production enhancements (Vrijhoef & Koskela, 2000). Furthermore, when the supply chain becomes a closed, in a circular economy, maximum use of waste takes place and it conserves virgin materials (Ghisellini,Cialani,&Ulgiati,2015). According to Chavan (2014), in the process of recycling, Extended Producer Responsibility (EPR) is used as a strategy in which manufacturer takes the responsibility of the product from the manufacturing up to final disposal.

As per Adams et al.(2017), construction product manufacturing, operation and designing of building, product and material recovery, awareness, economic and policies and legislations are identified as enablers for CDW management. Similarly, Zaman (2013) has also identified that for the WM in the construction industry, social, economic and environmental enablers can be used. When it comes to barriers that are faced in managing CDW are, inadequate knowledge about what is to be recycled, poor waste segregation practices and inadequate space for waste segregation, lack of technology usage for waste conversion to useful products, deficiencies in markets for recycled products, high recycling cost, lack of government policies for recycling, knowledge deficiencies on WM practices in the construction industry (Zou, Hardy, & Yang, 2013).

1.2. Problem Statement

In any organisation, one of the key objectives is to optimize resource usage (Kulatunga et al., 2006). As stated in the background study, in the constrction sector, less attension is paid to waste minimisation although it helps to optimise resource usage. Moreover, to improve the construction industry performance through sustainability, economic and quality, CDW management plays an important role (Kulatunga, et al., 2006). Though the attention is paid for the CDW, in the construction industry WM is still at an adolescence stage and it needs to be matured effectively (Wang et al., 2010). Construction waste occupies large landfill areas which further diminishes scarce land resource and as stated in the background study, in countries like Australia, and Hong Kong 20-30% and 11% of CDW get ended up in landfills respectively (Craven et al.,1994; Jaillon et al.,2009; Wanga et al., 2014). In addition to that, Wang et al. (2008) said that, construction waste has resulted in environmental pollution and has created negative impacts to the sustainable development of the industry. Moreover, Esin and Cosgun (2007) have identified CDW as a serious environmental issue. Similarly, Wang et al. (2010) have stated that many economies in the world is facing the challenge of effective reduction of CDW. Further, Curran and William (2012) have stated that, in order to overcome from the eco system threats at local, national and global levels, waste needs to be eliminated. Thus, as depicted in the background, management of CDW in the construction industry is a persuasive issue to be addressed.

In developing countries, as a result of large scale construction, project decision maker's focus is given to the traditional project objectives such as cost, quality, duration, safety and it has resulted in the huge construction waste generation (Yuan, 2012). Not only that, when considering about the Asian region, laws and regulations, regional and national policies are inadequate for the CDW management in the construction industry (Nitivattananon & Borongan , 2007). In addition to that, in Sri Lanka there are no any specific CDW regulations to manage CDW (Karunasena et al., 2012). According to Jayawardane (1992), waste generated in the construction sites of Sri Lanka is a considerable problem to be addressed. Similarly, Kulatunga et al. (2006) have stated that, wastage of materials on Sri Lankan construction sites is beyond the acceptable limit (as cited Jayawardena, 1994). In addition to that, Karunasena et al. (2012) have stated that, in Sri Lanka, to manage CDW, landfilling has selected as the first option although it is the least preferred option in WM. When considering Sri Lanka, Construction Waste Management (COWAM) project was initiated to manage the building waste of Tsunami disaster which took place in the year 2004 and currently it helps to manage the CDW to a certain extent (Karunasena, Amaratunga , Haigh, & Lill, 2009). Though COWAM project is available to manage CDW in Sri Lanka, due to the lack of technology, funds, unfamiliarity and unawareness of recycled building materials, projects related to recycling of CDW has not been initiated in Sri Lanka

(Karunasena, Amaratunga , Haigh, & Lill, 2009). Hence, to manage the CDW in Sri Lanka, different CDW management strategies need to be followed.

As discussed in the background, in the traditional WM system, which comprises of a linear flow, at the end life of the product is considered as waste (Zaman, 2014). Moreover, Zaman and Lehman (2011) have stated that, critical innovations have been taking place in the historical development of WM. As a result of the innovations and to challenge the traditional WM system, ZW management was created and waste is turned into a resource through ZW (Zaman, 2014). Furthermore, Curran and Williams (2012) have said that, ZW concept is a concept in which different measures are focused to eliminate waste. According to Curran and Williams (2012), with the waste elimination through ZW concept, pollution issues affecting to the ecosystem can be sorted, and the sustainability in the construction industry can be achieved through the optimum usage in renewable sources and raw materials. Thus, it is certain that ZW is a precise alternative for the CDW management. Although different researches are available for the WM in the construction industry, no researches have been carried out to check the applicability of the ZW concept to Sri Lankan construction industry. Hence, there is a need to find the applicability of ZW concept to the Sri Lankan construction sector.

1.3. Aim

The aim of this research is to investigate the applicability of ZW concept to the Sri Lankan construction industry.

1.4. Objectives

1) Review the concepts of Construction and Demolition waste (CDW), Zero Waste (ZW) and current Construction and Demolition waste (CDW) management in the construction industry
2) Examine enablers and barriers to apply Zero Waste(ZW) concept in Sri Lankan construction industry
3) Propose suitable suggestions to minimize the identified barriers.
4) Develop a framework to apply the Zero Waste (ZW) concept in Sri Lankan construction industry

1.5. Research Methodology

To achieve the ultimate aim of the study, initially a critical literature review was carried out. In the literature review, CDW waste, ZW concept, strategies, enablers, and barriers were discussed. Subsequently, as the approach for the study, qualitative approach was selected. As the research strategy for the study, case study method was followed and for the study eight (08) cases were selected. Similarly, for the data collection semi structured interviews were carried out with twenty-seven (27) participants from eight (08) cases. In order to analyse the collected data, individual case analysis and cross case analysis were carried out. Collected data were validated from the five (05) experts those who are specialized in the fields of WM and in the construction industry.

1.6. Scope and Limitation

The scope of this research is to identify the applicability of ZW concept and to develop a framework for ZW considering the Sri Lankan construction industry. Thus, this research is limited to the Sri Lankan construction industry.

1.7. Chapter Breakdown

Chapter 1 - Introduction

This chapter provides an overview of the research. This chapter includes the research background, problem statement, aim, objectives, research methodology, scope and the limitations and chapter breakdown.

Chapter 2 - Literature review

This chapter includes theoretical background on CDW in construction industry, C&D strategies, enablers, barriers, ZW concept, ZW strategies, enablers, barriers and application of ZW concept to Sri Lanka.

Chapter 3 - Research methodology

This chapter elaborates the research methodology with data collection and analysis techniques.

Chapter 4 - Data collection, analysis and framework development

This lead includes data collection, analysis on the applicability of the ZW concept and development of a framework to apply ZW in the construction industry.

Chapter 5 - Conclusions and recommendations

This chapter concludes the research with suggestions, recommendations, and further research areas.

1.8 Summary

This chapter elaborated comprehensive findings on background to the study, problem statement, aim and objectives of the study. Further, research methodology, scope and limitation and chapter breakdown was also illustrated in this chapter**.**

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Introduction

Chapter two represents the in detail explanation of the research background. At the beginning of the chapter, discussion is carried based on CDW, definitions of CDW, origins and causes of CDW, and composition of CDW. Then the study elaborates the findings on CDW generation in construction industry based on developing and developed countries. After that, study discusses on impacts of CDW, CDW management strategies, enablers of CDW management, and barriers of CDW management. Further, concept of ZW, development of ZW concept, ZW strategies, ZW enablers and ZW barriers are discussed. Finally, discussion on the application of ZW concept to the Sri Lankan construction sector and development of conceptual framework is carried out.

2.2. Construction and Demolition Waste

Construction industry being an economic driver, contributes to the gross national product along with employment and business opportunities (Sapuay, 2016). Similarly, Elgizawy et al. (2016) have stated that construction industry is considered as one of the main natural resource consumer and also as one of the largest polluters. Moreover, the authors have stated that, in most countries, CDW may count for a bigger portion of SW generation. Hence, the construction industry is facing difficulties to reduce the generated CDW during the construction activities (Banihashemi et al., 2018). Although researchers have paid attention to the effective and efficient CDW management since the 1980s, CDW management still needs improvements (Hao et al., 2007).

Building life cycle comprises of the period starting from cradle to grave and building life cycle process includes planning, designing, construction drawings, construction, operation, maintenance and demolition (Lai, et al., 2016). As a result of construction, toxic, heavy and bulky waste gets generated (Sapuay, 2016). When it comes quantification of CDW, it is measured by the volume (Nitivattananon & Borongan, 2007). According to Marchettini et al. (2007), the final destination of the waste which cannot be segregated or recovered is considered as landfilling. In addition to that, Agamuthu (2008) has said that, nearly 10-30% of CDW gets ended up in landfills. Moreover, Kofoworola and Gheewala (2009) have stated that, the landfill is the least favoured method for CDW disposal.

2.3. Definitions of CDW

In a construction project, design and construction stages are significant as they are inter-related, and systematic WM in one stage makes a direct impact over the next stage (Ding et al.,2018). According to Sapuay (2016), construction waste is heavy, bulky, and occasionally, toxic. Furthermore, Elgizawy et al. (2016) stated that, most of the countries in the world face real threat due to the large amount of CDW generation. Table 2.1 shows different CDW definitions given by different authors.

Table 2.1: CDW definition

Source of Reference	Definition
Hsiao et al. (2002)	All wastes generated in construction works
Wang et al. (2014)	CDW means the waste of valuable natural resources.
Yuan and Shen (2011)	Solid waste generated in the construction sector is defined as the CDW.
Shen et al. (2004)	Construction wastes are mixtures of inert and organic materials arising from all construction related activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation along all stages in implementing a construction project.
Christensen and Andersen (2011)	Waste generated during the building, repair, remodeling or removal of constructions
Ghosh and Ghosh (2016)	Waste arising from the construction, repair, maintenance and demolition of buildings, structures and roadways
Kofoworola and Gheewala (2008)	The waste produced during new construction, renovation, and demolition of buildings and structures
Fatta et al. (2003)	The waste generated from various activities such as clearing of sites, and the building of new structures or infrastructure
Hsiao et al. (2002)	Construction waste is defined as legal and illegal construction activities encompassing new construction, addition, renovation, rebuilding, and repair as well as the associated demolition. Demolition waste is defined as legal reported demolition, demolition of structures under government requisition, demolition of structures destroyed by natural force, demolition of illegal structures, and illegal demolition.
Statistics Canada (2003)	Waste materials from the construction and demolition of roads, bridges and buildings

2.4. Origins and Causes of CDW

Number of reasons leads to the origins of CDW generation and section 2.4.1. discussed them as follows.

2.4.1. Origins of CDW

CDW generation takes place due to sudden changes in building design, raw material remains, design errors, poor material handling, improper procurement and planning (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). Furthermore, generation of CDW can be explained as a result of inadequate data to select the most appropriate construction method, inexperience of the designer, and due to lack of knowledge in construction activity sequence (Ekanayake & Ofori, 2004). Review of waste origins is shown in Table 2.2.

Table 2.2: Review of CDW origins

Origins of waste	Osmani, et al. (2008)	Gavilan& Bernold (1994)	Osmani, et al.(2006)	Formoso et al. (1999)	Begum et al. (2006)	Poon et al. (2004)	Li et al. (2015)	Osmani (2012)	Kulatunga et al. (2006)
Contractual issues	√					√			
Design issues	√	√	√	√	√		√	√	√
Procurement issues	√	√		√				√	√
Transportation issues	√			√					√
On-site management and planning issues	√				√	√	√	√	
Material storage issues	√								
Material handling issues	√	√							√
Site operation issues	√	√	√				√	√	
Residual issues	√	√			√	√			
Other issues (Weather, Vandalism)	√			√					√

2.4.2. Causes of CDW

As per Osmani (2012), CDW generates as a result of lack in communication, inadequate information on the design, and long project period of time. Further, Jaillon et al. (2009) stated that design and requirement changes of clients generate vast amounts of waste. According to Kofoworola and Gheewala (2009), CDW generates due to contractor's lack of interest, lack of knowledge in the designing stage, use of poor-quality products, and poor material handling. Furthermore, the authors have identified causes for concrete waste creation as, dimension deviation in structural elements and ordering of surplus of concrete to carry out the work. Moreover, the authors explained that material delivery issues and poor handling of materials cause brick and block waste and tile waste.

Changes in design during the construction, contract documentation errors, and incomplete documents to start construction, issues related to quality control and quality assurance procedure specifications, and designer unfamiliarity of products are identified as the causes of CDW generation (Bossink & Brouwers, 1996). Further, the authors have identified that lack of knowledge of constructability and construction are the root causes for CDW generation in the design stage. Insufficient environmental awareness and structural selection, lack of management skills, lack of training to manage waste, and the use of outdated technology for construction are the reasons for the generation of CDW (Wang et al., 2008). These authors highlighted landfilling is the method used by the contractors to dump CDW. Furthermore, Magalhaes et al. (2017) explained that construction planning and designing decisions also lead to the CDW generation.

2.5. Composition of CDW

The CDW composition differs according to the construction technique, building type, and country (Elgizawy et al., 2016). CDW comprises of glass, bricks, asphalt, gypsum, wood, tiles, plastic, tarred products, metals soil and dredged soil, concrete, insulation materials, ceramics, electrical wiring, mixed C&D, and hazardous components (Ghosh & Ghosh, 2016). According to Hsiao et al. (2002), CDW includes waste from concrete, pottery and porcelain sand, timber, tile, concrete, glass, asphalt remaining mud, bamboo, paper, dirt brick, plastic, metal stone, and construction works. Similarly, Agamuthu (2008) has identified masonry, raw or semi-processed wood, drywall and engineered wood as examples of CDW. Moreover, Yeheyis et al.(2013) have explained that CDW consists of masonry, asphalt, metals, paper concrete, shingles, plastics, wood products, drywall, and cardboard. As per Wang et al. (2008), construction activities generate waste types such as sludge, soil, timber and steel, from which, 95% can be recycled while remaining 5% is unrecyclable.

In the view point of Shen et al. (2004), CDW can be identified in the form of steel, concrete, timber rubble, mixed site clearance materials, earth, and building debris. Moreover, Fatta et al. (2003) have explained that based on the origin, CDW can be classified as worksite waste materials, road planning and maintenance materials, excavation materials and demolition materials. According to the authors, in geotechnical engineering works and underground constructions waste such as gravel, soil, rocks, sand, clay as excavation materials and in the road planning and maintenance materials waste such as asphalt, all pavement materials such as sand, gravel, metal get generated. Further, Shen et al. (2004) have stated that in the demolition material waste comprise of gypsum, gravel, glues, paper, dressed stone, bricks, metal, pigments, sand, pieces of concrete, enamels, porcelain and in the worksite waste material, overlay plates, wood, plastic, lime-cast, glass, wires, covers, and soil can be identified. Hao et al. (2007) have explained that CDW is divided into materials, machinery, energy, and labour. Moreover, as per Lai et al. (2016), CDW that gets generated during the life cycle of the building can be elaborated as in Figure 2.1.

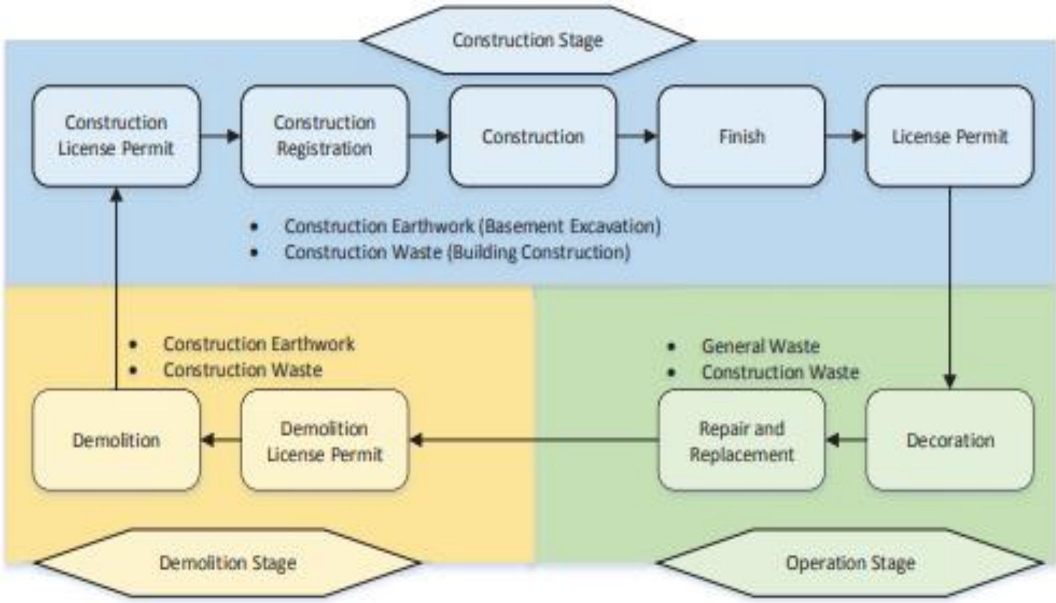


Figure.2.1. : CDW in life cycle of a building

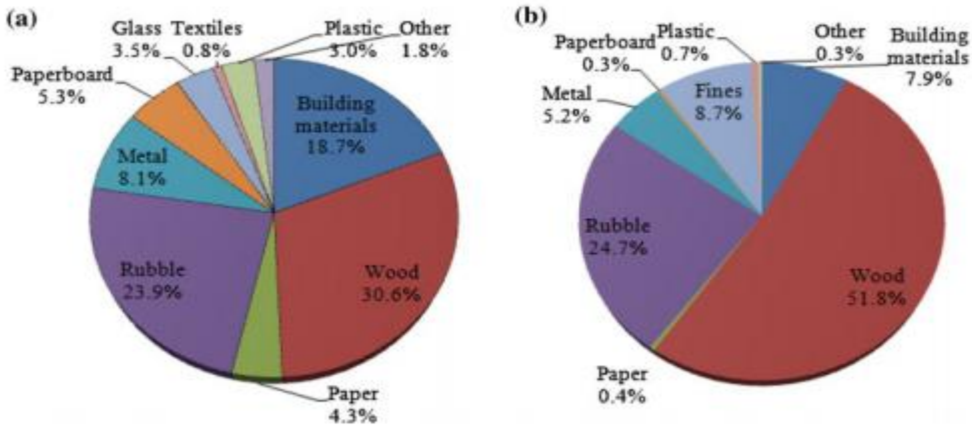
Source : Lai et al. (2016)

Elgizawy et al. (2016) have identified that CDW comprise of glass, metal ferrous (Steel), wood, metal Nonferrous (Copper, Aluminum), plastic (PVC pipes, plastic films for packaging, wall coverings), ceramic tiles, drywall or gypsum board, insulation material (mineral wool insulation, Styrofoam), masonry (bricks and mortar), filling material (gravel, sand and soil), paper and cardboard, concrete, marble and granite. Similarly, Ghosh and Ghosh (2016) have identified CDW as brick, concrete, hard core subsoil, topsoil, timber, metal, plastics. According to Kofoworola and Gheewala (2009), a sizable proportion of the generated CDW consist of paper and plastic waste from the usage of packaging materials, formwork, and wood waste from scaffoldings. Further, Wang et al. (2008) disclose that concrete waste generation is higher in CDW, i.e., approximately 80%- 90%, due to the concrete demolition, plastering flow, excess ordering, and template leakage. The authors have also explained that block wastage happens due to the damages and cutover, whereas timber and brittle material wastage generates due to cutover and transportation issues. According to Jaillon et al. (2009), CDW is a mixture of inert and non-inert materials, and out of the CDW, 70% of the construction waste is from the inert materials that can be reused for reclamation and earth-filling works. The authors have also stated that, from the CDW, non-inert waste account for 15% - 18% and they are either recycled or disposed to landfills. Out of the generated CDW, a certain percentage of waste is reduced and recycled while the remaining CDW is incinerated or sent into landfills, as illustrated in Table 2.3

Table 2.3: CDW generation and management in various countries

Country	Waste generation	Waste Management		Source of Reference		
	C&D waste (MT)	% Reduced/ recycled	%Incinerated/ land filled	(Jaillon et al., 2009)	(Symonds Group Limited, 1999)	(Franklin Associates, 1998)
Germany	59	17	83	√		
UK	30	45	55	√		
France	24	15	85	√		
Italy	20	9	91	√		
Spain	13	<5	>95	√		
Netherlands	11	90	10	√		
Belgium	7	87	13	√		
Austria	5	41	59	√		
Portugal	3	<5	>95	√		
Denmark	3	81	19	√		
Greece	2	<5	>95	√		
Sweden	2	21	79	√		
Finland	1	45	55	√		
Ireland	1	<5	>95	√		
Luxemburg	0	n/a	n/a	√		
Europe-15	180	28	72		√	
US in 1996	136	30	70			√
Hong Kong in 1999	13.55	79	21	√		
Hong Kong in 2005	21.45	89	11	√		
Singapore in 1999	0.41	70	30	√		
Singapore in 2005	0.49	94	6	√		

Further, in Canada, out of the Solid Waste (SW) one third (1/3) is CDW and nearly 9Million Tons (MT) of CDW gets generated (Yeheyis et al., 2013). Furthermore, authors have said that, out of the total municipal SW, 27% which is landfilled are from CDW. Further, Yeheyis et al. (2013) have also stated that, Canadian CDW rate of recycling is at a lower stage and CDW management plan needs to be implemented. When considering about the recycled or reused CDW in Canada, it is comparatively lower than other developed countries (Ghosh & Ghosh, 2016). According to the findings, they have stated that, in Canada, concrete is the largest CDW that is generated in the construction industry and it is nearly 52%. Figure 2.2 shows the CDW composition in Canada in two pie charts and in pie chart (a), it shows the composition of construction waste and in pie chart (b), it shows the composition of demolition waste.



(a) Composition of construction waste (b) Composition of demolition waste

Figure 2.2. : Composition of CDW in Canada

Source : Ghosh and Ghosh (2016)

2.6. CDW Management in the Construction Industry

Starting from the raw material extraction up to the demolition and waste disposal, massive quantities of waste gets generated from the construction industry, and the massive consumption of raw materials in the construction industry has resulted in unsustainability in the industry (Elgizawy et al., 2016). Further, Osmani et al. (2008) stated, starting from pre-construction up to the completion of the construction, CDW gets generated. Furthermore, changes in the WM system has taken place due to the new waste handling methods and due to new waste approaches (Hottle et al., 2015). As per the CDW definitions in different countries, CDW generation is vary from country to country (Kofoworola & Gheewala, 2008). Furthermore, in developing countries high attention is paid to CDW management (Yuan & Shen, 2011). Moreover, in Asian countries, CDW management is difficult as they are heavy, bulky and most of all they are unsuitable for disposal through composting or incineration (Nitivattananon & Borongan, 2007).

2.6.1. CDW management in developing countries

In Asia for the CDW management, regional and national policies, laws and regulations available are inadequate (Nitivattananon & Borongan, 2007). When considering about Indonesia, it is identified that for the waste minimization, stakeholders such as clients, suppliers, construction managers, foreman and laborers involvement are necessary (Nitivattananon & Borongan, 2007). Similarly, Begum et al. (2010) stated, in Malaysia CDW gets generated from projects like housing, infrastructure and commercial building. Further authors have stated that there is a persuasive necessity to reduce CDW in the Malaysian construction industry. Moreover, Nitivattananon and Borongan (2007) have stated that in countries like China, India, Sri Lanka, Thailand and Vietnam, there are no any specific CDW regulations to manage waste. On the other hand, although there is a lack of regulations to manage CDW, Ghosh and Ghosh (2016) have stated that, in India, cities such as Chennai, Mumbai, Kolkata and Bangalore have initiated CDW management through the introduction of CDW handling rules.

In Brazil, although information related to CDW in the whole country is unavailable, in specific cities like Salvador, Rio de Janeiro and Sao Paulo an average of 0.49 kg per inhabitant/day get generated (Nunes , Mahler , Valle, & Neves, 2006). Further, the authors have stated that out of the generated CDW in Brazil, the large part is not recycled due to lack of recycling centers. According to Kofoworola and Gheewala (2008), in Thailand, CDW is considered as a part of Municipal SW and as a result of the rapid urbanization huge amount of CDW gets generated. Subsequently, as per Ghosh and Ghosh (2016), in China nearly 600MT of CDW get generated annually and it is considered as 30 to 40 percent of the total urban waste. Authors have further stated that, 500 to 600 tons of waste get generated through the construction of 10,000 m^2 building and the demolition waste of 7,000 to 12,000 tons get generated through the demolition of a 10,000 m^2 old building.

2.6.2. CDW management in developed countries

Since 1994, Austria and Denmark report an average recycling of 76% and 90% in CDW respectively (Agamuthu, 2008). Further, Christensen and Andersen (2011) have stated that in Denmark, building waste comprise of Concrete, mortar and tiles which are nearly 62-93% and during the renovation nearly 26% of waste get generated from wood and other combustibles. In Germany, CDW management practices are being followed and starting from 2002, with proper legislative instruments and treatment methods, disposal of CDW into landfills were banned (Agamuthu, 2008). Moreover, Ghosh and Ghosh (2016) have stated that, in 2002 and 2003 CDW generated in Germany are 63.2% and 61.0% respectively. When considering about Italy, in 2001 out of the generated wasted 67.1% was disposed in landfills,8.7% was incinerated and remaining were recycled (Marchettini, Ridolf, & Rustici, 2007).

In Taiwan, CDW generation accounts for 1.2-1.9 million tons per year and 64% to 80% of waste are reused (Lai, Yeh, Chen, Sung, & Lee, 2016). Further, Agamuthu (2008) has stated that CDW accounts for 33-65% in landfills of USA, Canada, UK and Hong Kong although they follow 3R initiatives within their countries. Similarly, Ghosh and Ghosh (2016) stated that in the UK, more than 50% of the CDW are landfilled. In addition to that, in UK, 51.2% (27.4 MT) of CDW is directly disposed to landfills and 39.6%(21.2 MT) are used for land modelling (Lawson , et al., 2001). Further, the authors have mentioned that, 9.2% (5 MT) of CDW is used to produce graded products.

In the USA, CDW ranges from 20 to 30 kg/m^2 and on a per capita basis, it is nearly 500 kg/person/year (Peng , Scorpio, & Kibert , 1997). Moreover, the authors have stated that, in the USA nearly 31.5 million of construction waste is produced and demolition waste is nearly equal to the double amount of the generated construction waste. Apart from that, Ghosh and Ghosh (2016) have stated that, in the USA, 170 million tons of waste per year get generated and 48% of that is recovered. In the USA, it is a challenging issue to recycle the CDW as the secondary market for recycled materials are still in an adolescent stage (Peng , Scorpio, & Kibert , 1997).

When considering about the construction industry in Greece, it has been developed and with the CDW generation, materials such as glass, wires, door frames and window frames are being reused and some quantities of waste get ended up in landfills (Fatta, et al., 2003). Table 2.4 shows the CDW generation in Greece from 1996 to 2000.

Table 2.4.: Total quantities of CDW

Year	Quantities of C&D waste (tonnes)
1996	1,636,298
1997	2,006,625
1998	2,130,939
1999	1,899,075
2000	2,092,387

Source: Fatta et al. (2003)

As a result of the construction activities in Hong Kong, it was found that in 2011 out of the 13,458 tonnes of Municipal Solid Waste (MSW), CDW accounts for quarter of the MSW (Ghosh & Ghosh, 2016). Authors have further stated that in order to handle the CDW issue in Hong Kong, Construction WM policies are introduced. Moreover, the authors have also said that, nearly 7890 tonnes of CDW were landfilled in 1999 and after the introduction of two off-site waste sorting facilities from the off-site Construction Waste Sorting (CWS) program, nearly 5.11 tonnes of CDW are handled in the two off-site CWS facilities during 2006 to 2012. In addition to that, Nitivattananon and Borongan (2007) have stated that, as a result of infrastructure projects in Hong Kong, over the past decades, there is a significant increase in CDW generation. Further, Ghosh and Ghosh (2016) have stated that, in Victoria, Queensland, South Australia, Western Australia, Tasmania and Australian Capital Territory, CDW management practices have been followed. Apart from that, in Australia, nearly 5 MT of CDW are generated within a year (Nitivattananon & Borongan , 2007). In the European Union (EU), CDW accounts for 855 million tons per year which is 33.3% of the total EU waste and out of the generated CDW, nearly

75% of the waste get landfilled (Ghosh & Ghosh, 2016). Table 2.5 shows CDW generation in developed countries.

Table 2.5 : CDW generation and recycling in developed countries

Country	Construction and Demolition waste (million tonnes/year)	Concrete being recycled (%)
Canada	11	36
US	136	50-57
UK	30	45
France	24	15
EU-15	180	28
Australia	5	41
Sweden	2	21
Spain	13	<5
Belgium	7	87
Germany	59	17
Italy	20	9
Netherlands	11	90
Portugal	3	>5
Denmark	8	81
Greece	2	<5
Finland	1	41
Ireland	1	<5

Source: Ahimoghadam (2018) (as cited in Venta, 2001)

2.7. Impacts of CDW

Effective CDW management is a challenging issue for many countries, as they make an adverse impact on the environment (Wang et al., 2010). Sapuay (2016) states that the improper management of CDW leads to adverse environmental impacts and health issues of humans. The author further indicates that although the development takes place in the society, waste issues can lead to an environmental catastrophe. Similarly, Wang et al. (2010) specified, in the current global context, CDW creates numerous environmental issues, and as per Coelho and Brito (2012), CDW damage the ecological environment, consume the land resource, and leads to soil and water pollution. Correct management of CDW reduce the adverse environmental impacts, undesirable landfill site creation, and health risks related to construction waste

(Lingard et al., 2000). Magalhaes et al. (2017) have pointed out that designing strategies should focus on the environmental impacts of the construction stages. For sustainable construction activities, policies and regulations are introduced by governments to reduce the negative impacts of CDW (Oluwole & Olaniran, 2013).

In Asian countries for the disposal of CDW, landfills are not adequate (Nitivattananon & Borongan , 2007). The authors have also identified that CDW as a main contributor to the environmental pollution. In addition to that, Elgizawy et al. (2016) have stated that landfilling of CDW resulted in the depletion of natural resources. Moreover, Kofoworola and Gheewala (2008) have stated that, unregulated CDW dumping and scarcity of landfills have become a serious issue. Furthermore, if CDW is not managed in a proper manner it will make impacts on the human life style as well as in environment (Fatta, et al., 2003). Similarly, Wahi et al. (2016) have stated that if CDW is not managed properly, it will cause destructive effects on environment. Further, due to the biodegradation of CDW materials in landfills, environmental and health problems take place (Elgizawy, El-Haggar, & Nassar, 2016). In order to protect the natural environment and public health, CDW management is much needed and it will help to overcome from issues like landfill shortage, increment in CDW volume, adverse social, ecological and economic impacts due to CDW disposal (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). Furthermore, the authors have elaborated that, in the ecological perspective, due to CDW impacts like soil, water, and air pollution, adverse impacts on flora and fauns, changes in climate take place while in economic perspective, primary resource loss, effects on tourism and international reputation issues take place. Moreover, authors have explained, in the perspective of social and health life, issues such as health risks, impacts on safety while working, and use of public space gets generated. Thus, CDW management is a persuasive issue to be addressed.

2.8. CDW Management Strategies

CDW management system include waste prevention and reduction through reuse, recycle, energy conversion and proper disposal (Marchettini, Ridolf, & Rustici, 2007). For the CDW diversion from the landfills, most of the countries follow waste reduction, recovery, reuse and recycling methods (Kofoworola & Gheewala, 2008). In countries like, Sri Lanka, Japan, Hong Kong, Malaysia and Singapore, for the management of CDW, 3R concept is being practiced (Nitivattananon & Borongan , 2007). In addition to that, the authors have also stated that, in some countries awareness on the CDW management is being practiced. Further, CDW management strategies need to be developed by the waste managers from the planning phase to establish waste diversion goals (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). According to Yuan et al. (2011), the 3R concept is comprised of WM strategies to manage CDW . Tam and Tam (2006) have proposed strategies such as waste reduction at source, reusing and recycling of waste, and landfilling for CDW management. Moreover, Baldwin et al. (2009) indicate that Waste Minimisation Design is a crucial strategy for effective CDW management, while Bossink and Brouwers(1996) propose to manage CDW through strategies such as waste prevention at the site and to consider environmental impacts from the designing stage. Client awareness, adhering to building regulations, and checking client demand can be other useful schemes in the construction industry (Pitt, Tucker, & Riley, 2009).

Further, if CDW creation is out of control, strategies like recyclig of discarded metals and metal dumpsters, using the remaining unused construction materials for other projects, resending the products to corporate inventory for future use, and reselling of unused remaining materials for third party can be used (Yates, 2013). Further, author has highlighted, training and supervisons of employees, material handing, procurement strategies, material control, employee and subcontractor management, proper documentation and communication can also be applied to manage CDW. Furthermore, Acosta, et al. (2012) have stated that capacity development, bridging policy gaps and harmonizing policies, creating economic opportunities, social marketing and advocacy, sustainable financing, knowledge management on technologies and innovation, good governance, organizational development and enhancing inter-agency cooperation, caring for vulnerable groups, compliance monitoring, enforcement and recognition, and reducing disaster and climate change risks can also be used to manage CDW .When the construction industry focuses on waste minimisation, construction material flows through a closed loop system to preserve natural resources and to reduce waste landfilling (Akinade et al., 2018).As stated by Kofoworola and Gheewala (2009), reduce, reuse, and recovery of construction waste helps to realise employment opportunities and cost savings.Moreover, Ajayi et al. (2017) stated that through prevention and minimisation, waste can be managed effectively.

WM strategies in a construction site can be categorised into two as planning and controlling (Ekanayake & Ofori, 2004). As per the authors, to minimise the CDW, best practice is use of planning strategies comprising of design, material procurement, site layout and construction scheduling. Similarly, to manage waste, authors have stated controlling strategies like, monitoring of waste collection and storage, security, training, machine maintenance, material handling and delivery. Moreover, for the management of CDW, as per Ghosh and Ghosh (2016), strategies such as, use of polluter pays system, CDW collection method specialization, use of new recycling technologies, implementation of integrated disposal method, and environmental awareness can be followed. Ekanayake and Ofori (2004) have also said that, to reduce waste on site, proper material management is a must. In addition to that, Agamuthu (2008) has said that, in countries like Germany, Australia, Finland and Denmark policies are available to encourage 3R concept. As per Akinade et al. (2016), Building Information Modelling (BIM) tools can be applied along with platforms such as Revit, Micro station, Archi CAD, and Teklato manage CDW. Further, Ajayi et al.(2017) have stated that CDW can be managed through the use of minimisation and prevention strategies. Moreover, in past few years strategies relavent to waste treatment have shifted from landfilling to incineration (Chen & Lo, 2016). By the same token, Huang et al. (2018) have said that, for the management of CDW , strategies such as, reinforce the source control, economic incentives, use of innovative technologies, management and supervision enhancement and design effective circular model can be used. Strategies of 3R concept, waste heirachy and ZW concept are discussed in the following sub sections.

2.8.1. 3R Concept

Basic principles to conduct CDW management is identified as the three strategies of reduce, reuse and recycle which is also known as the 3Rs (Yuan & Shen, 2011). In order to reduce waste material landfilling, the 3Rs are being followed by different sectors (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). Although the 3R is considered as a basic principle to manage CDW, some industry practitioners still do not use the 3R concept on the sites (Wahi, Joseph, Tawie, & Ikau, 2016). According to Addis (2006), clients, designers, laborers, contractors and suppliers, the key parties in the construction industry, need to address the 3R concept and client can influence other key players to use 3R. As per the author, clients can influence the designers to implement 3R by, use of appropriate designs to site waste minimisation, use of less resources in construction, influence on material handling to reduce wastage. When it comes to Asian countries, to manage CDW with the 3R concept, participation of stakeholders, strategies related to waste minimisation, following environmental measures related to 3R, formulation of policies are needed (Nitivattananon & Borongan , 2007). Reusing and recycling potentials of CDW materials are shown in Table 2.6

Table 2.6.: CDW materials and its recycling/reuse potential

C&D waste	Recycle/reuse potential	Biodegradable potential	Potential for landfilling	Potential for incineration
Concrete	Recycled aggregate for road base, and for concrete	No	Yes	No
Steel	Recyclable to steel	No	No	No
Brick and block	Backfill, recycled aggregate	No	Yes	No
Insulation	Insulate attic or as sound proofing on interior walls	No	No	Yes
Glass	Finer glass as pozzolans in cement	No	Yes	No
Ceramic	Possibly recyclable as filling material as a coarse aggregate for concrete	No	Yes	No
Aluminum	Recyclable to aluminum	No	No	No
Plastic	Recyclable to any form	Some can be biodegradable	No	Yes
Paint	Reusable as paint/concrete admixture	Some can be biodegradable	No	Yes
Wood	Recyclable to veneer board/paper pulp	Yes	Yes	Yes
Gypsum boards	Recyclable to new board, crushed wall as clay and silt mixture and can be composed	Yes	No	No
Cardboards	Composting, fire kindling, paper production	Yes	Yes	Yes
Asbestos	No	No	If properly sealed	No

Source: Yeheyis et al. (2013)

- **Reduce**

Optimum use of resources or the reduction at source is defined as reduce (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). The authors further stated that, before waste to become a physical problem, different methods are being followed to reduce the waste generation. Moreover, the authors have shown examples to reduce CDW as, reduction of packaging amounts that comes to the site, use of efficient framing techniques, and change of design principles.

- **Reuse**

For the reuse of CDW materials, there is a high potential (Peng , Scorpio, & Kibert , 1997). Yeheyis et al. (2013) have defined reuse as the use of a part of the waste stream of product repeatedly for the same purpose. As per the authors, with the effective reuse of materials present structures of the materials can be conserved and CDW can be reused in the forms of reuse of remaining materials for an ongoing or future project and reuse of materials from demolition projects for an ongoing project. In addition to that, reduce strategy helps to conserve natural environment and resources, reduction of landfills, energy saving and reduction of pollution (Yeheyis et al.,2013).

Reuse can be done by the means of use of materials for the same function like use of timber formwork in construction and reuse of marital in the form of new life like, use of cut corner steel bar for shelves (Duran, et al., 2005; Ling & Leo, 2000). Furthermore, Kofoworola and Gheewala (2008) have stated that, materials like wood is reused many times within the project and scrap metals like off-cuts of metal sheets and bars and salvageable materials are resold.

- **Recycle**

Use of material which is initially planned to be thrown away by separating, collecting, processing and marketing is identified as recycling (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). Recycling of CDW helps environmentally by diverting waste from landfills and convert it into new products (Peng , Scorpio, & Kibert , 1997). In addition to that, as per Ghosh and Ghosh (2016), in countries like USA, Canada, Europe, Australia, India, Japan, Hong Kong, and Taiwan number of recycling projects related to CDW have been carried out and processing capacity of CDW plants are in the range of 100 to 1500 per day. Before recycling of CDW, the waste generator should perform waste sorting (Wahi et al., 2016). Furthermore, Elgizawy et al. (2016) reports, once the building is demolished, waste get ended up in landfills, and this creates the need to consider alternative methods for waste recycling. The authors further explained that a recycling process and profitability aspects should be available to make a sustainable environment, where recycling products of CDW are provided with a good market. Table 2.7 presents the CDW materials, their recycling technology and the products that can be produced after recycling.

Table 2.7: Technology used for recycling components of CDW

CDW materials	**Recycling technology**	**Recycled product**
Brick	• Burn to ash • Crush into aggregate	• Slime burnt ash • Filling material Hardcore
Concrete	• Crush into aggregate	• Recycled aggregate • Cement replacement (replace cement by fine portion of demolished concrete) • Protection of levee • Backfilling and Filler
Asphalt	• Cold recycling • Heat generation • Parallel drum process • Elongated drum • Microwave asphalt recycling system • Finfalt • Surface regeneration	• Recycled asphalt • Asphalt aggregate
Masonry	• Crush into aggregate • Heat to 900°C to ash	• Thermal insulating concrete • Traditional clay brick • Sodium silicate brick

CDW materials	Recycling technology	Recycled product
Timber	• Reuse directly • Cut into aggregate • Blast furnace deoxidization Gasification or pyrolysis • Chipping • Molding by pressurizing timber chip under steam and water	• Whole timber • Furniture and kitchen utensils • Lightweight recycled aggregate • Source of energy • Chemical production • Wood-based panel • Plastic lumber • Geo fiber • Insulation board
Ferrous metal	• Melt • Reuse directly	• Recycled steel scrap
Non Ferrous metal	• Melt	• Recycled metal
Glass	• Reuse directly • Grind to powder • Polishing • Crush into aggregate • Burn to ash	• Recycled window unit • Glass fiber • Filling material • Tile • Paving block • Asphalt • Recycled aggregate • Cement replacement • Man-made soil
Plastic	• Convert to powder by cryogenic milling • Clipping Crush into aggregate • Burn to ash	• Panel • Recycled plastic & Plastic lumber • Recycled aggregate • Landfill drainage • Asphalt • Man-made soil
Paper and cardboard	• Purification	• Recycled paper

2.8.2. Waste Hierarchy

By following waste hierarchy in the construction, it helps to achieve sustainable construction by reducing resource consumption and environmental issues (Peng, Scorpio , & Kibert, 1997). As Bhamra (2004) stated, WM hierarchy led to Eco design strategies. Moreover, Wahi et al. (2016) explained that, in some construction sites, still 3R concept is not being implemented as the construction practitioners are unaware of it. Figure 2.3. depicts the waste hierarchy used for CDW management.

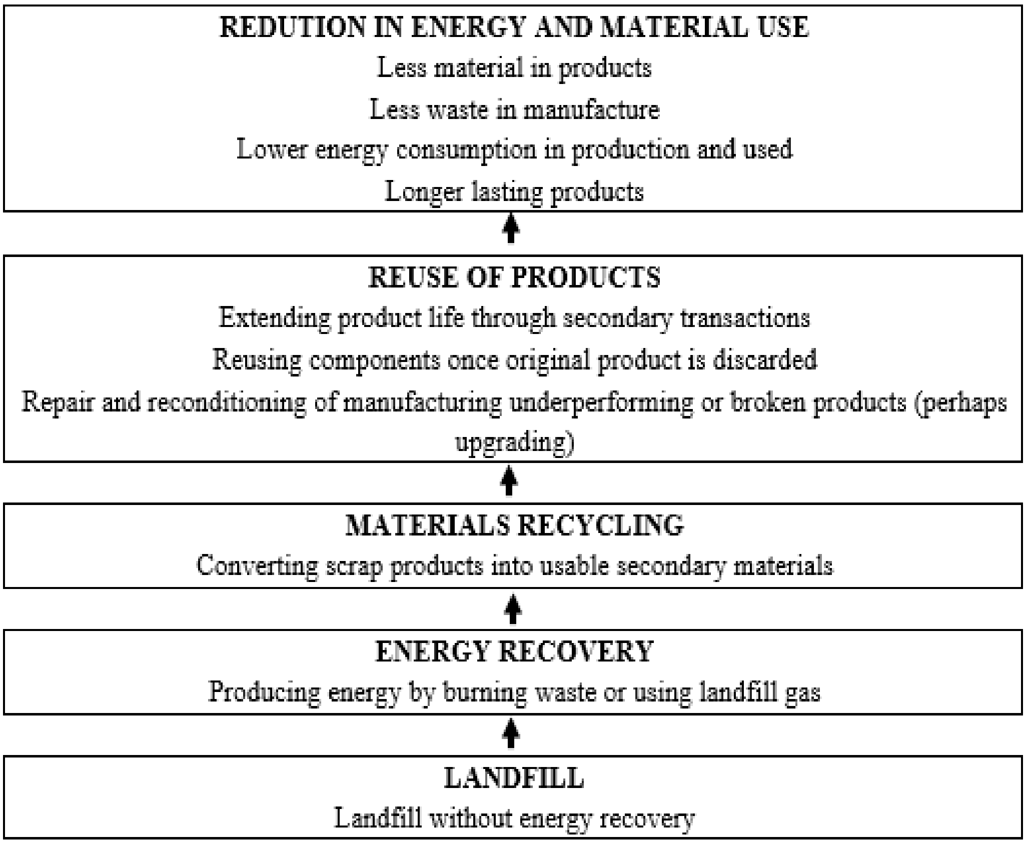


Figure 2.3.: Waste hierarchy

Source : Bhamra (2004)

2.8.3. Zero Waste(ZW) Concept

With the current WM issues like poor conservation of resources, uncontrol pollution and recovery in the WM approach has resulted in the innovation of “ZW” approach (Zaman, 2014). As stated by Zaman (2015), in order to solve the issues relavent to waste management, ZW is considered as the ideal concept. Similarly, with the ZW concept CDW issue can be solved in an effective way through reusing and redesigning of the life cycyle of the resource (Song et al., 2015). Moreover, Curran and Williams (2012) stated that, through the implementation of the ZW concept, traditional thoughts of WM are being challenged. In addition to that, Zaman (2014) has stated that through ZW concept, all waste is recovered or changed by using a natural process or waste get recycled without causing any harm to the natural environment.

According to Zaman (2015), none of the articles published from 1995 to 2014 has focused on the CDW documentation for ZW. Further, Osmani (2012) reports that ZW achievement is a highly challenging target for the construction industry. The author has further elaborated, to achieve ZW target in the construction industry, waste reduction at source and material, and component reuse and recycle can be performed. With the implementation of ZW concept reduction in environmental problems and optimal use in natural resources can be achieved. (Zaman, 2014). With the elimination of waste through zero-waste concept, pollution issues affecting the ecosystem can be sorted, and the optimum use of raw materials and the use of renewable sources will bring the construction sustainability (Curran & Williams,2012). Thus, ZW can be identified as the key strategy to eliminate CDW from the construction industry.

2.9. Enablers of CDW Management

For the CDW management, enablers such as, environmental dimensions, economic dimensions, and social dimensions are needed (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). As per the authors, under environmental dimensions, for the management of CDW, indicators such as CDW quantities, composed CDW, recycled CDW, landfilled CDW and avoided CDW are considered. When considering about the economic dimension indicators, CDW disposal cost, cost of maintenance and operation of recycling facilities, and fuel consumption cost for transport are included (Yeheyis, et al., 2013). Similarly, the authors have also stated that, for social dimension indicators, acceptance of CDW management plans and actions by the public, involvement of the public in planning and implementation, safety working environment and human health impacts are considered. In addition to that, Shen and

Tam (2002) have said that to manage CDW enablers like, CDW reduction and recycling, in-house environmental management training, development in WM plans and implementation of legal measures to protect the environment can be considered. As stated by Adams et al.(2017), as the construction industry WM enablers, understanding and awareness, product and material recovery, operation and desiging of buildings, policy and legislations, and economics were identided.

Zaman (2013) explained that social, economic, and environmental enablers could facilitate WM in the construction industry. Further to authors, behaviors of human, use of materials and waste generation, current WM practices by the locals are identified as critical social enablers, while tax related to landfilling, benefits of treatment facilities, and waste value economic enablers. Authors further elaborated that, main enablers such as global climate change, the environmental movement, and awareness can also assist to manage CDW. Moreover, enablers can be divided into four sectors as institutional, technological, internal action and market influence where institutional enabler creates an environment which both stimulates and enforces change (Abidin et al., 2013). Similarly, authors have stated that, technological enabler provides the means and opportunity to make the changes while changes are required through market influence enabler. Further, the authors have stated that resources and capability to change are considered as institutional enablers. In the same manner, several researchers have focused on analyzing the influencing factors for WM and factors such as technical, political, legal, socio cultural, environmental and economic have identified as the influencing factors (Gahana et al., 2018).

2.10. Barriers of CDW Management

In managing CDW, as per Yuan and Shen (2011), the main reason for the limited effectiveness of CDW management is due to the involvement of two major stakeholders which consist of public, non government organisations (NGO), authorities and other stakeholder category comprise of clients of the project, subcontractors and contractors. Therefore, authors have explained that in managing CDW, the stakeholder group that consist of general public, authorities and NGOs concern more to limit the waste landfilling through waste minimisation while the other stakeholder group consist of clients, contractor, subcontractors to look into benefits and profits that they can gain through CDW management and they do not pay their attention towards the environmental impacts of CDW. According to Agamuthu (2008), the main barrier to manage CDW is lack of legislature to manage CDW. Hence, authors have elaborated that, when the quality control of the building materials is poor due to the lack of proper legislation, after the demolition, waste that gets generated are non-recyclable and create harmful impacts to the environment. Thus, the authors have emphasized that, lack of regulations also lead to landfilling of CDW.

CDW barriers that are identified by the Shen et al. (2004) are, availability of lots of waste handling processes, lack of interest in waste recycling, poor waste sorting process, lack of interest to reuse waste, contribute to air pollution through the collection and transporting of waste, lack of coordination and supervision among the staff those who handle waste, plastic bag usage to collect waste, and unsafe operation to handle waste. Moreover, poor CDW categorization also leads to issues in managing CDW (Agamuthu, 2008; Burlakovs, et al., 2018). Zou et al. (2013) discussed some barriers to manage CDW ; i.e., poor knowledge on opportunities in recycling and ways of recycling, poor waste separation of contaminated recyclable products, lack of recyclable material market, poor technological development to convert waste into useful product, cost of recycling process being higher than the income received from the recycling products, and failure to incorporate design for deconstruction. Besides, less costly alternatives, low gate prices for landfilling, lack of government involvement for recycling activities, poor infrastructure and communication, inadequate knowledge in the construction industry about recycling, lack of market for recycling products are also considered as barriers. Further, Guerrero et al. (2017) identified obstacles such as inadequate waste reduction plan development, lack of regulations related to environment, and inadequate information on norms relevant to environment.

For the effective CDW management, barriers such as lack of policies, lack of legal framework, low level of public education, poor payment and training for waste workers, negative public attitude, and availability of open dumping grounds creates hinders (Ezeah & Roberts, 2012). Further, Crawford et al. (2017) have said that, to improve the environmental performance of CDW management, barriers related to cost and time associated with on-site WM, industry culture, lack of education, competing project priorities, and lack of financial incentive make adverse impacts. Moreover, weak political will, ineffective representation of communities in decision making bodies, lack of knowledge on green procurement, lack of planning, monitoring and performance evaluation activities are also identified as barriers for effective CDW management in the construction industry (Muchangos et al., 2015). Similarly, other barriers that affect for the CDW management are, ineffective CDW dismantling, sorting, transporting and recovering process, undeveloped individual engagement, over emphasizing recycle and non-environment friendly methods during C&D phases of construction projects, ineffective CDW management (Mahpour, 2018).

Ling and Nguyen (2013) have identified another set of barriers that make impact for CDW management due to the lack knowledge of the participant of project which leads for waste generation, project players were unwilling to implement WM, over-reliance on subcontractors to implement WM strategies, client not expecting WM to be done, client focusses their attention most on the progress of the construction activities rather than the WM, inadequate time for apply WM in the project, inadequate experience of people and inadequate knowledge to initiate strategies relevant to WM, lack of money to implement WM in the project, lack of mutual understanding within the project team to apply WM, difficulties in quantifying CDW, lack of regulations, policies and laws for WM, and insufficient enforcement of regulations and laws on WM. More importantly, to reduce CDW primary barriers that have been identified are, inadequate design standards for building to reduce CDW, CDW disposal cost and poor planning in urban designs. Further, inadequate guidance on CDW sorting and collection, inadequate standard and knowledge on reuse of CDW and lack of market for CDW reuse were identified as the barriers for reuse CDW. In addition to that, barriers that affect for recycling of CDW are identified as an ineffective management system, immature recycling technology, under developed market for recycled CDW products and immature recycling market operation (Huang et al., 2018).

2.11. Concept of ZW

In linear economy, recyclable materials are not directed into the production process and it causes issues in the long run in the perspective of sustainability (Curran & Williams, 2012). Hence, authors have said that with the rejection of one-way linear method and by using a circular closed loop system, ZW can be implemented. In addition to that, Elgizawy et al. (2016) have stated that for the efficient use of materials, cradle to cradle approach needs to be used. Figure 2.4 shows linear and circular resource flow.

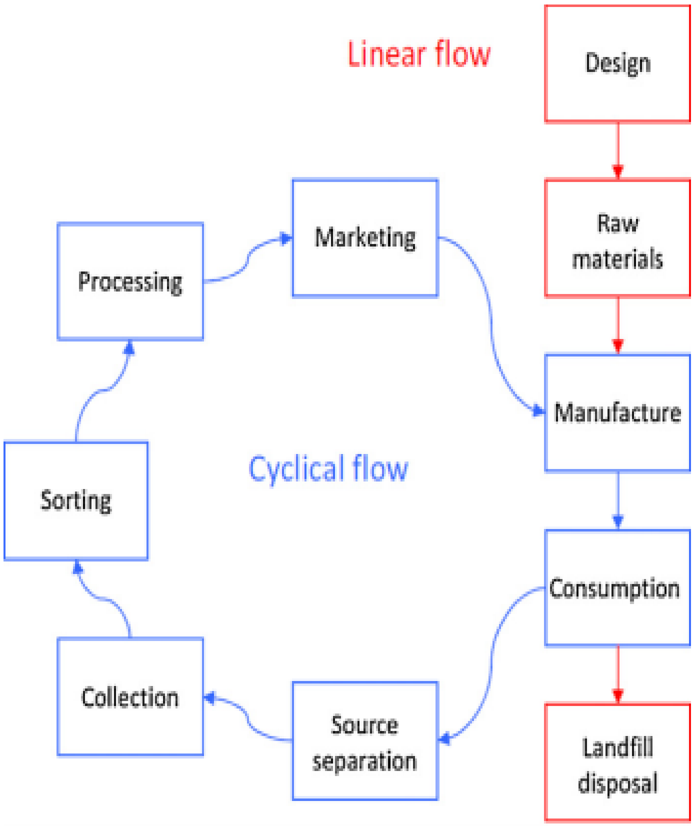


Figure 2.4. : Linear and circular resource flow

Source : Curran and Williams (2012)

ZW challenges the traditional WM system within which at the end of life of product is considered as waste (Zaman, 2014). The author has stated that, waste is transformed into a resource through ZW and it is redirected to the production process holistic ZW management systems. Further, the author explained that as a result of design integration and WM philosophies, ZW management get created. With the implementation of ZW, high recycling levels, valuation of resources that are generated from waste, prevention of waste and changes in behaviours take place (Pietzsch, Ribeiro, & Medeiros, 2017).

To remove the environmental threats which are caused as a result of human consumption and unsustainable behaviors, designing of the product and principles of WM are looked into within the ZW philosophy (Zaman, 2014). The authors emphasized that, in order to extend the lifecycle of the product in a ZW product design, desginig of the products take place in a way that they can be repaired or reused. In addition to that, the authors have also stated that, pollution of natural environment is avoided through the ZW management process as waste is recycled, recovered. Moreover, ZW encourages diversion of waste from incineration and landfills (Curran & Williams, 2012). In a single framework, ZW includes producer responsibility, eco-design, waste reduction, reuse, and recycle (Murray, 2002). Zaman (2014) defines ZW management as the combination of WM philosophies and integrated design. Moreover, Curran and Williams (2012) mentioned that ZW concept could be implemented by eliminating waste at the source and throughout the supply chain, and encouraging waste diversion from incineration and landfills. Critical innovations have been taking place in the development schematic waves of innovation WM system (Zaman & Lehmann, 2011). Figure 2.5 illustrates the historical development of WM up to ZW system

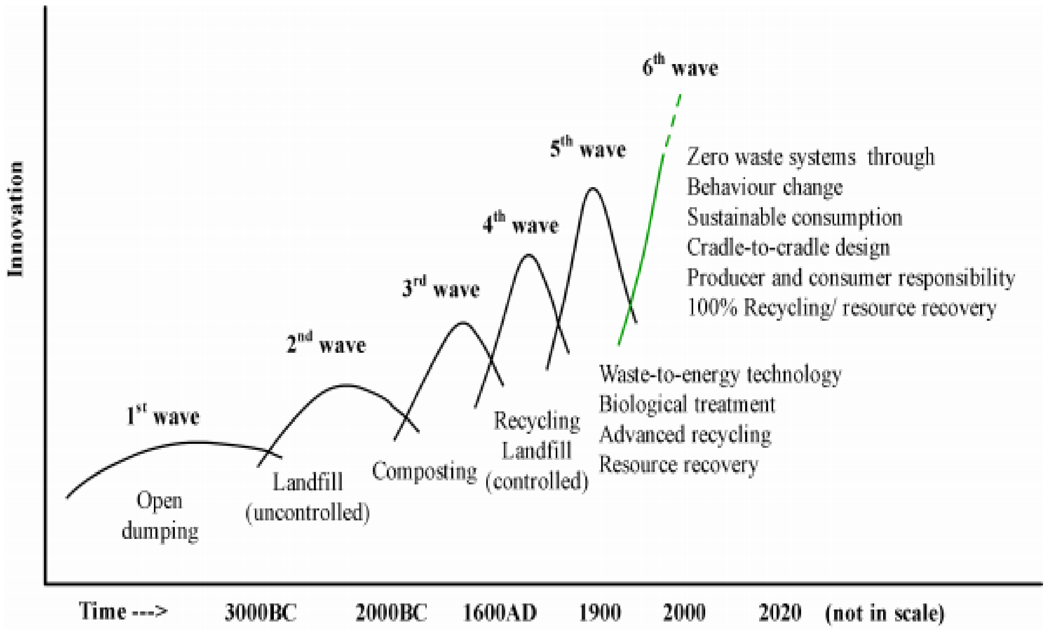


Figure 2.5.: Schematic waves of innovation management system

Source : Zaman and Lehmann (2011)

In the schematic waves of innovation WM system, open dumping is the first wave which is still practiced in low income countries and uncontrolled landfills are considered as the second wave while third wave is considered as composting (Zaman & Lehmann, 2011). Moreover, the authors have stated that fourth wave focused on systematic landfilling and waste recycling whereas fifth wave has focused on plasma arc, incineration, gasification and pyrolysis which are considered as technologies which converts waste into energy. Finally, in the sixth wave of innovation has focused on sustainable WM system through ZW and include resource recovery through waste, consumption of sustainable resources, and closed loop design system.

2.12. Development of ZW Concept

According to Cole et al. (2014), the ZW concept includes prevention of waste, behavioural change and high level of recycling and resource recovery. Through ZW concept, waste materials are converted into useful resources (Ksiazek et al., 2016; Pietzsch et al., 2017). When it comes to the definitions of ZW, Curran and Williams (2012) have defined ZW as an approach which focuses on the elimination of waste through the whole system without managing the waste. Further, all waste materials becoming as a resource for another purpose is also defined as ZW (ZWIA, 2015). Moreover, Zaman and Lehmann (2011) defined ZW as the recovery of all resources from waste materials. When ZW concept is adopted, community benefits, economic and financial benefits, environmental benefits and industry and stakeholder specific benefits can be achieved (Pietzsch et al., 2017). Authors have elaborated community benefits such as public health risk minimisation, increase in job offers by recycling and usage practices, and by the opening and consolidation of waste collection and separation cooperatives can be gained .

Further, through economic and financial benefits, reduction in cost and increase in profit, prevention of the costs of environmental restoration and losses related to process inefficiency, increase in profits from the sales of recycled materials, and increase of income flow can be identified (Pietzsch et al., 2017). Moreover, authors have stated that, reduction of waste generation and its negative impacts, extension of the useful life of sanitary landfills, increased efficiency in using raw materials and reduction of virgin raw material extraction, reduction of the emission of greenhouse gases, opportunity to produce energy through wastes and the sale of carbon credits, reduction of energy consumption because of the higher eco efficiency of the production and recycling processes, increased environmental protection, and reduction of the use of toxic materials in the products can be identified as environmental benefits. Similarly, Pietzsch et al. (2017) have said that, industry and stakeholder that can be achieved are improved efficiency and productivity, improved product design to extend life cycle, increment of companies' competitive potential through customer satisfaction and increased reliability, incentive to the elaboration of a sustainable chain of suppliers, and industrial symbiosis practices. Table 2.8 shows the development of the ZW concept over the past years.

Table 2.8 : Key milestones of zero waste concept development

Year	Country	Milestones/Events
1970	USA	The term "ZW" was coined by Paul Palmer
1986	USA	The National Coalition against Mass Burn Incineration was formed
1988	USA	Seattle introduced the Pay-As-You-Throw (PAYT) system
1989	USA	The California Integrated Waste Management Act was passed to achieve 25% waste diversion from landfills by 1995 and 50% by 2000
1990	Sweden	Thomas Lindhqvist introduced "Extended Producer Responsibility"
1995	Australia	Canberra passed the "No Waste by 2010" bill
1997	New Zealand USA	• The ZW New Zealand Trust was established • The California Resource Recovery Association (CRRA) organized conference on ZW
1998	USA	ZW was included as guiding principles in North Carolina, Seattle, Washington, and DC
1999	USA	The CRRA organized ZW conferences in San Francisco
2000	USA	The Global Alliance for Incinerator Alternatives were formed
2001	USA	Grass Roots Recycling Network published "A Citizen's Agenda for ZW"
2002	New Zealand USA	• The book Cradle to Cradle was published • ZW International Alliance was established • The first ZW summit was held in NEW Zealand
2004	Australia USA	• ZWIA gives a working definition for ZW • GRRN adopts ZW business principles • ZW SA was established in South Australia
2008	USA	The Sierra Club adopted a ZW producer responsibility policy
2012	USA	• The documentary film Trashed premiered at the Cannes Film Festival • The ZW Business Council was established in the USA

Source: Zaman, (2015)

Source: Zaman, (2015)

2.13. ZW Strategies

For the ZW management,performance measurement which are reliable and effective strategy implementation is needed (Zaman, 2014). In the application of ZW, mainly four levels such as, design, manufacturing, application, recycling and disposal are included in the ZW system (Song et al., 2015). Firstly, in design level, method of energy and environmental analysis can be used through eco design, life cycle assessment, new technologies, product stewardship and closed loop supply chain management (Song et al., 2015). Secondly, in manufacturing level, cleaner production strategies are used in the design and manufacture processes to minimise waste emissions and also to maximize product output (Song et al., 2015). Thirdly, in the application level, strategies such as eco labeling and environmental awareness are followed to meet environmental criteria (Song et al., 2015). Finaly, in the recycling and disposal level, effective environmental management plans, schedules, implementation and monitoring of activities to improve environmental performance take place (Song et al., 2015). All the above mentioned four levels are summarised in Figure 2.6

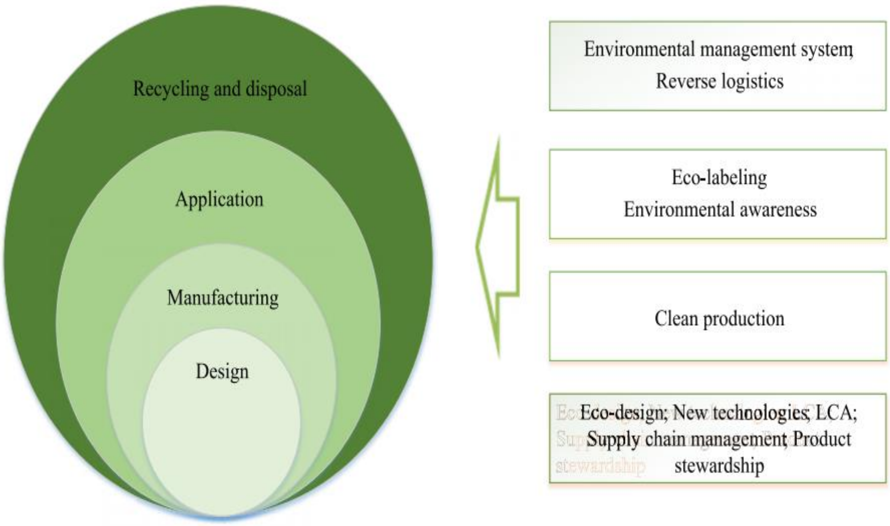


Figure 2.6 : ZW system

Source : Song et al. (2015)

According to Curran and Williams (2012), to apply ZW in the construction industry, strategies that can be followed are elaborated in Figure 2.7 along with the external influences and constraints. Out of the identified strategies, the authors have selected Eco design, IS, closed loop supply chain management, Innovative technology, EPR, Life cycle assessment, and Environmental Management System (EMS) as leading strategies to implement the ZW concept and in detail discussion about these strategies are carried out in the next section.

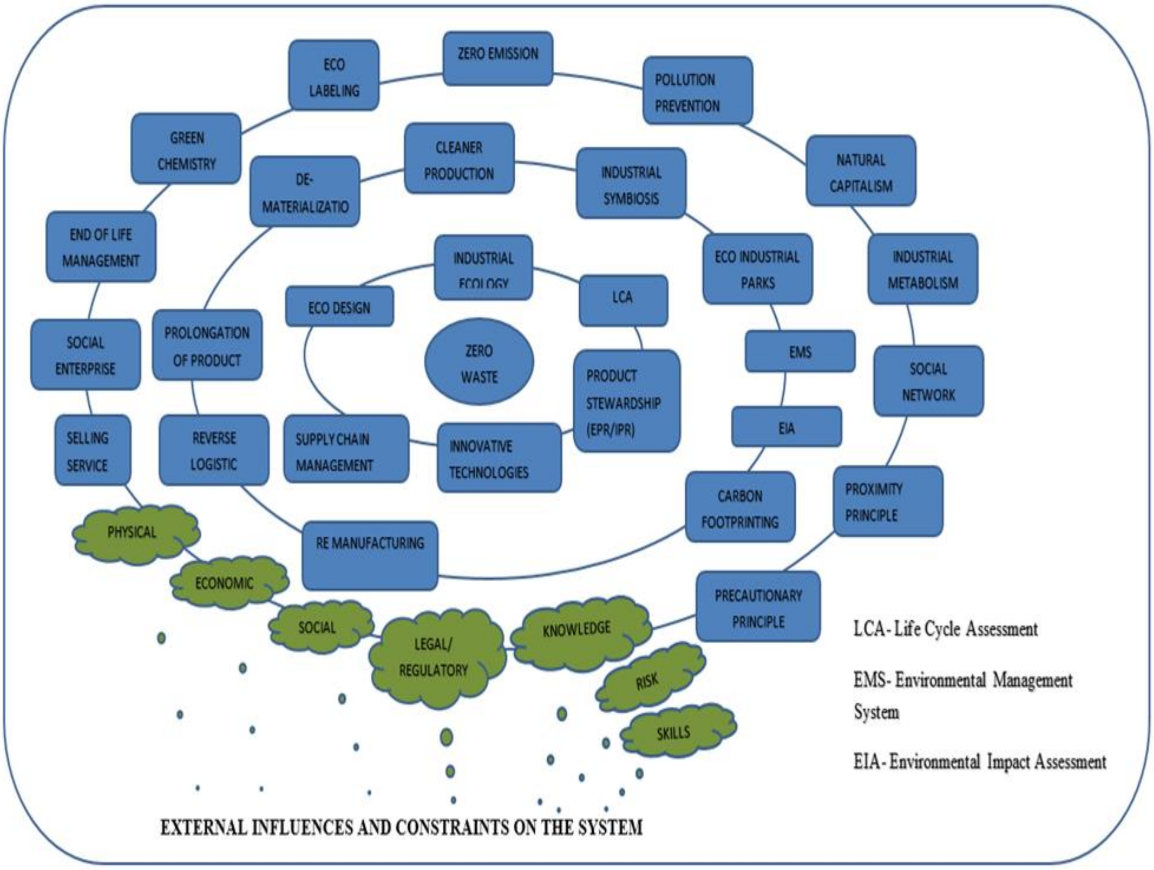


Figure 2.7: ZW system to achieve ZW

Source: Curran and Williams (2012)

- **Industrial Symbiosis(IS)**

Industrial Symbiosis is identified as a part of industrial ecology concept (Curran & Williams, 2012). Yazan et al. (2016) have stated that in the production economies more attention is paid towards waste reduction. Moreover, the authors have also said that, IS has forced to provide waste as a primary resource to other companies which will ultimately reduce the adverse environmental impacts near the industrial areas.

- **Life Cycle Assessment (LCA)**

Measurement of impacts throughout the whole life cycle starting from the raw material extraction up to end disposal of the product helps to recognize the impacts that effect on the environment due to the product and also to have sustainable production and consumption patterns (Curran & Williams, 2012).

- **Eco Design**

Eco design can be defined as, starting from the origin of the product thinking about the whole life cycle and reduction of adverse impacts of the product on the environemnt (Vallet, Eynard, & Millet, 2015). As per Bhamra (2004), Eco design is defined as the integration and balancing of the existing design practice considering cost, quality and functionality. In order to manage ecological disputes related to the types CDW, client and design team awareness needs to be given (Ball , 2002). Further, for an eco-friendly construction industry, sustainable construction techniques and materials are needed (Torgal & Jalali , 2012). Moreover, in the eco system, for the achievement of real waste reduction, waste is designed out of the system (Curran & Williams, 2012).

- **Closed-Loop Supply Chain Management**

When it comes to the closed loop supply chain management, as per Krikke et al. (2004), it comprises of reverse and forward supply chain. Further authors elaborated that, loops can be closed through reusing of the whole product, components or materials. Moreover, Morana and Seuring (2011) stated that closed loop supply chain deals throughout the product life cycle. Furthermore, supply chain of the industry can be explained under four roles as, focus in the on-site supply chain activities, inventory, logistic cost and lead time reduction by focusing the supply chain, activity transferring to the initial stages of the supply chain from the site, and finally supply chain improvements and management integration (Vrijhoef & Koskela, 2000).

- **Product Stewardship / Extended Producer Responsibility (EPR)**

Management of a product all over the lifecycle of the product until disposal is identified as product stewardship (Zaman & Lehmann, 2011).. Further authors have elaborated that, in product stewardship once the consumer stop using the product, the producer has to take back the product. According to Zaman and Lehmann (2011) EPR is also identified as product stewardship principle and take back principle. Authors have stated that in the innovative packaging and product design, to reduce the waste generation in the production process, EPR is an important tool. Further, authors have said that EPR takes the responsibility for each action and work. EPR is used for recycling process and through EPR manufacturer takes the total responsibility of the product from the manufacturing up to the up to the product discarding (Chavan, 2014). Furthermore, Manomaivibool (2008) have explained that, EPR model comprised of four responsibilities as informative, physical, financial, and liability. Moreover, EPR is considered as an important tool in order to control and eliminate waste from the production process (Lindhqvist, 2000).

- **Environmental Management System (EMS)**

EMS helps to accomplish goals relevant to performance and environmental duties by identifying problems and solving the problem with a systematic management of environmental activities of the organization (Curran & Williams, 2012). Moreover, they have also stated that in order to improve the environmental performance through EMS, plans, schedules, implementation and monitoring of activities take place.

2.14. ZW Enablers

Appreciating the current possibilities or enablers in the construction industry is important to implement the ZW concept effectively. For the successful implementation of the ZW concept, as per Zaman (2014), there are seven domains as, organizational, management, economic, socio- cultural, location, policies and governance, and environment. Moreover, Zaman and Lehmann (2013) have stated that, to implement ZW concept, changes need to be carried out in the consumption and behavioral patterns of the citizens. Similarly, Zotos et al. (2009) have also agreed that, programs and campaigns need to be carried out for the proper waste segregation and waste disposal in order to achieve ZW. Nevertheless, establishment of value for the waste is also necessary (Pietzsch, et al., 2017;Yazan, et al., 2016; Zaman, 2014). Furthermore, to implement ZW, product redesigning is necessary (Binnemans, Jones, Blanpain, Gerven, & Pontikes, 2015).

To achieve ZW concept, enablers such as education and awareness, ZW management, waste treatment and disposal, regulatory strategies, governance and infrastructure, market creation and adaptive ZW strategy can be followed (Zaman, 2014). According to the author, to control waste problem, long term policies, sustainable consumption behavior, and understanding of waste have to carry out in education and awareness while under the ZW management, waste is considered as a resource and used within the production process and ZW management system comprise of design of product, product consumption, and recovery of resources. As per the author, under waste treatment and disposal to enable ZW, technologies like biological and thermal treatment need to be transformed into zero landfill and zero incineration. Further, author said that, through regulatory strategies such as limiting of mass burn technologies, restricted disposal to landfills, provide of incentives to support maximum resource recovery helps to enable ZW while through governance and soft and hard combination of infrastructure is needed. Hard infrastructure comprises of collection of waste, waste sorting, storing of waste, and waste recycling, waste disposal and waste treatment facilities and soft infrastructure consist of regulations, education and financial system. In the market creation, WM is efficient and cost effective in a positive market (Zaman, 2014). Finally, the author has discussed to implement ZW concept, adaptive ZW strategy can be used with long term and flexible WM strategies.

When considering about enablers in ZW concept, as per Pietzsch et al. (2017) financial, community, environment, economic benefits and stakeholder and industry benefits can be identified. Authors have explained that under the community benefits, change of lifestyle and consumption patterns and waste disposal attitudes are considered while under the economic and financial benefits control of the waste generation reduction of costs related to environmental restoration take place. Similarly, under the environmental benefits, to enable ZW, management in generation of waste, use of sanitary landfills, limitations in using raw materials, restrictions on the emissions of greenhouse gas, reduction in toxic material usage, production of energy through waste and use of environmental protection are considered (Pietzsch, Ribeiro, & Medeiros, 2017). Moreover, the authors have elaborated that under industries and their stakeholders, through product design to enhance the life cycle of product, production of more product with productivity and efficiency, providing incentives to suppliers those who practice sustainable methods, IS practices like organization providing the generated waste to another company as a resource to be used are considered as the enablers to implement ZW.

In addition to that, enablers such as design tools and guidance, measure the value of material/product, financial incentives to use secondary materials, assurance schemes for reused/secondary materials, awareness raising campaigns, development of enabling technologies to recover material, development of higher value secondary markets, and viable take back scheme have identified to enable ZW in the construction industry (Adams et al., 2017). Further, working together with government, professional bodies and academia to revisit existing standards, rules, encourage local suppliers to produce green products, and knowledge sharing and training on the use of new green technology also help to enable ZW in the construction industry (Abidin et al., 2013).Based on the findings of enablers to implement ZW concept in the construction industry, enablers such as institutional effectiveness, robust policy and legal framework, public participation, innovative and cost effective technology, financial stability, improved resource availability, effective waste segregation and collection, recycling and reproduction can be followed (Gahana et al., 2018). In addition to that, Pietzsch et al. (2017) have stated that, governance and planning and operationalizing can be used to achieve ZW in the construction industry. Through governance and planning enablers like substantial change in behavior and consumption, regulations of rates and financial incentives, modifications in the logistic system, green innovation can be used while enablers such as product redesigning, and qualifying infrastructure can be used in operationalizing. Consequently, to apply ZW Consequently, to apply ZW, initiation has to be taken by the government through introducing regulations for CDW management, by collecting waste in regular time periods, enhancing waste recycling practices through environmental policies, and through claiming fee for waste disposal (Yuan, 2017). Figure 2.8. illustrates key domains in ZW management that can be used to achieve ZW in the construction industry.

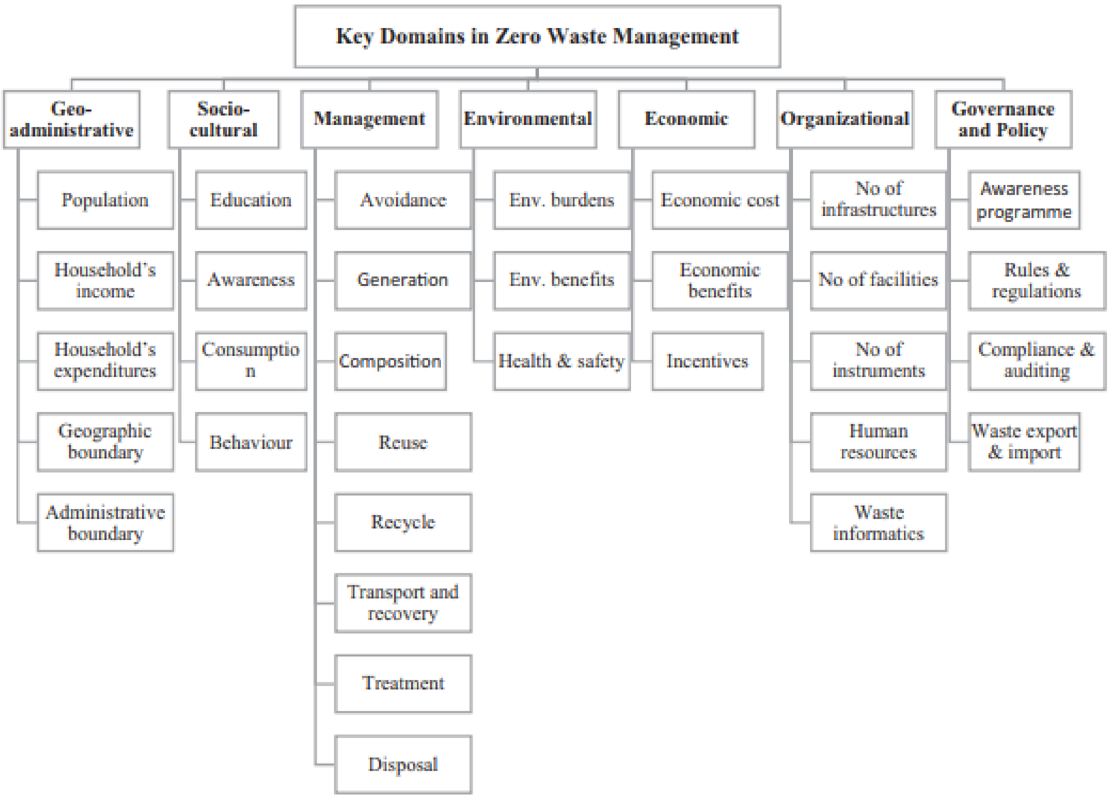


Figure 2.8 : Key domains in ZW management

Source : Zaman (2014)

2.15. ZW Barriers

Barriers in initiating ZW concept can be discussed under three categories as macro, meso and micro environment (Pietzsch, Ribeiro, & Medeiros, 2017). Authors have elaborated that in the macro environment, political issues such as the lack of compulsory WM guidelines, environmental sustainability issues, involvement of particies to make policies while cultural issues like environmental problems due to consumption patterns and behaviors of citizens create adverse impacts on enabling ZW concept. Similarly, the authors have also said that social issues such as purchasing power, small families and economic issues like the inadequacy of taxation to control waste generation, lack of taxation for landfilling of SW and lack of regulations to purchase and sell the waste to carry out the recycling process are the barriers in implementing the ZW concept. In the technological aspects, the authors have also identified issues like, investment needs for WM technologies and their distribution.

When it comes to the meso and micro environment which consist of industry, stakeholders and municipalities, inadequate knowledge on ZW, and difficulties in conducting ZW operations due to high cost are the main barriers that are faced in implementing the ZW concept (Pietzsch, Ribeiro, & Medeiros, 2017). To achieve ZW, poor construction planning, large population, inadequate commitment towards the environment, poor waste disposal practices, lack of effective process administration, poor technical expert involvement were identified as the barriers (Gahana et al., 2018). Similarly, as the barriers to achieve ZW in the construction industry, lack of waste disposal awareness, lack of involvement and understanding among the parties involved, inadequate processes for CDW management within the project, inadequate facilities for waste processing, lack of stakeholder engagement and resistance among the project teams for CDW diversions were identified (Menegaki & Damigos, 2018). In the same way, lack of management and political commitment, and lack of programs to give awareness on ZW concept were also identified as barriers to implement ZW concept (Cole et al., 2014).

2.16. Application of ZW Concept to the Sri Lankan Construction Industry

When it comes to the construction industry of Sri Lanka, no specific regulation is available for the management of CDW and CDW is classified under SW (Karunasena, Amaratunga, & Haigh, 2012). Further, Jayawardane (1992) has stated that, in the Sri Lankan construction industry, wastages of resources like plant, labour, and space are beyond reasonable limits. Moreover, the author has identified that in Sri Lanka, CDW in the construction sites is a problem which needs to be addressed. In addition to that, according to Kulatunga et al. (2006), material wastage has exceed the limit that is acceptable in the industry (as cited Jayawardena, 1994). As per Jayawardane and Gunawardena (1998) in the current context, operations of the construction industry are regulated by the Institute for Construction Training and Development (ICTAD) which is currently known as Construction Industry Development Authority (CIDA). In Sri Lanka, the value added of construction activities grew by 3.1 percent in 2017 and a number of large scale residential and mixed development projects and infrastructure projects have contributed to the growth in the construction activities (Annual Report, 2017).

In carrying out construction activities, materials are the largest input into the construction activities where it leads to the generation of waste (Rameezdeen, Kulatunga, & Amaratunga, 2004). Further, Kulatunga et al. (2006) have stated that in the Sri Lankan construction industry, there is a major impact on the cost of CDW. In addition to that, Karunasena et al. (2012) have stated that, although landfilling is considered to be the least preferred option in waste process, in Sri Lankan context landfilling has become the first option to manage CDW. Table 2.9 illustrates the C&D material wastage in Sri Lanka.

Table 2.9.: Material wastage in Sri Lanka

Material	Material Waste as a Percentage
Sand	25
Lime	20
Cement	14
Bricks	14
Ceramic Tiles	10
Timber (Formwork)	10
Rubble	7
Steel (Reinforcement)	7
Cement blocks	6
Paint	5
Asbestos sheets	3

Source : Rameezdeen et al. (2004)

The main causes for CDW in Sri Lanka are due to cutting waste which gets generated as a result of incorrect decision making and lack of supervision (Rameezdeen et al., 2004). Furthermore, as a result of the Tsunami disaster which took place in the year 2004, 450000 tonnes of building waste were generated in Sri Lanka and a post Tsunami programe called COWAM project was started to manage CDW that occurred due to the Tsunami disaster in Sri Lanka (Karunasena, et al. 2009,2012). Although COWAM project manage CDW, recycling projects for CDW have not initiated in Sri Lanka due to the lack of technology, funds, unfamiliarity and unawareness of recycled building materials (Karunasena et al., 2009). Therefore, as discussed in the Sub Section 1.2 and considering all the above discussed facts, it is clear that CDW management in the Sri Lankan context is still in a primary stage. Thus, applying ZW concept is a precise solution to overcome from the CDW management issue in the Sri Lanka.

2.17. Conceptual Framework

To manage the generated CDW, procedure and strategies to manage CDW were identified and out of the strategies ZW concept was identified as the key strategy to eliminate CDW. In order to apply the ZW concept in the construction industry, strategies, enablers, barriers and suggestions to overcome the barriers need to be identified. Then the ultimate aim of the study can be achieved by eliminating the CDW from construction industry. Thus, Figure 2.10 illustrates the developed conceptual framework which was developed based upon the literature findings.

2.18. Summary

Firstly, this chapter has discussed on CDW and the definitions of CDW, origins and causes of CDW, composition of CDW, and CDW generation in construction industry based on developing and developed countries. Secondly, the study has covered the literature findings on impacts of CDW, CDW management strategies, enablers of CDW management, and barriers of CDW management. Thirdly, concept of ZW, development of ZW concept, ZW strategies, ZW enablers, ZW barriers, and the application of ZW concept to the Sri Lankan construction industry were discussed. Finally, conceptual framework was developed.

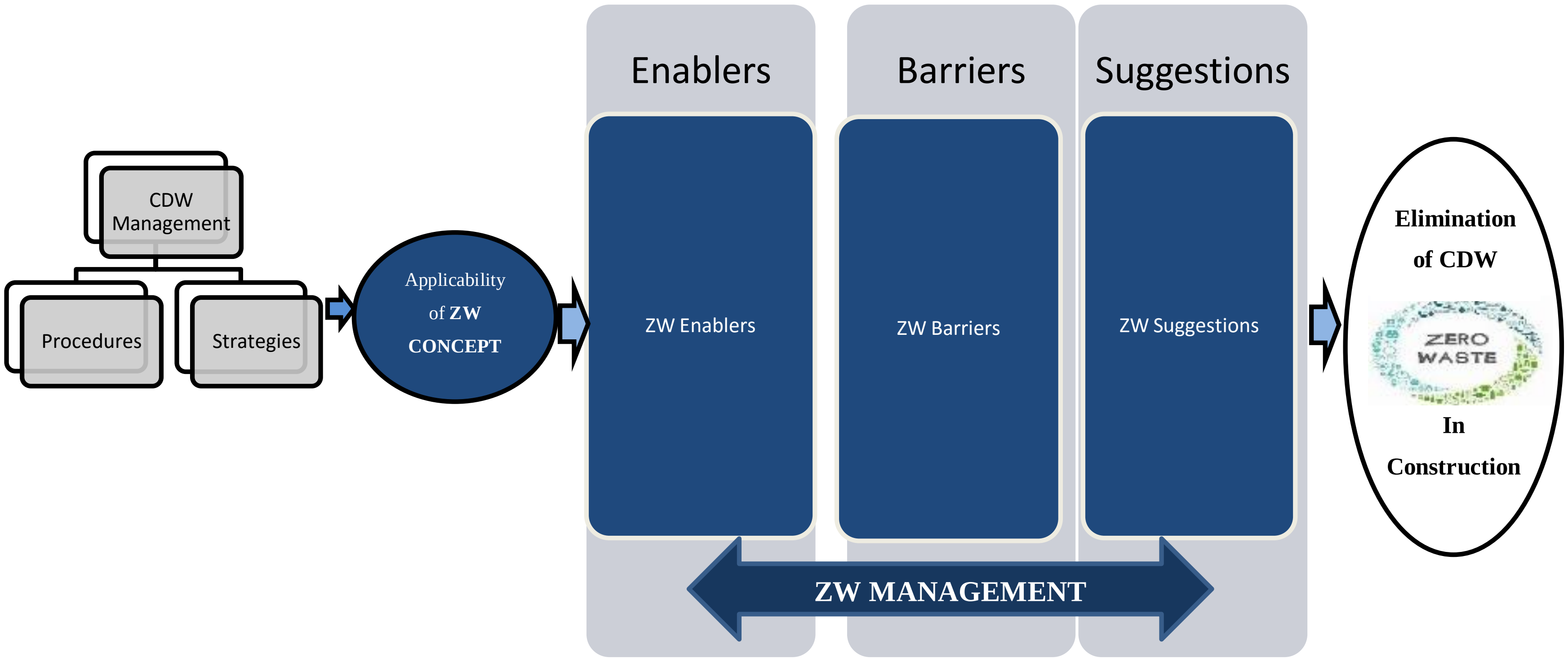


Figure 2.10 : Conceptual Framework to Implement ZW Concept in the Construction Industry

CHAPTER THREE

3.0. METHODOLOGY

3.1. Introduction

This chapter defines the manner in which research conducted. The chapter comprises of research design, research approach, research strategy, data collection and analysis. For the study, out of the three approaches, qualitative, quantitative and mixed, qualitative approach is used. As the strategy under qualitative approach, case study method is followed and for the data collection, semi structured interviews were carried out. Collected data was analyzed in as individual cases and also through cross case analysis.

3.2. Research Design

Overall strategy, which integrates the different components of the study in a logical way to ensure that the research problem is being addressed is defined as the research design (De Vaus, 2001). Furthermore, Kumar (2011) stated that, in order to achieve the desired objectives of a research study, it is necessary to identify the most appropriate research policy, approach, strategy and techniques. As per Saunders, Lewis, and Thornhill (2009), research design provides answers to research problem through data collection methods and research strategies. Moreover, research design comprise of the decisions like how much, when, by what means, where and what related to the research decisions (Kothari, 2004).According to Saunders et al. (2009), “research onion” shows the most appropriate methodology for a study and it shows the key aspects that needs to be investigated in selecting the most suitable methodology. Reseach design of this study comprise of a background study on ZW concept to manage CDW in the construction industry, a literature review, data collection, analysis, validation, conclusions and recommendation to apply the ZW concept in the construction industry.

3.3. Research Approach

Research approach can be discussed under three categories as qualitative, quantitative and mixed approach (Creswell,2014). For the selection of scientific and best approach, there have been arguments and discussions (Dawson, 2002). Authors have further stated that there is a misconception among the researches that the quantitative approach is better than the qualitative approach. Moreover, Dawson (2002) further explained that each approach consists of their own pros and cons and there is no any specific best approach. Further, Creswell (2014) has identified the characteristics of the three(03) approaches as shown in Table 3.1.

Table 3.1. Qualitative, Quantitative and Mixed Approaches

Tend to or typically	Qualitative Approaches	Quantitative Approaches	Mixed Approaches
• Use these philosophical assumptions • Employ these strategies of inquiry	• Constructivist/ transformative knowledge claims • Phenomenology, grounded theory, ethnography, case study, and narrative	• Postpositivisit knowledge claims • Surveys and experiments	• Pragmatic knowledge claims • Sequential concurrent and transformative
• Employ these methods	• Open ended questions, emerging approaches, text or image data	• Closed ended questions, predetermined approaches, numeric data	• Both open ended and close ended questions, both emerging and predetermined approaches and both qualitative and quantitative data and analysis
• Use these practices of research as the researcher	• Positions him or herself. • Collect participant meanings • Focuses on a single concept or phenomenon • Brings personal values into the study • Studies the context or setting of participants • Validates the accuracy of findings • Makes interpretations of the data • Creates an agenda for change or reform • Collaborates with participants	• Tests of verifies theories of explanations • Identifies variables to study • Relates variables in questions or hypotheses • Uses standards of validity and reliability • Observes and measures information numerically • Uses unbiased approaches • Employs statistical procedures	• Collects both qualitative and quantitative data • Develops a rationale for mixing • Integrates the data at different stages of inquiry • Presents visual pictures of the procedures in the study • Employs the practices of both quantitative and qualitative research

Source : Creswell (2014)

3.3.1. Quantitative Approach

To prove the objectives through the development of relationships among the variable, quantitative approach is being used and for the measurements and analysis of the data, stastical procedures are being followed (Creswell, 2014). Furthermore, Conrad and Serlin (2011) have stated that findings are simplified and objectives are maximized through the quantitative research study. In addition to that, through a quantitative study, results related to a sample population can be generated (Harwell, 2011).

3.3.2. Qualitative Approach

Qualitative researches are used to acquire in-depth opinions of the participants and attitudes, experience and behaviours can be observed while conducting the interviews with the participants (Dawson, 2002). Similarly, Creswell (2014) also stated that, in a qualitative approach, participants' behavior, opinions, attitudes and experience can be observed.

3.3.3. Mixed Approach

In simple terms, mixed approach is defined as the combination of both qualitative and quantitative approaches (Caruth, 2013). In addition to that, Creswell (2014) has stated that in the mixed approach, detailed understanding about the research problem is provided. Furthermore, through the mixed approach, weaknesses of the study are removed while the strengths are highlighted (Greene, 2007).

3.3.4. Selected approach for this study

ZW is a new concept to Sri Lankan Construction industry. According to Marshall (1996), in order to select the most suitable approach, it is necessary to identify the research question. When research requires the experience and different perspective of the people, the most ideal approach is the qualitative approach (Bricki & Green, 2007). Since ZW concept is novel to the Sri Lankan construction industry, performance and the applicability of the concept to the construction industry cannot be checked by using different variables. Thus, quantitative approach cannot be used for this study. Similarly, mixed approach also cannot be used in this study as mixed approach consist of both quantitative and qualitative approaches. Therefore, in order to find the applicability of the ZW concept to the Sri Lankan construction industry, qualitative approach is being used. According to Kothari (2004), research process depicts the methodical way in which research needs to be carried out. Figure 3.1 illustrates the research process of this study.

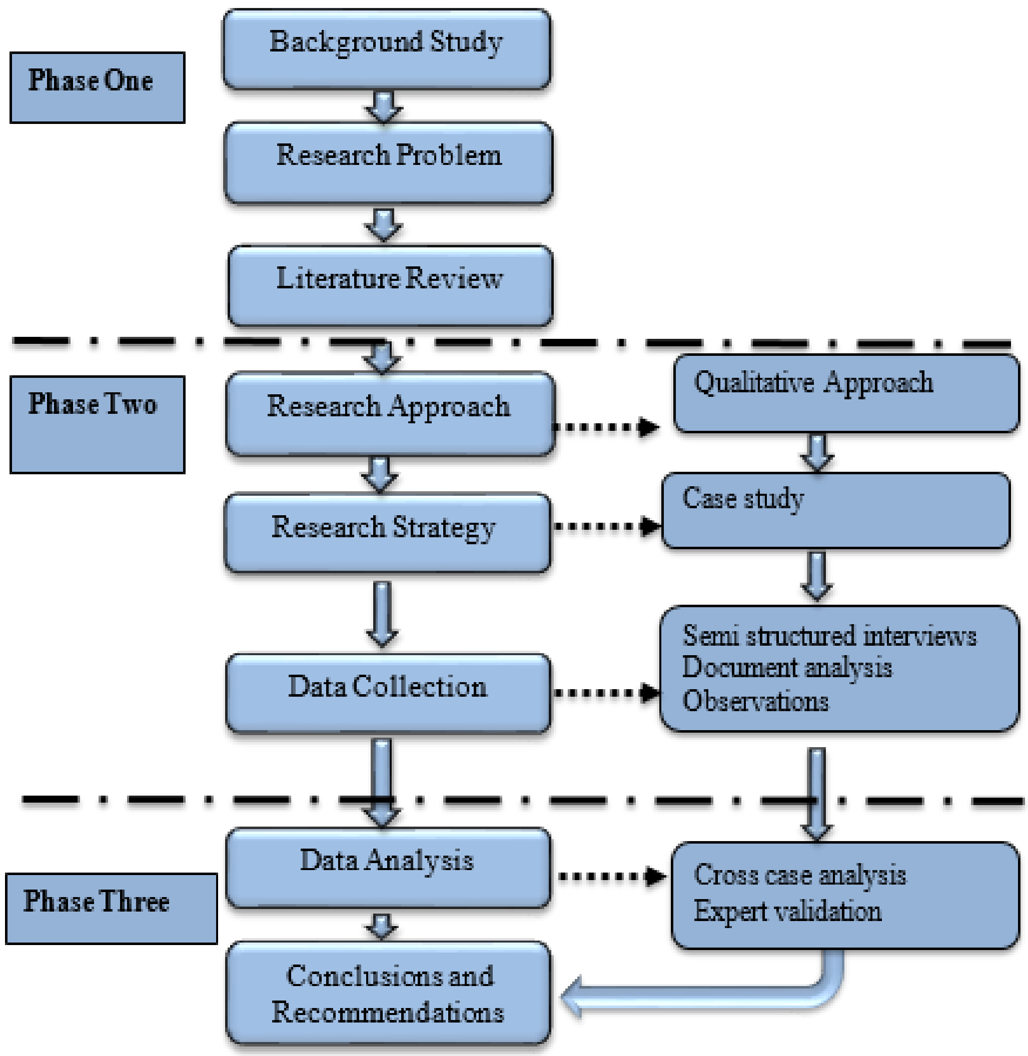


Figure 3.1 : Research process

3.4. Research Strategy

Punch (2014) said that research strategies change according to the research approach. In qualititative approach, phenomenology, grounded theory, ethnography, case study, and narrative are used as the research strategies (Creswell, 2014). Qualitative approach strategies are discussed in the following sub section.

3.4.1. Qualitative approach strategies

As the selected approach for the study is qualitative approach, following section discusses the qualtitative strategies briefly.

- Phenomenology

According to Sokolowski (2000), phenomenology is defined as the study of expressing the experiences of the humans and the methods of presenting those experiences to the expected audience. Further, phenomenology strategy represents the way of seeing things (Gallagher,2012). Moreover, phenomenological strategy focuses on the lived experience by the means of psychology and the philosophy of the participants in a specific phenomenon (Creswell, 2014).

- Grounded theory

Grounded strategy as the strategy which involves the sociological inquiry from the participants by the means of process of a theory, interaction or action (Creswell, 2014). Further, collected data get synthesised, analysed and conceptualised through the theory (Charmaz, 2001). Furthermore, author has stated that through the grounded theory platform is provided to develop and conceptualize new theories.

- Ethnography

The study of behaviours, interactions and perceptions that take place among the communities, groups, organisations and teams is identified as the ethnography strategy (Reeves, Kuper, & Hodges, 2008). Further, **e**thnography strategy focuses on the study of the cultural group for their language, behavior and actions for a certain period of time(Creswell, 2014). Moreover, Reeves et al., (2008) stated that ethnography study provides detailed observations on people's nature, actions and views.

- Narrative

Narrative strategy means the strategy within which the researcher looks into the livelihoods of one individual or more and provide the information about their livelihoods (Creswell, 2014). According to Paiva (2008), narrative research studies can be found in communication, semiotics, psychology, women studies, nursing, etc. Further, author has stated that through nattartive studies, stories are gathered regarding a theme and data is collected relating to a specific phenomenon.

- Case study

Case study is the strategy in which an in-depth analysis is carried out for a specific case by the researcher (Creswell, 2014). In case studies, theorittical ideas are being developed before the data collection as they are important in case study design (Suter, 2012).Furthermore, Yin (2009) stated that through the research question, research strategy can be identified. In addition to that, comprehensive understanding and in depth analysis can be gained through case studies (Bloor & Wood, 2006). Moreover, if the research question of the study can be seen in the form of "why"and "how"then case study strategy can be used (Yin,2009).

3.4.2. Selected strategy for this study

As this study focuses on the qualitative approach, available strategies for qualitative approach are dicussed under section 3.4.1. Out of the discussed strategies, case studies can be used for this study. Case studies are conducted as single case study or muliple case studies where single case study used for unique circumstance while multiple cases derive better results through the same process (Yin, 2009). Due to the lack in specific regulations, technology, and funds for CDW management in the Sri Lankan context, CDW generation in the construction sites is beyond the acceptable limit. Therefore, in order to eliminate CDW from the construction industry, ZW is an ideal concept and to find the applicability of the ZW concept to the Sri Lankan construction industry multiple case studies can be used. Thus, multiple case studies were selected for the study.Hence, following section describes the importance of unit of analysis, case boundary and case selection of the study.

a) Unit of Analysis and Case Boundry

According to Yin (2009), unit of analysis is reffered as the case in a study and unit analysis is directly connected to the research problem. Considering the study, unit analysis of the study is "process of ZW application" and the boundry of the research is "construction sites in Sri Lanka" as presented in Figure 3.2.

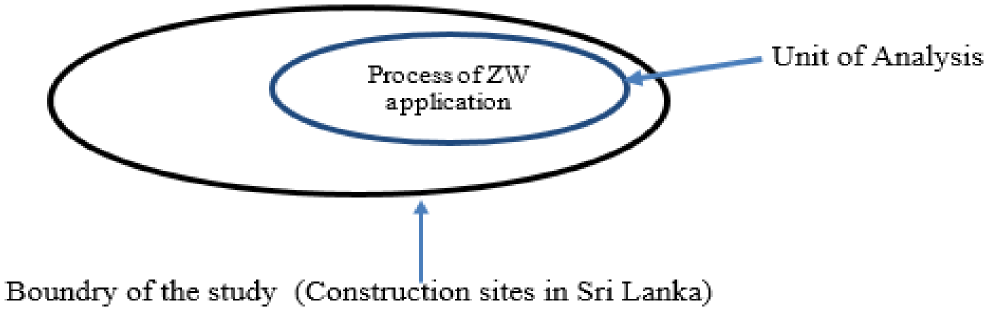


Figure 3.2 : Unit of Analysis and Case Boundry

b) Case Selection

When it comes to the case studies, in the process of selecting cases, researcher should not depend on the random sampling as competitive advantages can be enjoyed over the random sampling (Patton & Appelbaum, 2003). Thus, sampling technique that is used for this study is, non-probability purposive sampling. In addition to that, Yin (2009) has stated that minimum number of case studies for a certain study is two to four while ten to fifteen of maximum cases. Hence, for this study eight cases were selected from the CS2 category.

3.5. Research Techniques for Data Collection

For the data collection different researches use different methods and some of the methods are observations, interviews, document surveys, questionnaires, simulation and participation (Kumar,2011). Further, in order to select the most suitable data collection method, it is necessary to pay attention into the criteria of validity, reliability, amount of data that can be collected and the appropriateness (Polonsky & Waller, 2011). Moreover, interviews, documents and observations are identified as the most common sources of data collection in qualitative approach (Suter, 2012). Thus, under case studies for the data collection, semi structured interviews, document review and observations were carried out for this study.

3.5.1. Adapted Techniques for the Study

To collect the required data from the case studies, semi structured interviews, observations and document analysis were carried out following sub section discusses about each method briefly.

3.5.1. Semi-structured interviews

According to Kumar (2011), meeting is identified as the communication between two or more for a specific reason. As per Punch (2014), interview is the technique used by the most researches as it helps to gain in-depth human opinions. Further, interviews were categorized as structured interviews, semi structured interviews and unstructured interviews (Yin, 2009). In addition to that Sekaran (2003) explained that through semoi structured interviews doubts of the respondent can be cleared and the researcher can make sure that the respondents have a clear understanding about the questions. Moreover, when open ended questions are being used in the semi structured interviews, respondents perspectives on different situations can be studied clearly (Bryman, Bresnen, Breadsworth, & Keil, 1988). Hence, for the study semi structured interviews with open ended questons were used and twenty seven (27) respondents were interviewed from eight cases.

3.5.2. Expert validation

In order to link the gap between the generally available data with the case studies, expert interviews can be used (Dorussen, Lenz, & Blavoukos, 2005). Further, expert interviews are considered as the more effective method than the systematic quantitative survey and participatory observation (Bogner, Littig, & Menz, 2009). In addition to that, Angkananon, et al. (2013) stated that, the process of taking ideas, recommendations and feedback from expert as the expert validation. Thus, for the data validation of this study, five (05) expert interviews were conducted with those who are experts in the fields of WM and in construction industry.

3.6. Data Analysis Techniques

According to Bricki and Green (2007), the most difficult part in the case study of qualitative approach is considered as the data analysis. Further, Rowley (2002) stated that, data examination, classification and evidence arrangement of the data analysis take place to cross check whether the evidences supports the initial plan. Moreover, coding method is being used to divide the qualitative data and codes are developed or combined to create issues or themes (Lacey & Luff, 2009).

Content analysis is defined as the process of coding the qualitative information to categories the data to develop patterns and to repot the information (Kumar, 2011). Similarly, Guthrie, Petty, Yongvanich, and Ricceri (2004) also defined content analysis as the process of qualitative data codification which are taken from the interviews. In addition to that, Rose et al. (2015) said that tabular presentation of the summary of the findings and conducting cross case analysis for the collected data through the case studies are useful. Thus, to analyse the data of the eight case studies individual case analysis and cross case analysis were used. For the individual case analysis was followed in the identification of current CDW waste management procedure and in the CDW strategies which leads to ZW in the construction industry. Therefore, cross case analysis was followed in analyzing the enablers, barriers and suggestion that leads to ZW concept.

3.7. Summary

This chapter described and justified the use of qualitative research methodology and case study method was selected to carry out the research. Semi structured interviews were used as the data collection techniques in case study findings. Further, individual case analysis and cross case analysis were selected as the data analysis technique. Collected data were validated through expert interviews.

CHAPTER FOUR

4.0. DATA ANALYSIS AND FINDINGS

4.1. Introduction

This chapter explains the findings of eight (08) case studies, based on current WM practices of the construction industry, strategies, enablers and barriers to manage CDW to achieve ZW concept in the Sri Lankan construction industry. Further, all the findings are brought into one picture and framework is developed. Finally, developed framework is validated from experts in construction industry and in WM.

4.2. Profile of the Cases

For the study, eight (08) cases were selected from CS2 grade from the builing construction category of Construction Industry Development Authority (CIDA).Selected cases were named as Case A, Case B, Case C, Case D, Case E, Case F, Case G and Case H and cost of the project and project durations are presented in Table 4.1. All the selected cases were in the Colombo district.

Table 4.1 : Profile of the cases

Criteria	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
Cost of the project (Billion)	4.0	0.28	1.2	0.76	1.89	7.0	3.08	0.4
Duration of the project (Months)	36	18	18	18	24	26	18	20

- **Case Study A**

The selected case was a hotel and the main purpose of this hotel is focused on business. The project progress was 42% out of the total completion from the project. This hotel comprises of twenty nine (29) storeys and thirty (30) apartements.

- **Case Study B**

Case B is an apartment complex with five (05) storeys with a roof top. The completion stage of the project is 54%.

- **Case Study C**

The selected case is a training center which includes a hostel building and a canteen. The current project progress is 36%.

- **Case Study D**

Under the Case D, the type of building construction is an apartment and the current completion stage of the case is 41%.

- **Case Study E**

The Case Study is a housing project for low income people and there are 525 apartments in the total project.The completion stage of the project is 34%.

- **Case Study F**

Case Study F is an apartment tower comprises of fifty five (55) storeys. Current project progress is 32%.

- **Case Study G**

Case G is a main laboratory expansion, and an accomodation building expansion project in which the completion stage is at 47%.

- **Case Study H**

The selected case is an apartment building complex comprise of tweleve (12) storeys. Completion stage of the project is 45%.

4.3. Profile of the Respondents

As the main data collection method, semi structured inerviews were carried out. Therefore, from all eight (08) cases, interviews were conducted with the respondents those who have a responsibility for WM in the selected construction project. Thus, for the study project managers, planning engineers, site engineers, safety officers, labours, a mason and a store keeper were interviweed from different cases. Table 4.2 shows the profile of the respondents in each case.

Table 4.1 : Profile of the respondents

Profession	Code	Interviewee from each case	Experience
Project Manager	PM	C-PM	26years
		E-PM	18years
Planning Engineer	PE	A-PE	7 years
		B-PE	5 years
		F-PE	13 years
		H-PE	4 ½ years
Site Engineer	SE	C-SE	4 years
		D-SE	6 years
		F-SE	3 years
		G-SE	5 ½ years
		H-SE	3 ½ years
Safety Officer	SO	A-SO	7 years
		B-SO	5 years
		C-SO	8 years
		D-SO	4 ½ years
		E-SO	4 years
		F-SO	12 years
		G-SO	2 ½ years
		H-SO	8 years
Labourer	LA	A-LA	10 months
		C-LA	1 year
		D-LA	1 ½ years
		F-LA	1 ½ years
		G-LA	8 months
		H- LA	1 year
Mason	MA	E-MA	1 ½ years
Store Keeper	SK	B-SK	1 year

4.4. Composition of CDW material

In the construction industry, CDW management is a critical issue that needs to be addressed. Thus, during the case study survey, interviewees were asked to explain the types of CDW materials that get generated in their sites. In the study, almost all the respondents have identified concrete, plywood, cement, and steel offcuts as the main type of CDW in their sites. Minimum number of respondents have identified, cardboard, plastic, PVC, paper, tile offcuts, concrete nails, wire nails, glass welding rods in their CDW composition. Based on the opinions of the respondents, summary of the findings are presented in Table 4.3.

Table 4.3. : CDW materials

Type of Waste	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
Plywood	√	√	√	√	√	√	√	√
Concrete	√	√	√	√	√	√	√	√
Cement	√	√	√	√	√	√	√	√
Steel/ Offcuts	√	√	√	√	√	√	√	√
Blocks	√				√	√		√
Bricks		√	√	√			√	√
Sand	√			√	√		√	
Soil		√	√					√
Wood waste	√	√	√		√	√	√	√
Polythene	√	√	√			√	√	
Cardboard	√					√		
Plastic/ PVC	√					√	√	
Paper		√						
Aggregate	√							
Tile offcuts			√					
Concrete nails						√		
MEP waste	√							
Wire nails						√		
Welding rods						√		
Tool wastage						√		
Glass waste						√		
Food waste	√	√	√			√	√	√

4.4.1. Discussion on composition of CDW materials

Similarly, through the existing literature, different types of CDW materials were identified as discussed in Section 2.5. Basically, through the literature findings, CDW materials like, concrete, bricks, tile, gypsum, wood, glass, plastic, paper, brick, tile, sand, stone, soil, metal, wires, and gravel were identified (Refer to Section 2.5). In the case study findings, CDW materials identified were, plywood, concrete, cement, steel, blocks, bricks, sand, aggregate, soil, MEP waste, wood, polythene, cardboard, plastic, paper, tile offcuts, concrete nails, wire nails, welding rods, glass, tool wastage and food. As the case study focused on ongoing projects that are within the completion stage of the 30%- 60%, waste types like glass, paint waste, pigments, and glues which were identified in the literature (Refer to Section 2.5) were not identified in the case studies as those types of waste starts to get generated in the latter part of the construction. Further, the case study findings reveled that in the construction sites food waste as another type of waste that get generated in the construction industry.

4.5. Origins and Causes of CDW

Numerous number of reasons lead to CDW in the construction industry. Hence, respondents were asked to provide their views on 'what are the origins and causes of CDW material generation?'. Thus, following section discusses the origins and causes that leads to CDW generation

Project Manager of Case C (C-PM) stated that, waste get generated due to client, architect, and structural engineer changes. Further C-PM stated, "*in the stage of ducts establishment for services like Air Conditioning (AC) and fire, there will be chances of ducts start to cross over each other. In such scenario, focus needs to be paid for the ducts as well as towards the standards of minimum height in between the floors. So in order to maintain the standard height in between the floors and to avoid duct crossing, sometimes beam needs to be drilled or needs to be break to solve the issue in ducts and waste gets generated as a result of drilling and breaking the beams".* In addition to that, he also explained, "*tile and ceramic wastages can occur due to transport*". Furthermore, D-SE stated, "*when the bricks are brought into the basement of the site, bricks need to be transported to the upper flows of the site*". During the case study analysis, the study revealed that for the transport of bricks, hand transport method is used. In the process of brick transportation, at first (1st) it is unloaded to the site basement. Then from the basement, bricks are put into the hoist. From the hoist, bricks are transported to the upper floors. So in this instance of brick transportation, brick is nearly transported 4 times before they are being used to the construction. So in this transportation process, brick waste gets generated. Moreover, respondent D-SE stated, "*few amount of sand waste gets generated in the process of transportation from the basement of the site to the upper storeys of the building".*

Site Engineer of Case C (C-SE) and respondent Project Manager of Case E (E-PM) explained that due to the mismatch in materials required and materials available, waste get generated. Further, E-PM elaborated this through the example of steel bar. As stated by the respondent E-PM, for a specific work, required length of a steel bar size is 10m, but the available steel bar sizes are 6m and 12m. So it ultimately generates a steel offcut of 2m which is a waste from that specific activity. Furthermore, respondent E-PM stated, *"if the supplier is informed specifically regarding the needed bar length size as 7.1m and asked them to provide the quantities, then there will be no any wastage. But, to do a procurement as such, at least 20 tons of steel bars from the same size need to be ordered".* As per the findings, weather condition is another waste origin source. Safety Officer of Case E (E-SO) stated, "*sand wastages and steel corrosion take place due to weather conditions".* In the site, sand is collected in an open yard, and due to rain, sand can get washed away by creating a waste. Further, respondent E-SO explained, "*due to weather conditions, steel get rusted and sometimes it creates waste*". E-SO also said that most of the time, such steel is reused after doing the wire brushing. Safety Officer also emphasized that, these strategies lead the site towards the ZW concept (E-SO).

Interviewee E-SO also stated, "*CDW get generated from the material handling methods also".* When there is a slab construction, measurements and quantities are taken before hand. There may be changes in the quantities and measurements. That means, there may be instances of excess material purchase. In such instances, excess can be used for fillings in the floors or to prepare drains. Such activities need to be pre-planned in the material handling stage and in material purchasing stage. Similarly, E-

SO also said, "*waste like plywood get generated as a result of the end of the product life cycle*". Normally in the site plywood are used for 4- 5 times and when they get mixed with water, layers of the plywood get widen and lead to wastages.

According to the Planning Engineer of Case F (F-PE), waste get generated due to human mistakes and due to the negligence. Further, study revealed that when there are calculation errors in the stage of procurement, there are few wastages. In an instance where concrete is purchased, due to the errors in volume calculation, there can be excess quantity of concrete. Respondent further elaborated, "*if such thing take place in the site, it is being sent back to the main batching plant and they are being reused. In this site, for the construction, high grading concrete like grade 50 to 70 are being used. These concrete can be degraded by mixing with sand. So it can be used for domestic construction, as 20 grade concrete is being used for domestic construction*". Based on the case study findings, Table 4.4 shows the summary of origins and causes of CDW material generation at construction sites.

4.5.1. Discussion of origins and causes of CDW generation

From the literature review, as the origins and causes for CDW generation, issues such as contractual, design, procurement, transportation, on-site management and planning, material storage, material handling, site operation, residual, weather and vandalism were identified (Refer to Section 2.4). Similarly, through the eight (08) case studies design changes, transport issues, change requirements of clients, human mistakes, poor quality of work, issues in labour skills, weather conditions, end of product life, mismatches in required materials for the construction, changes in the building by the engineers and architects during the construction, negligence, and material handling were identified as the origins and causes for CDW generation. Apart from the literature findings, through the case study findings it was also identified that negligence is also one of the key reasons for CDW generation.

Table 4.4. :Origins and causes of CDW

Origins and Causes	**Case A**	**Case B**	**Case C**	**Case D**	**Case E**	**Case F**	**Case G**	**Case H**
Design changes	√	√	√	√	√	√	√	√
Transport	√	√	√	√	√	√	√	√
Human Mistakes	√	√	√	√		√	√	√
Quality of works	√			√	√	√	√	√
Client Changes	√		√			√		√
Mismatches in required materials		√	√		√	√	√	√
Labour skills	√				√	√		√
Weather Condition		√			√			
End of product life		√					√	
Negligence					√	√	√	
Material handling					√	√		√
Changes by Architect and Engineer during the construction			√					

4.6. CDW Management Procedure

To manage CDW by implementing ZW concept, current WM procedure needs to be identified. Therefore, respondents were requested to explain the current WM procedure in their sites. Based on the respondent perception, WM procedures of each case is presented as follows.

- **Case A**

The respondents in Case A emphasized that collected waste are segregated as construction waste, food waste, paper waste, polythene and plastic waste in the site. It was observed that all the collected waste is sorted in the basement floor of the site. Further, Planning Engineer (A-PE) said, "*all the generated paper and polythene waste in the site are handled by a private company*". Moreover, Safety Officer said that two (02) labours are allocated for the WM within the site(A-SO). Once the waste gets collected in the basement of the site by the laborers, collected waste is transported away from the site by using lorries and they are used for landfilling.

- **Case B**

When considering Case B, it was observed that in each floor waste is collected and they are brought down to the collection yard in the basement as shown in Figure 4.1. To bring the waste from upper floors to the basement, bags are being used and separate labourers are allocated to that. In addition to that, B-SO stated, "*food waste, polythene and paper waste also separated in the basement of the site and bins are arranged to segregate those waste*" (Figure 4.2). Then those collected food, polythene and paper waste is taken by the municipal council once a week. Once construction waste is collected in the waste yard of the site and they are being transported through lorries once a week to a site. According to the Planning Engineer of Case B (B-PE), construction debris of the site are being sent to another site where waste gets further sorted and an average of $5m^3$ volume of waste debris which cannot be used at all get generated after the sorting. Out of the $5m^3$ debris, $1/2m^3$ of the are used to fill pits in the land. Other 4 ½ m^3 is used for backfilling. Store Keeper (B-SK) who is responsible to check the waste transportation from the site to dumping yards said that, "*8 ton lorries are used to transport waste*". Further, B-PE stated that, due to the limited space in the site waste incineration practices are not being followed.

Figure 4.1: Waste collection in the ground floor in Case B

Figure 4.2 : Waste bin arrangements in Case B

- **Case C**

Similar to Case A and Case B, when respondents of the Case C asked for the current WM procedure in their site, for the WM within the site two labourers have been allocated. Waste in the site are sorted in the waste yard of the site and it is shown in Figure 4.3. Then the collected waste like paper and plastic waste, get disposed through municipal council. Further, Project Manager of the site (C-PM) stated, "*separate areas are allocated to collect, steel, timber, jacks, scaffolding, and food waste in the site and disposal is done through the sub-contractors*". To transport waste away from the site, trucks are being used.

Figure 4.3 : Steel and wood waste collection in Case C

- **Case D**

In Case D, respondents stated that when CDW gets generate, they are collected in floor wise and waste is collected and brought to the waste collection yard in the basement of the site. During the data collection procedure, it was observed that in the site of Case D, bricks and plywood are collected separately in the site and other waste types are collected together. Further, food waste is collected daily from the site and the waste is given to a poultry farm as foods for pigs. Site Engineer (D-SE) said "*chipped grouts, plywood waste gets collected twice a week by a recycler"*. Further both D-SO and D-LA stated that from the site waste is transported through trucks to waste dumping areas.

- **Case E**

In Case E, waste is collected in each floor and collected waste is brought to the corner of the floor corridor. Then through a garbage chute all the waste is sent to the basement of the site. The garbage chute is made by removing the top and bottom part of the barrel and these barrels are welded as shown in Figure 4.4. Once the waste is collected in the basement, they are used for the fillings in the site and remaining waste will be taken by a 3rd party waste collectors for landfilling. From the site, waste is transported in every two weeks' times and lorries and tractors are used to transport waste form the site to landfilling sites.

Figure 4.4: Garbage chute made out of barrels in Case E

- **Case F**

Same as other cases, it was observed that waste is collected in floor wise in Case F also. Planning Engineer (F-PE) said that, waste is not getting 100% sorted in the floors. From the floors, waste is sent to the basement by a bucket connected to hoist or crane as shown in Figure 4.5. Once waste is received to the basement, they are being stacked and sorted. In the sorting process, priority is given for waste materials like concrete, plywood, and polythene. Further, F-SO stated, *"rebar is handled by a separate team called rebar teams and rebar is resold to steel recyclers in tonnage. This process is carried out by the head office of the Case F. What we do here is, we collect full steel load and we scale them. Then they are being sent to the dumping yards of the company* *and from that point they are being resold*". To transport waste from the site to dumping yards, lorries are being used as shown in Figure 4.6. These lorries transport one to two tonnes of waste thrice a week. Site Engineer of Case F (F-SE) stated that, waste is landfilled to another site.

Figure 4.5: Bucket used to bring waste from upper floors to the basement in Case F

Figure 4.6 : Lorry used for waste transport waste in Case F

- **Case G**

In Case G, separate labours are allocated to WM in the site. Waste collected in the floors are brought to a collection area in the ground floor. G-SO stated "*there are two ducts within the site to transfer waste from upper floors to the ground floor. One duct is used for plywood waste and other duct is used for cement, and brick waste*". Once waste get collected in the site, waste is dispatched depend on the quantities of collected waste. Site Engineer (G-SE) said, "*sometimes waste is dispatched from the site on a daily basis and some days' waste is sent twice a day. For the transportation, lorries are used*". In site G, waste materials like soil, cement, bricks, sand are sent to landfilling. In addition to that, G-SE stated that due to the limited space in the site, waste burning is not practiced in the site.

- **Case H**

Similarly, when considering the WM procedure in Case H, same as other cases, at first waste is collected in each storey of the building. Then those waste are brought to the down floor by using a metal bucket that is attached to a hoist. When the waste is bought to the ground floor waste collecting area, waste is kept in the site until they are dispatched. In the waste collection area, steel and wood waste are collected separately. Planning Engineer of Case H (H-PE) said, "*waste get dispatched to landfilling only when there is a load of waste".*

4.6.1. Current CDW management procedure in Sri Lankan construction industry

Considering all the responses of the respondents from each case, the current CDW management procedure comprises of few steps. As discussed in the individual cases, it could have identified that when the CDW get generated in the site, those waste are collected into a one place in each storey of the building and the collected waste is brought down to the waste collection area in the ground floor. Once the waste is collected in the floor, to bring the waste to the ground floor garbage chute or labours are used. Then the collected waste is sorted in the ground floor and some of the collected waste is used within the site while some waste gets transported away from the site (Reuse of CDW within the site are discussed in detail under the section 4.7.). Before transporting waste away from the site, some of the waste get resold for waste collectors (refer to section 4.7). Then the remaining waste gets transported and gets landfilled. By considering all the findings of the eight case studies, current CDW management procedure in the Sri Lankan construction sites can be summarized as shown in Figure 4.7.

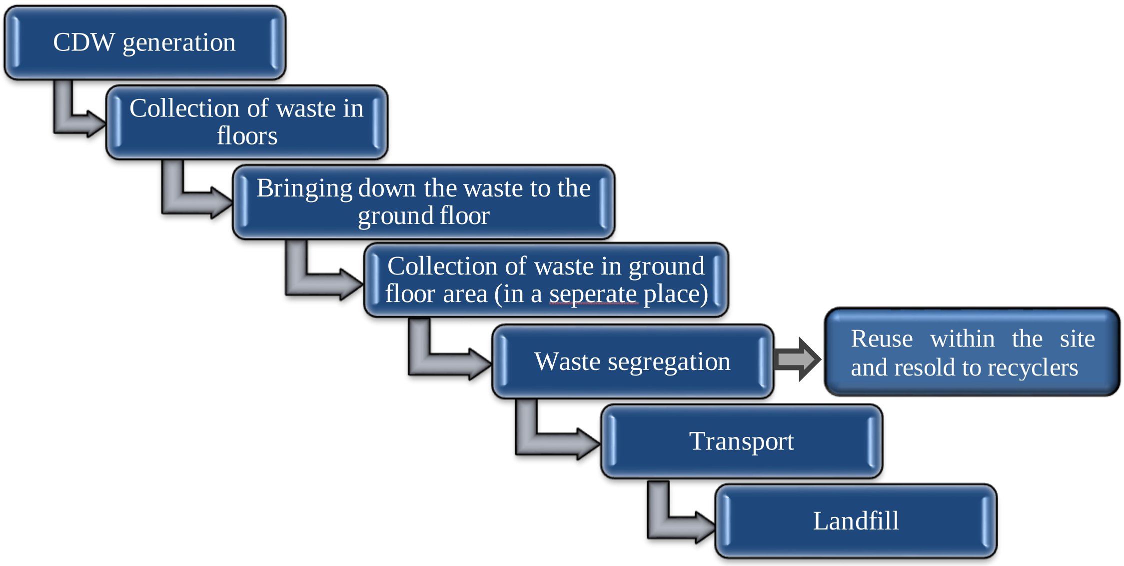


Figure 4.7 : CDW management procedure in Sri Lankan construction sites

4.7. CDW Strategies Which Leads for Zero Waste

The respondents were queried on the current CDW management strategies used in the construction sites and strategies which motivate the industry to apply ZW concept. Therefore, at first, strategies used in each case are discussed. Afterwards, common CDW management strategies are presented with identifying opportunities for applying ZW concept in the construction sites.

- **Case A**

In case A, respondents A-PE, A-SO and A-LA stated that within the site, different strategies are being followed in the reduce, reuse and recycle categories. Further, respondents A-PE and A-SO stated some examples for "reuse" strategies in site as, "*in the process of construction, aluminum formwork system is used instead of the plywood formwork and couplers are used in lap where a cut is needed in reinforcement*". In addition to that, A-SO said, "*a pipe is being used to transfer cement from ground floor to upper floors. Inside the pipe, there are cement remains and these are getting generated as waste. What we do in the site is, paving blocks are prepared out of those cement. Similarly, steel offcuts are used for temporary works like in cabins creation, and for external brackets*". Further, Safety Officer of Case A also stated that, these strategies avoid waste generation, and help in achieving ZW in the construction sites.

Moreover, respondent A-LA stated, "*for WM within the site, separate colour coded bins are being used to collect food waste, polythene, paper and plastic get sorted*". Furthermore, it was observed that employees have sorted the waste according to the bin arrangement. As stated by the Safety Officer (A-SO), food waste, plastic, polythene, and paper waste are given to waste recyclers. Similarly, A-SO also highlighted that food waste generated in the site are given to a poultry farm as the food for pigs. Safety officer of Case A (A-SO) also emphasized that by giving food waste to the farm they are achieving 100% in ZW in the food waste category. In addition to that, Planning Engineer of the Case A (A-PE) stated, "*recycling is the best strategy to achieve ZW in the construction industry as it restricts the waste generation and also recycling strategy ensures that waste is being used within the supply chain as a resource without dumping them to landfills*".

- **Case B**

According to the Planning Engineer in Case B (B-PE), reuse, recycle and onsite waste sorting are used in the construction site premises as the WM strategies. Further, B-PE elaborated, "*soil wastage that is generated in the site is being used as a backfilling within the site itself while plywood waste is used in formwork of stiffener columns*". In addition to that, Safety Officer (B-SO) stated, "*within the site plywood is used for 3 to 4 times*". Not only that, B-SO further stressed that, use of plywood for three to four times can also be taken as a strategy to achieve ZW in the construction industry. Moreover, Safety Officer (B-SO) stated, "*when using steel bars, there are offcuts and these offcuts are used for different purposes depending on the size of the remaining offcuts without throwing them as waste*". Similarly, respondents B-PE, B-SO and B-SK said that, all the concrete waste remaining is used to prepare paving blocks within the site. It was observed that, in the basement of the site all the prepared paving blocks are kept until they are being sold as shown in Figure 4.8. Once a bulk of paving blocks are being sold and it brings an additional income to the site.

Figure 4.8 : Paving blocks from concrete waste in Case B

- **Case C**

Project Manager of Case C (C-PM) said, "*when ordering the concrete, we look into the history and we check for the actual and theoretical quantities and then we are mapping them into a map. We are trying to minimize the concrete waste generation. Through this we are looking into ways of waste avoidance at source of generation which ultimately leads for no waste generation. Thus, this can be stated as a strategy to apply ZW in the industry*". C-PM also elaborated "*concrete remaining is used in labour huts and some are given to the nearby villagers depend upon their early requests*". In addition to that, Safety Officer of Case C (C-SO) stated that, "*in some places of the site, concrete waste is used to fill the ramps and entrance areas*". Respondent C-SO also said that, steel offcuts are used in the site safety fence and also some offcuts are used to close lift hole openings. Site Engineer of the Case C (C-SE) said, "*steel offcuts are used for trench cover slabs*". Further, both C-SO and C-SE stated that, "*Soil waste generated in the site is used for backfilling in the site*". Furthermore, Project Manager highlighted that in the Case C (C-PM), *"main issue is related to timber offcuts and unusable soil. In areas out of Colombo, timber is used as a fuel. But it is an issue in the Colombo construction sites*". Thus, C-PM suggested that to overcome from the timber offcuts problem, if paper is produced, this issue can be sorted. Further, Project Manager (C-PM) suggested that, other timber like 50x50mm and 50x100mm which is normally made out of giniseria plant, needs to be checked whether they can produce alternative products like matchboxes, paper or cardboard. Moreover, C-PM also suggested, "*unusable soil, which cannot be used for backfilling can be used by mixing with 2% of cement and enrich the properties of soil*". Respondent C-PM said that "*in North East area, roads with gravel are used to prepare the roads. After soil enrichment by mixing 2% of cement soil stabilization take place and they can be used for alterative as road preparations*". Moreover, when it comes to construction debris, as per the Project Manager, "*most suitable option is to use the construction debris for fillings. If the building consists of suspended floor slab, construction debris can be used to fill such areas. As the slab load does not need to bear such alternative options can be followed to manage waste within the construction sites and in our site also we have followed this strategy*" (C-PM).

Moreover, in Case C, plywood is used 6 times and if the plywood is double coated, then such plywood is used 10 times in Case C. After reusing the plywood for several times, debris of the plywood is taken by the recyclers and they are given to bakery owners to use in kilns. In addition to that, C-PM said, "*plywood that is being used for the construction are class 2 or class 3. These plywood needs to be checked whether they can be used to prepare the plywood compressed doors and windows*". Moreover, Project Manager also stated, "*when ceramic waste gets generated all the ceramic waste from the site are sent to a waste yard. From the yard the remains are used for temporary washrooms of employees in different sites and with the available ceramics we do some designs in the washrooms. Not only that, some of the offcuts are taken for army camps to use within their bunkers*" (C-PM). Similarly, to reduce the paper waste within the office in site, computer based programs are used. When it comes to the recycling strategies in Case C, different recyclers are allocated for recycling activities and food waste is given to a nearby farm as the foods for pigs. C-PM said, "*we give the waste to recyclers because if we do recycling within the site, it costs more*". Finally, C-PM said, "*although ZW concept is not fully implemented in Sri Lankan construction industry, we do look into different strategies to avoid waste generation and also to use the generated waste as a resource without releasing them to the environment. If the strategies of reuse, recycle are followed in the proper manner, ZW concept can be achieved*".

- **Case D**

Respondents of Case D stated that, within their site strategies like, bin arrangement, reduce and reuse are being used to control CDW generation within the site. In order to reduce the CDW, quality checking is carried out at the stage of procurement. Both respondents D-SE and D-SO said that normally plywood needs to be used twice or thrice a week. So plywood needs to be in the required quality. Due to that reason, in the stage of procurement quality of the product is being checked and if the product does not meet the required standard, then the products get rejected. Further, in the brick procurement stage if the bricks are not up to the required standard and quality, they are being rejected. Other than that, Site Engineer (D-SE) said, "*at times brick waste is used in the process of hand mix concrete into the proportion of 1:2. Then those mix concrete is used in the construction of drains*". Further, respondent D-SO stated, "*for the temporary works, ½ bricks are used*". Moreover, Site Engineer of Case D said, "*normally plywood board is 1200mm and if a specific beam needs 700mm, then there is a wastage and such remains are used for lintels*" (D-SE). As reuse strategies in Case D, steel offcuts are used for handrail, deck, and in safety fence. All steel works within the site are handled by the subcontractors.

- **Case E**

When interviewees of Case E asked for the CDW management strategies to achieve ZW, respondents stated that strategies like, waste bin arrangement, on site waste sorting, reduce, reuse and recycle are being used. In Case E, at first through identification, materials are quantified. When doing the quantification, as an example, when purchasing steel, steel is purchased to an offcut length. In order to purchase like that, bulk amount needs to be purchased. Steel bar diameter range from 8mm to 25mm.So from each bar, it is difficult to purchase an exact amount. E-PM stated, "*if we take the 8mm bar, it is a small one. So bars as such are difficult to purchase in offcut lengths. In cases as such we need to purchase the full bar and cut into the required amount. If we are going for ZW the remaining offcuts from the 8mm bar, it needs to be pre planned and needs to be followed a long process with the involvement of huge amount of labours*". Further, Project Manager elaborated, "*when it comes to cement, for a specific single house unit in the site, we are aware of the amount of cement that is being used. So while the construction goes on, we can monitor the* *number of cement bags that are being used for a specific single house unit in the project and we can monitor why an excess was used. With the material reconciliation we plan everything and we can justify all the material usage*” (E-PM). In addition to that, E-SO said, “*concrete waste can be used to make paving blocks and post bases in road construction. In order to make these things, activities need to be pre-planned considering the scenario of excess production*”.

Similarly, soil waste generated within the site of Case E are used for the backfilling in the site. Respondents of Case E stated that most of the time, there are debris from cement mortar and bricks. Further, Project Manager of Case E (E-PM) further emphasized, “*in the construction process, English bond is used and it creates brick waste. In order to reduce the brick wastage, we have asked the manufacturers to prepare half size blocks so that it helps to reduce the brick wastage. Currently it is not practiced in the site. We are in the process of ordering the blocks. In the current situation, brick waste that get generated are used for backfilling and sometimes the remaining bricks are crushed and used instead of sand after sewing. So through these strategies, we can reduce wastage and can move towards the implementation of ZW concept*”. Further, Safety Officer stated, “*when it comes to blocks, supervisors are provided to look into the remaining blocks and it is the responsibility of supervisors to make the maximum use of the remaining block pieces without making them as waste*” (E-SO). In Case E, plywood is used for 3 to 4 times within the site and once they turn into debris, waste is incinerated within the site. In addition to that, E-SO added that, “*some of the plywood waste are used for kilns in bakeries and also to cover sky ducts in the site. When the plywood is used in kilns, ultimately it avoids the waste dumping to the landfills and also it is a good practice to be followed in the sites to achieve ZW targets*”. Similarly, study on Case E revealed that, steel offcuts are used for dowel bars, lintels, stiffener beams and to cover slabs. Safety officer of Case E stated that, steel offcuts are also used for precast panels in drainage, and for pins in acro jacks as observed during the data collection as shown in Figure 4.9. Although the material reconciliation is followed in the site, there are chances of controlling waste generation. For example, steel, aluminium, plastic and general metals are given to resellers for recycling.

Figure 4.9: Steel offcuts used in acro jacks in Case E

- **Case F**

When queried on CDW management strategies to implement ZW concept in the construction industry from the respondents of Case F, responses were given as, 5S, bin arrangement to dispose waste, reduce, reuse, recycle and WM plan. Respondent F-SO stated that, for every 1m^3 concrete, 4 test cubes are made in the labs. Those prepared test cubes were observed in the data collection and it is shown in Figure 4.10. In the site nearly 5000m3 are used monthly. So there are nearly 20000 cubes are made and cubes are collected by waste recyclers. These blocks are given free of charge. Further, general safety and lifting manual is used in the site and in the manual there is a separate area for WM. Safety officer (F-SO) said, "*manual is provided in brief as it is given to staff and workers. In the Operational Control Procedures of the manual, they have explained about WM within the site*". Other than that, there is a separate WM plan for WM in the site. Moreover, Planning Engineer (F-PE) said, "*if there are any client requirements, then general WM plan that is being used in all the projects are deviated. That means, in this site, there is no any batching plant due to the limited area. So what we do is, from the batching plants, cement is brought to the site through trucks and we used it for our own purposes in the site. Therefore, due to this reason very few concrete waste is generated in the site and the remains are used for small filling works in the site and the other concrete waste which cannot be used are sent to landfills. Therefore, when the remaining concrete waste is used to make paving blocks, it leads to reuse of* *waste to produce another product. This restrict the waste generation and ultimately it leads as a strategy to implement ZW".*

Figure 4.10 : Concrete Cube in Case F

In addition to that, Site Engineer of site F(F-SE) stated, "*steel off cuts are used for stools which is in between two mesh. In the site we use double mesh. In order to keep the required distance, stools are used. Other than that, off cuts are used for the places where short lap length is needed. That is for rebar lap length. For the thread coupler off cuts are used".* Safety officer also said, "*concrete waste gets remained in the concrete pump. In the site, first we prepare 1m x 1m boxes from wood as a skeleton. Then the concrete remains in the pump are filled into these boxes and once the box get filled up, a hook from steel offcuts are attached to the top of the cube. Then these cubes are dispatched to another site and from there, people take these cubes to create gabion walls or to create retaining walls*" (F-SO). Further, Safety Officer stated that, polythene waste is given to recyclers those who are registered in the Central Environment Authority (CEA). In addition to that, F-SO also stated that, to avoid the generation of dengue breeding places, collected waste is transported based on the generated waste bulk. Moreover, Planning Engineer(F-PE) stated, *"plywood and timber were used up to the height of level 5(story). After the level 5, aluminium formwork is being used. Therefore, wood waste is controlled in the site".* Moreover, through the findings of Case F, it was identified that 20 tons of steel is being used per day. For the wastage of steel, 3% of margin is kept. Similarly, for concrete, allowable concrete wastage is 4% and in Case F, concrete wastage is maintained at 0.5% on average. Plywood is used 4 to 5times before they are sent as waste.

- **Case G**

Similar to other cases, in Case G also Reduce, Reuse, Recycle, and bin arrangement strategies are being used. In the site of Case G, steel offcuts are used for lintels and masonry work. Further, to reduce waste generation, material reconciliation is being followed. Thus, procurements within the sites are done according to the correct scale making no wastages. Moreover, G-SO stated, "*plywood is used as a platform in scaffolding. Through this objects falling from top of the building to the ground floor is avoided*". Further, Site Engineer (G-SE) also added that, after using plywood for 4 to 5 times, plywood waste is given for bakeries to use as fuel. In addition to that, for each floor of the building, supervisors are allocated and they look into wastages and make sure to reduce wastage. It was observed that polythene, plastic, paper and food waste is collected separately in separate bins and all the respondents stated that, polythene, plastic and paper waste is given for recyclers.

- **Case H**

As per the findings of Case H, plywood formwork was used only for 2 storeys of the building. For other floors of the building, aluminum formwork system is used. Plywood that is being used in the site are used for 4 to 5 times. Further, plywood waste is used for safety sign boards in the site and for the basement of the scaffolding. Moreover, to reduce waste generation, when ordering the materials, orders are given based on the material requirements for the construction activities. Safety Officer (H-SO) said, "*concrete usage is pre planned in the site. If a wastage occurs in the planning stage, then plans are made on where to use the excess concrete. As an example, to prepare precast items, to prepare paving blocks or to do the fillings in ramps*". It was observed that some cubes are used for temporary works in the site as shown in Figure 4.11. Further, Planning Engineer (H-PE) said that, "*if there are any steel bar waste, then we are looking into places where we can use them through the rebar schedule*". Respondent H-PE also stated that, "*steel offcuts are used for safety ducts*".

Figure 4.11 : Concrete cubes used for temporary works in the Case F

4.7.1. Common CDW management strategies and opportunities in applying ZW in the construction industry.

According to the eight case studies on site waste sorting, colour coded bin arrangement and use of 3R (Reduce, Reuse, Recycle) are the common CDW management strategies used in the construction sites. Other than the key strategies, strategies like, 5S, material reconciliation and use of WM plan are also used. Respondents also highlighted that, same C&D strategies can be applied as ZW strategies. Based on the findings of all cases, it could identify that possible strategies will help to implement ZW concept in the construction sites and the identified strategies to eliminate CDW with their possible actions are summarised in Table 4.5.

Table 4.5 : Strategies and actions to eliminate CDW materials to achieve ZW

CDW material	Strategy	Possible action to eliminate waste
Plywood	Reduce	• Replace with aluminium formwork
	Reuse	• Used in formwork of stiffener columns • Used as platform in scaffoldings to avoid objects falling from top of the building • Used in safety sign boards

CDWmaterial	Strategy	Possible action to eliminate waste
		• Used in basement of the scaffolding • Given to bakeries to use in kilns • Single coated plywood can be used for 6 times, double coated plywood can be used for 10 times and incinerated • Can be used to prepare the plywood compressed doors and windows • Used to cover sky ducts
Concrete	Reduce	• Mapping the places to be used in case of excess purchase
	Reuse	• To produce paving blocks • Used in the construction of labour huts. • Given to the villagers based upon their early request • Used to prepare post bases in road construction. • Used for small filling works • To do the fillings in ramps
Cement	Reduce	• Material reconciliation
	Reuse	• Production of paving blocks
Steel Offcuts	Reduce	• Purchasing to an offcut length
	Reuse	• Used for lintels and masonry work • Used for safety ducts • Used for temporary works like in cabins creation, and for external brackets • Used in the site safety fence • Used to close lift hole openings • Used for trench cover slabs • Used for handrail, deck, and in safety fence. • Reselling the offcuts through the audit team • Used for dowel bars, lintels, stiffener beams and to cover slabs • Used for precast panels in drainage • Used for pins in acro jacks

CDWmaterial	Strategy	Possible action to eliminate waste
		• Used for stools which is in between two mesh (to keep the required distance) • Used for places where short lap length is needed • Used for thread couplers
Paper, food, polythene and plastic waste	Recycle	• Recyclers are allocated to handle the waste
Soil waste	Reuse	• Used for backfilling in the site • By mixing the soil with 2% of cement, can be used for road preparation
Timber offcuts	Reuse	• To produce alternative products like matchboxes, paper or cardboard
Construction debris	Reuse	• Can use to fill the land area of a building which consists of suspended floor slab
Ceramic/ Tile waste	Reuse	• Used for temporary washrooms of employees in different sites • Taken for army camps to use within their bunkers
Paper waste	Reduce	• Use of computer based programs
Brick waste	Reduce	• Manufacturers are asked to prepare half size bricks to avoid waste generation in the construction activities which follows English bond method
	Reuse	• Used in the process of hand mix concrete into the proportion of 1:2 and used for drains
Aluminium, and general metal waste	Recycle	• Given to the recyclers

4.8. Enablers to Apply ZW Concept in Sri Lankan Construction Industry

To apply the ZW concept in the construction industry, enablers of ZW concept that are applicable for Sri Lankan construction industry needs to be identified. Therefore, respondents were queried on, “what are the motivating factors that enable the application of ZW concept in the site?". According to the responses of the respondents, findings of the individual cases are discussed under organizational enablers and national enablers.

4.8.1. Organizational level enablers

This section discusses the enablers for ZW concept in the Sri Lankan construction industry under the organizational level as follows.

- **Daily meetings, skilled employees and management staff**

Almost all the respondents of the eight cases identified daily meetings, skilled employees and management staff as the key enablers to achieve ZW. Respondent A-LA said, "*in the site, meetings are conducted twice a week to explain the importance of WM and ways to control waste".* Similarly, respondent B-SK stated that in their site, management use daily meetings to convey ideas and methods of the importance and ways of WM within the site to the labourers. Moreover, C-PM also stated, "*engineers, store assistants and technical officers are being sent for trainings where they get comprehensive ideas on material usage without creating waste. These trainings help the employees to take the maximum benefits of the materials that they are using"*. Further, D-SO said that in their site, for the daily meetings contractors and direct labourers are involved. In addition to that, Project Manager (E-PM) said, "*through training and awareness and with proper WM practices, profit can be increased. Therefore, training and awareness is one of the key enabler to manage CDW"*. Apart from that, according to F-SO, through the induction also employees are encouraged to do the WM within the site. Further, in the induction, employees are being educated regarding the WM in the site. Moreover, G-SO stated, "*if the employees are skilled enough, then they will try to manage the wastages by using the maximum benefits of the materials that they are using"*.

- **Fine systems, incentives scheme and appreciation of the employees**

According to the response of Safety Officer of Case A (A-SO) on the enablers to implement ZW, A-SO said, "*to enable ZW in the construction sites, fine systems need to be inaugurated. When a fine system is available, employees will look into alternative* *methods to use the excess materials*". Further, A-SO also stated that, in the construction activities allowable wastage is limited to 5% and it also help to control waste generation beyond 5%. Moreover, Project Manager of Case C (C-PM) stated, "*in a project, project profit margin can be decided based upon the WM. If proper WM take place within the site, most of the materials that are being thrown away as waste can be used for an alternative purpose where cost savings can be achieved through that. Along with the cost savings, CDW can also be eliminated and achieve ZW goal"*. Similarly, when the respondents of Case E were asked for the enablers to manage CDW which leads to implement ZW concept in the construction industry, respondent E-PM stated, "*in their site, labourers are asked to collect the unused nails and depending on the amount of nails that labourers collect, money value is given to the labourers for the collected amount of nail waste"*. This has encouraged labourers to collect the nails and it also helps to enhance the safety of the site. Further, respondent Project Manager said, "*to implement a concept like ZW, employee involvement plays an important role. So we need to encourage the employees to manage waste*" (E-PM). Such practices can be motivated through practices where employees are given with incentives for WM. As per the findings, respondent F-PE stated, "*in their site WM is encouraged through the appreciation of work"*. That means, when cardboard waste gets generated during the interior designing stage, within the site, it is planned to give the cardboards to recyclers. So, what they have planned in their site is to give half of the amount that is received from the recycler to the employees those who collect those cardboard waste. As per the respondent F-PE, this method encourages WM within the site.

- **Monitoring of employees by supervisors and the management team**

Although different strategies are available to manage CDW, supervisors and management team needs to pay their attention towards the employees and the employees need to be monitored for their activities. According to the Safety Officer (B-SO) and Store Keeper (B-SK) of Case B, proper involvement of managers and supervisors through the instruction on correct ways to sort and reuse the waste materials help to eliminate waste which will ultimately leads to ZW achievement. Furthermore, C-PM stated that with the involvement of the management and supervisors, labourers are provided with knowledge on material usages and their alternative uses.

Nevertheless, E-SO of Case E said that through the allocation of supervisors to monitor the activities of the labourers within the Case E, supervisors will look into material usage of the labourers and asked them to use the material in a maximum way. Safety Officer (E-SO) said, "*as an example, if there are too much of block waste in a specific floor, then the supervisor will look into this matter and asked them to use the material in a maximum way*". Moreover, Project Manager (E-PM) stressed that, when the employees are monitored during the working time, supervisors can guide the employees to use the excess materials to another needed area of the site without making the excess material as a waste. Further E-PM said, "*such practices will lead to implement the ZW concept in the construction industry in a more systematic way*". In addition to that, G-SO stated that in their site for each floor they have allocated separate supervisors so that they will look into wastages and make sure to reduce waste generation. Moreover, in Case H, as the current practice in their site, respondent H-PE stated that, for every 10 labourers one supervisor is allocated and through a thorough inspection, waste is managed within the site

- **Procurement coordination**

This is another strategy highlighted by the respondents during the data collection. In the material purchase stage, it is necessary to coordinate the materials that are required for the construction activities within the site. If the correct coordination is available, then it will not create any C&D wastages due to excess ordering of materials. Project Manager (C-PM) stated, *"if the materials are planned from the initial planning stage, then if an instance where excess materials are available in the site, then those materials can be used to another purpose as they have pre planned the places to use the excess materials"*. Further, for the control of waste in Case D, according to the Site Engineer (D-SE), attention is being paid to procurement coordination. Through procurement coordination, maximum use of materials take place within the site of Case D. Furthermore, respondent H-SE explained that, waste needs to be planned at the initial stage of the construction. H-SE said, "*If concrete is taken as an example, at the initial stage it cannot be ordered accurately. So while in the construction stage, if there are any excess amount of concrete, from the initial stage it should be planned where to use the excess materials. Thus, it helps to reduce CDW and pre plaining of excess material usage can be practiced to enable ZW concept".* In addition to that, H-SE also stressed that, it is necessary to plan what is to be done for the waste from the initial stage. When the waste is planned from the beginning, CDW can be controlled and it will also help to achieve ZW concept in the industry.

- **Use of machinery, techniques and proper documentation**

Out of the all cases, Project Manager of Case C (C-PM) highlighted that proper use of techniques and machineries for WM as a key enabler which helps for the CDW management. Furthermore, Safety officer of Case E (E-SO) also said that proper documentation is also one of the key enabler which motivates the CDW management. As per the idea of C-PM, "*ZW concept can be achieved in high profile projects in Sri Lanka. But it will be difficult in other construction projects. If there are projects with foreign funding, they always look into sustainable development. So in the process of sustainable development, they look into different ways of development by preserving the nature. Therefore, when moving towards sustainable development, it will ultimately look into WM in the construction industry*". Moreover, case study findings show sustainability is a very important factor in modern construction and modern technology. In addition to that, C-PM also stated, "*use of machineries reduce the material wastages in transportation of materials to upper storeys of the site*". Respondent E-SO said that, when issuing the materials for labourers, issued materials are being documented in the site. Through the documentation practice, in the Case E, they check for the excess use of materials by the labourers.

- **Attitude and behavior of employees**

When respondents of each case were queried on the enablers to implement ZW in the construction industry, respondents of Case E and Case H mentioned employee attitudes and behaviors as an enabler to eliminate CDW from the construction industry4. Site Engineer (H-SE) said*, "attitude of the employees is a key enable in the*

CDW management procedure". In addition to that, Project Manager of Case E(E-PM) emphasized "*ZW is a concept that can be found in developed countries. It can be applied in Sri Lanka also. But, before applying the concept to Sri Lanka, we need to check whether we can apply such concept or not. We need to check whether the culture to apply such concept is available in the country or not. Trend needs to be set in the construction industry. It is necessary to change the employee behaviors and attitudes".*

- **Organisational policies and regulations**

Another enabler which was identified through the data collection from the eight cases is, organizational policies and regulations. Respondents C-PM and respondent F-SO stated that to implement a concept like ZW, policies and regulations need to be developed in the organization. Further, Project Manager of Case C said that through quality control policies and through standards like ISO 9001, and ISO 14001 material wastage is being controlled in the site. Moreover, C-SO and C-SE of the Case C said, "*during the construction of buildings, attention is being paid for the environment and it helps to regulate the CDW generation".*

- **WM targets and housekeeping practices**

Housekeeping practices and WM targets were also identified as the enablers of CDW management which leads to achieve ZW in the construction industry. In Case B, according to the respondent B-SK, two labourers are allocated for the WM within their site. Moreover, respondent F-SO stated, "*WM targets are given to the WM team in the site. If the WM team achieve more than the given target, then the employees are given with an incentive. These practices help to control the waste generation and in the long run it will also enable the ZW concept".*

4.8.2. National level enablers

This section discusses the national level enablers to implement ZW concept in the construction industry.

- **Policies and regulations for CDW management**

During the data collection, most of the respondents stressed that proper CDW management and regulations need to be implemented by the government. Project Manager of Case C (C-PM) said that when considering the Sri Lanka, there is a lack in proper policies and regulation to CDW management. Therefore, it is necessary to implement policies and regulations focusing on the CDW generation, collection, transportation and disposal. Furthermore, G-SO said that when proper set of guideline is available to manage the generated CDW, then ultimately it will be followed by the sites. Moreover, D-SE stated that, industry professionals need to team up and need to identify the importance of having CDW rules and regulations to manage the waste.

4.9. Barriers to Apply ZW Concept in Sri Lankan Construction Industry

As the above section discussed on enablers to implement ZW concept, this section discusses about the barriers in implementing ZW concept in the construction industry. Therefore, in order to identify the barriers respondents were asked their ideas on barriers to implement ZW concept in the construction industry to manage CDW. Hence, the findings of the case study related to the barriers are analysed according to the cross case analysis under the two (02) criterias of organizational level barriers and national level barriers.

4.9.1. Organizational level barriers

This section discusses the barriers to apply ZW in Sri Lankan construction industry.

- **Lack of supervision, lack of awareness of ZW concept by the supervisors and management**

When the respondents were asked for the barriers in applying ZW concept in the construction industry, respondents A-SO and A-LA said that, poor supervision of the supervisors and management team and lack of awareness in WM also demotivate the effectiveness in CDW management process. Similarly, when the same question is directed to the respondents of Case B, Planning Engineer (B-PE) said, "*lack of monitoring of the workers by the supervisors is one of the major barrier to manage*

CDW. It is because, if the employees are not monitored for their work, they will use the materials in a negligent manner". Further, Safety Officer of Case E(E-SO) highlighted, *"lack of employee awareness on WM leads to poor WM practices within the sites"*. In Case F, respondent F-PE stated, *"lack of WM team to manage waste within the site is one of the key barrier they face in the process of WM"*. Furthermore, Safety Officer (G-SO) stated, *"if the workers are unaware about the WM procedures and practices in the site, then proper WM does not take place and it will result in difficulties in achieving ZW target in the construction industry*". On the same note, E-PM also said, "*there is knowledge lack in the employees and poor rethinking patterns of the people. Employees are not thinking of ways to do a specific work through alternative methods"*.

- **Lack of skilled employees and poor employee attitude**

As the barriers to apply ZW, poor employee attitude and lack of skilled employees were identified. Both Safety Officer (B-SO) and Store Keeper (B-SK) stated that, lack of employee attitude towards WM is a barrier to manage CDW. Further, B-SO also stated, "*workers are the people those who conduct the construction activities. They do not pay their attention towards the WM practices as they just focus on finishing their work*". Moreover, when it comes to the responses of the respondents in Case C, respondent C-PM stated that, if more focus is given to the WM, then it will lead to issues in the progress of the site. As an example, C-PM elaborated, "*if we take a plywood and if we are going to reuse them, then there is a long process. Due to the reluctances and laziness of the labourers, this long process creates issues in reusing"*. As per the findings in Case E, respondent E-SO explained, *"employers and employee perspectives on WM also make a direct impact on WM within the sites"*. Furthermore, F-PE added stating, *"no one is considering WM as their responsibility and they do not focus much on waste separation*". Similarly, Project Manager also highlighted, "*industry people are not adoptive to the ZW objective. Scope of production is always changing and there is an issue in the additivity of the industry people. Thus, benefits of the ZW concept need to be highlighted" (E-PM).*

- **Lack of housekeeping, technology and facilities**

As per the responses of the respondents in Case A, Planning Engineer(A-PE) stated that, lack of facilities to manage waste, and issues in external WM parties are the key barriers in CDW management. Further, respondent A-PE stated, "*ZW is a good concept to implement in the construction industry. But there are difficulties in the implementation process".* In Case B, respondent B-PE was in the opinion of, "*with the implementation of ZW concept whole waste needs to be removed. In a construction site, it is difficult to achieve ZW due to the rapid changes. Further, we are landfilling our waste as there are no any proper waste recyclers to recycle the waste".* In addition to that, C-PM also highlighted that, lack of labour force to WM and poor housekeeping create issues in proper CDW management. According to the responses of Site Engineer (D-SE) and Safety Officer (D-SO), "*ZW is a good concept. But the biggest issue in achieving a concept like ZW is due to the issues in storage and transportation of waste. For the transportation of the waste, cost is incurred. Other than that, for the WM, there are practical issues like time allocation and labourer allocation.*

Further, material quality needs to be checked before purchasing them. Site Engineer of Case F(F-SO) said, "*if poor quality products are purchased, then it will lead to waste generation".* Furthermore, Safety Officer (F-SO) stated, "*when construction materials are involved there is a wastage. Due to that reason waste factor is being kept. And when considering about the secondary materials that are being used in the interior designing stage like bathroom fittings, they are having polythene wrappings, rigifoam and cardboard boxes. When we take cardboard, it can be 100% recycled and polythene too can be recycled up to 75%. But when we take the rigifoam, it will remain as a wastage. So it will create practical issues in achieving ZW and such issues need to be addressed".* In addition to that, respondent F-PE said that due to the lack of staff commitment and lack of housekeeping procedures also WM does not take place in a proper way. Moreover, respondent G-SO said, "*in relation to the cost and profit in construction projects, most of the time less attention is being paid to WM.*

- **Lack of preplanning and onsite sorting**

When the respondents were questioned on barriers, respondent A-PE stated, "*ZW is a good concept to implement in the construction industry. But there are difficulties in the implementation process".* Similarly, Site Engineer of Case C (C-SE) also stated, "*with the current practices of WM in Sri Lanka, it is bit difficult to achieve ZW concept. But if proper solutions are provided through preplanning of activities, ZW can be achieved*". Further, as the barriers to achieve ZW concept in managing the CDW, respondent D-SE said, "*in construction sites everyone focusses on profit*". At the initial stage of the construction, less attention is paid for WM during the pre-tender stage. So in the process of construction, if a waste gets generated, there is no any alternative method to be used as there are no any pre planned alternative options that have planned in the initial stage. Moreover, D-SE stated that "*there is a lack of budget allocation for waste transportation from the site".* Nevertheless, lack of proper sorting, and speed of the project also leads to poor CDW management within the construction sites. Furthermore, F-SO explained that, when the speed of the project is high, it is difficult to balance the construction activities and WM within the site as they are in the goal of reaching the deadlines. Site Engineer of Case H (H-SE) said that, there are difficulties in achieving hundred percent ZW concept due to the issues like employee behaviors and material mismatch for the usage.

4.9.2. National level barriers

This section discusses the national level barriers to implement ZW concept in the construction industry.

- **Lack of government support, policies and regulations**

As per the responses of the respondents, government role in implementing rules and regulations to manage CDW is at a poor stage. Respondent A-PE said that there is a lack in adequate government support to manage CDW. Further, B-SO highlighted, "*as the available regulations are not adequate, both employees and employers are not giving their attention towards the WM. Instead they focus more towards the profit. Therefore, there is a need for the proper rules and regulations".* Moreover, Planning

Engineer of Case F (F-PE) said that there is a lack in regulations for the waste dumping. As there are no any proper regulations for waste landfilling, CDW gets dispatched from the sites and get dumped into landfills. This can cause environmental problems in the long run. Thus, proper regulations need to be implemented.

4.10 Suggestions to Overcome the Barriers to Apply ZW Concept in the Sri Lankan Construction Industry

In order to overcome the identified barriers in CDW management to achieve ZW target, suggestions need to be identified. Hence, respondents were asked to provide suggestions to identified barriers. Provided suggestions are discussed under two criteria of organizational and national level as follows.

4.10.1. Organisational level suggestions

Organizational level suggestions to overcome the identified barriers in the Section 4.9 are discussed in this section.

- **Providing training, awareness and attitude improvements of the employees**

In order to overcome the barriers of lack of skilled employees and poor employee attitude, respondents gave their opinions as to provide training, awareness and attitude improvement of the employees. Planning Engineer of Case A (A-PE) said, "i*f waste is reduced within the sites, it will smoothen the process of WM*". Further, Safety Officer (B-SO) stated, "*in order to have a systematic WM system within the construction sites, specific time needs to be allocated for the labours to manage waste and during that period of time, management and supervisors within the site premises need to look into the WM activities of the labors*". Moreover, Project Manager of the Case E(E-PM) was in the opinion of, "*behavioural changes in labours can be done through seminars and workshops and national level restrictions needs to be available to control waste generation within the sites*". In addition to that, E-PM also emphasized, *"thinking patterns of the employees needs to be changed to have a proper WM system in the construction industry and national level approaches needs to be implemented to manage CDW in the Sri Lankan construction industry".* Furthermore, Safety Officer

(E-SO) said, "*people's perspective on WM in the industry needs to be changed by explaining the importance of WM and what sort of benefits they can achieve through WM*". Similarly, E-PM said *"though concept like value engineering is available, there is a practical issue on the usability of such concept in the industry. Most of the people are unaware about the benefits of value engineering. Therefore, minimum cost and minimum wastage is given with poor attention. Same practice is continued for a long period of time and they are reluctant to think out of the box*". Moreover, G-SO said that in order to achieve ZW by eliminating CDW, labour behaviors needs to be changed.

- **Proper housekeeping practices, preplanning and waste collector allocation**

According to the collected data from the data collection, one of the respondent of case A stated "*for proper WM within the site, waste collectors need to come site on specific time intervals. Thus, it will help to manage waste on time and also proper WM practices will be motivated in the labours also*" (A-LA). Moreover, respondents D- SE and D- SO said, "*before starting the construction, everything needs to be planned. So it will help to manage waste generation from the initial stage and the excess materials can be used for the alternative purposes without any wastages*". Further, G-SO said, *"if specific recyclers are available to manage CDW, then it is good for the environment as well as to the construction site as well. Therefore, if concept like ZW is applied in the construction industry, it will bring positive impacts*". In addition to that, Site Engineer of Case H (H-SE) said that through proper coordination in the material procurement stage, material mismatching issues can be solved.

- **Proper supervision and WM practices**

To manage the generated waste, supervision of the management and WM team is important. Respondents of Case B, B-PE explained that involvement of management team is vital to achieve the ultimate aim of ZW in the construction industry. Management needs to involve in the WM process. So with their experience, they can guide the workers in the construction sites where to use the remaining products before they are being disposed. In addition to that, D-LA stated that, when a concept like ZW is implemented within the site, then the working environment is very pleasant which will ultimately motivate the workers to carry their work in more systematic manner by avoiding waste generation. Further, F-PE said that management needs to motivate the employees for WM by giving incentives. Furthermore, F-SO emphasized that when a WM team is available in the site, it will motivate the systematics CDW management. Moreover, G-SO stated that if the employees are provided with WM targets then employees will control the material usage for unnecessary activities and waste generation can be controlled.

- **Implementation of regulations and policies in the organization**

Another solution provided by the respondent was, implementation of regulations and policies to manage CDW in the organizational level. Respondent B-PE said that when policies are implemented within the organization, then it helps to have a systematic WM within the organization. Furthermore, D-SO stated that ZW management targets and objectives need to be established in the organization. D-SO also stressed, "when the targets are given, employees are trying to achieve them. Then ultimately it will lead to achieve ZW in the sites". In addition to that, C-PM said that in order to achieve green certificates there are some projects which are looking into ways to minimize waste. Therefore, in order to achieve those certificates, through the budgets of the projects funds are allocated for WM. Hence, in such projects ZW can be achieved and those practices can ultimately have followed in other projects in the industry. Further, Site Engineer (C-SE) stated, "*through the implementation of ZW concept maximum resource usage take place*".

- **Introduction of new technologies, resources and facilities to manage CDW**

Safety officer of Case A(A-SO) stated, "*due to the dynamic nature in the construction sites, achieving hundred percentages in ZW will be difficult. But strategies like implementation of fine systems, asking subcontractors to use the formwork system from their budget as they will look into ways to reduce the wastages*(A-SO)". Further, he(A-SO) also said, "*if a recycling plant is implemented within the site, then it will enable recycling within the site itself*". Further, in Case B, respondent B-PE said, *"if a system is being established, then ZW can be achieved. As an example, through concrete* *waste, paving blocks are being prepared. Likewise, if there is a proper system to prepare bi products, it will help construction industry to achieve ZW".* Similarly, interviewees of Case B highlighted that, there are some issues in achieving ZW concept practically. Though practical issues are available, if proper practice and the proper resources are available to do the WM, ZW can be achieved. Moreover, D-SE stated that, facilities for waste storage and transportation need to be provided. Further, D-SO said that time needs to be allocated to carry out WM activities within the construction sites. According to the findings of Case F, respondent F-SO said that in order to apply the ZW concept, focus needs to be given towards systematic transportation and storage needs as it will reduce the waste generation. Similarly, in Case G the Site Engineer (G-SE) stated, "*it is necessary to produce bi-products from waste materials to achieve ZW concept in Sri Lankan construction industry. If the industry produces different types of alternatives and if there is adequate amount of technology, then construction industry can achieve ZW*".

4.10.2. National level suggestions

This section discusses the suggestions provided by the respondents to overcome from the identified barriers in the national level.

- **Implementation of national level standards, regulations and policies**

To manage the generated waste in the construction industry, it is vital to have properly defined standards, regulations and policies. Project Manager of Case C (C-PM) emphasized, "*regulations need to be implemented by focusing on the construction industry and there should be competency certificates like British Construction Skill Certification Scheme. If such certificates are implemented in Sri Lankan construction industry also, it will become the passion in the industry*". In addition to that, Project Manager of Case E (E-PM) stated that CDW management needs to be identified as a requirement of the contactors and if the contractors are given a recognition or a reward then it will ultimately make the contractors to look into CDW management. Further, E-PM also stressed that through documentation, if WM is highlighted as a path way in achieving the grading in CIDA like CS1, CS2, industry will focus more towards the

WM practices. Furthermore, E-PM concluded his idea on WM stating, "*Waste against money and time".* So, if concept like ZW is developed, competiveness and productive outputs can be produced in the construction industry and proper regulations and policies needs to be implemented by the government.

4.11. Development and Validation of the Framework

This section discusses the development and validation of the proposed framework to achieve the ultimate aim of ZW in the construction industry through the data collection and validation.

4.11.1. Development of the framework

Based on the literature findings, main criteria were identified and conceptual framework was developed. Then with the case study findings, conceptual framework was enhanced and developed the proposed framework. Out of the identified CDW management strategies through the literature findings, ZW concept was identified as the ideal strategy to eliminated CDW from the construction industry. In order to eliminate the waste, at first current CDW management procedure was identified. Then in order to achieve the ZW concept in the construction industry, enablers, barriers, and suggestions were identified. Finally, those identified data were presented under the subsections of organizational and national level under the enablers, barriers and suggestions criteria. When all these identified data are followed in a construction site, they can eliminate the CDW and can achieve the ZW.

4.11.2. Validation of the framework

Developed framework was validated through five experts those who are specialized in the fields of construction and WM. Profile of the experts those who were interviewed are shown in Table 4.6.

Table 4.6: Profile of the experts

Respondent	Designation	Years of experience
E-PD	Project Director	40
E-SO	Safety Officer	15
E-PM1	Project Manager	26
E-SE	Site Engineer	16
E-PM2	Project Manager	20

In order to validate the framework, semi structured interviews were carried out with the five (05) experts. In the process of validation, interviewees were asked to rate the framework under the criteria of understanding level of the framework, clarity of the information provided, overall content of the framework and recommendation of the proposed framework to achieve ZW in the construction industry. Respondents were asked to rank the criteria in a five point Likert scale of very high, high, moderate, low and very low. Feedbacks received are shown in Table 4.7.

Table 4.7 : Feedback on proposed framework validation

Criteria	Expert Respondents				
	E-PD	E-SO	E-PM1	E-SE	E-PM2
Understanding level of the framework	Very High	Very High	Very High	High	Very High
Clarity of the information provided	Very High	High	Very High	High	High
Overall content of the framework	High	Very High	Very High	Moderate	Very High
Recommendation of the proposed framework to achieve ZW in the construction industry	Very High	Very High	High	Very High	High

Feedback received for each criteria can further elaborate in graphical representation as shown in Figures 4.12, 4.13, 4.14 and 4.15

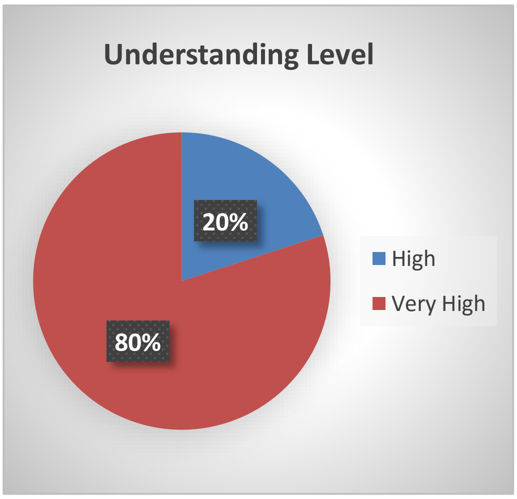


Figure 4.12 : Understanding level

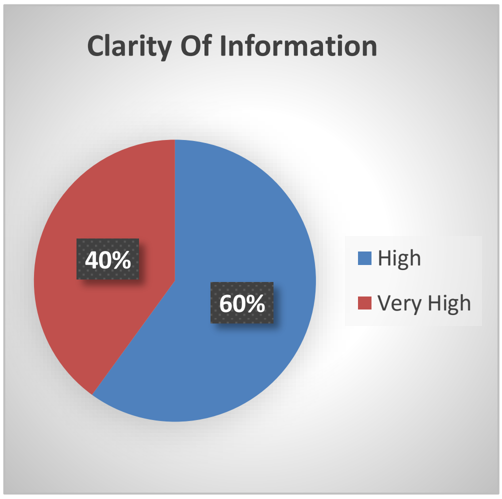


Figure 4.13 : Clarity of information

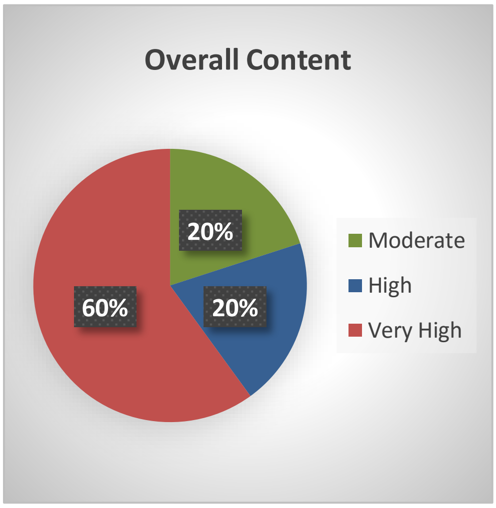


Figure 4.14 : Overall content

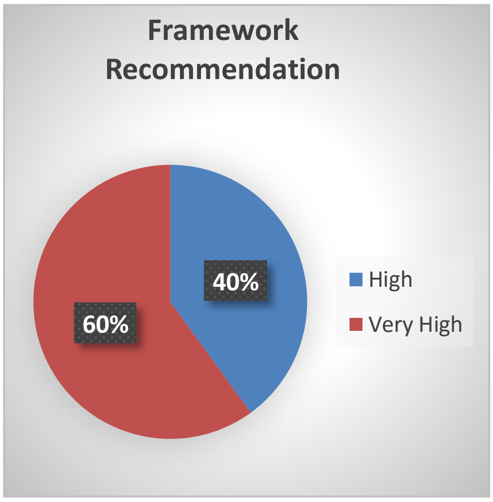


Figure 4.15 : Framework recommendation

In addition to the ratings, interviwees were asked with two open ended questions on additional information that needs to be included in the proposed framework and suggestions to improve the overall framework. Respondent E-SE stated that, "*its better to reword the findings like 'labour attitutude' in the barriers section as 'poor employee attitude' as it helps to get the accurate idea of the finding to who ever refer this proposed framework as a guideline"*. These comments were addressed and proposed framework was redeveloped as presented in Figure 4.16.

4.14. Summary

This chapter presented the case study findings of eight (08) cases and detail description of the cases were provided in the beginning of the chapter. Through the case studies, types of CDW materials in Sri Lankan construction industry were identified along with the origins and causes for CDW generation. Further, current WM procedure of the construction sites was identified 1st objective of the study was achieved. Moreover, CDW management strategies, enablers, barriers and suggestions to implement ZW concept in the construction industry were identified and objective two (02) and (03) were achieved respectively. Similarly, importance of ZW concept to the construction industry were discussed. All the findings were brought into one figure and framework was developed to achieve the fourth objective. Framework was validated from five (05) experts and finally a discussion was carried out to compare the existing literate findings and the case study findings.

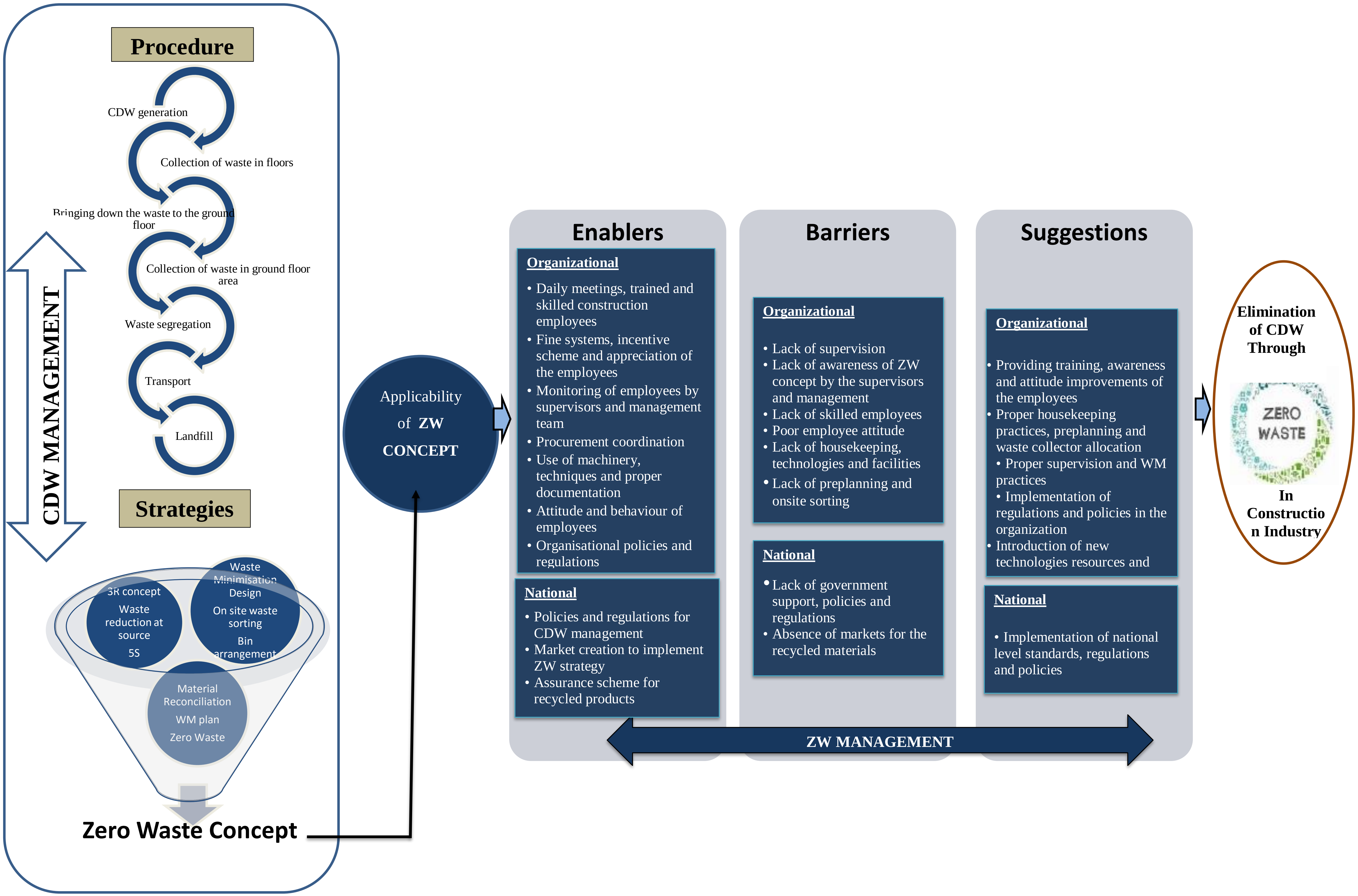


Figure 4.16 : Framework to Eliminate CDW Through ZW in Construction Industry

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

Summary of the literature findings, case study findings, contibution to the knowledge through the study and recommendations for industry practioners and for academic research are elaborated in this chapter. In additon to that, this chapter shows how research objectives were acheived in the study.

5.2. Conclusions

Due to the dynamic nature and rapid growth in construction activities, huge amount of CDW gets generated from the construction industry. Thus, attention needs to be paid for the CDW management in the construction industry. When it comes to the Sri Lankan construction industry, plywood, concrete, cement, steel offcuts, blocks, bricks, sand, soil, wood, polythene, cardboard, plastic, paper, aggregates, tile offcuts, concrete nails, MEP waste, wire nails, welding rods, tool wastage, and food wastage were identified as the CDW. Furthermore, these CDW gets generated due to design changes, transport issues, human mistakes, poor quality of works, client changes, mismatches in required materials, lack in labour skills, weather conditions, end of product life, negligence, material handling methods and changes done by the architects and engineers during the construction. Thus, to manage CDW different strategies such as on site waste sorting, bin arrangement, 3R concept, 5S, material reconciliation, and waste management plan are being followed to eliminate CDW and to achieve ZW concept in the construction industry (refer to section 4.7 and section 4.7.1). Hence, this study focused on the applicability of ZW concept to the Sri Lankan construction industry. With the achievement of four (04) objectives in the study, ultimate goal of the study was accomplished.

5.2.1. Objective One - Review the concepts of Construction and Demolition waste (CDW), Zero Waste (ZW) and current Construction and Demolition waste (CDW) management in the construction industry

As the first objective of the study, CDW concept and ZW concept was reviewed through literature findings. Different authors have defined CDW in different ways (refer to section 2.3). As a common definition, CDW can be defined as the waste materials that get generated from the new construction, repair, renovation, and through demolition of buildings. Further, when it comes to ZW, it is defined as the elimination of waste through the supply chain by making the supply chain a closed loop system (refer to section 2.11). Moreover, current CDW management in the construction industry starts with CDW generation, collection of waste in floors of the building, bringing down the waste through garbage chute or through a basket attached to a hoist, collection of waste in the ground floor, waste segregation, transport and landfill. Thus, first objective of the study was accomplished.

5.2.2. Objective Two - Examine enablers and barriers to apply Zero Waste (ZW) concept in Sri Lankan construction industry

Through the case study findings, to apply ZW concept to the Sri Lankan construction industry enablers and barriers were identified under the criteria of organizational level and national level. Before the identification of enablers and barriers to implement ZW concept, strategies that lead to the ZW implementation were identified (Refer to Table 4.5). As the organizational level enablers, daily meetings, trained and skilled construction employees, fine systems, incentive scheme and appreciation of the employees, monitoring of the employees by the supervisors and management team, procurement coordination, use of machinery, techniques and proper documentation, attitude and behavior of employees, organizational policies and regulations, and WM targets and housekeeping practices were identified. Further, under national level, enablers such as policies and regulations for CDW management, market creation to implement ZW strategy and assurance scheme for recycled products were identified. When it comes to the barriers to apply ZW concept under organizational level criteria, barriers such as lack of supervision, lack of awareness of ZW concept by the supervisors and management, lack of skilled employees, poor employee attitude, lack of housekeeping, technologies and facilities and lack of preplanning and onsite sorting were identified. Furthermore, as the national level barriers, lack of government support, policies, regulations, and absence of markets for recycled products were identified. Moreover, out of the identified enablers in the organizational and national level, in order to achieve the zero waste concept daily meetings, trained and skilled construction employees, fine systems, incentive scheme and appreciation of the employees, monitoring of the employees by the supervisors and management team, and procurement coordination were identified as the key enablers while lack of supervision, lack of awareness of ZW concept by the supervisors and management, lack of skilled employees, poor employee attitude, lack of housekeeping, technologies and facilities were identified as the key barriers to implement ZW in the construction industry. Hence, second objective was achieved as thus.

5.2.3. Objective Three- Propose suitable suggestions to minimize the identified barriers

To achieve the third objective, suggestions were provided by the interviewees to overcome the barriers in implementing ZW concept. Suggestions were provided under the criteria of organizational and national level. As per the respondents, organizational suggestions were to provide training, awareness and attitude improvements of employees, proper housekeeping practices, preplanning and waste collector allocation, proper supervision and WM practices, implementation of regulations and policies in the organization, and introduction of new technologies resources and facilities to manage CDW. Similarly, implementation of national level standards, regulations and policies were identified as the national level suggestions to implement ZW concept in the Sri Lankan construction industry. Moreover, out of the identified suggestions provide training, awareness and attitude improvements of employees, proper housekeeping practices, preplanning and waste collector allocation, proper supervision and WM practices, implementation of regulations and policies in the organization were identified as the key suggestions to overcome from the identified barriers. Therefore, third objective was achieved as thus.

5.2.4. Objective Four - Develop a framework to apply the Zero Waste (ZW) concept in Sri Lankan construction industry.

Fourth objective, which is the final objective of the study was achieved by developing a framework to apply ZW concept in the Sri Lankan construction industry. All key findings were brought into one place and a framework was developed.

Therefore, ultimate aim of the study was achieved with the accomplishment of four objectives as described above.

5.3. Recommendations

Based on the research findings, following recommendations are made to implement ZW concept in the construction industry.

1. Collaboration with multi- national high profile projects, as those projects look into sustainable practices throughout the construction project.
2. National level policies need to be implemented to manage the CDW and landfilling of CDW needs to be controlled through adequate infrastructure and recycling facilities.
3. CDW needs to be pre-planned from the designing stage and has to be managed by following strategies like 3R concept, waste mapping, and material reconciliation.

5.4. Contribution to Knowledge

This research study contributes to the knowledge on application of ZW concept to the Sri Lankan construction sector. Outcomes of the research study can be shown as follows.

1. Identification of CDW materials and current CDW management practice in the Sri Lankan construction industry.
2. Identification of enablers and barriers to implement ZW in the Sri Lankan construction industry in terms of organizational and national level.
3. Key strategies that enables ZW in the construction industry of Sri Lanka were identified.

4. Framework was developed to apply ZW concept to the Sri Lankan construction industry.

5.5. Contribution to Industry Practitioners

In order to implement zero waste concept in the construction industry, industry practioners can follow various approaches. Key recommendations to the practitioners in the industry can be highlighted as below.

1. Developing a direct relationship with end disposer of the product to evaluate the final disposal activities.
2. Evaluation of waste handling processes to eliminate waste disposal to landfills.
3. Development of WM maps to identify the points of wastages.

5.6. Further Research

Though the objectives of this study is achieved further developments for this research can be carried out as shown below.

1. Investigation of national level contribution to adopt ZW Concept in Sri Lankan context.
2. Exploring the opportunities to apply ZW concept for other industrial contexts like apparel industry in Sri Lanka.

5.6. Limitations

As the study focused on the applicability of ZW concept to the constrction industry there were some key limitations of the study as shown below.

1. Cases are limited to ongoing construction sites who's completion stage is between 30%- 60%
2. Cases were selected from the CS2 (grade) under building construction category of CIDA
3. Cases are limited to Colombo district construction sites

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APPENDIX A: Interview Guideline

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……………………….

……………………….

Dear Sir/ Madam,

<u>Questionnaire for the Thesis on "Applicability of ZW Concept to the Sri Lankan Construction Industry"</u>

I am a Research Scholar in Department of Building Economics, University of Moratuwa and currently reading for the MSc by Research. I am carrying out a research on the above topic and attached questionnaire is used to identify the applicability of ZW concept to the construction industry.

Please be kind enough to spend your valuable time to fill the questionnaire that is attached herewith. I assure you, all the collected data will be used for research purpose only. Confidentiality will be maintained throughout the research.

I would like to express my sincere gratitude for your valuable time and consideration in providing data for the research.

Thank You.

Yours faithful,

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Section A – Background Information

Project	…………………………………………
Cost of the project	…………………………………………
Duration of the project	…………………………………………
Location	…………………………………………
Name(Optional)	…………………………………………
Designation	…………………………………………
Number of years of experience	…………………………………………
Date	…………………………………………

Section B – Current Waste Management (WM) Practice

1) What are the main types of Construction & Demolition Waste (CDW) materials generated in your site and what are the origins of their generation?
2) What is the current WM procedure of your site?
3) Please explain the strategies used in your site to manage waste?
4) What are the steps that you have taken to reuse and recycle the generated waste in your site?

Section C - Enablers, Challengers and Suggestions to Implement ZW

5) What is your idea about ZW concept?
6) What are the factors that motivate ZW in your site?
7) What are the factors that demotivate ZW in your site?
8) In your opinion, what are the ways to overcome the identified waste demotivating factors?

Thank You for Your Contribution.

Section A – Background Information

Project	Housing Project
Cost of the project	1.89 Bil
Duration of the project	24 Months
Location	Nawala
Name(Optional)	
Designation	Project Manager
Number of years of experience	18 years
Date	05.12.2018

Section B – Current WM Practice

1) What are the main types of CDW materials generated in your site and what are the origins of their generation?

In the initial stage of the project there is demolition. It is because, the selected site area is a halfway through abandoned project. With the time management, there are some structural issues in the existing structure. So in the project at the initial stage there were Concrete demolition and rebar demolition. Other than that in general there are waste like,

Concrete, rebar, cement, plywood, 2x2, wire nails, concrete nails, welding rods, cement blocks, sand, tool wastages like shovels, wheel barrows, drills. When it comes to origins of waste generation there are number of methods. First one is based on design. When we take steel bars, in the market we can get bars in the length of 6m and 12m. If not, by preplanning the length of the bar, that is to a specific length or to a specific decimal point which is a difficult task. But if we specify them, that for a specific work, if we need 7.1m bar, then we need to at least make an order of 20 tons at least. If not, we need to go for 12m length bar for the construction activities which will ultimately create a huge waste from the bar. In order to reuse, we need to preplan to which part we can use the remaining part. For that, cutting wizard needs to be run to check the appropriate place where the remaining bar piece to be used.

Other thing is due to adoptability of workplace. That means nature of work place. Furthermore, as a known waste. Known waste is the waste that we are aware of generation. Moreover, due transport issues, material handling issues, and due to the negelence waste get generated

2) What is the current WM procedure of your site?

All collected debris, in a floor is collected to the corner of the floor corridor. Then through a garbage chute all the waste is sent to the basement. The garbage chute is made out by welding barrels after removing the top and bottom part of the barrel. Once they are collected in the basement, they are used for the fillings in the site. Remaining will be taken by a 3rd party for landfilling. Waste that collected in floors are sent to the waste collection yard of the site every two weeks' time. In a floor there are 16 houses.

3) Please explain the strategies used in your site to manage waste?

- *Bin arrangement*
- *Onsite waste sorting*
- *Reduce*
- *Reuse*
- *Recycle*

4) What are the steps that you have taken to reuse and recycle the generated waste in your site?

- *Recycle : Brick and concrete waste is used as an alternative to backfilling. They are being used as a by product. Debris are removed and used as a backfilling*
- *Reduce : Monthly material reconciliation.*
- *Reuse : After sewing, brick is used as an alternative to sand.*
  Plywood waste is incinerated within the site
  Steel/ Aluminum/ Plastic/ General metals are given to resellers. To reduce the generation of these material reconciliation is followed.
  Offcuts are used for dowel bars, lintels, stiffener beams and to cover slabs

At first through identification, materials are quantified. When doing the quantification, as an example, when purchasing steel, they are purchased to an offcut length. In order to purchase like that, bulk amount needs to be purchased. There is a bar diameter range from 8mm to 25mm.So from each bar, it is difficult to purchase an exact amount. If we take the 8mm bar, it is a small one. So bars as such are difficult to purchase in *offcut lengths. In cases as such we need to purchase the full bar and cut into the required amount. If we are going to ZW the remaining offcuts from the 8mm bar, it needs to be preplanned and needs to be followed a long process with the involvement of huge amount of labours. When it comes to cement for a specific house in the site, we are aware of the amount of cement that is being used for a single unit. So while the construction goes on, we can monitor the number of bags that are being used for a specific house in the project and we can monitor why an excess was used. With the material reconciliation we plan everything and we can justify all the material usage.*

Waste generated within the site are used for the backfilling in the site. Most of the time, there are debris from cement mortar and bricks. In the construction process, English bond is used and it creates brick waste. In order to reduce the brick wastage, currently we have asked the manufacturers to prepare half size blocks so that it helps to reduce the brick wastage. Currently it is not practiced in the site. We are in the process of ordering the blocks. In the current situation, brick waste that get generated are used for backfilling and sometimes the remaining bricks are crushed and used instead of sand after sewing.

Section C - Enablers, Challengers and Suggestions to Implement ZW

5) What is your idea about ZW concept?

ZW can be found in developed countries. It can be adopted in Sri Lanka. Before adopting it to Sri Lanka, we need to check whether we can adopt such concept or not. We need to check whether the culture is available or not in the country. Trend needs to be set in the industry. There is knowledge lack in the employees. Other thing is poor rethinking patterns of the people. Employees are not thinking of ways to do a specific work through alternative methods. Though concept like value engineering is available, there is a practical issue on the usability of such concept in the industry. Most of the people in the industry are unaware about the benefits of value engineering. Therefore, minimum cost and minimum wastage is given with poor attention. Same practice is continued for a long period of time and they are reluctant to think out of the box. Other thing is, industry people are not adoptive to the ZW objective. Scope of production is always changing and there is an issue in the additivity of the industry people.

ZW helps to achieve number of benefits. It is all about "Waste against money and time". If such concepts are developed competiveness and productive outputs can be produced.

6) What are the factors that motivate ZW in your site?
   - *To collect nails, depending on the amount labourers collect, money value is given to the collected amount of nail waste. This has encouraged labourers to collect the nails and it also help to enhance the safety of the site.*
   - *Management guidance*
   - *When issuing the materials, it is being checked and in the deduction it can be checked if a specific labourer has used excessive amount*

7) What are the factors that demotivate ZW in your site?
   - *Human behavior*
   - *Lack of knowledge*

8) In your opinion, what are the ways to overcome the identified waste demotivating factors?
   - *Behavioural changes can be done through seminars and workshops.*
   - *National level restrictions need to be available. Regulations need to be implemented focused on the construction industry.*
   - *There should be competency certificates like British Construction Skill Certification Scheme. If such things are implemented it will become the passion in the industry.*
   - *Thinking patterns of the employees needs to be changes.*
   - *National level approaches need to be implemented.*

Thank You for Your Contribution.

APPENDIX B : Framework Validation

……………………….

……………………….

……………………….

Dear Sir/ Madam,

<u>Framework Validation for the Thesis on "Applicability of ZW Concept to the Sri Lankan Construction Industry"</u>

I am a Research Scholar in Department of Building Economics, University of Moratuwa and currently reading for the MSc by Research. I am carrying out a research on the above topic and attached questionnaire is used to identify the applicability of ZW concept to the construction industry.

Please be kind enough to spend your valuable time to fill the questionnaire that is attached herewith. I assure you, all the collected data will be used for research purpose only. Confidentiality will be maintained throughout the research.

I would like to express my sincere gratitude for your valuable time and consideration in providing data for the research.

Thank You.

Yours faithful,

………………….

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Section A – Background Information

Name (Optional) ……………………………………………………………
Organization ………..…..………..………………………………………
Designation …..………………………………………………………
Number of years of experience ………………………………………………………….
Date …………………………………………………………..

Section B – Validation of Framework

1. How would you rate the applicability of the framework to eliminate Construction & Demolition (C&D) waste from the construction industry through the implementation of ZW concept? Please use the given Likert Scale and tick (√) the relevant box.

Very High 5 High 4 Moderate 3

Low 2 Very Low 1

Criteria	**Very Low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very High 5**
Understanding level of the framework					
Clarity of the information provided					
Overall content of the framework					
Recommendation of the framework to achieve ZW in the construction industry through the proposed framework					

2. Any additional things to be added to the proposed framework?

…………………………………………………………………………………………

…………………………………………………………………………………………

3. Any suggestions to improve the overall framework?

…………………………………………………………………………………………

…………………………………………………………………………………………

Thank You for Your Contribution

Section A – Background Information

Name (Optional) ………………………………………………………
Organization ………………………………………………………
Designation Project Director
Number of years of experience 40 years
Date 21.03.2019

Section B – Validation of Framework

1. How would you rate the applicability of the framework to eliminate Construction & Demolition (C&D) waste from the construction industry through the implementation of ZW concept? Please use the given Likert Scale and tick (√) the relevant box.

Very High 5 High 4 Moderate 3

Low 2 Very Low 1

Criteria	**Very Low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very High 5**
Understanding level of the framework					√
Clarity of the information provided					√
Overall content of the framework				√	
Recommendation of the framework to achieve ZW in the construction industry through the proposed framework					√

2. Any additional things to be added to the proposed framework?

If the findings on enablers, barriers and suggestions are subcategorised, it is easy to identify the presented data easily

3. Any suggestions to improve the overall framework?

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……………………………………………………………………………………

Thank You for Your Contribution