The Relationship between Construction and Demolition Waste Minimisation and Sustainable Construction

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Abstract. Increasing urbanisation has become a global environmental concern, as half of the extracted natural resources are used for building construction. In addition, the factual claims made on socio-economic benefits achieved through Construction & Demolition (C&D) waste minimisation approaches are yet to be fully explored. Further, the majority's vested interest has neglected the life cycle approach for waste minimisation. Hence, this research provides a review of literature on C&D waste minimisation, considering cradle to cradle thinking to advocate Sustainable Construction. This research highlighted the state of the art of C&D waste minimisation approaches worldwide, including factors influencing waste generation, challenges in waste minimisation, and provides a conceptual waste minimisation framework. The framework identified key waste minimisation challenges over the project's life cycle. Some of the challenges are: poor building standards; lack of waste sorting and limited secondary market. Subsequently, the framework provides remedy(ies), including but not limited to the use of design to dissemble approach, Waste management and Resource recovery plan, use of multiple bins and setting technical standards for recycled materials. The waste minimisation framework attempts to promote a circular economy in building construction and help academics and industry practitioners to herald a new era of research in sustainable construction. Further, this research is an attempt to contribute to United Nations's Sustainable Development Goal 12 that ensures sustainable consumption of resources by achieving the Target 12.5 (substantially reduce waste generation through prevention, reduction, recycling and reuse).

Keywords: C&D Waste, C&D Waste Minimisation Approaches, Waste Minimisation Framework.

1 Introduction

The increase in infrastructure demand puts the construction sector at the core of the global economy. Construction accounted directly for 6% of global Gross Domestic Product (World Economic Forum, 2017) with the industry being one of the largest in most countries and predicted to grow. The global construction output is forecasted to grow from USD 10.7 trillion in 2020 to 15.2 trillion in 2030 (Oxford Economics,

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2021). The construction industry (CI) is an essential feature of any country's overall growth which often comes with concerns such as health and well-being of the community, natural resources consumption, waste, economic growth, and pollution (Presley & Meade, 2010). Social, economic and environmental concerns introduced the need for sustainability in construction (UNEP, 2018).

The definition of SC includes social, economic, and environmental aspects and is deemed a broad concept. This concept gives equal consideration to all aspects and maintains balance throughout the process of construction (UNEP, 2018) and are interdependent. For example, natural resources are extracted from nature for construction, providing employment and economic benefits (Vatalis et al., 2011). Figure 1 shows all three aspects and their interdependency on each other.

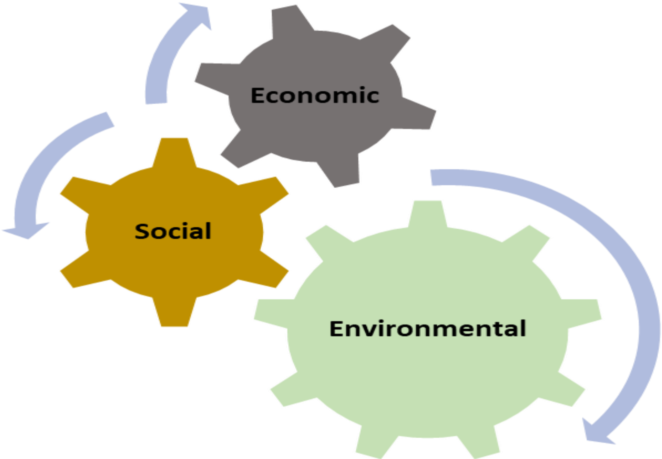

Fig.1. Sustainable Construction (Gan et al., 2015)

Applicatio of a life cycle approach in advocating SC to facilitate a circular economy has become a common interest for academics and practitioners in recent years.

The purpose of this research is to find out the state-of-the art of C&D waste, how it is minimise worldwide, understand waste minimisation challenges and opportunities, its contribution to SC; ultimately, to propose a waste minimisation framework considering the life cycle of a construction project to achieve SC. This aim is achieved through an extensive literature review of journal articles, conference papers, government publications (policies, regulations, etc.), and non-governing origination's published work.

2 The growing construction and demolition waste issue

Typically, C&D waste is defined as the leftover materials generated during the construction, refurbishment, repair, and demolition of any building (UNEP, 2015). However, the definition of C&D waste varies across the world. For example, countries such as New Zealand, Australia, and Germany consider soil excavated from contaminated land during land clearance as C&D waste (Brennan et al., 2014), while the USA and Netherlands do not consider excavated soil as a part of C&D waste (European Commission, 2016). Further, in the USA, debris generated due to natural disaster are not considered as a part of the C&D waste (USEPA, 2015). In contrast, countries like Lebanon and Sri Lanka include such debris in their C&D definition (Karunasena, 2012).

In 2000, C&D contributed 3 billion tonnes (BT) to waste generated worldwide (El-Haggar, 2007), and it was the beginning of the recognition of it as an environmental pollution issue. C&D waste has increased since the beginning of this century with, for example, Europe going from 450 million tonnes (MT) per annum in 2005 (Osmani, 2011) to 860 MT in 2010 (Eurostat, 2012) and 900 MT in 2020 (Wu et al., 2022). Similarly, China went from 100 MT at the beginning of this century to outstripping Europe's production in 2014, generating 1.13 BT of C&D waste and became the largest C&D waste generator in the world (USEPA, 2009; CIB, 2011; Wu et al., 2017). These quantities of waste put the environment in danger (CIB, 2011).

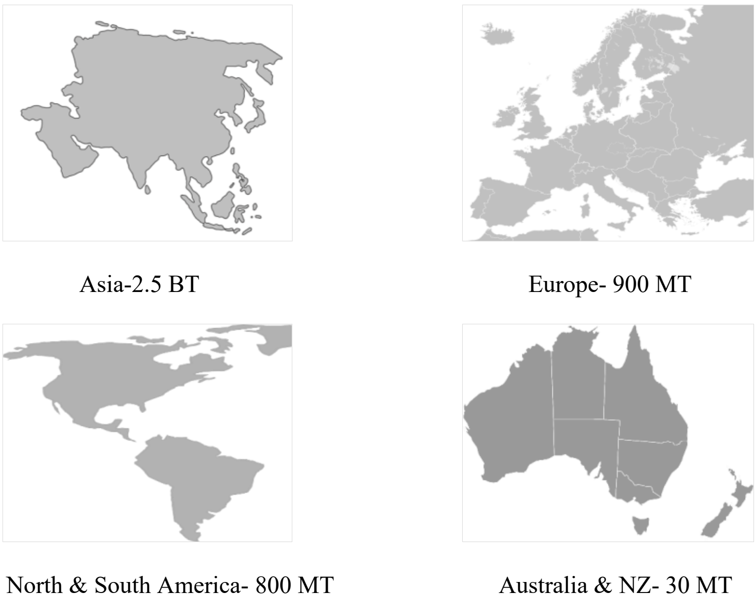

Fig.2. C&D waste in different regions (Wu et al., 2022)

In 2020, Worldwide, more than 10 BT of C&D waste was generated. With over 2.3 BT of C&D waste per year, China was the largest C&D waste producer (Wu et al., 2022). C&D waste produced in Europe was half of Asia and almost similar to North and South America (European Commission, 2020). The South Pacific region (Australia and NZ) combined generated 30 MT (Shooshtarian et al., 2020; MfE, 2021b).

3 C&D waste minimisation and its challenges

C&D waste minimisation is often guided by the need for a sustainable built environment and is a subset of waste management (Domingo & Luo, 2017). The different perspectives to define C&D waste minimisation are considered under two broad categories: i) at source; and ii) by recycling. On-site reuse, reuse and recovery are part of the recycling category (Begum et al., 2007; Gálvez-Martos et al., 2018; Ma et al., 2020). Some of the definitions of waste minimisation from both perspectives are listed in Table 1.

Table 1. Definitions of C&D waste minimisation

By Source	By Recycling	Reference
Design out, reduce or eliminate waste in the design process so there will be none to manage in further stages	Activity to replace consumption of new resources by recycling used ones	Gálvez-Martos et al., 2018
Eliminate waste production in design stage	Reuse or recycling materials to manage waste generated	Ma et al., 2020
Technique or task that reduces or eliminate the waste generation at the source, usually within a process	Recovery and/or reuse of waste generated during and/or after the process.	Begum et al., 2007

The benefits of waste minimisation depend upon how effectively the waste minimisation challenges are addressed. Table 2 overviews C&D waste minimisation challenges during different project stages.

Table 2. Challenges in C&D waste minimisation (Esa et al., 2017; Islam et al., 2019)

Pre-design	Design
Eco-labelling of materials Lack of innovation and motivation Early involvement of stakeholders	Material specification writing Change in scope and design Waste management plan
Construction	**Demolition**
Material storage and handling Prefabrication and standardisation Waste collection and sorting	Regular waste audits Lack of deconstruction Secondary market

The pre-design stage of a project produces a rough estimate of the project and approximate statistics on consumption of both renewable and non-renewable resources (Poon et al., 2004).

The design stage converts ideas into reality, resulting in precise and specific designs of buildings (Gupta et al., 2020). Lack of detailed specification of materials and poor quantity survey of such materials are some of the prime concerns for this stage. The construction stage deals with physical waste resulting from design waste. Construction work needs proper guidance on material storage and handling, which is often considered simple work but performed with poor standards (Esa et al., 2017). Buildings at their end of life are deconstructed or demolished, which result in demolition waste. Demolition projects often don't have a site-specific enivornment management plans to address issues such as contamination and handling of materials with hazardous substances (Ali et al., 2019). The waste audit covers some of the important factors such as type of building, demolition plans, and cost of demolition.

4 C&D waste minimisation approaches

Modern developments in C&D waste minimisation approaches happened in the last few decades (Domingo, 2011) and variety of instruments has been used since then by industry practitioners (Wu et al., 2019). Worldwide, the approaches are divided into three broad categories: waste management hierarchy; regulations and guidelines; and tools.

4.1 Waste Management Hierarchy

Waste can be generated at any stage (design to end of life) and hence needed more than one option to manage it which introduces waste minimisation or management using a 'Waste Management Hierarchy' (EU, 1975). The waste management hierarchy was the origin of waste minimisation and deemed as mature and commonplace for C&D waste.

All waste hierarchies follow a common pattern of steps with the aim of maximum environmental benefits and minimum waste generation. Figure 3 shows a generalised management hierarchy.

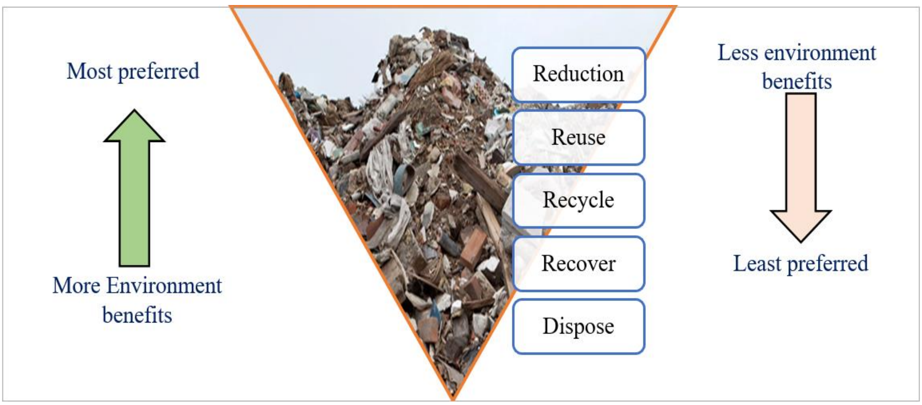

Fig.3. Waste management hierarchy (EU, 1975; UNEP, 2013)

4.2 Guidelines and regulations for C&D waste minimisation

The disposal of C&D waste to landfill was the best-known method to deal with it until the 1980s (UNEP, 2015). As the number of landfills increased worldwide, the negative impact on the environment due to heavy disposal of contaminated soil changed society's perception about landfilling the waste, which introduced need for waste handling and disposal guidelines and regulations (Huang et al., 2018). Table 3 shows the guidelines and regulations used around the world for C&D waste minimisation.

Table 3. Guidelines and regulations for C&D waste minimisation in different regions

Region	Country	Provision for waste minimisation	Regulatory tools
North America	USA	Effective procurement of resources	Waste Reduction Act, 1990
	Canada	Promotion of environmental responsibilities	Canada's Green Plan, 1990
South America	Brazil	Generators responsibilities from design to disposal	Waste Management Resolution (307/2002),
Europe	Europe	Technical guidance for selecting materials	Construction Product Regulations (305/2011)
	UK	A mandatory waste management plan	Site Waste Management Plan Regulations, 2008
Africa	South Africa	Guidelines on material selection and procurement	National Environmental Management Act, 1998
Asia	China	Optimise resource consumption to reduce off-cuts	Construction waste disposal specifications
	India	Ecological design standards for building materials	National Housing and Habitat Policy, 2007
	Japan	Guidelines for selecting construction materials	Ministry of the Environment, 2004
South Pacific	Australia	Sustainable procurement of building materials	Framework for material Procurement, 2007
	New Zealand	Sustainable management of resources	RMA, 1991

4.3 Tools for C&D waste minimisation

Different tools and approaches are used to minimise waste, predict quantities of waste, and forecast recyclable content. For example, a designing out waste tool for buildings) helps contractors identify opportunities to prevent waste, record design solutions and calculate their impact on waste (Gupta et al., 2020). Further, the Net Waste Tool focuses on environmental and commercial costs of waste and calculates the potential waste quantities throughout the project. It also predicts quantities of recyclable material and optimises its consumption (Akinade et al., 2018). Apart from these tools and approaches, several other tools have been used in different parts of the world to minimise C&D waste. Table 4 present some of the widely used tools.

Table 4. Tools for C&D waste minimisation

Tools	Remark	Reference
Lean Tools	Value Stream Mapping and Just in Time are commonly used to control inventory	Vinodh et al., 2011
Supply Chain Management	Controls inventory and creates a smooth flow of information which assists procurement of sustainable building materials.	Vrijhoef & Koskela, 2000
Building Information Modelling	Present a virtual copy of a project and expected physical issues before actual execution. Can be used effectively to design buildings for deconstruction	Moayeri, 2017
Linear Programming	Deals with a single objective function such as minimisation of waste. Output model gives optimised resource consumption	Maués et al., 2020
Vector Optimisation	Target multiple objective functions but is a supportive tool for managing projects.	Rudloff et al., 2017
Dynamic Programming	Future decisions based on the previous decisions. Substantial coding work required.	Zhou et al., 2013

5 Waste minimisation Framework

The review of literature on C&D waste minimisation, helped to develop a waste minimisation framework. It is built on the traditional practices of construction industry and its successful implementation depends on all the personnel (material manufacturer, supplier, contactors, clients, engineers, labours, public bodies, non-governing organizations). The framework identifies C&D waste minimisation challenges over the life cycle of building projects and offers remedial measures. Figure 4 shows the waste minimisation framework for C&D waste.

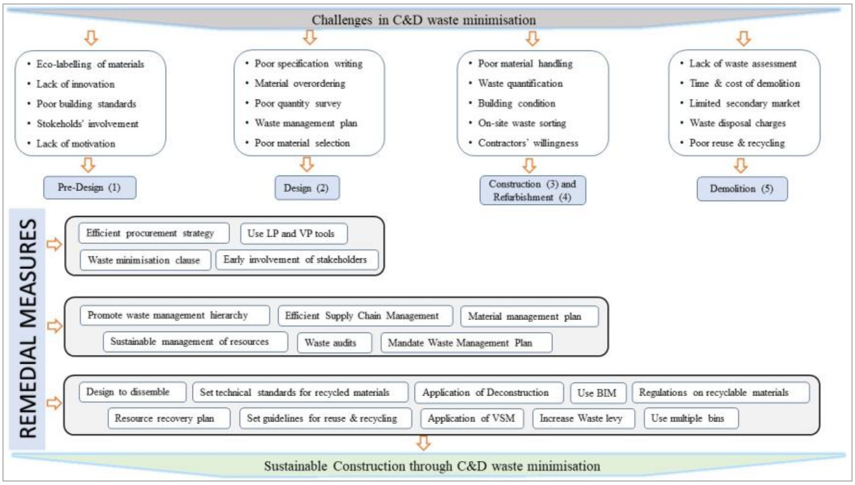

Fig.4. Waste minimisation framework

6 Conclusions

The profit-driven nature of CI continues to increase the infrastructure demand with sustainability concerns. Despite SC's well-developed definition and understanding, its current status globally, especially through C&D waste minimisation, is far from optimum. C&D waste is growing as an issue worldwide and becoming one of the greatest threats to SC. In addition, state-of-the-art waste minimisation approaches advocating SC throughout the lifecycle remain distant in promoting a circular economy.

C&D waste minimisation challenges occur during all project stages, i.e. pre-design, design, construction, refurbishment and demolition. Some of the key challenges are: poor building standards; lack of waste sorting and assessment, and limited secondary markets for recycled products. To counter the challenges, waste minimisation approaches gave remedies such as: waste management plan; use of BIM; guidelines for reuse and recycling, waste audits and an increase in the waste levy.

Combining waste minimisation challenges and approaches practiced worldwide resulted in a conceptual waste minimisation framework. This framework is built on a life cycle approach and is a comprehensive mechanism to demonstrates the direct relationship between C&D waste minimisation and SC. In addition, the findings of this framework add novelty to the growing body of literature on advocating SC through C&D waste minimisation. This research is an attempt to contribute to United Nations's Sustainable Development Goal 12 that ensures sustainable consumption of resources by achieving the Target 12.5 (substantially reduce waste generation through prevention, reduction, recycling and reuse).

The boundary of this paper offered a standalone perspective on C&D waste minimisation approaches and introduced a conceptual waste minimisation framework. This achievement calls for more studies in this field to integrate and streamline this framework. In addition, future study could focus on validating the waste minimisation framework through its implementation in different construction contexts.

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