LEC.505

From Waste to Resource: Enhancing Circularity in Construction through Aggregate Recycling and Soil Reuse

Emelye Gill

36526754

Lancaster University

Lancaster

LA1 4YQ

UK

Submitted September 2024

Supervisor Professor John Quinton

This Dissertation is submitted in partial fulfilment of the degree of

MSc Environmental Management

The work contained within this report is the result of my own investigations. All sections of the text and results which have been obtained from other work are fully referenced. I understand that plagiarism constitutes a breach of University regulations and will be dealt with accordingly.

*I do consent for this submission to be stored in electronic format for use in the LEC.505 archive and for sharing with future students, relevant funding bodies and external partners (*delete as appropriate)

Word count: 9946

Abstract

The construction industry consumes large volumes of raw materials and is one of the largest generators of waste, making it one of the least sustainable industries in the UK. The industry has significant potential for reducing its environmental impact and pressure for more sustainable practices from government, regulators and investors, is increasing. Minimising the use of natural resources and maximising the reuse of materials is essential to reduce waste generation and a new framework has emerged in recent years, the circular economy, which views waste as a resource. However, the construction sector has been slow to adopt this approach. This study investigates the barriers and opportunities to implementing a circular economy in the construction industry, with a focus on recycled aggregates and soil reuse. A primarily sociological approach, combining qualitative and quantitative methods, was employed. Data was collected through three focus group discussions involving 25 industry and government experts, followed by thematic analysis. The emerging themes (legislative, economic, technical and social) guided a review of secondary source stakeholder perspectives and relevant literature on waste recycling and reuse technologies. The findings of the three methods are discussed as a series of recommendations for implementing a circular economy in the construction industry and include (1) regulatory and legislative reform; (2) increased taxation and incentives; (3) improved certifications, specifications and material quality; (4) improved project planning and management; and (5) education, training and stakeholder engagement. Several challenges were identified which are currently hindering the implementation of a circular economy. However, by embracing the recommendations suggested in this study, the construction industry has the potential to successfully implement a circular economy and reduce its environmental impact.

Acknowledgements

I would like to thank Professor John Quinton for his ongoing support and supervision throughout this project. I also wish to extend a big thank you to Professor Jess Davies, Dr Mirian Calvo and the entire Soil Research Project team for their invaluable advice and for granting access to the focus group data. Thank you to Fox Brothers for proposing this project.

Finally, I am deeply thankful to my family and friends for their encouragement, with special thanks to my Mum. I could not have done it without you.

Contents

1 Introduction

Waste is a by-product of economic development, and the management of waste has both economic and environmental implications. The construction industry is a significant contributor to economic development, accounting for 13% of the global economy (Ajayi et al., 2016), and 6.2% (approximately £117 billion) of the UK's economic output (Panjwani, 2023). By its nature, construction is a large consumer of natural resources (Hossain et al., 2020), generating an estimated 30% of all global waste production (Ginga et al., 2020) and contributing 40% of global CO_2 emissions (Tafesse et al., 2022). With growing concerns over climate change, and the finite nature of natural resources, there is increasing pressure on the industry to reduce its environmental impact (Low et al., 2020).

The construction industry currently follows a Linear Economy (LE) framework, a straight-line approach of 'take, make, use, dispose' (Marino and Pariso, 2016). Many construction materials are designed for single use (Ginga et al., 2020), and traditional construction methods generate substantial amounts of waste during construction and demolition phases. Approximately 35% of global construction and demolition waste (CDW), and over half of UK CDW, is landfilled (Ghaffar et al., 2020). This waste has many adverse environmental effects, including water and soil contamination, environmental degradation and land deterioration (Crawford et al., 2017). It also negatively affects public health and can be a financial burden on both companies and governments (Park and Tucker, 2017). In contrast to the LE, the Circular Economy (CE) model has gained attention due to its consideration of waste as a useful resource, and its promotion of reducing, reusing, recycling and recovering materials (Ghaffar et al., 2020). While there are challenges involved in adopting sustainable construction methods, there are also many benefits (Hossain et al., 2020).

1.1 Construction and Demolition Waste Management

Sustainable waste management is essential for preserving natural resources, minimising environmental impacts and protecting public health (Umar et al., 2017). The construction process produces waste (e.g., mishandled and overordered supplies) (Ginga et al., 2020) but also includes material and debris from demolition and excavation works (Noor et al., 2020), with the majority of UK CDW being soil and mineral waste (Figure 1).

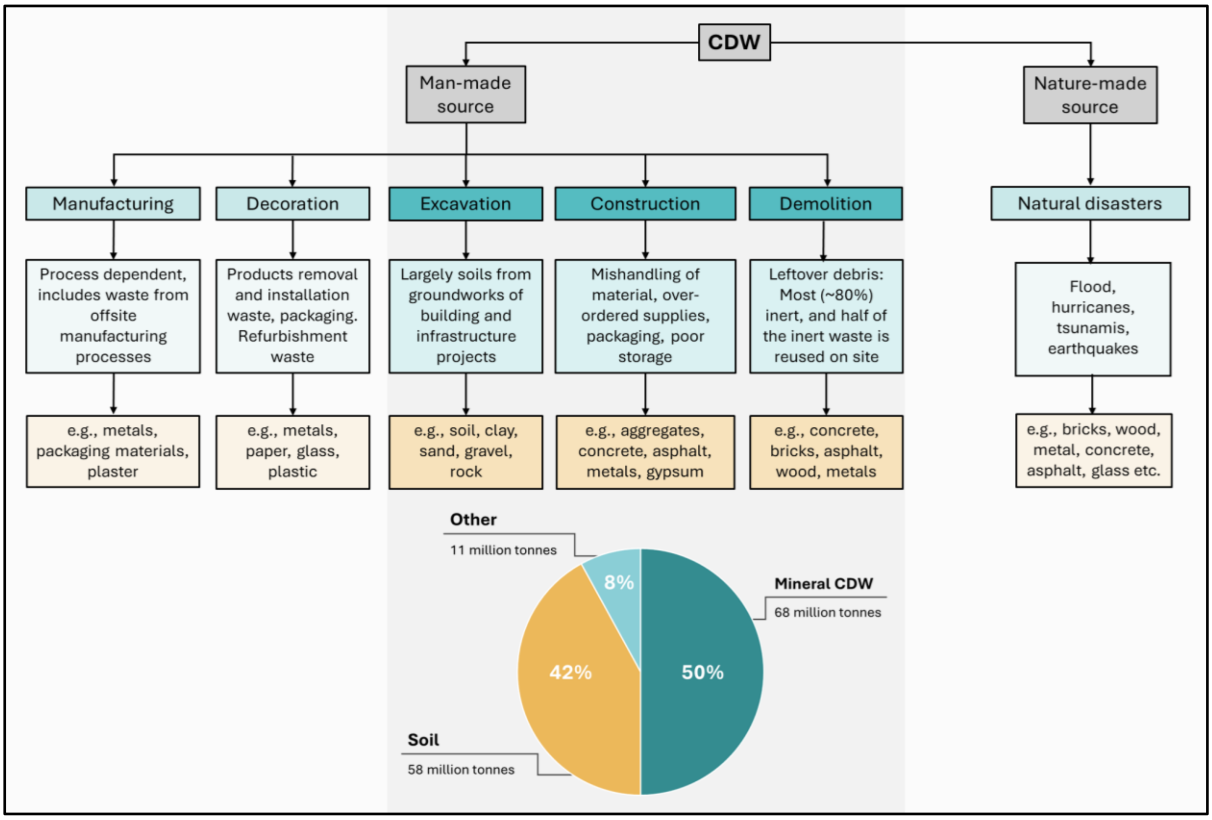

Figure 1: Sources of construction and demolition waste, highlighting the key waste streams discussed in this study. The pie chart illustrates the main sources of UK construction and demolition waste as percentages and also notes waste generated in tonnes (Figure designed by author using information sourced from Chen et al., 2021; Papamichael et al., 2023; Ginga et al., 2020; Construction Leadership Council, 2021; ICEC-MCM, 2023).

Technical Guidance WM3: Waste Classification (Environment Agency, 2021) contains two main waste categories: hazardous and non-hazardous (further subdivided into inert and non-inert) (Stelzer et al., 2023). What constitutes CDW varies across sources; for example, whilst 85% of CDW in the EU is concrete, ceramic and masonry (Soto-Paz et al., 2023), Defra declared that around 43% of UK CDW is soil (Defra, 2021). Definitions of CDW often exclude excavated waste (soil), and inconsistent reporting of classes of CDW impacts the effectiveness of waste management principles and priorities (Menegaki and Damigos, 2018).

Most CDW has a residual value (Peng et al., 2022), yet landfilling is still a dominant CDW management strategy, as it is an easy and inexpensive decision (Umar et al., 2017). Whilst government priorities are usually environmental, industry stakeholders are motivated by financial gains, and yet a 5% reduction in CDW can generate savings of £130 million in the UK construction industry (Ajayi et al., 2015). A number of fiscal measures, such as the UK Landfill Tax, exist to encourage the diversion of waste away from landfill (ICEC-MCM, 2023). However, the cost of landfilling material, especially excavated material, is such a cheap and convenient choice that it continues to be the most widely used method of handling waste. CDW management/polices appear ineffective as the reuse of CDW is often ignored, and current policy focuses upon landfill diversion (Ajayi and Oyedele, 2017).

Transitioning to a CE would have a number of benefits, ranging from social to economic to environmental. By narrowing, slowing, and closing resource loops (Ginga et al., 2020), the CE opens up new markets for reused and recycled CDW, providing other sources of income for businesses and reducing the environmental and social impacts of waste (Ibrahim, 2016). However, various legislative, economic and social barriers are discouraging the implementation of a CE in the UK construction industry (the "industry").

1.2 Aims and Objectives

The overall aim of this research is to highlight the barriers and opportunities to implementing a CE in the industry, with particular reference to recycled aggregates and soil reuse.

The research fulfils this aim through the following objectives:

1) Highlight deficiencies within current legislation which are discouraging circularity within the industry;

2) Use industry perspectives (from primary and secondary sources) to review the barriers impeding the recycling and reuse of CDW;
3) Provide recommendations to improve circularity in the industry, addressing both government and industry priorities.

1.3 Scope of Study

This study focuses on the recycling and reuse of CDW, specifically aggregates and soil, within the broader scope of sustainable waste management. This decision reflects the importance of these waste streams within CDW (Figure 1), and the financial impact of soil loss to landfill of around £1.5 billion per year (Soils in Planning and Construction Task Force, 2022). The decision to focus exclusively on recycling and reuse was informed by current legislative frameworks, the specific research objectives and the data collected. The exclusion of other waste management strategies is a purposeful narrowing of the study's focus, to offer a more detailed exploration of recycling and reuse in the industry.

1.4 Overview of Study

Background information provides the essential context needed to understand the research aim. The research methods, the approach to data collection and analyses, and the findings of the research will then be discussed. The results section will comprise: (1) primary stakeholder perspectives from the focus groups conducted, (2) secondary source stakeholder perspectives on the relevant themes identified, and (3) recent technological advancements within the industry, including discussions on the challenges limiting CDW recycling/reuse. The findings of the three methods will be discussed as a series of recommendations. Conclusions will be drawn, with recommendations made for future study.

2 Background

2.1 Legislative Overview

There are a number of existing UK policies and guidance documents that address CDW. Figure 2 outlines the key pieces of legislation, policy and guidance as of August 2024.

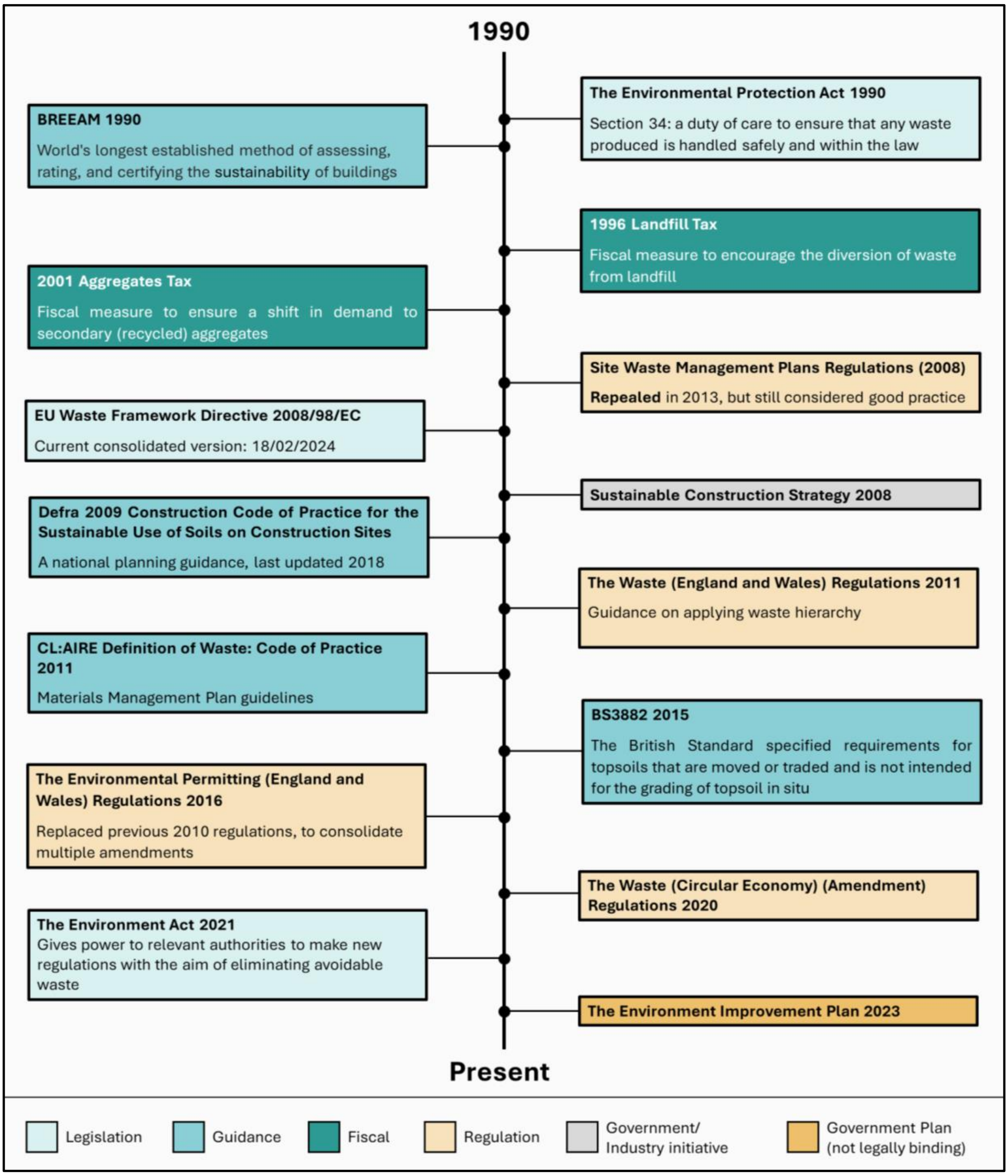

Figure 2: Key pieces of legislation, policy and guidance relating to construction and demolition waste (Figure designed by author using information sourced from BREEAM, 2024; BERR, 2008; CL:AIRE, 2011; Defra, 2009; Defra, 2013; Defra, 2021; Defra, 2023; Environment Act 2021; Gov.uk, 2024).

The **main framework** which regulates waste management is the EU Waste Framework Directive 2008/98/EC (WFD), which has been implemented in the UK through the Waste (England and Wales) Regulations 2011 (Ghaffar et al., 2020). The WFD introduced the waste hierarchy (the "hierarchy"), a "preferential order of waste treatment options which aims to reduce environmental impacts by prioritising prevention, reuse, recycling, and recovery over landfill" (Van Ewijk and Stegeman, 2016, p.123) (Figure 3). Higher levels of the hierarchy (i.e., prevention and reuse) place the onus to reduce waste on the companies that create it (Purchase et al., 2021). However, as regulation emphasises the 'practical feasibility' of the hierarchy (which includes disposal), the decision to dispose of CDW rather than reusing or recycling it often goes unchallenged (Van Ewijk and Stegeman, 2016; Rose and Stegemann, 2018).

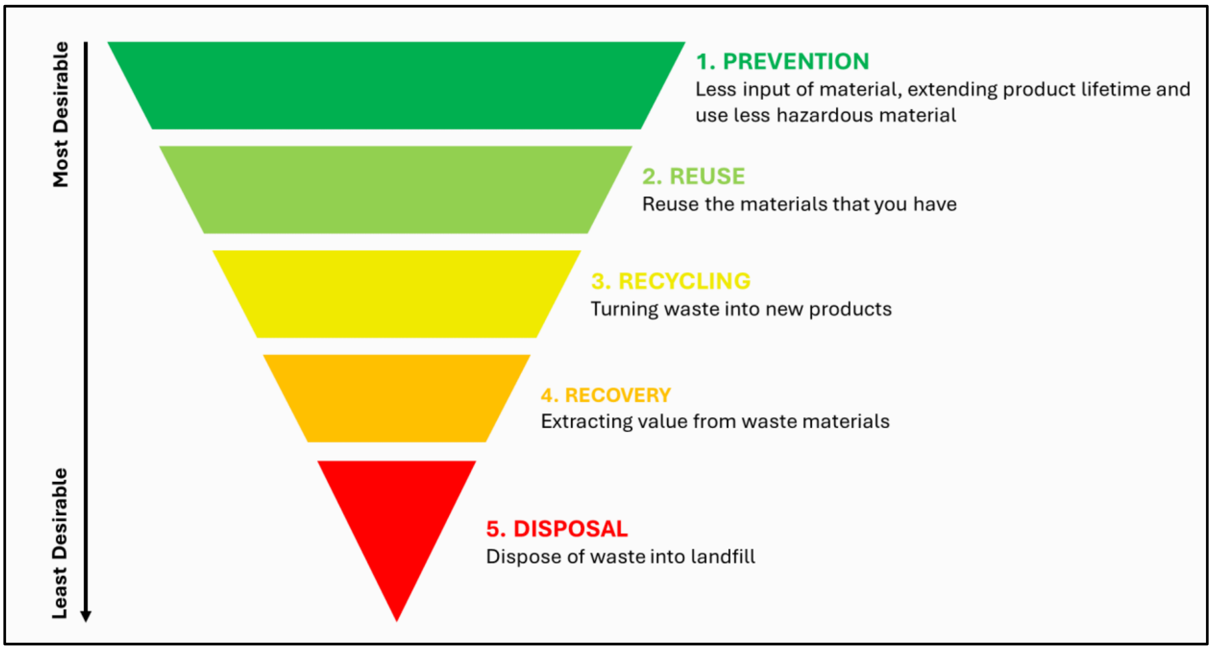

Figure 3: Waste hierarchy, ranking waste management options from most to least desirable (Figure designed by author using information sourced from Defra, 2011).

Guidance documents for the reuse of CDW include the CL:AIRE Definition of Waste: Code of Practice (DoW CoP), which outlines the process for the reuse of excavated CDW without permitting in England and Wales (Bardos et al., 2021), including the need for a Materials

Management Plan (MMP) for the reuse of soil. Defra published a 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' in 2009, which was to be revised in 2022 but to date has not been updated by the Government (Soils in Planning and Construction Task Force, 2022).

Standards include BS3882 for topsoil (British Standard), which sets out the requirements for classification and composition, and advises about handling, to ensure topsoil is not degraded during excavation, delivery or placement (Soils in Planning and Construction Task Force, 2022). **Certifications** include BREEAM which focuses on minimising waste in construction projects through effective planning, however, it is voluntary (BREEAM, 2024) and remains beyond the mandate of government guidelines (Umar et al., 2017).

2.2 Fiscal Measures

Industry is driven by financial gain, therefore fiscal policies are considered to be a suitable method of diverting CDW from landfill (Ajayi and Oyedele, 2017). The UK Landfill Tax was intended to encourage sustainable waste management by applying a cost to disposal, therefore shifting waste management up the hierarchy. However, the cost per tonne to landfill of uncontaminated soil has risen from only £2 per tonne in 1996, to £3.30 in 2024 (Martin and Scott, 2003; Gov.uk, 2024), a cheap and convenient choice for CDW management, undermining its original purpose. Similarly, to increase the reuse of aggregates the Government introduced the Aggregates Tax in 2001, at a rate of £1.60 per tonne of natural aggregates (Ajayi and Oyedele, 2017). As the current rate is only £2.03 per tonne, it does not function as a motivator in encouraging the use of recycled aggregates.

2.3 Key Concept: Circular Economy

As a waste intensive industry, construction has the potential to benefit from a CE business model. Using the CE framework (Figure 4) involves a shift in thinking (Ginga et al., 2020), placing greater awareness on the value of resources and a more sustainable use of them (Hossain et al., 2020). The hierarchy underpins the framework, with the ultimate goal of preventing waste production.

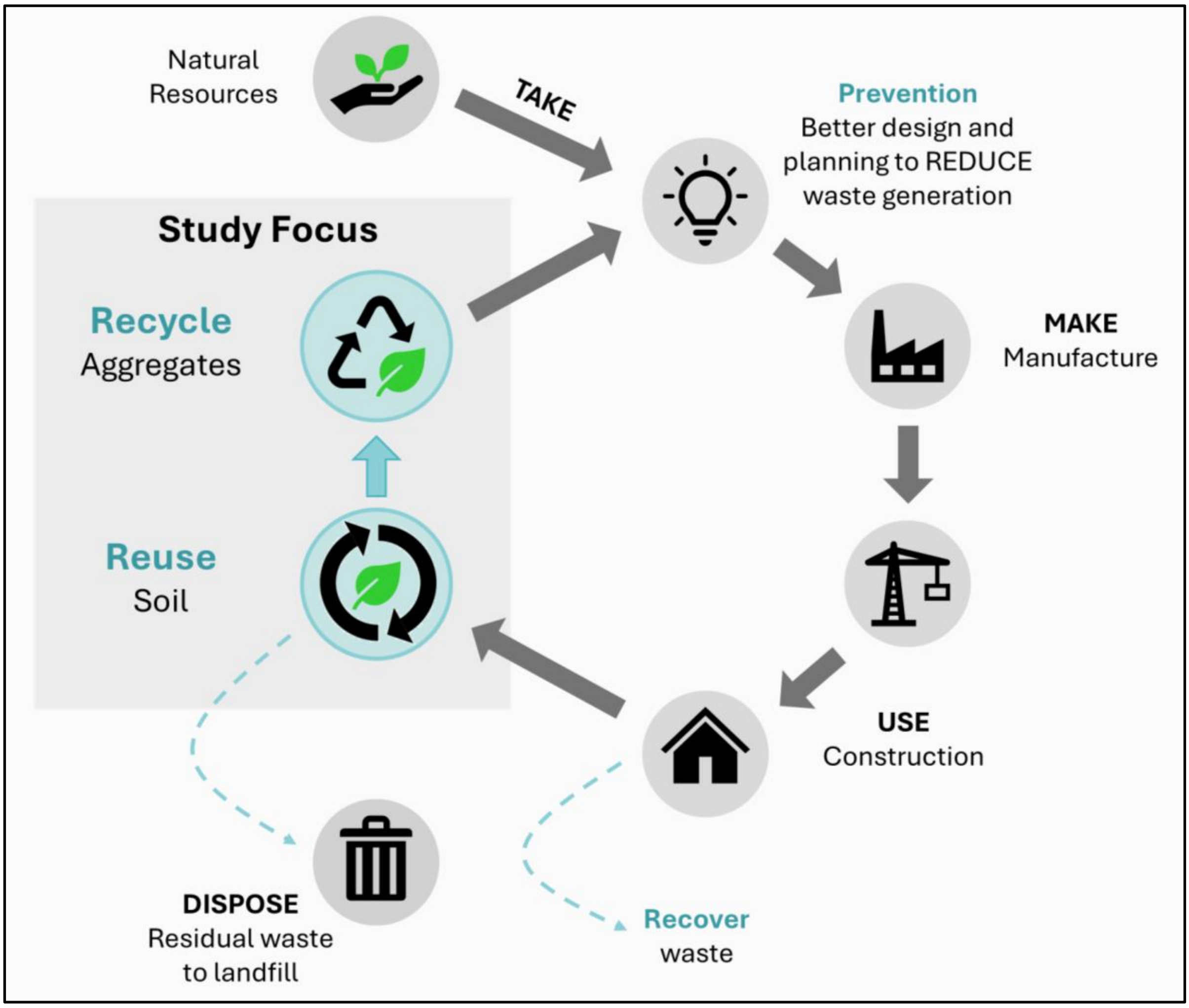

Figure 4: Ideal Circular Economy structure based upon analysis of literature, highlighting the key aspects of this study, reusing soil and recycling aggregates (Figure designed by author using information sourced from Ginga et al., 2020; Ghaffar et al., 2020).

Initially, the CE model emerged from the 3R's principle (reduce, reuse, recycle) but has expanded to include forethought of design (prevention) and recovery of waste for other projects (Purchase et al., 2021). The CE model not only prioritises environmental goals but promotes economic growth and social development (Baldassarre et al., 2019) and encompasses the three main principles of sustainability: planet, people and profit (Purchase et al., 2021). The CE is relatively new to the industry and therefore presents a number of challenges which are discussed in further detail in Section 5.

3 Methodology

3.1 Study Approach

To address the research objectives set out Section 1.2, a primarily sociological approach was adopted for the methodology, incorporating qualitative and quantitative methods. This approach looks to gain empirical knowledge and an understanding of how the law, policy and guidelines impact on the parties involved, and influences their actions.

3.2 Methods

The approach adopted involved: (1) qualitative data collection of primary stakeholder perspectives, (2) determination of secondary source stakeholder perspectives, and (3) a review of technological advances in the recycling and reuse of CDW. The conceptual framework is presented in Figure 5.

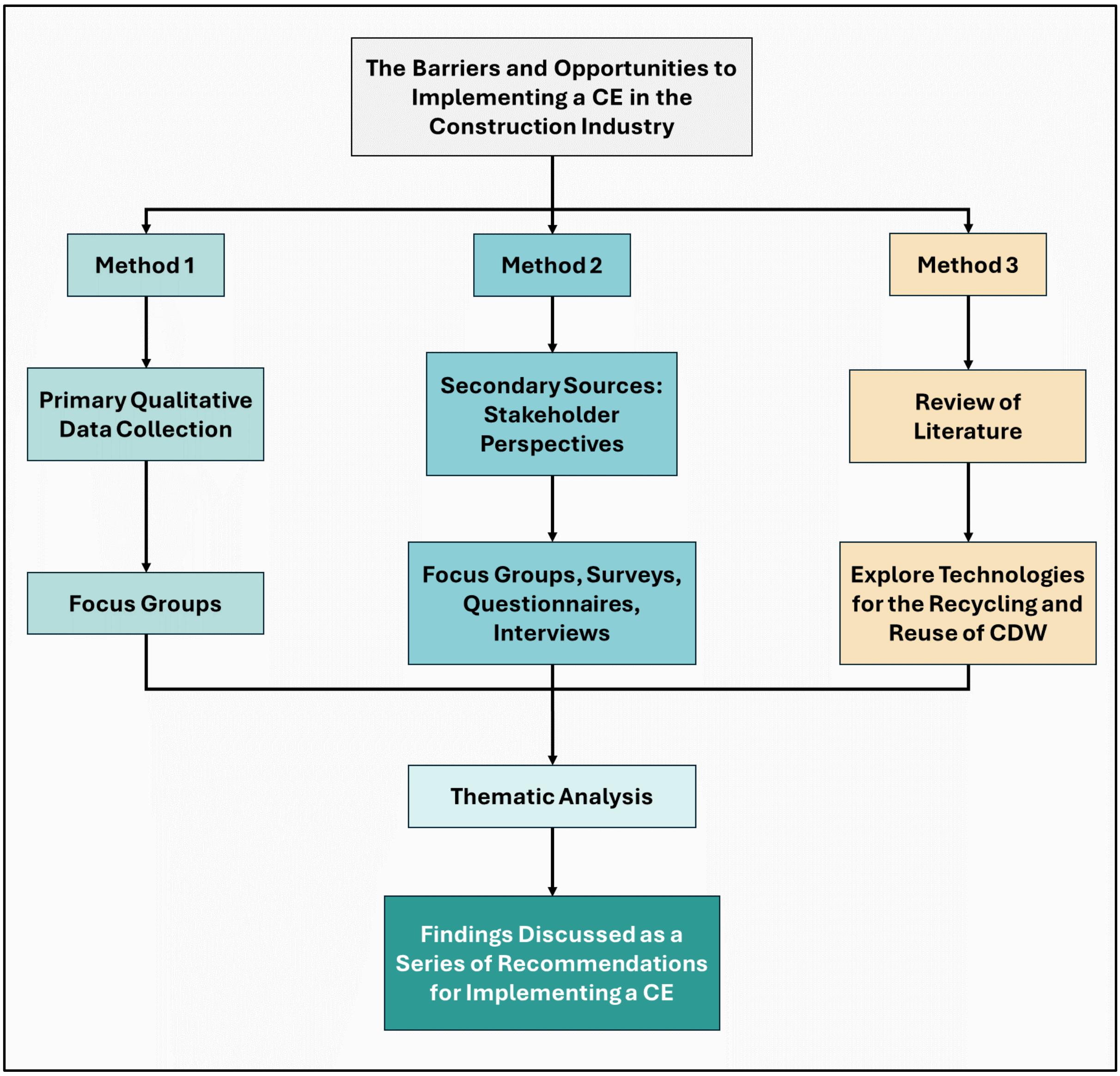

Figure 5: Conceptual framework of methods used in this study.

3.2.1 Method 1: Focus Groups

The findings of the Literature Review (Appendix 1) suggested that stakeholder commitment is essential to the successful implementation of a CE in the industry. Stakeholder perspectives are key in informing policy development, as they often have different interests in a system (Freeman, 2010), and yet most waste management policies rarely consider contributions from industry professionals (Kabirifar et al., 2020; Shooshtarian et al., 2022; Ajayi and Oyedele, 2017). Therefore, the first stage of research takes a qualitative approach to data collection, using focus groups.

This study uses focus group data collected as part of a larger research project *Local Planning Policy for Sustainable Soils*, conducted by Lancaster University. This project aims to establish collaboration between industry stakeholders and local authorities, to accelerate the adoption of soil sustainability principles in local planning policy. As a project research assistant, it is permissible to use the data collected from the focus groups within this study under the ethics forms completed in relation to the project, and consent forms signed by all participants. The findings drawn from the focus groups were established by a number of researchers, however, the research aim for this study varies from that of the Soils Research project, and so whilst there is some overlap, the interpretations made within this study are that of this author.

Focus groups target those whose opinions are often not asked and have the distinctive characteristic of the use of 'interactions' as data (Carter and Henderson, 2005), a benefit of focus groups over interviews. The participants easily converse and interact with one other, with the potential of generating unexpected findings that would not arise in 'one-to-one' interviews (Carter and Henderson, 2005).

Participants were selected through purposive sampling from a wide array of professions relating to the industry, and included planning officers, land managers, consultants, local authorities and regulators. This variety encourages a diversity of perspectives relating to soil waste management. Participants received a Participant Information Sheet and a Consent Form before attending the focus groups in order to familiarise themselves with the study and ensure they had the chance to ask any questions.

A total of 25 industry experts participated across three focus group discussions, with the same three facilitators present in each. The number of participants aligns with Polkinghorne's (1989) assertion that qualitative research requires between five and 25 information-rich participants. There were eight participants in groups 1 and 2, and nine in group 3, following Carter and

Henderson's (2005) assertion that the ideal number of participants for a focus group is between six and eight. Participant details are included at Appendix 2. Each focus group was recorded, with the permission of each participant, and lasted approximately 105 minutes. Given that confidentiality and anonymity are paramount in research work, each participant was given a numerical identifier, but the relevant sector noted as it was important that analysis gauged how opinions differ across the industry.

The focus group recordings were transcribed into written statements and cleaned to eliminate any potential errors in the autogenerated script. A thematic analysis of the focus group data was then conducted, using a deductive approach. The data was coded, and key themes generated (Caulfield, 2024). Analysis concluded when 'theoretical saturation' occurred, whereby further data did not contribute to new themes (Creswell, 2014).

3.2.2 Method 2: Secondary Source Stakeholder Perspectives

Secondary source stakeholder perspectives were analysed and categorised into the key themes generated from the focus groups, adding depth and breadth to the initial findings. These perspectives were primarily gained through: (1) focus groups, (2) surveys, (3) interviews, and (4) questionnaires.

3.2.3 Method 3: Review of Literature

This involved an in-depth review of relevant literature in relation to innovative technologies available for the recycling and reuse of CDW, and conducting a thematic analysis based on the findings of the focus groups and secondary source stakeholder perspectives, of the challenges of implementing technological advancements. All research was sourced from Google Scholar.

3.3 Limitations and Barriers

The main limitations of using focus groups are the 'messy' data collection, and the time-consuming process of tidying scripts and analysing data (Carter and Henderson, 2005).

However, it was determined that the benefits of group interactions on the topic outweighed any limitations. As the focus groups primarily considered sustainable soil management, and excluded other types of CDW, secondary source stakeholder perspectives were used to evaluate CDW management more widely and broaden the findings established from the focus groups.

The main barrier arising from the secondary source stakeholder perspective data was the lack of government department or NGO views. However, this weakness was mitigated by the inclusion of a regulator, CL:AIRE employee, and multiple local authority participants in the focus groups. Combining the findings of the focus groups with the secondary source stakeholder perspectives provides validity to the research findings. The final results represented methodological triangulation, whereby the final themes were representative of analysis from three sources of data: focus groups, secondary sources and literature reviews (Noble and Heale, 2019).

4 Results

This section presents the results of the study in the form of focus groups and secondary source stakeholder perspective analysis, together with the findings of a review of literature on technological advances in the recycling and reuse of CDW. All results are examined in the form of thematic analysis.

4.1 Focus Groups

Each of the written transcripts were read multiple times, to ensure a detailed analysis of the data and as the analysis was content driven, over time key themes became clear. Participant interactions were noted in addition to participant quotes. The findings are presented under the following themes: legislative, economic, technical and social.

Table 1: Summary of key discussion points from three focus groups, categorised by theme: legislative, economic, technical, and social. Ticks indicate which focus groups discussed each issue.

Theme	**Issue**	**Focus Group**		
		1	**2**	**3**
Legislative	Regulations for soil reuse too strict	✓	✓	✓
	Current specifications for soil too prescriptive	✓	✓	
	Landfilling regulations too lenient	✓		
	Gaps in policy	✓		✓
	Need national level interventions	✓	✓	✓
	Unclear and complex guidelines		✓	✓
	Need policy pressure to initiate change in behaviour	✓	✓	✓
Economic	Financial motivations	✓	✓	✓
	Cheaper to treat soil as a waste	✓	✓	✓
	Financial disincentives for reusing soil	✓		
	Waste itself is a commodity	✓		
	Need fiscal incentives for change	✓		
	Cost constraints	✓	✓	✓
Technical	Site-space constraints		✓	✓
	Lack-lustre MMPs	✓		
	Natural topsoil does not meet specifications	✓	✓	
	Recycling facility capacity too small to deal with soil volumes			✓
	Mixing subsoil and topsoil so cannot reuse	✓		✓
	Lack of monitoring		✓	✓
Social	Lack of knowledge	✓		✓
	Lack of collaboration	✓	✓	✓
	More education needed	✓		
	Client motivations	✓		✓
	People still think in LE way		✓	
	Easier to treat soil as waste	✓		

4.1.1 Legislative

All focus groups expressed that regulations governing soil reuse were too strict, and negatively impacted upon soil reuse, even though the industry has a clear desire to. A key interaction occurred during Focus Group 2, in which Participant 10 (Industry) criticised the regulatory constraints placed on soil reuse by relevant regulatory bodies (the Environment Agency) and expressed a clear desire to have fewer restrictions.

> *"The Environment Agency put so many restrictions on what we can and can't do with soil ... we really want to use soils, and we want to find good places to use it, but we need less restrictions, we need less costs, we need less authorisations in order to enable us to do that"* – Participant 10, Industry

Both Focus Groups 1 and 2 emphasised that current standards and specifications are too prescriptive to allow soil reuse and Focus Group 3 highlighted the need to introduce policy to enforce codes which are currently voluntary (such as CL:AIRE). In particular, Participant 9 (Regulatory Body) emphasised that clearer guidelines were needed, with Participant 22 (Industry) mentioning, "*regulation and guidance need to be more straightforward"*.

Participants from Focus Groups 1 and 3 noted that there were gaps within policy frameworks, with current landfill regulations too lenient, and highlighted the importance of policy to ensure accountability across the construction supply chain.

> "*There is definitely a hole, I think, in terms of the policy framework*" – Participant 4, Planning Authority
>
> "*Policy is a great way to get everyone in the supply chain to step up a bit*" – Participant 1, Industry

A key issue raised by all three focus groups was the need for policy intervention covering waste management at the pre-design stage of a construction project, including policies at a national level to ensure waste was considered before being generated. The participants also emphasised that national policy would remove the variability in local authority enforcement of CDW management, as consistency is necessary across regions to prevent bias towards site location selection.

4.1.2 Economic

One of the more common themes across the three focus groups was the financial motivations of industry stakeholders. Nine out of 25 participants commented on the economic barriers/opportunities of soil management reuse. These comments related to the financial viability of reusing CDW, the fact that soil has been economised and the consequent value of soil. Participants also highlighted that waste itself was a part of the economy, and many jobs rely on the generation and disposal of waste.

4.1.3 Technical

According to industry practitioners, one of the greatest barriers to soil reuse is space-constrained construction sites. Participants expressed that without adequate space, it is difficult to properly store soil, and soil which would have had value if reused, is removed. During Focus Group 2, this was a prominent issue as space constraint was mentioned six separate times. Another barrier highlighted was the negative impact from mixing topsoil and subsoil, reducing its ability to be reused in high-grade applications (a theme highlighted during all three focus groups). Other technical themes drawn out were the lack-lustre MMPs completed by industry practitioners, and the lack of monitoring of soil once planning has been granted. Focus Group 3 emphasised the limited number of facilities available to deal with excavated soil. The volume of soil removed across UK construction sites far exceeds the capacity of available facilities; as Participant 20 (Industry) explained, "*With few facilities and long permit backlogs, many resort to disposal or landfill as the most practical solution*".

4.1.4 Social

Whilst most participants agreed on the benefits of the CL:AIRE DoW CoP, with Participant 10 (Industry) stating "*it definitely serves a purpose, and it helps us to prove to the regulator that we're doing the right thing*," they (Participant 10) also believed "*it doesn't really have full regulator support*." This caused slight tension in the group and revealed an underlying friction between construction companies and environmental agencies, particularly relating to policy and regulation. This also raised the point of effective cooperation between differing stakeholders, with improved communication necessary.

Of the 25 participants, 10 made comments about the lack of knowledge and awareness of soil functions and its value as a resource. They also emphasised that stakeholders need more education to improve this knowledge deficiency, to encourage a move away from a LE approach.

> *"Unfortunately, there are a good deal in the industry who still think in a very linear way when it comes to soils."* – Participant 15, CL:AIRE

When discussing which key stakeholders should be involved in improving sustainability in the industry, all three focus groups highlighted the need for government departments/officials to become more involved, with increased collaboration between government and industry.

Increasing the extent of government involvement was linked to client motivations, which are primarily driven by cost variables, with one participant explaining that "*ultimately it always came down to cost and program in the end, in terms of clients drivers*" (Participant 22, Industry). Participants explained that clients set the standards, and so if contracted by a client the task will be done, including sustainably managing CDW.

4.2 Secondary Source Stakeholder Perspectives

Whilst the focus group data provided insightful results, it is important to cross-reference the findings with other sources to provide validity and eliminate any potential bias arising from the focus group participants and/or personal knowledge of the researchers. Stakeholder perspectives on all forms of CDW were needed, as the focus groups only considered sustainable soil management.

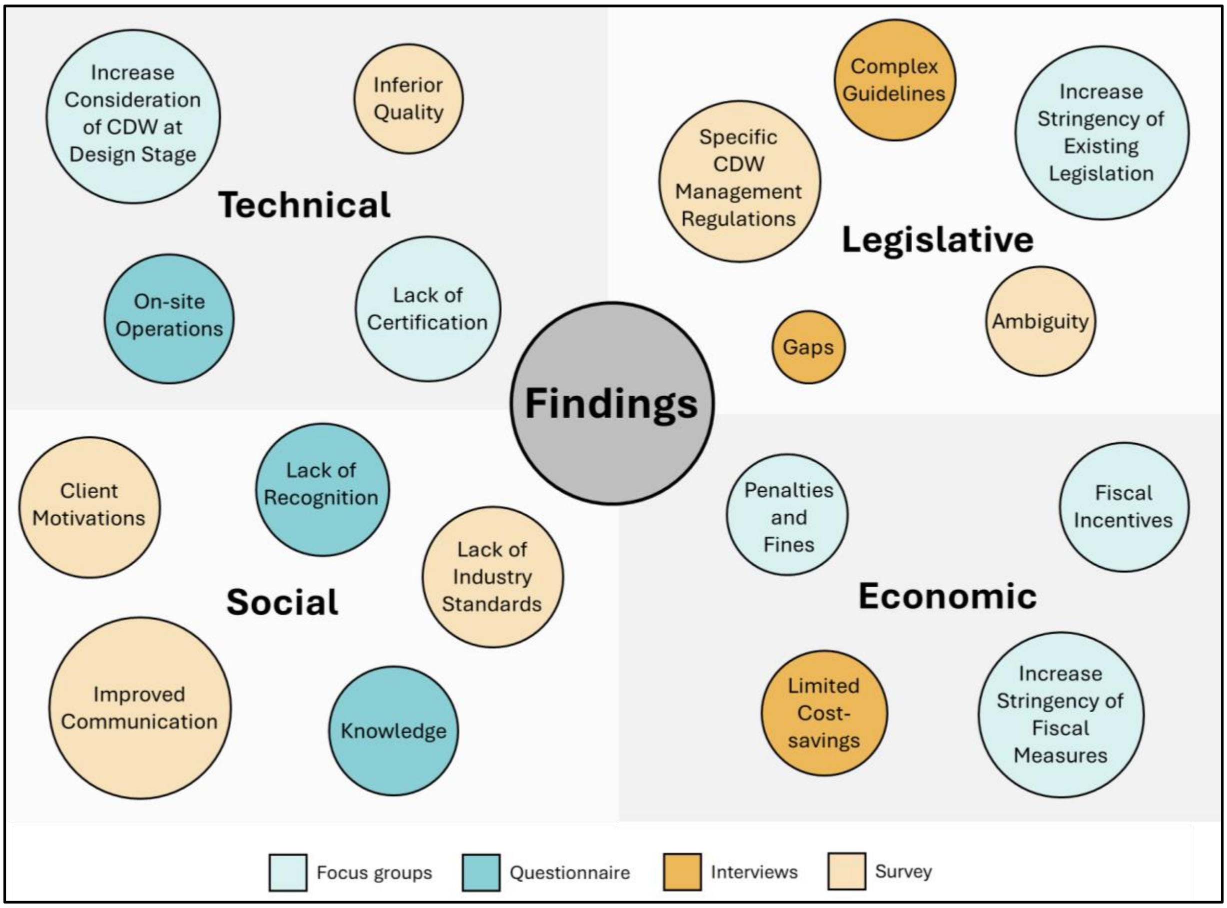

Figure 6: Summary of main findings from secondary source stakeholder perspectives, categorised by theme: technical, legislative, economic, and social. The findings are derived from focus groups, questionnaires, interviews, and surveys (Figure designed by author using information sourced from Ajayi and Oyedele, 2017; Ghaffar et al., 2020; Jin et al., 2017; Adams et al., 2017).

4.2.1 Legislative

Data from focus groups conducted by Ajayi and Oyedele (2017) found that participants believe that increased stringency of existing legislation is needed to increase waste diversion from landfill. The data also showed that waste preventative measures were needed to improve the market for, and ease the use of, recycled products. A survey by Adams et al. (2017) expressed a need for more specific regulation relating to CDW management, especially in relation to the CE.

Interviewees in Ghaffar et al.'s (2020) study noted that more regulation was necessary to improve sustainable CDW management, with 78% of questionnaire responses stating they are not currently satisfied with current recycling processes, and one stating "*these could be improved but it relies on […] increased investment and regulation of the waste industry*". Other interviewees expressed that current regulations were "s*ometimes overly bureaucratic to operate,"* with greater rewards for recycling and reusing CDW needed.

4.2.2 Economic

Clear economic themes were found by Ajayi and Oyedele's (2017) focus groups, with key waste management policy measures identified as tax breaks, incentives, and increased stringency of fiscal provisions. These included 'Increasing Aggregates Tax' and 'Increasing landfill disposal fees' and penalties for poor waste management. Whilst Ghaffar et al.'s (2020) study focused more on stakeholder awareness of the CE and legislation, a comment from an interviewee highlighted that cost savings from using recycled materials was not always reflective of the effort required.

4.2.3 Technical

Although only raised in half of the focus groups, the largest number of codes (58) in Ajayi and Oyedele's (2017) study were on the topic of 'Increased consideration of design stages over actual construction'. In Ghaffar et al.'s (2020) questionnaire, 44% of participants believed that on-site operations must be improved, and 85% believed that contract clauses should enforce the use of recycled materials.

4.2.4 Social

A dominant theme of all secondary source stakeholder perspectives were the opinions and behaviours of clients, and industry practitioners. Ghaffar et al.'s (2020) questionnaire identified that 100% of respondents would be more likely to recycle if they received more recognition for doing so and also that a lack of knowledge was a major challenge, as 85% of respondents were unaware of CE principles, with 100% believing they should be more heavily promoted.

In Jin et al.'s (2017) survey, over 75% of respondents agreed with 14 of the 20 identified challenges of enhancing CDW recycling/reuse, with top challenges being 'Lack of demand from the client' (92%) and 'Lack of industry standards' (87%). Over 90% of respondents agreed with 8 of the 9 suggestions made for enhancing CDW recycling/reuse, with only 'Increase the Landfill Fee' scoring lower, as viewpoints of industry practitioners varied significantly. However, given the majority of positive answers, the analysis showed a strong will of industry stakeholders to change current practices.

4.3 Technological Development

4.3.1 Recycling CDW

Aggregates (sand, rock and gravel) are the largest tonnage of material used in construction (66 billion tonnes by 2025) (Silva et al., 2019). Natural aggregates are more widely used, but recycled aggregates, the most common product from the recycling of CDW, have the potential to take their place in various applications and present an opportunity for the industry to build sustainably (Di Maria et al., 2018; Behera et al., 2014; MPA, 2022). Of significant environmental benefit, recycled aggregates have a global warming potential seven times lower than natural aggregates and reduce greenhouse gas emissions by around 65% (Braga et al., 2017; Hossain et al., 2016). Studies on using recycled concrete as an aggregate show substantial cost savings (Purchase et al., 2021) and high quality products, such as new concrete, can be produced (Gálvez-Martos et al., 2018), aligning with the CE model as the end product is gaining value.

When CDW is sorted and washed, clay and other fine particles are removed, and a filter cake of silt remains (Lampris et al., 2009). Often, this by-product goes to landfill, but dry washing (a modern technology), turns this waste into a resource: a replacement for natural aggregates in certain applications (Rønning et al., 2024). This has positive environmental and economic impacts through decreasing the extraction of natural aggregates and prolonging the life cycle of waste. However, currently recycled aggregate volumes produced from crushed concrete are insufficient to meet the demands for aggregates (Lupo et al., 2020).

4.3.2 Reusing CDW

In 2018, of the 138 million tonnes of UK CDW, 58 million was excavated material (42%), with half recovered and half going to landfill (ICEC-MCM, 2023). If it meets the requirements outlined in BS3882, a sizeable proportion of the landfill material has the potential to be reused. However, as soon as soil is removed from site, it is classed as waste, making reuse onerous. If excavated soil and rock is reused, the costs and climatic impacts of a project can be reduced, as transport and landfilling are reduced (Magnusson et al., 2015).

Over 300,000 hectares of soil in the UK is contaminated (Environment Agency, 2019) and to reuse on site, the contaminants must be removed. This is conventionally achieved through soil washing which has been used for many years, however, technological advances have improved the quality of contaminant removal, and mobile soil washing plants are becoming more commonplace (Quinnan et al., 2022) (Figure 7). The treatment of soils on site increases reuse, decreasing costs for companies. This is an effective waste minimisation strategy as it is a flexible approach that can be tailored to individual clients (Quinnan et al., 2022).

Figure 7: Image of a mobile soil washing plant removing contaminants from soil, to facilitate its reuse on site (photo from CDE, n.d.).

4.3.3 Carbon Savings

Recycled aggregates have the ability to sequester CO_2, due to their alkalinity. Fine recycled aggregates are preferred, as smaller particle sizes have higher carbonation rates, i.e., sequester more CO_2 (Kaliyavaradhan and Ling, 2017). Therefore, products made from recycled aggregates, such as concrete blocks, have the potential to uptake CO_2 and become value-added products, rather than waste (Kaliyavaradhan and Ling, 2017). Reusing soil has many carbon savings, with studies estimating a saving of up to 14 kg of CO_2 per tonne (Magnusson et al., 2015). With 29 million tonnes of soil sent to landfill, 191.1 million tonnes of natural aggregates and 69.9 million tonnes of recycled aggregates produced each year, the potential carbon savings are significant (ICEC-MCM, 2023, Mineral Products Association, 2023) (Figure 8).

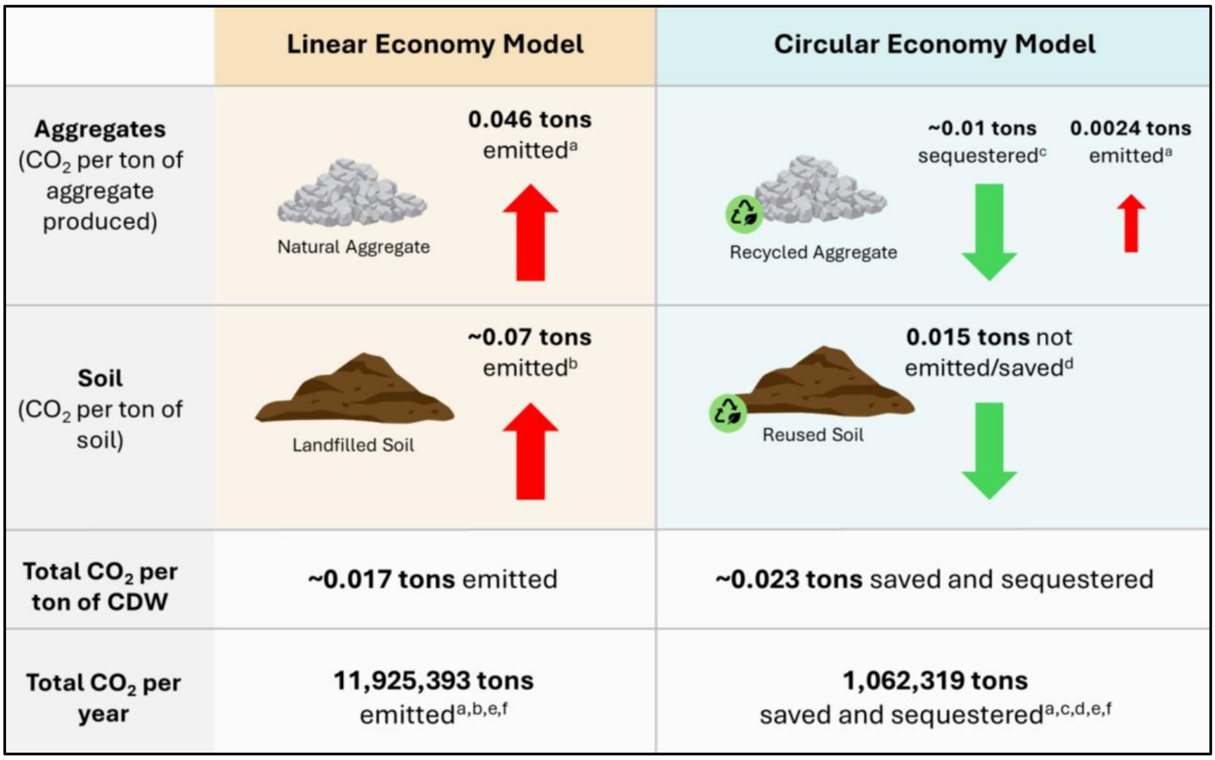

Figure 8: The carbon emissions and savings/sequestration for soil and aggregates based upon the current linear economy model, as compared to an ideal circular economy model. Includes calculations for total CO_2 emitted and sequestered/saved per year based on tons of soil sent to landfill and tons of natural and recycled aggregates produced (see Appendix 3 for calculations) (Figure designed by author using information sourced from: (a) Tam et al., 2018; (b) Eurofins Agro, n.d.; (c) DFA, 2022; (d) Kaliyavaradhan and Ling, 2017; (e) Magnusson et al., 2015; (f) Mineral Products Association, 2023; and (g) ICEC-MCM, 2023).

4.3.4 Challenges of Technological Development

Whilst there are many benefits to recycling and reusing CDW, there are also challenges. A major barrier to using recycled products is customer perception (Tam et al., 2018), as many stakeholders distrust the quality and integrity of the products (Silva et al., 2017). The WFD does not specify quality standards for recycled aggregates and products can be uncertified. Under EU regulations, products without certified performance are illegal to use for construction purposes (Ghaffar et al., 2020; Di Maria et al., 2018). Also, some technical limitations have been found when using recycled aggregates within new concrete, such as inferior mechanical performance (Hossain et al., 2016).

Inconsistency in supply of recycled aggregates and inconvenient locations of recycling facilities limit the profitability, and environmental advantages of using recycled aggregates

(Purchase et al., 2021; Silva et al., 2017). Many recycling plants often do not correctly sort CDW to obtain the best quality recycled aggregates, due to cost and time constraints (Menegaki and Damingos, 2018), this can affect the final product as it cannot be used in high quality applications (Silva et al., 2019). This is known as downcycling, and whilst many class this as a form of recycling, the process is closer to a LE ideology, as the final product is less valuable, lower quality, and after a few cycles needs to be landfilled (Horodytska et al., 2020).

The reuse of soil has certain challenges arising from lack of space on site, and time constraints. Given stringent specification requirements, soil can only be used if it is uncontaminated and stays on the same site. Once removed from site, it is classed as a waste and becomes much more difficult to reuse. If soil is to be removed from site, it must be included in a MMP, be granted a U1 exemption by the Environment Agency or sent to a permitted off-site waste receiver (holding an Environmental Permit) (Bardos et al., 2021; Plimmer, 2023). This is often costly and time-consuming. Figure 9 summarises the challenges related to the recycling and reuse of CDW.

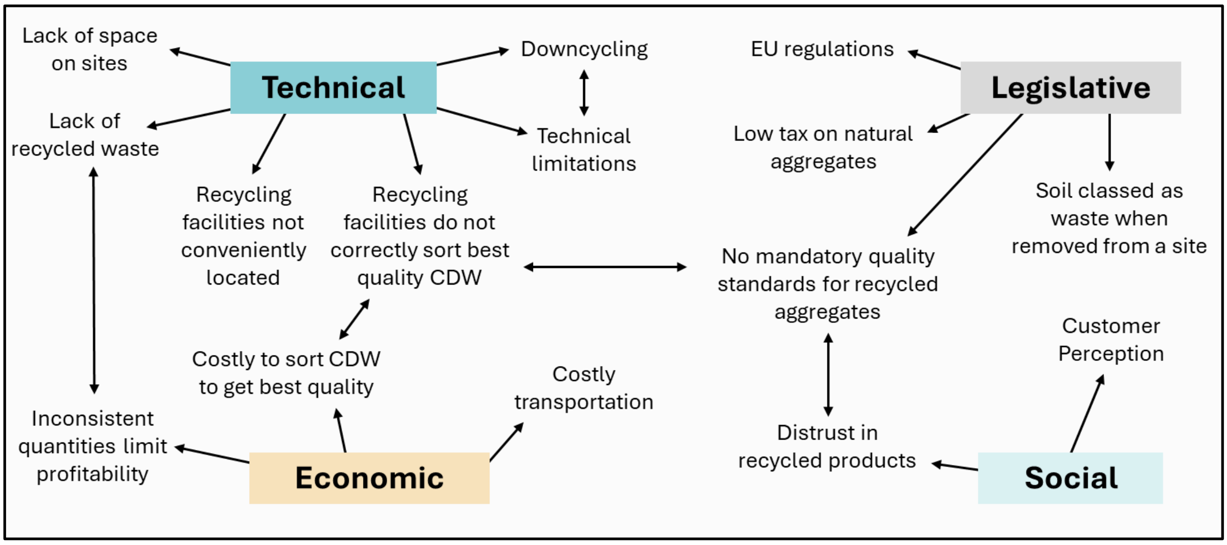

Figure 9: Schematic diagram presenting the main findings from the literature review, categorised by theme as identified in focus groups. The diagram sets out the challenges of adopting technological advancements when implementing a circular economy.

4.3.5 Case Studies

To demonstrate the benefits of reusing and recycling CDW, case studies of successful implementations are presented in Figure 10, with further detail in Appendix 4.

Channel Tunnel Rail Link	**CDW a priority from design phase of project**	**~£110 million savings**
Newport Southern Distributor Road	**452,500 tonnes of recycled aggregates used**	**~£2 million savings**
A34 Chieveley/ M4 junction 13 improvement	**56,000 tonnes of recycled aggregates used**	**~£70,000 savings**

Figure 10: Summary of case studies which demonstrate the benefits achievable when successfully implementing the recycling and reuse of construction and demolition waste (Figure designed by author using information sourced from Silva et al., 2019).

5 Discussion

This study used thematic analysis as a form of data exploration, with the following key themes identified: legislative, economic, technical, and social, with the findings often appearing in more than one theme. To effectively interpret the complex data, this discussion section focuses upon a series of recommendations, taking data from each theme as applicable.

5.1 Recommendation: Regulatory and Legislative Reform

5.1.1 Imbalances

The focus groups emphasised that legislative barriers are impeding the effective implementation of a CE. In particular, regulations in relation to the reuse of soil were too restrictive and would need to be eased to increase circularity. Focus group participants stressed the need for regulators to support sustainable practices, and for this to occur there needed to be less regulation of clean and reusable materials and the easing of soil restrictions was vital. Participant 10 (Industry) expressed that the industry has a clear desire to reuse soils, but *"we need less restrictions, we need less costs, we need less authorisations in order to enable us to do that"*.

Conversely, participants stressed that legislation surrounding waste disposal to landfill is too lenient, encouraging disposal over recycling/reuse and this was confirmed by Ajayi and Oyedele's (2017) focus groups. Returning excess materials to a supplier participating in a 'take-back' scheme ensures useable materials do not go to waste and are a part of the recovery stage of the hierarchy. An interviewee in Ghaffar et al.'s (2020) study noted the use of contractual requirements, to "*force companies to start innovating and investing time and money into new recycling techniques"* and *"contracts could be used to re-enforce legislation"*.

Mandatory use of a waste efficient contract clause in waste management regulations.

5.1.2 Gaps

Regulations introduced in 2008, including Site Waste Management Plans (SWMPs), were repealed in 2013 to "remove unnecessary legislation to free-up business" (Defra, 2013) (see Appendix 1). The economic priorities of companies took precedence over effective CDW management. This retrograde step deprioritised waste management, downgraded sustainability commitments and diminished the accountability of companies not meeting environmental standards. Participant 1 (Industry) and other interviewees in Ghaffar et al.'s (2020) study highlighted that legal requirements would enforce accountability within the industry.

However, it was not until the introduction of The Environment Act 2021 that a new framework of environmental protection was put in place. The gaps left by the repealing of the 2008 regulations could have been addressed in the 2021 Act, however, aggregates, concrete and soil are not included in the requirements for recycling (*Environment Act 2021 Part 3, 45AZB England: separate collection of industrial or commercial waste*) nor are there specific soil reuse targets (Soils in Planning and Construction Task Force, 2022). Ambiguity in end-of-waste regulations was ranked as the greatest legislation and policy challenge by those in Adams et al.'s (2017) study, with a need for specific regulation for circular CDW management. Whilst these gaps, in part, have been addressed under Regulation 5(c)(iii) pt (d)(v) and (f) of the Waste (Circular Economy) (Amendment) Regulations 2020, they lack clear steps to follow which would promote circularity in the industry.

Current legislation needs to be updated with guidance from industry experts to facilitate diverting waste from landfill and increasing recycling/reuse to improve circularity within the industry.

5.1.3 Inconsistent Enforcement

Enforcement of legislation is essential in achieving the goals of regulatory measures and it is the remit of local authorities to regulate CDW. When enforcement is left to the judgement of individual authorities, a disconnect arises between policy and practice. Research by Umar et al. (2017) shows that this inconsistency, together with uncertainty about the roles and responsibilities of different regulatory bodies, impedes the effective implementation of sustainable CDW management practices and enforcement of regulations. To ensure consistency across regions, the focus groups identified a need for regulation and policy to be set at a national level and consistently enforced.

Enforcement actions should be determined at a national level.

5.1.4 Outdated Guidelines

The absence of legislative development covering sustainability is actively discouraging circularity. The lack of updates to government guidelines such as the 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' (last updated 2011), underlines how lack of legislative development is hindering progressive policy on CDW sustainability.

Within the literature, studies have added further levels to the hierarchy, of re-design (minimising waste generation through forethought of design) and re-think/re-imagine (acknowledging the environmental impacts of CDW alongside traditional, profit driven, construction methods) (Esa et al., 2017) (Figure 11). Currently, Defra has not adopted these added levels, continuing a lack of attention/innovation from the Government to CDW management. Construction practitioners use the emphasis of 'practical feasibility' when following regulations and this facilitates disposal as a means of CDW management, the lowest level of the hierarchy (Van Ewijk and Stegemann, 2016).

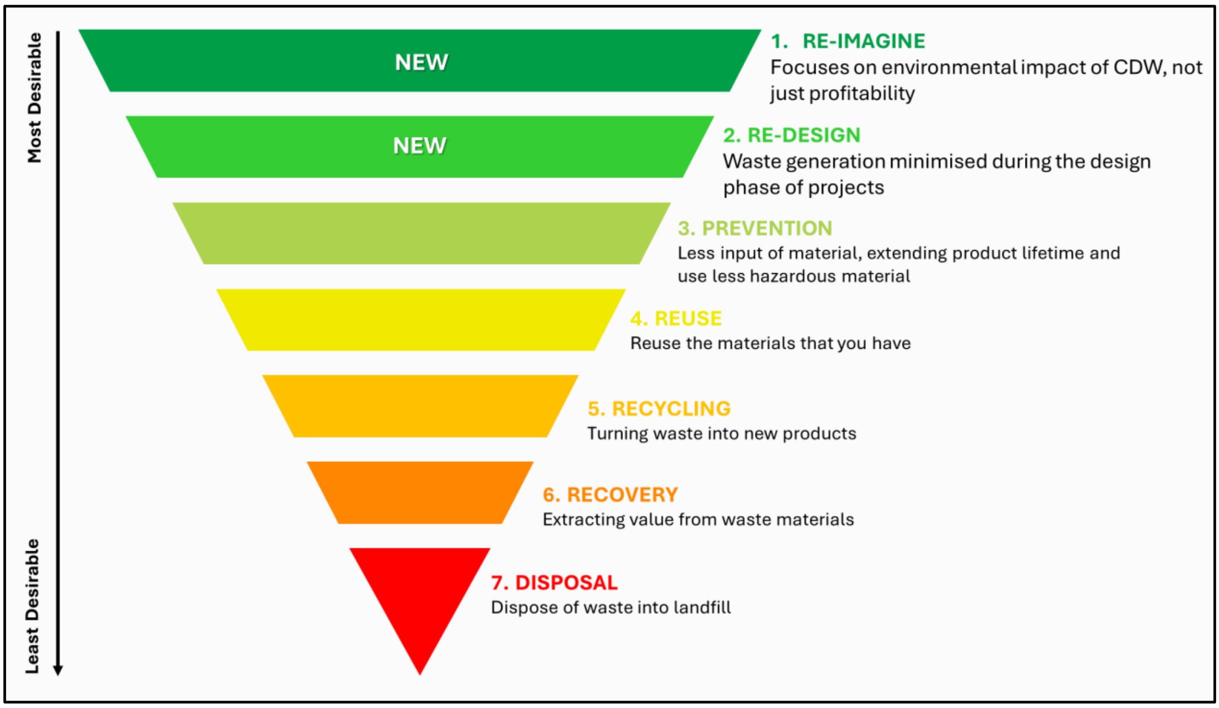

Figure 11: A revised waste hierarchy acknowledging the additional levels proposed in literature, re-design and re-imagine (Figure designed by author using information sourced from Esa, 2017; Defra, 2011).

Policy relating to sustainable CDW management needs updating to reflect the current understanding and goals of circularity and acknowledge the new levels of the hierarchy. Regulations and policy should hold clear steps on how to achieve these levels in an updated Code of Practice.

5.1.5 Voluntary Nature of Current Codes

The lack of a regulatory framework for sustainable CDW management, results in the industry and local authorities relying on codes such as CL:AIRE DoW CoP and BREEAM. These in turn, due to their voluntary nature, rely heavily on the goodwill of construction practitioners to manage CDW sustainably. The focus groups found that practitioners have little motivation to change to more sustainable methods.

"If planning policy is the tool for change, then I'm sorry to say it has to be forced because I've been trying for 20 years to convince my clients who are developers to make changes in a more sustainable way." – Participant 19, Planning Authority

As noted by the focus groups, CL:AIRE and BREEAM have the guidance needed to incorporate sustainable steps at the pre-design stage, but these need to be a legal requirement rather than a voluntary code. Additionally, most practitioners already complete MMPs under the DoW CoP, therefore, making these codes mandatory would allow authorities to include requirements for comprehensive MMPs and compulsory soil surveys before planning permission is granted.

Voluntary codes should become a legal requirement.

5.2 Recommendation: Taxation and Incentives

5.2.1 Inadequate Fiscal Measures

Landfill Tax is an environmental tax in place to encourage alternative disposal routes for waste (Ajayi and Oyedele, 2017). Whilst a landfill tax does little to alter construction methods (Ann et al., 2013), there is evidence to suggest that it improves CDW management. However, the current price to landfill at £3.30 per tonne of inert waste provides a cheap and convenient disposal option, with half of excavated waste going straight to landfill (Gov.uk, 2024; ICEC-MCM, 2023). As discussed by Focus Group 1, current Landfill Tax provides a "*cash incentive for doing the wrong thing*" (Facilitator 1, Soil Research), by economising soil as a waste commodity. Ajayi and Oyedele's (2017) focus groups suggested increasing the cost of disposing waste to landfill. This allows recycling to become an economically competitive CDW management choice (Caro et al., 2024).

Aggregates Tax is an environmental tax in place to ensure that the environmental impacts of aggregates extraction is more fully reflected in prices to encourage a shift in demand to secondary (recycled) aggregates. Current fiscal measures are too low to sufficiently alter CDW management practices. At £2.03 per tonne of natural aggregates, virgin materials are still widely used in the industry. Increasing the cost of use of natural aggregates would apply an added cost to companies for using virgin material (Ajayi and Oyedele, 2017). Countries with relatively high tax rates have higher recycling rates (Tam et al., 2018) and whilst the current Aggregates Tax is low, it has assisted in a reduction of resource use (Söderholm, 2011), and so an increase should further deter the use of natural aggregates.

As shown in Figure 8, the industry is carbon intensive. Therefore, a landfill tax that is levied on carbon content per tonne, rather than absolute tonnage (Burke et al., 2019) and an aggregates tax based on production carbon emissions would have a significant impact on soil waste disposal and natural aggregate production. Placing a far greater cost on disposal of soil would motivate companies to prioritise soil management earlier in the project and use recycled aggregates, achieving higher levels in the hierarchy.

Increasing the Landfill and Aggregates taxes would move the industry towards a circular economy. Further investigation is required to determine how a tax based on actual and potential carbon emissions and sequestration would be structured and implemented.

5.2.2 Financial Motivations

As discussed by the focus groups and secondary source stakeholders, the dominant driver of industry is financial impact. Therefore, to promote circularity, any decision must be the most financially beneficial option available. Many stakeholders are deterred by the costly early stages associated with CE practices (Purchase et al., 2021), with Participant 7 (Planning Authority) stating "*a lot of clients and developers are reluctant to spend money on site investigation early in the process*".

Also, to many, the cost savings of using reused/recycled materials is so small, that it proves meaningless on largescale projects, "*The saving made from reusing materials is insignificant for them, such as a £10,000 saving on a £250 million job*" (Ghaffar et al., 2020). Many in the industry assume that the reuse of CDW increases costs, and so they lack the motivation to promote reuse within a project (Park and Tucker, 2017).

Participant 1 (Industry) noted that unless there is a legal requirement, an effective way to initiate change in the industry would be by using financial incentives. This was confirmed in the findings of Ajayi and Oyedele's (2017) focus groups, noting that economic carrots are an effective way of encouraging sustainable (circular) behaviour. Although subsidies can greatly increase the amount of recycled and reused waste within construction projects (Pomponi and Moncaster, 2017), if the cost to landfill or cost of virgin materials is still considered the cheapest option, they will be ineffective.

Placing a subsidy or tax incentive on the use of reused/recycled material will provide a financial reward for improving circularity within construction but this must be combined with stringent fiscal measures to prove effective.

5.2.3 Enforcement and Penalties

UK enforcement of waste management regulations include: warnings, formal cautions, prosecution or a fixed penalty notice up to £50,000. However, these only relate to illegal activities such as dumping, or unpermitted waste management (*Environmental Protection Act 1990*). There is no procedural enforcement or penalties for poor waste management, such as failure to recycle/reuse CDW, poorly sorted waste or landfilling of uncontaminated soil. Financial penalties can decrease the amount of waste going to landfill but do little to motivate companies to recycle and reuse (Liu et al., 2022), as they function as a deterrent rather than as an incentive. Ajayi and Oyedele's (2017) focus groups emphasised that new policies should impose penalties on poor waste management, as it is an essential requirement for reducing CDW generated within the industry.

Reintroduce mandatory completion of CDW management plans, subject to overview and compliance checks by local authorities with financial penalties for poor waste management and/or incomplete CDW management plans.

5.2.4 Other

The production of aggregates and the collection and transportation of waste, alongside the management of landfill sites, creates job opportunities which may be lost as the industry moves to more sustainable CDW management. Participant 1 (Industry) stated "*there are a lot of other people further down the supply chain that are reliant on soil […] to make their money*". However, EU projects have shown that improving the circularity of construction materials can create jobs (Caro et al., 2024).

As recycling facilities are not often conveniently located to construction sites, transportation is needed, which makes moving CDW expensive, unprofitable and can counteract the environmental benefits of using recycled CDW (Ghaffar et al., 2020). This can be addressed through fiscal measures.

An effective CE needs to be developed such that waste generation and economic growth are decoupled by adopting waste avoidance, sustainable business practices and effective waste management. This includes sufficient Landfill and Aggregates taxes, so that it becomes cost effective for companies to take on the transportation costs of moving CDW to recycling facilities.

5.3 Recommendation: Certifications, Specifications and Material Quality

5.3.1 Lack of Certification for Recycled Aggregates

The UK has a regulated, though not universally mandatory, quality certification process for recycled aggregates. However, under EU Regulation No 305/2011, it is illegal to use construction products without certified performance (Ghaffar et al., 2020). While there is a growing market for quality-assured recycled CDW (Kabirifar et al., 2020), the lack of a universally recognised certification process can lead to consumer distrust and reduce motivation to use these products.

The criteria for the production of recycled aggregates from inert waste is set out in a Quality Protocol and compliance is "considered sufficient to ensure that the fully recovered product may be used without undermining the effectiveness of the WFD and without the need for waste management controls" (WRAP, 2013, p. 3). The Protocol aims to improve market confidence in the quality of recycled and recovered waste products and encourage their use by the industry, but use is voluntary. Further, if a product previously complying with the Protocol is discarded, it reverts to a waste and is subject to waste management controls (WRAP, 2013). This limits the longevity of recycled products, and ultimately does not support circularity.

Despite efforts to recycle aggregates (primarily concrete), natural aggregates still meet over 70% of demand (MPA, 2022). The quality of recycled aggregates is often compromised due to inadequate off-site sorting procedures and insufficient market incentives (De Brito and Silva, 2016; Shooshtarian et al., 2022). In Jin et al.'s (2017) survey, 87% of respondents believed a lack of industry standards in CDW recycling/reuse is a major challenge in obtaining top levels of the hierarchy. The findings of Ajayi and Oyedele's (2017) focus groups confirmed that a policy measure for the facilitation of waste prevention was required whereby certification ensured an adequate awareness of materials and supported waste diversion from landfill.

Enhancing the sorting process and setting up a mandatory quality certification process for recycled aggregates will improve their quality, build trust in the products, and enable their use in high-grade applications, improving circularity in the industry.

5.3.2 Lack of Appropriate Soil Specifications

The focus groups confirmed that the provisions of BS3882 are generally followed when considering soil reuse on construction projects. However, Defra's 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' (2009) states that BS3882 is "not intended for the grading, classification or standardisation of in situ topsoil or subsoil". Therefore, soils are assessed using incorrect specifications and this is negatively affecting their reuse. As soon as natural topsoil is excavated it must meet the criteria of BS3882, and as the specifications are too restrictive, a substantial proportion does not, *"leading to removal of materials that would be fine in place"* (Facilitator 1). This conflicts with the CE framework, as soil which could be reused is instead disposed of as waste to landfill.

The focus groups found the need to introduce new specifications/standards for soil, appropriate to the industry, which align with CE principles. Participant 10 (Industry) explained contractors and engineers work to specifications, so "*if you give them a specification, they will build to that specification*".

A standard applicable to in-situ topsoil on construction projects would support regulatory compliance, competitiveness, the environment and sustainability.

5.3.3 Material Quality

The absence of specific standards for material recycling/reuse forces them to compete with virgin materials, which typically comply with established quality standards. Unlike virgin materials, recycled/reused materials have unknown qualities, which may affect their performance and market access (Ferriz-Papi et al., 2024) and unregulated materials tend to be used in low-grade applications (Section 4.3.5). This reduces the usage of virgin materials, meeting the CE principle of conserving resources, yet does not add value to the recycled/reused material, or extend its life as it needs to be landfilled after a few cycles, in line with the LE framework.

Concerns over the technical integrity of recycled products contribute to their use in low-grade applications. In Jin et al.'s (2017) survey, 62% of respondents identified the inferior quality of recycled products as a major obstacle to effective recycling of CDW. Additionally, Ghaffar et al. (2020) found that 15% of participants opposed contract clauses requiring the use of recycled materials, citing concerns about expense and warranty issues due to inferior quality. In contrast, contract clauses to mandate the reuse of soil could be beneficial, as concerns over expense and quality are not valid (inexpensive and does not affect building integrity), allowing for an increase in its reuse during projects.

Introduce legislation mandating minimum requirements for the use of recycled materials and reuse of soils in projects.

5.4 Recommendation: Project Planning and Management

5.4.1 Early Waste Management Consideration

A major barrier to sustainable construction described by all three focus groups was the lack of waste management consideration before a project began (previously included in SWMPs); this was verified by Ajayi and Oyedele's (2017) study, which highlighted the importance of increased consideration at the design stage. The inclusion of MMPs in the initial phases of a project are essential but, as discussed by Participant 1 (Industry), can be superficial and add little value to industry circularity in their current format.

"We'll often see sites try and do a Materials Management Plan, but it's very lacklustre. It's not really adding much value." – Participant 1, Industry

A particular issue arises when a construction site does not have the requisite space to store soil throughout the project (Figure 12). The focus groups noted that those in the industry have a desire to reuse more soil, but do not have the capabilities, so must landfill useable soil.

"In order to deal with soils properly so that they're not damaged and do retain their value, we need space and often we don't have that space." – Participant 10, Industry

Figure 12: Image showing excavated material being loaded onto a lorry for removal from site, due to a lack of on-site storage space (Photo by the author, 2024).

The reuse of soil is promoted as part of a CE framework given its carbon sequestering potential. Solutions need to be flexible and adaptable, to meet individual client needs (Quinnan et al., 2022). For example, mobile soil washing facilities on-site increase the amount of soil able to be reused on a given project. The lack of space on site also limits the recycling of other CDW, as there is often insufficient space for on-site sorting. In Ghaffar et al.'s (2020) questionnaire, 44/100 respondents believe that increased recycling needs on-site operations to improve.

Plans for managing CDW should be finalised before a project begins, enhancing value by considering CE principles and ensuring management of waste is designed in. For example, a comprehensive MMP should address soil management and promote sustainability.

5.4.2 Insufficient Monitoring

If it is not known what proportion of recovered materials have the potential to be recycled, then achieving a CE is complex (Young, 2019) and establishing a market for recycled products difficult. The focus groups identified that there is a lack of monitoring once planning has been granted, and from thereon it is difficult to track whether CDW is correctly recycled/reused, and planning requirements met.

"It's very difficult to monitor what happens once planning approvals are granted because I step away from the process. Often, when I revisit a scheme, I find that monitoring hasn't occurred." – Participant 19, Planning Authority

Reduced waste volumes will lead to lower emissions from landfills and from transporting waste to landfill, whilst increased recycling reduces the need for new, raw materials, conserving natural resources. Monitoring would address the unknown movements of CDW, and the "*big unknown movements of soil*" (Participant 15, CL:AIRE).

Frameworks for monitoring should be developed to increase recycling rates, leading to more materials being recovered and reused, which is economically beneficial.

5.5 Recommendation: Education, Training and Stakeholder Engagement

5.5.1 Lack of Industry Knowledge

Limited awareness and education are considered major challenges in the industry. Adams et al. (2017) observed that designers, clients, and subcontractors are the stakeholders with lower CE awareness. In Ghaffar et al.'s (2020) questionnaire, 85/100 industry experts said "No", when asked if they were aware of CE concepts in the industry, and all 100 said CE concepts should be promoted more. Many focus group participants said that the industry lacked an understanding of the value of soil, and the benefits that go with it.

"People don't see it (soil) *as that beneficial resource and ecosystem service that is actually there."* – Participant 6, Industry

Soil disposal into landfill increases when "*the mixing of topsoils with subsoils creates an inability to reuse them*" (Participant 21, Local Authority) and is often caused by a lack of subcontractor knowledge of different soil horizons. Topsoil has a commercial value, *"Most topsoil is actually recycled and reused, so from construction sites, it's almost sold as a commodity"* (Participant 7, Planning Authority).

Education will help develop the market for recycled/reused CDW products (Kabirifar et al., 2020), helping meet government sustainability goals while also satisfying industry economic priorities. This must include the revised hierarchy (Figure 11), with a greater emphasis placed on stakeholders to consider CDW before project commencement and recycling/reuse can then be conducted without unanticipated time, space, and cost constraints.

Education should also cover the polices and guidelines which, if followed, do promote circularity within the industry, such as CL:AIRE DoW CoP for the sustainable use of soil, and the Protocol criteria for aggregates. Currently, insufficient stakeholder knowledge on the benefits of circular CDW management make voluntary guidelines and policies ineffective.

By increasing knowledge and awareness through education and training, CE principles can be promoted and practised by industry stakeholders.

5.5.2 Complex Regulations and Guidelines

An interviewee in Ghaffar et al.'s (2020) study acknowledges that whilst stricter regulation has driven the industry to more sustainable practices, "*the processes involved are sometimes overly bureaucratic to operate*". Guidelines can often be complex and confusing and may deter stakeholder participation in sustainable CDW management schemes (Caro et al., 2024).

Companies are more likely to follow voluntary codes if the guidance is easier to navigate than complex legislation. The focus groups expressed a need for comprehensive and 'user-friendly' guidelines, confirmed by Participant 22 (Industry) who emphasised that "*the DoW CoP is complicated"* and "*regulation and guidance need to be more straightforward".*

Provision of uncomplicated, straightforward, 'user-friendly' guidance would improve adoption of sustainable practices, including the reuse of soil.

5.5.3 Lack of Demand for Sustainable Practices

Clients are focused upon profitability, and it is perceived that CDW management increases costs and extends project timeframes, whilst recycled products are of lower quality and a higher price. In Jin et al.'s (2017) survey, 92% of respondents agreed that lack of demand from clients was to blame for difficulties in recycling CDW. If the client bears the cost of circularity, then the industry will complete construction and waste management in a sustainable way.

"If the customer says do it [...], we'll pay to do it. It will get done to a good quality that adds value." – Participant 1, Industry

In Ghaffar et al.'s (2020) study, an interviewee said: "*we change our methods for individual projects only when the client requests us to. [...] Without a law or request from a client, I have no incentive to use it or else I risk losing the job to other companies.*" Focus group participants highlighted the need for legislation to support circularity, as industry stakeholders are not self-motivated in moving toward change.

Mandates or incentives would increase the recycling/reuse of materials in projects and improving education would ensure clients understand the benefits of CE principles.

5.5.4 Insufficient Communication and Collaboration

Industry stakeholders feel governmental recognition for applying CE principles is lacking. All respondents in Ghaffar et al.'s (2020) study noted that they would be more motivated to recycle if they received more recognition, showing a lack of engagement between policymakers and industry. Jin et al.'s (2017) survey also stated that 94% of respondents agreed that effective communication enhances CDW recycling/reuse. Sustainable CDW management requires active participation, and effective communication, but a major barrier in the industry is insufficient communication and collaboration between the different stakeholder groups

(Domingo and Luo, 2017). This was demonstrated when a focus group discussion highlighted confusion between participants in interpretation of regulatory support of the CL:AIRE DoW CoP.

Enhanced collaboration between industry stakeholders and policymakers in the development of new regulations will ensure that both industry and government priorities are met.

6 Conclusion

This research aimed to show the main barriers and opportunities to implementing a CE in the industry, with a focus on aggregates recycling and soil reuse. The three methods employed highlighted key themes of: legislative, economic, technical and social, which then influenced a set of recommendations to improve circularity within the industry.

Current regulation is imbalanced, discouraging circularity, with overly restrictive regulations in relation to soil reuse and lenient regulation for waste disposal to landfill. As found by many studies, there are gaps in legislation, meaning CDW is often overlooked. Instead, voluntary codes of practice are looked to by industry practitioners but as these are not mandatory, they rely too heavily on the goodwill of users. Further, many government guidelines relating to sustainable waste management are outdated and show a lack of attention and priority by the Government. As enforcement of regulations is left to individual local authorities, there are often discrepancies across regions, impeding the effective implementation of CE principles. Therefore, the first recommendation is **Regulatory and Legislative Reform**. This involves reducing restrictions on soil reuse, setting national standards, making voluntary codes mandatory, and prioritising regulatory developments for sustainable waste management.

The second recommendation implements **Taxation and Incentives**, as a means of encouraging circularity. Current Landfill and Aggregates taxes are too low, making landfill a cheap and convenient option, and virgin materials the primary choice. The study found industry stakeholders are driven by profitability, therefore increasing the Landfill and Aggregates taxes and imposing penalties for poor CDW management would function as an effective deterrent to adopting unsustainable practices. In addition, the introduction of financial incentives will encourage the adoption of sustainable practices, thereby promoting CE principles. Economic policies are essential in ensuring that the most financially viable option for stakeholders aligns with the CE model, therefore making circularity the most workable, and preferred, strategy.

A key finding was the lack of industry trust in recycled products, which is hampering market developments. Therefore, the third recommendation is improving **Certifications, Specifications and Material Quality**. Currently, there is no mandatory regulatory quality certification process for recycled aggregates, meaning this CDW has no added-value as a product, and is often sent to landfill. Establishing an approved, mandatory certification process should improve the use and quality of recycled CDW. In addition, soil is currently assessed against an incorrect, and consequently restrictive, BS3882 specification and so it is recommended that a new standard for in-situ topsoil is issued to support reuse, encouraging circularity.

The fourth recommendation encourages improved **Project Planning and Management** to minimise waste generation. Several barriers impede circularity, including site space, distance to recycling facilities, time and cost constraints. To overcome these challenges waste management should be considered earlier in the process, so it can be designed in and improvements to on-site recycling practices promoted. The requirements of MMPs need to be more robust, and monitoring of CDW needs to be improved by developing monitoring frameworks, which address unknown movements of CDW, and increase recycling/reuse on sites.

There is a growing awareness for sustainable practices to be at the forefront of global development, yet this ideology has not been fully embraced by the sector as industry stakeholders lack motivation to adopt more circular practices. The research found this stems from a lack of knowledge of the value of CDW, and CE principles. As client demands are a major driver of construction activities, recommendation five is to influence behaviour through enhanced **Education, Training and Stakeholder Engagement**. Focus group participants stressed guidelines and regulations are too complex, and to increase the adoption of sustainable practices they need to be simplified and more ‘user-friendly’. In addition, or alternatively, legal mandates could enforce sustainable practices, ensuring that CE principles become the standard rather than a choice based on the opinion of stakeholders. Combining social strategies with stringent legal and economic measures ensures sustainable behaviour is adopted.

Limitations and Recommendations for Future Work

As mentioned in the introduction, the main limitation to this study is that it focused specifically on recycling and reuse as methods for sustainable CDW management. Therefore, future research should address how prevention and re-design can play a role in policy development, as these strategies are integral to comprehensive waste management. In addition, future studies should explore the effectiveness of various fiscal measures, including potential carbon pricing and taxes on CDW. Policy development would benefit from a collaborative, interdisciplinary approach, integrating perspectives from industry practitioners, policymakers, and academic researchers to form more robust and effective CDW management strategies.

To conclude, several challenges are hindering the implementation of a CE in the construction industry. However, with targeted improvements to legislative and fiscal measures, alongside the adoption of regulatory certification, new standards and improved education, the industry has the potential to successfully and effectively implement circular practices.

References

Adams, K.T., Osmani, M., Thorpe, T. and Thornback, J., 2017, February. Circular economy in construction: current awareness, challenges and enablers. In Proceedings of the institution of civil engineers-waste and resource management (Vol. 170, No. 1, pp. 15-24). Thomas Telford Ltd

Ajayi, S.O. and Oyedele, L.O., 2017. Policy imperatives for diverting construction waste from landfill: Experts' recommendations for UK policy expansion. *Journal of cleaner production*, *147*, pp.57-65.

Ajayi, S.O., Oyedele, L.O., Akinade, O.O., Bilal, M., Owolabi, H.A., Alaka, H.A. and Kadiri, K.O., 2016. Reducing waste to landfill: A need for cultural change in the UK construction industry. *Journal of Building Engineering*, *5*, pp.185-193.

Ajayi, S.O., Oyedele, L.O., Bilal, M., Akinade, O.O., Alaka, H.A., Owolabi, H.A. and Kadiri, K.O., 2015. Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. *Resources, Conservation and Recycling*, *102*, pp.101-112.

Ann, T.W., Poon, C.S., Wong, A., Yip, R. and Jaillon, L., 2013. Impact of construction waste disposal charging scheme on work practices at construction sites in Hong Kong. *Waste management*, *33*(1), pp.138-146.

Baldassarre, B., Schepers, M., Bocken, N., Cuppen, E., Korevaar, G. and Calabretta, G., 2019. Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives. Journal of cleaner production, 216, pp.446-460.

Bardos, P., Shao, X., Lal, J. and Yong, R., 2021. The regulatory policy and guidance regime for the management of land contamination in England. Remediation Journal, 31(4), pp.71-82.

Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R. and Maiti, S., 2014. Recycled aggregate from C&D waste & its use in concrete–A breakthrough towards sustainability in construction sector: A review. *Construction and building materials*, *68*, pp.501-516.

BERR, 2008. 'Strategy for Sustainable Construction June 2008' Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20121212135622/http://www.bis.gov.uk/files/file46535.pdf (Accessed: 2nd May 2024)

Braga, A.M., Silvestre, J.D. and de Brito, J., 2017. Compared environmental and economic impact from cradle to gate of concrete with natural and recycled coarse aggregates. *Journal of cleaner production*, *162*, pp.529-543.

BREEAM, 2024. Available at: https://breeam.com/ (Accessed: 23rd July 2024)

Burke, J., Byrnes, R., and Fankhauser, S., 2019. 'How to price carbon to reach net-zero emissions in the UK Policy Report' Available at: https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2019/05/GRI_POLICY-REPORT_How-to-price-carbon-to-reach-net-zero-emissions-in-the-UK.pdf (Accessed: 18th July 2024)

Caro, D., Lodato, C., Damgaard, A., Cristóbal, J., Foster, G., Flachenecker, F. and Tonini, D., 2024. Environmental and socio-economic effects of construction and demolition waste recycling in the European Union. *Science of the Total Environment*, *908*, p.168295.

Carter, S. and Henderson, L., 2005. Approaches to qualitative data collection in social science. *Handbook of health research methods: Investigation, measurement and analysis*, *1*, pp.215-230.

Caulfield, J., 2024.'How to Do Thematic Analysis | Guide & Examples'. Scribbr. Available at: https://www.scribbr.co.uk/research-methods/thematic-analysis-explained/ (Accessed: 25th July 2024)

CDE, n.d. 'Contaminated Soil Washing Equipment' Available at: https://www.cdegroup.com/applications/waste-recycling/contaminated-soils-washing (Accessed: 22nd August 2024)

Chen, K., Wang, J., Yu, B., Wu, H. and Zhang, J., 2021. Critical evaluation of construction and demolition waste and associated environmental impacts: A scientometric analysis. Journal of Cleaner Production, 287, p.125071.

CL:AIRE., 2011. The Definition of Waste: Development Industry Code of Practice. Available at: https://www.claire.co.uk/component/phocadownload/category/8-initiatives?download=212:definitionof-waste-development-industry-code-of-practice (Accessed: 23rd July 2024)

Construction Leadership Council, 2021. 'Launch of the Green Construction Board Zero Avoidable Waste Routemap' Available at: https://www.constructionleadershipcouncil.co.uk/wpcontent/uploads/2021/07/ZAW-Routemap-launch-22.7.21-FINAL.pdf (Accessed: 23rd July 2024)

Crawford, R.H., Mathur, D. and Gerritsen, R., 2017. Barriers to improving the environmental performance of construction waste management in remote communities. *Procedia engineering*, *196*, pp.830-837.

Creswell, J. (2014) Research design: qualitative, quantitative, and mixed methods approaches. 4th Ed. Thousand Oaks: SAGE Publications Inc

De Brito, J. and Silva, R., 2016. Current status on the use of recycled aggregates in concrete: Where do we go from here?. *RILEM Technical Letters*, *1*, pp.1-5.

Defra., 2009. 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' Available at: https://assets.publishing.service.gov.uk/media/5b2264ff40f0b634cfb50650/pb13298-code-of-practice-090910.pdf (Accessed: 23rd July 2024)

Defra., 2011 'Guidance on applying the Waste Hierarchy' Available at: https://assets.publishing.service.gov.uk/media/5a795abde5274a2acd18c223/pb13530-waste-hierarchy-guidance.pdf (Accessed: 23rd July 2024)

Defra., 2013. 'Proposed repeal of construction Site Waste Management Plan Regulations (2008) Summary of responses and Government response' Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/237398/site-waste-manage-consult-sum-resp-20130830.pdf (Accessed: 23rd July 2024)

Defra., 2021. 'Waste Management Plan for England' Available at: https://assets.publishing.service.gov.uk/media/60103f71d3bf7f05bc42d294/waste-management-plan-for-england-2021.pdf (Accessed: 23rd July 2024)

Defra., 2023. 'Environmental Improvement Plan 2023' Available at: https://assets.publishing.service.gov.uk/media/64a6d9c1c531eb000c64fffa/environmental-improvement-plan-2023.pdf (Accessed: 23rd July 2024)

DFA, 2022. 'What is soil organic carbon?' Available at: https://www.agric.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon#:~:text=Soil%20organic%20carbon%20is%20a,biological%20function%20of%20agricultural%20soils. (Accessed: 24th August 2024)

Di Maria, A., Eyckmans, J. and Van Acker, K., 2018. Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making. *Waste management*, *75*, pp.3-21.

Domingo, N. and Luo, H.A.O., 2017. Canterbury earthquake construction and demolition waste management: issues and improvement suggestions. *International journal of disaster risk reduction*, *22*, pp.130-138.

Environment Act 2021. Available at: https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted (Accessed: 23rd July 2024)

Environment Agency., 2019. 'The state of the environment: soil' Available at: https://assets.publishing.service.gov.uk/media/5cf4cbaf40f0b63affb6aa55/State_of_the_environment_ soil_report.pdf (Accessed: 27th July 2024)

Environment Agency., 2021 'Waste Classification Technical Guidance WM3' Available at: https://assets.publishing.service.gov.uk/media/6152d0b78fa8f5610b9c222b/Waste_classification_tech nical_guidance_WM3.pdf (Accessed: 23rd July 2024)

Environmental Protection Act 1990. Available at: https://www.legislation.gov.uk/ukpga/1990/43/contents (Accessed: 23rd July 2024)

Esa, M.R., Halog, A. and Rigamonti, L., 2017. Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *Journal of Material Cycles and Waste Management*, *19*, pp.1144-1154.

Eurofins Agro., n.d. 'How do you calculate how much CO2 is captured in organic matter?' Available at: https://www.eurofins-agro.com/en/faq/how-do-you-calculate-how-much-co2-is-captured-in-organic-matter#:~:text=To%20calculate%20climate%20impact%2C%20soil,tons%20of%20CO%202%20capture. (Accessed: 10th August 2024)

Ferriz-Papi, J.A., Lee, A. and Alhawamdeh, M., 2024. Examining the Challenges for Circular Economy Implementation in Construction and Demolition Waste Management: A Comprehensive Review Using Systematic Methods. *Buildings*, *14*(5), p.1237.

Freeman, R.E., 2010. *Strategic management: A stakeholder approach*. Cambridge university press.

Gálvez-Martos, J.L., Styles, D., Schoenberger, H. and Zeschmar-Lahl, B., 2018. Construction and demolition waste best management practice in Europe. *Resources, conservation and recycling*, *136*, pp.166-178.

Ghaffar, S.H., Burman, M. and Braimah, N., 2020. Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of cleaner production*, *244*, p.118710.

Ginga, C.P., Ongpeng, J.M.C. and Daly, M.K.M., 2020. Circular economy on construction and demolition waste: A literature review on material recovery and production. *Materials*, *13*(13), p.2970.

Gov.uk, 2024. 'Landfill Tax rates' Available at: https://www.gov.uk/government/publications/rates-and-allowances-landfill-tax/landfill-tax-rates-from-1-april-2013 (Accessed: 11th August 2024)

Horodytska, O., Kiritsis, D. and Fullana, A., 2020. Upcycling of printed plastic films: LCA analysis and effects on the circular economy. Journal of Cleaner Production, 268, p.122138.

Hossain, M.U., Ng, S.T., Antwi-Afari, P. and Amor, B., 2020. Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable and Sustainable Energy Reviews*, *130*, p.109948.

Hossain, M.U., Poon, C.S., Lo, I.M. and Cheng, J.C., 2016. Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA. *Resources, Conservation and Recycling*, *109*, pp.67-77.

Ibrahim, M.I.M., 2016. Estimating the sustainability returns of recycling construction waste from building projects. Sustainable Cities and Society, 23, pp.78-93.

ICEC-MCM, 2023. 'Policy Brief – Landfill Tax - December 2023'

Jin, R., Li, B., Zhou, T., Wanatowski, D. and Piroozfar, P., 2017. An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. *Resources, Conservation and Recycling*, *126*, pp.86-98.

Kabirifar, K., Mojtahedi, M., Wang, C. and Tam, V.W., 2020. Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of cleaner production*, *263*, p.121265.

Kaliyavaradhan, S.K. and Ling, T.C., 2017. Potential of CO2 sequestration through construction and demolition (C&D) waste—An overview. *Journal of CO2 Utilization*, *20*, pp.234-242.

Lampris, C., Lupo, R. and Cheeseman, C.R., 2009. Geopolymerisation of silt generated from construction and demolition waste washing plants. *Waste Management*, *29*(1), pp.368-373.

Liu, J., Gong, E. and Wang, X., 2022. Economic benefits of construction waste recycling enterprises under tax incentive policies. *Environmental science and pollution research*, *29*(9), pp.12574-12588.

Low, J.K., Wallis, S.L., Hernandez, G., Cerqueira, I.S., Steinhorn, G. and Berry, T.A., 2020. Encouraging circular waste economies for the New Zealand construction industry: Opportunities and barriers. Frontiers in Sustainable Cities, 2, p.35.

Lupo, R., Tyrer, M., Cheeseman, C.R. and Donatello, S., 2020. Manufactured aggregate from waste materials. In *Sustainable Construction Materials and Technologies* (pp. 763-767). CRC Press.

Magnusson, S., Lundberg, K., Svedberg, B. and Knutsson, S., 2015. Sustainable management of excavated soil and rock in urban areas–a literature review. *Journal of Cleaner Production*, *93*, pp.18-25.

Marino, A. and Pariso, P., 2016. From linear economy to circular economy: research agenda. International Journal of Research in Economics and Social Sciences, 6225(6), pp.2249-7382.

Martin, A. and Scott, I., 2003. The effectiveness of the UK landfill tax. *Journal of environmental planning and management*, *46*(5), pp.673-689.

Menegaki, M. and Damigos, D., 2018. A review on current situation and challenges of construction and demolition waste management. *Current opinion in green and sustainable chemistry*, *13*, pp.8-15.

Mineral Products Association., 2023. 'Profile of the UK Mineral Products Industry' Available at: https://mineralproducts.org/MPA/media/root/Publications/2023/Profile_of_the_UK_Mineral_Products_Industry_2023.pdf (Accessed: 21st August 2024)

MPA, 2022. 'Aggregates recycling reaching 'upper limit' says MPA'. Available at: https://mineralproducts.org/News-CEO-Blog/2022/release07.aspx (Accessed: 10th July 2024)

Noble, H. and Heale, R., 2019. Triangulation in research, with examples. *Evidence-based nursing*, *22*(3), pp.67-68.

Noor, T., Javid, A., Hussain, A., Bukhari, S.M., Ali, W., Akmal, M. and Hussain, S.M., 2020. Types, sources and management of urban wastes. In *Urban ecology* (pp. 239-263). Elsevier.

Panjwani, A., 2023. 'Industries in the UK' Available at: https://commonslibrary.parliament.uk/research-briefings/cbp-8353/ (Accessed: 19th July 2024)

Papamichael, I., Voukkali, I., Loizia, P. and Zorpas, A.A., 2023. Construction and demolition waste framework of circular economy: A mini review. Waste Management & Research, 41(12), pp.1728- 1740.

Park, J. and Tucker, R., 2017. Overcoming barriers to the reuse of construction waste material in Australia: a review of the literature. *International Journal of Construction Management*, *17*(3), pp.228-237.

Peng, Z., Lu, W. and Webster, C., 2022. If invisible carbon waste can be traded, why not visible construction waste? Establishing the construction waste trading 'missing market'. *Resources, Conservation and Recycling*, *187*, p.106607.

Plimmer, M., 2023. New Guidance on Classification of Waste Soil from Construction. Available at: https://www.gea-ltd.co.uk/blog/detail/new-guidance-on-classification-of-waste-soil-from-construction.html (Accessed: 23rd July 2024)

Polkinghorne, D.E., 1989. Phenomenological research methods. In *Existential-phenomenological perspectives in psychology: Exploring the breadth of human experience* (pp. 41-60). Boston, MA: Springer US.

Pomponi, F. and Moncaster, A., 2017. Circular economy for the built environment: A research framework. *Journal of cleaner production*, *143*, pp.710-718.

Purchase, C.K., Al Zulayq, D.M., O'Brien, B.T., Kowalewski, M.J., Berenjian, A., Tarighaleslami, A.H. and Seifan, M., 2021. Circular economy of construction and demolition waste: A literature review on lessons, challenges, and benefits. *Materials*, *15*(1), p.76.

Quinnan, J., Morrell, C., Nagle, N. and Maynard, K.G., 2022. Ex situ soil washing to remove PFAS adsorbed to soils from source zones. *Remediation Journal*, *32*(3), pp.151-166.

Rønning, A., Engelsen, C.J., Norman, S.H., Mooselu, M.G., Døssland, L.T. and Thorstensen, R.T., 2024, June. Beneficial use of recycled aggregates from concrete sludge using a new dry washing technology. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1363, No. 1, p. 012102). IOP Publishing.

Rose, C.M. and Stegemann, J.A., 2018. From waste management to component management in the construction industry. *Sustainability*, *10*(1), p.229.

Shooshtarian, S., Caldera, S., Maqsood, T., Ryley, T. and Khalfan, M., 2022. An investigation into challenges and opportunities in the Australian construction and demolition waste management system. *Engineering, construction and architectural management*, *29*(10), pp.4313-4330.

Silva, R.V., De Brito, J. and Dhir, R.K., 2017. Availability and processing of recycled aggregates within the construction and demolition supply chain: A review. *Journal of Cleaner Production*, *143*, pp.598-614.

Silva, R.V., De Brito, J. and Dhir, R.K., 2019. Use of recycled aggregates arising from construction and demolition waste in new construction applications. *Journal of Cleaner Production*, *236*, p.117629.

Söderholm, P., 2011. Taxing virgin natural resources: Lessons from aggregates taxation in Europe. *Resources, conservation and recycling*, *55*(11), pp.911-922.

Soils in Planning and Construction Task Force., 2022 'Building on soil sustainability: Principles for soils in planning and construction'. Available at: https://wp.lancs.ac.uk/sustainablesoils/files/2022/09/Soils-in-Planning-and-Construction-Sept-22.pdf (Accessed: 22nd July 2024)

Soto-Paz, J., Arroyo, O., Torres-Guevara, L.E., Parra-Orobio, B.A. and Casallas-Ojeda, M., 2023. The circular economy in the construction and demolition waste management: A comparative analysis in emerging and developed countries. Journal of Building Engineering, p.107724.

Stelzer, V.B., da Silva, A.A., Penteado, C.S.G. and Cristale, J., 2023. Organophosphate esters in inert landfill soil: A case study. Waste Management & Research, p.0734242X231190813.

Tafesse, S., Girma, Y.E. and Dessalegn, E., 2022. Analysis of the socio-economic and environmental impacts of construction waste and management practices. *Heliyon*, *8*(3).

Tam, V.W., Soomro, M. and Evangelista, A.C.J., 2018. A review of recycled aggregate in concrete applications (2000–2017). *Construction and Building materials*, *172*, pp.272-292.

The Environmental Permitting (England and Wales) Regulations 2016. Available at: The Environmental Permitting (England and Wales) Regulations 2016 (legislation.gov.uk) (Accessed: 23rd July 2024)

The Site Waste Management Plans Regulations 2008. Available at: https://www.legislation.gov.uk/uksi/2008/314/contents/made (Accessed: 23rd July 2024)

The Waste (Circular Economy) (Amendment) Regulations 2020. Available at: https://www.legislation.gov.uk/uksi/2020/904/contents/made (Accessed: 23rd July 2024)

The Waste (England and Wales) Regulations 2011. Available at: https://www.legislation.gov.uk/uksi/2011/988/contents/made (Accessed: 23rd July 2024)

The Waste Framework Directive 2008/98/EC. Available at: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX%3A02008L0098-20180705 (Accessed: 23rd July 2024)

Umar, U.A., Shafiq, N., Malakahmad, A., Nuruddin, M.F. and Khamidi, M.F., 2017. A review on adoption of novel techniques in construction waste management and policy. *Journal of Material Cycles and Waste Management*, *19*, pp.1361-1373.

Van Ewijk S, Stegemann JA. Limitations of the waste hierarchy for achieving absolute reductions in material throughput. Journal of Cleaner Production. 2016 Sep 20;132:122-8.

WRAP., 2013. 'Quality Protocol: Aggregates from inert waste: End of waste criteria for the production of aggregates from inert waste' Available at: https://assets.publishing.service.gov.uk/media/65fd7426f1d3a0001132add0/CD1.Y_Quality_Protocol.__Aggregates_from_inert_waste.__End_of_waste_criteria_for_the_production_of_aggregates_from_inert_waste._WRAP_October_2013..pdf (Accessed: 2nd August 2024)

Young, L.B., 2019. MSc in Environmental Protection and Management. *Regulation*, *3*, p.13.

Appendices

Appendix 1: Literature Review

Note to markers: the Literature Review is appended here for reference and is not intended for marking. This was agreed with the module convenor and my supervisor, as reference to it was determined necessary in this study.

1 Introduction

The construction industry is the backbone to economic development worldwide; it provides job opportunities and socioeconomic growth (Tafesse et al., 2022). Globally, it is the largest consumer of raw materials and the greatest contributor to waste production, generating one third of all waste (Ginga et al., 2020). Construction waste has a negative impact on the environment, causing soil and water contamination, landscape deterioration, environmental degradation and significantly contributing to global greenhouse emissions (40% of global carbon dioxide emissions) (Tafesse et al., 2022). Of particular concern in the UK is that "more than half of construction and demolition waste (CDW) is disposed directly into landfill" (Ghaffar et al., 2020, p. 1).

This review assesses current literature to gain an understanding of what CDW is, the policies and guidance in place and describes the current construction economy which is dominated by linear processes. It explores the concept of a circular economy, where waste is reduced to a minimum by replacing the 'end-of-life' concept with reducing, reusing, recycling, and recovering materials (Ghaffar et al., 2020). This review discusses the benefits and potential challenges to the construction sector of adopting a circular economy, using case studies, and then outlines the aims and objectives of the dissertation this literature review supports.

2 What constitutes construction waste?

CDW refers to the debris produced during the construction process and also the material and debris from demolition and excavation works (Noor et al., 2020) (Fig. 1). CDW is classified into two main categories: hazardous and non-hazardous (further subdivided into inert and non-inert) (Stelzer et al., 2023), in accordance with the Technical Guidance WM3: Waste Classification (Environment Agency, 2021a).

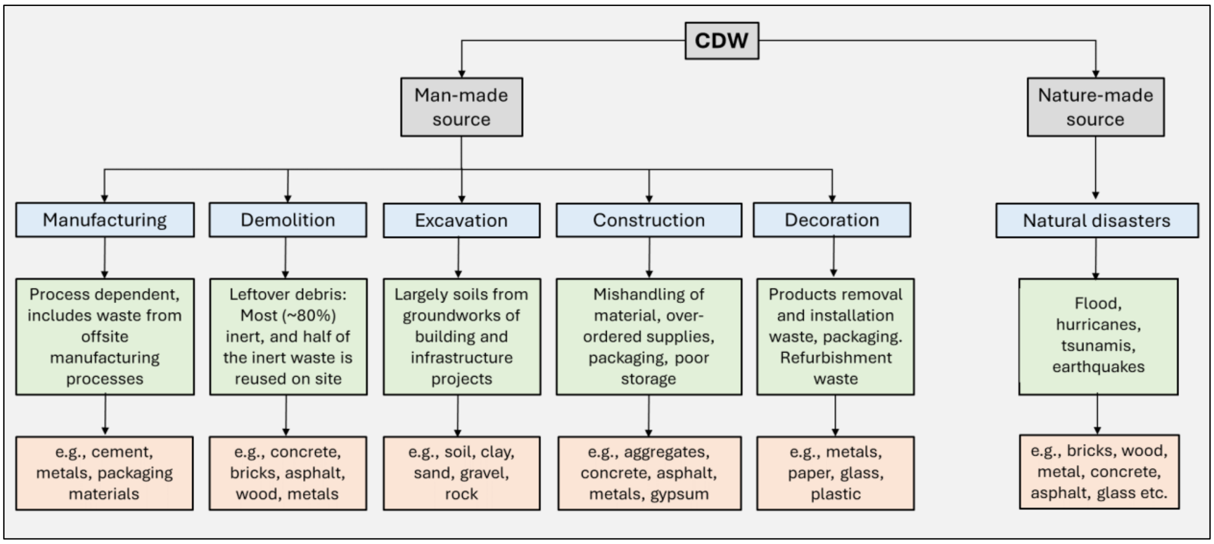

Figure 13: The different sources of CDW and examples (adapted from Chen et al., 2021; Papamichael et al., 2023; Ginga et al., 2020; Construction Leadership Council, 2021).

The definition of CDW in literature is varied and it is evident that excavation waste (soil) is often excluded. Coronado et al. (2011) define CDW as “concrete, asphalt, wood, metal, drywall, and smaller amounts of packaging materials, such as paper and plastic”, notably excluding excavated soil; similarly, Hiete et al. (2011) also exclude excavated soil and rock from the definition. By way of contrast, Noor et al. (2020) include excavated soil within their definition, together with green wastes. Soto-Paz et al. (2023) state that in the European Union 85% of construction waste is concrete, ceramic and masonry whilst Defra identified that around 43% of construction waste in the UK is soil (Defra, 2021). This lack of consideration of soil as a constituent of CDW also impacts construction management. Zhang et al.’s (2022) study on waste management in Europe excluded soil in their framework; this diminishes its role in CDW and prevents effective management of the total waste stream.

3 When is soil classed as a waste?

A major challenge in the construction industry is waste classification (Environment Agency, 2021b). In England and Wales, any soil which is discarded, is intended or is required to be discarded, is considered to be a waste product. If waste soil is being removed from a site, then it must be classified as either hazardous or non-hazardous (Plimmer, 2023). Soil is not classed as a waste if it is uncontaminated natural soil which is intended to be reused on the same site, but if reuse is intended on a different site, then certain permits/plans are needed (this is discussed further in Section 4). In several countries, such as in Norway and Sweden (Hale et al., 2021) and Scotland (Plimmer, 2023), once soil is removed from a site it is immediately classified as waste.

4 Policies and Guidance

The are many existing policies and guidance documents which address waste in construction, including some specific to soil management. Figure 2 outlines the key pieces of legislation, policy and guidance in place as of May 2024, relevant to this review.

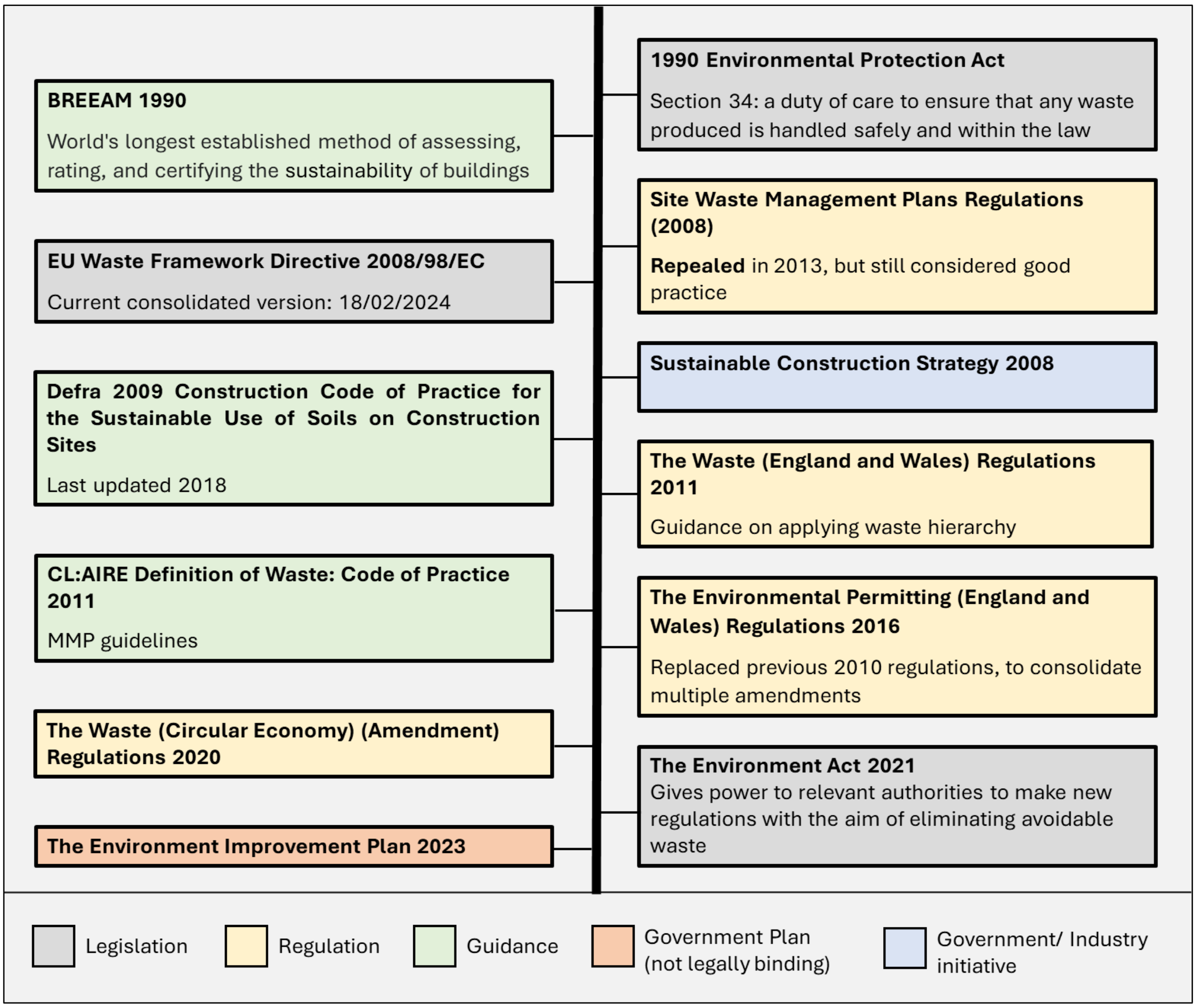

Figure 14: Key pieces of legislation, policy and guidance relating to CDW (BREEAM, 2024; BERR, 2008; CL:AIRE, 2011; Defra, 2009; Defra, 2013; Defra, 2021; Defra, 2023; Environment Act 2021).

Underlying UK waste management policy is the EU Waste Framework Directive 2008/98/EC (WFD), which was implemented through the Waste (England and Wales) Regulations 2011 (Ghaffar et al., 2020). It introduced the waste hierarchy (Fig. 3) into European policy, a guide to sustainable waste management, with priorities based upon what is best for the environment. Van Ewijk and Stegemann (2016) define the waste hierarchy as “a preferential order of waste treatment options that aim to reduce environmental impacts by prioritising prevention, reuse, recycling, and recovery over landfill”.

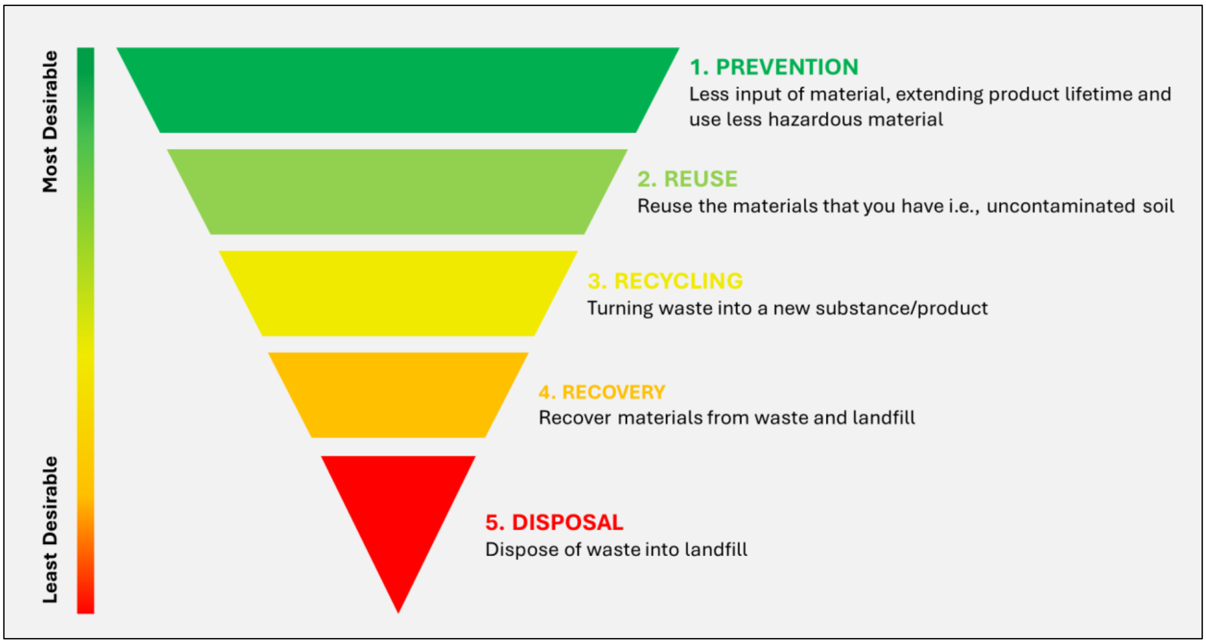

Figure 15: Waste hierarchy, ranking waste management options from most to least desirable (adapted from Defra, 2011).

Van Ewijk and Stegemann (2016) argue that regulations often emphasise the 'practical application' of the waste hierarchy, such as the "technical feasibility, economic viability and environmental protection" achievable. This allows regulation to undermine the hierarchy, and support the less environmentally desirable options (i.e., disposal), by facilitating a claim of lack of practicality. UK Landfill Tax was introduced to encourage diversion of waste away from landfill, however, one tonne of uncontaminated soil costs £3 to landfill, making it a cheap and convenient waste management choice (ICEC-MCM, 2023), thereby undermining its original purpose. Rose and Stegemann (2018) also state that the decision to dispose of CDW often goes unchallenged given the inclusion of disposal within the waste hierarchy. The Sustainable Construction Strategy 2008 (BERR, 2008) sets targets to divert CDW from landfill, however, Ghaffar et al. (2020) argue that even with strategies in place, landfill remains a dominant method of handling waste, and that CDW management is ineffective.

Adams et al. (2017) identified that one of the largest challenges to those in the construction industry was the ambiguity in regulations relating to the end-of-life of CDW. Policy has a greater focus on landfill diversion, which is to the detriment of CDW reuse. Regulations were introduced in 2008 with the purpose of identifying potential waste generated throughout the life of a construction project and establish waste management actions across the waste hierarchy including re-use, recycling, recovery, and disposal (Defra, 2009). These included Site Waste Management Plans. However, these Regulations were repealed by the Government in 2013 as part of the 'Red Tape Challenge' to "remove unnecessary legislation to free-up business" and allow businesses to save costs (Defra, 2013). The repeal process noted that further efforts were needed to reduce waste, with more thought given to the top priorities of the waste hierarchy i.e., waste prevention (Defra, 2013).

Under the terms of the Environmental Permitting (England and Wales) Regulations 2016, soil waste must be sent to a permitted off-site waste receiver (holding an Environmental Permit (EP)) for disposal, and landfill tax paid. An EP is either standard or bespoke, depending on the complexity of the scenario (Bardos et al., 2021). If soil waste is low-volume (less than 1000 tonnes) and low-risk, an exception can be granted by the Environment Agency commonly known as a U1 Exemption (Plimmer, 2023; Bardos et al., 2021).

CL:AIRE initiated the Definition of Waste: Code of Practice (DoWCoP) to provide a clear and consistent process for the "reuse of excavated waste without permitting in England and Wales" (Bardos et al., 2021, p74). A requirement in the DoWCoP is a Materials Management Plan (MMP), which allows the re-use of soil without the need for EP disposal or exemption.

As outlined in Defra's 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' (2009) (a National Planning Guidance), if excess soil from a site is disposed of without an EP, Waste Exemption or a MMP, it would be classed as unauthorised under the WFD. The Code of Practice further emphasises the need for soil resource surveys and a soil resource plan as part of a MMP. The Government failed to publish a revised Code of Practice in 2023 (previously expected in 2022) (Soils in Planning and Construction Task Force, 2022). This continued pushback highlights how legislation (or lack of) can undermine a progressive policy on CDW sustainability.

In the construction industry, the main British Standard for soils is BS 3882:2015 Specification for topsoil. This sets out the requirements for topsoil classification and composition, and advises about topsoil handling, to ensure soil is not degraded during excavation, delivery or placement (Soils in Planning and Construction Task Force, 2022).

The Environmental Improvement Plan 2023 outlines plans to develop a ‘Soil Re-Use and Storage Depot scheme’, to stop soil (otherwise classed as waste) going to landfill, with a greater focus on its reuse (Defra, 2023).

BREEAM (not mandatory in UK) is a certification that focuses on planning to minimise waste in construction projects (BREEAM, 2024).

5 Why is this topic important?

The construction industry accounts for 6.2% (around £117 billion) of the UK’s economic output and 6.2% of the workforce (Panjwani, 2023). It is instrumental in generating economic growth and continues to expand to meet the rising demand for infrastructure.

The industry also “generates 62% of UK waste, and accounts for 40% of waste sent to landfill” (ICEC-MCM, 2023, p1). In UK statistics, CDW comprises construction and demolition waste, with excavation waste separately reported. In 2018, it was claimed that of the 68 million tonnes of construction and demolition waste reported, 92% was recovered, with only 5 million tonnes sent to landfill. Yet, of the 58 million tonnes of excavation waste reported, 29 million tonnes were sent to landfill (50%) (ICEC-MCM, 2023). As previously noted, excluding soils from construction waste classification provides uncertainty as to the amount of waste generated and yet it is only with a clear understanding of what constitutes CDW, will it be possible to manage and reduce the waste stream.

5.1 Economic Implications

Ajayi et al. (2015) identified that reducing UK CDW by as little as 5% could save up to £130 million. Whilst CDW (excluding soil) has potential to be financially beneficial, the largest opportunity lies within soil sustainability.

When looking at the wider function of soil, the cost of soil loss to landfill in the UK is around £1.5 billion per year (Soils in Planning and Construction Task Force, 2022) and whilst environmental issues are the drivers of government action, industry professionals are usually influenced by financial gains (Ajayi et al., 2015). Downcycling (discussed further in Section 6.1) CDW can make a project seem more commercially viable, yet the ecological value placed on materials is rarely evaluated during the construction process (ICEC-MCM, 2023). To change this view, sustainable management practices must be more financially appealing to stakeholders than the disposal of CDW to landfill.

5.2 Environmental and Social Implications

The most common CDW management method is still landfilling (Ibrahim, 2016), which poses a threat not only to the environment, but also to public health. The conventional method of disposal to landfill ultimately leads to the saturation of landfill capacity (Ibrahim, 2016) when large proportions of CDW have further value. Soto-Paz et al. (2023) noted that of the 35% of global CDW landfilled, 75% has potential added value.

A major benefit to promoting sustainability within the construction industry is to reduce the amount of waste (including soil) going to landfill. Soil is a non-renewable resource as it takes hundreds of years for 1cm of soil to form (Hernandez-Soriano and Junod, 2019), and this can be lost within hours of a construction project starting. Soil is an essential natural resource, and is vital for human survival (Walsh et al., 2019), delivering an array of ecosystem services (O'Riordan et al., 2021). Whilst soil is returned to the ground in landfill, its benefits are lost as the impermeable landfill cell degrades the soil, and destroys its structure (ICEC-MCM, 2023).

Non-hazardous soil can be reused, and its many ecosystem functions retained. In the UK in 2018, of the 29 million tonnes of soil sent to landfill, only 0.6% was classified as hazardous (Soils in Planning and Construction Task Force, 2022). Therefore, a substantial proportion has potential to be re-used, helping to meet sustainability goals. Hale et al. (2021) state that sending uncontaminated excavated soil to landfill goes against the UN Sustainable Development Goal 11. Ogunmakinde et al. (2022) also highlight that the construction industry presents a major challenge for promoting sustainability goals due to its staggering resource consumption and waste generation.

Soil is the largest terrestrial store of carbon (European Commission, 2011), and one of its primary functions is carbon sequestration. UK soil contains around 10 billion tonnes of carbon, an amount equivalent to 80 years' worth of greenhouse gas (GHG) emissions (Environment Agency, 2019). When soil is excavated a considerable proportion of the carbon is released back into the atmosphere (Soils in Planning and Construction Task Force, 2022). Waste landfill itself produces about 91 kg of GHG per ton of waste (Liu et al., 2023). If CDW was sustainably managed, with a greater focus on recovery and reuse, the environmental benefits of soil could be retained and emissions from landfilled CDW reduced.

6 From a Linear to Circular Economy in Construction

Throughout the life cycle of construction, little consideration is given to waste management, with 50% of CDW produced from the end-of-life phase, as many materials are not reused (Benachio et al., 2020). The construction industry needs more sustainable practices, as many raw materials used are from finite resources.

6.1 Linear Economy

The construction industry currently follows a Linear Economy (LE) framework, a straight line from extraction of resources to disposal of waste (Fig. 4). The main focus is financial (obtain a profit), and waste management is not a priority (Low et al., 2020), with raw materials viewed as single use only.

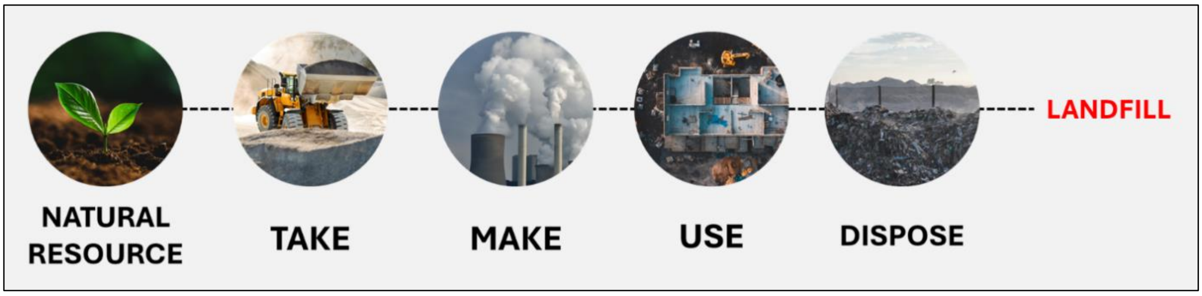

Figure 16: Linear Economy (adapted from Marino and Pariso, 2016).

The WFD highlights recycling as one of the main methods of waste management. Currently, the recycling method most widely used is the crushing of secondary aggregates (Zhang et al., 2020). Ajayi et al. (2015) note that recycling decreases the use of raw materials and ensures that waste materials are reprocessed and not disposed of in landfill. However, Zhang et al. (2020) conclude that many methods of recycling in the construction industry are actually downcycling. Horodytska et al., 2020 state that whilst downcycling is labelled as a form of 'recycling', the process is closer to the LE model, as the final recycled product is significantly less valuable and after a few cycles would, in any case, need to be landfilled. Therefore, whilst the construction industry appears to be taking steps towards more sustainable practices, ultimately it is still following a LE approach.

6.2 Circular Economy

In comparison to LE, a model known as the Circular Economy (CE) has gained attention given its consideration of waste as a useful resource, and not just something to be disposed of (Ginga et al., 2020). The principles of a CE are to replace the 'end-of-life' concept with reducing, reusing, recycling, and recovering materials (Ghaffar et al., 2020) (Fig.5). It strengthens sustainability (Hartley et al., 2023) by preserving natural resources (Purchase et al., 2021), and keeping materials in use as long as possible, thereby extending their value (Nasir et al., 2017). It involves a shift in thinking from waste as something to dispose of, to instead waste as a potentially useful resource (Ginga et al., 2020).

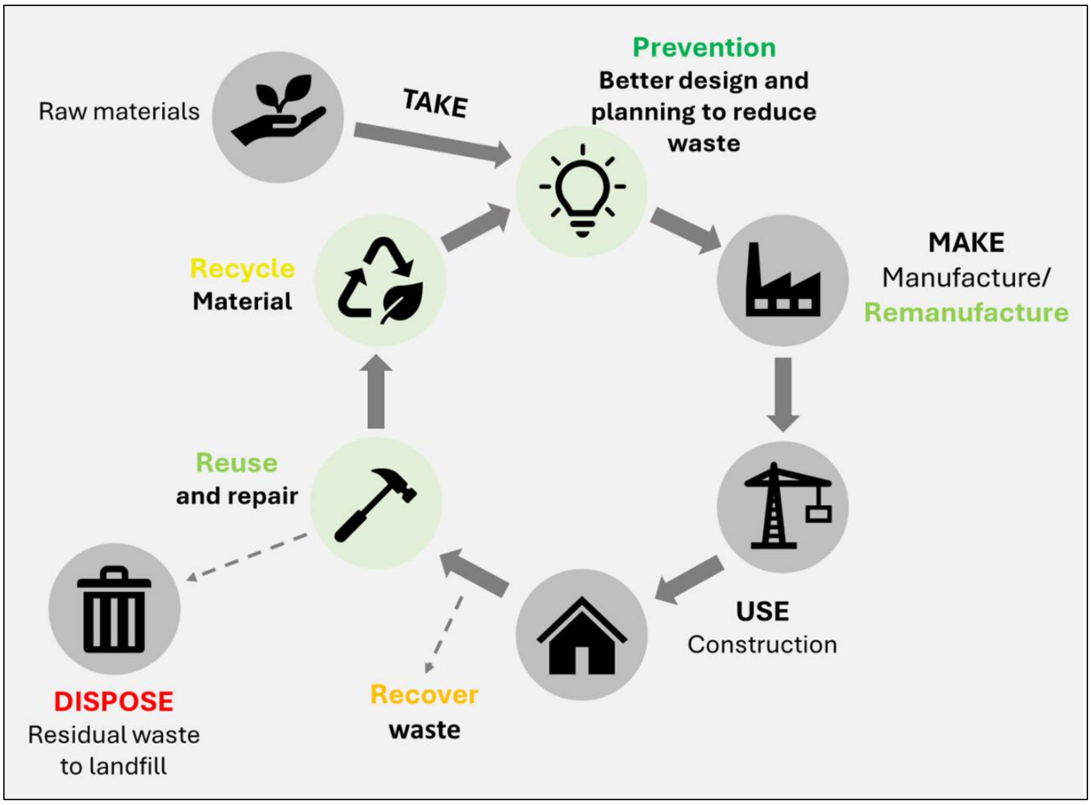

Figure 17: Ideal Circular Economy structure based upon analysis of literature (adapted from Ginga et al., 2020; Ghaffar et al., 2020; DTU, n.d.).

Baldassarre et al. (2019) suggest that CE is an attractive model as it not only promises to reduce resource use and prioritise environmental goals, but also promotes economic growth and goals, an essential requirement for business engagement. Within the construction industry there are three main framework strategies to a CE: narrowing resource loops (less material input equals less waste output), slowing resource loops (extending 'use' phase of materials), and closing the resource loop (including recycling and reuse) (Ginga et al., 2020).

6.2.1 Benefits

CE within construction has many benefits, ranging from economic to social to environmental. As new markets open up for using CDW (e.g., recycling into new construction material), other sources of revenue become available to businesses (Ibrahim, 2016). Soto-Paz et al. (2023) describe the reduced risk of environmental degradation, and public health impacts from limiting CDW in landfill. Chittoori et al. (2012) describe the economic and environmental benefits of reusing excavated soil, which can reduce the climatic impacts and material management costs by 85%. One of the greatest benefits of a CE approach is the potential carbon savings which occur through reusing construction waste. McKinsey & Company and the World Economic Forum reported that if a CE were established, the carbon dioxide emissions from the construction industry could be reduced by up to 75% by 2050 (Circular, 2024). Indirect benefits include lower emissions from vehicles, given reduced transportation of waste to landfill (Ginga et al., 2020).

6.2.2 Challenges

Purchase et al. (2021) identified that the main challenges to implementing a successful CE fall into the following categories: legal, economic, technical, and social/behavioural. This literature review found that most government policies inadvertently support disposal due to legislative gaps and relatively low landfill charges. Ghufran et al. (2022) emphasise that policy support and incentive schemes are vital in implementing a CE in the construction industry. Yu et al. (2020) also suggest a lack of incentives in government policy and regulation is a major challenge in implementing CE methods, such as recycling. Therefore, it is clear that current legislation lacks the guidance and tools needed to promote circularity. Munaro and Tavares (2023) highlight the inflexibility in building regulations, making the use of recycled/recovered material more challenging.

Adams et al. (2017) identified that the highest ranked challenge for stakeholders was financial uncertainty, a sentiment shared by 24% of respondents in a study conducted by Munaro and Tavares (2023). Stakeholders lack incentive to design for end-of-life issues in construction projects, taking the easier route of disposal often due to financial motivations (Adams et al., 2017). Raw materials are cheaper than their recycled counterparts, and the recovery and recycling of materials has to be financially and logistically workable (Munaro and Tavares, 2023; Adams et al., 2017), with many stating that there is little economic benefit associated with recycling (Husgafvel and Sakaguchi, 2021). Smaller companies lack the funds necessary to implement CDW management (e.g., deconstruction, separating, treating, transportation, and storage) (Purchase et al., 2021; Munaro and Tavares, 2023). To engage with circularity, commercial viability is an essential for stakeholders (Adams et al., 2017).

Low et al. (2020) observed that in a closed CE, over time the supply of quality reclaimed materials can decrease and be of inferior quality to raw materials. As they are considered lower quality, technological advancements are needed to achieve circularity to encourage use of recycled materials. In addition, there are limited tools available to identify, classify and certify recovered material (Munaro and Tavares, 2023).

Husgafvel and Sakaguchi (2021) referenced a general lack of understanding of CE opportunities. Similarly, Hossain et al. (2020) highlighted the lack of information within the construction sector on the importance of a CE, and limited knowledge amongst stakeholders of CE principles. Stakeholders emphasised that delivery by example, through awareness campaigns and best practice case studies are necessary (Adams et al., 2017).

7 Case Studies

Different approaches to CE, and the disparity in CDW definitions is explored through the use of case studies.

Austria: works with its own national list of waste, and strictly separates soil and stones from construction and demolition waste (European Commission, 2015). The majority of construction and demolition waste is recovered, and it was ranked as having one of the highest recycling rates by the European Environment Agency in 2021 (EEA, 2023).

The classification of CDW plays a crucial role in how effectively a country is deemed to apply a circular approach, as whilst Austria recycled almost 86% (7.2 Mt) of CDW in 2013 (Fig. 6a), seemingly showcasing a circular approach, its lack of inclusion of excavated soil and the consequent landfilling of this material (14.2 Mt, 53% of total) (Fig. 6b) (European Commission, 2015) indicates sustainable CDW management is not being fully addressed, and a true CE is missing.

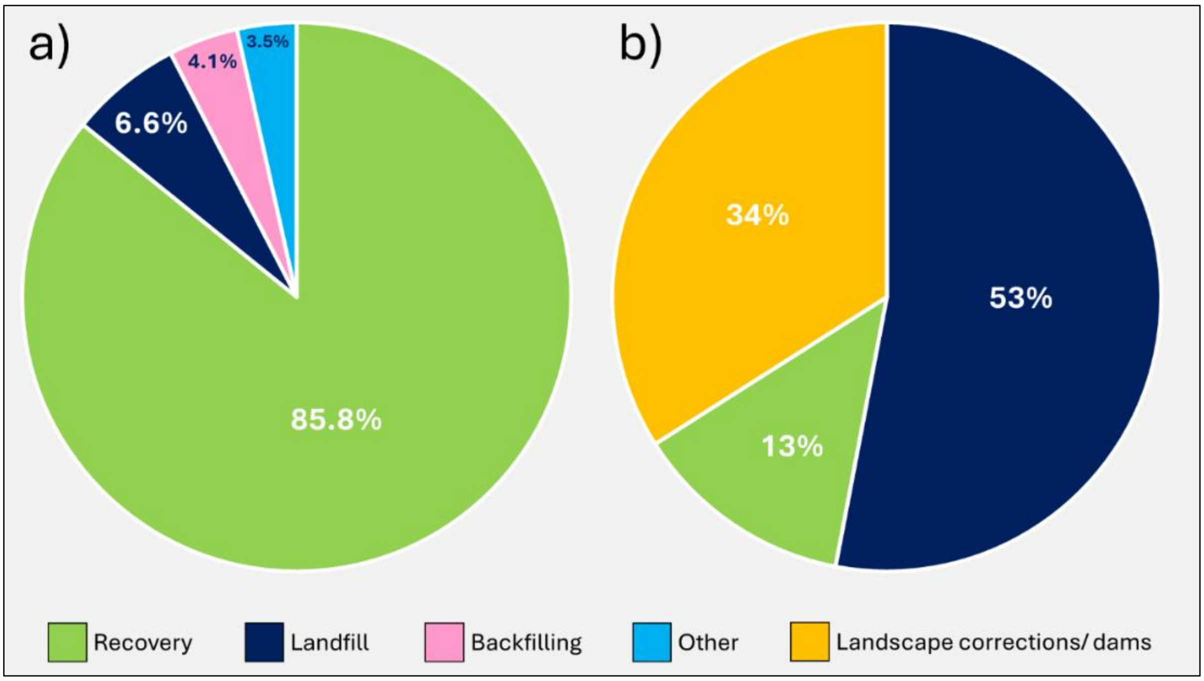

Figure 18: a) The percentage breakdown of CDW treatment methods in Austria in 2013 and b) the percentage breakdown of deposition of excavated materials in Austria in 2013, with over half sent to landfill (adapted from European Commission, 2015).

Further, a recovery method favoured in Austria is backfilling, a low-quality recovery method (EEA, 2020), which often involves soil compaction which destroys soil structure and has little benefit to soil sustainability.

The WFD sets a CDW recycling target of 70% by 2020, excluding soils (Sáez and Osmani, 2019), and many European countries met this target, but the question posed here is whether countries can be said to have met recycling targets, and achieved circularity, if a large category of waste has been excluded from reported data.

Japan: **"**the first country to enact CE legislation" (Ogunmakinde, 2019, p.7), where policy focuses upon recycling and reducing waste generation (Husgafvel and Sakaguchi, 2021) (high levels of the waste hierarchy). Circularity is vital to Japan, as landfill space is lacking given the mountainous terrain. There is effective collaboration between manufacturers and consumers, with support through incentives, advancing technology and improved education on CE (Ogunmakinde, 2019). Sumikura and Katsumi (2022) recognise the effect that continuous initiatives for recycling/reuse and the setting of clear/reasonable targets has had on CDW circularity (Fig. 7), and particularly noted the results on the reuse of excavated soils, which rose from 61% in 2000 to 89% in 2018.

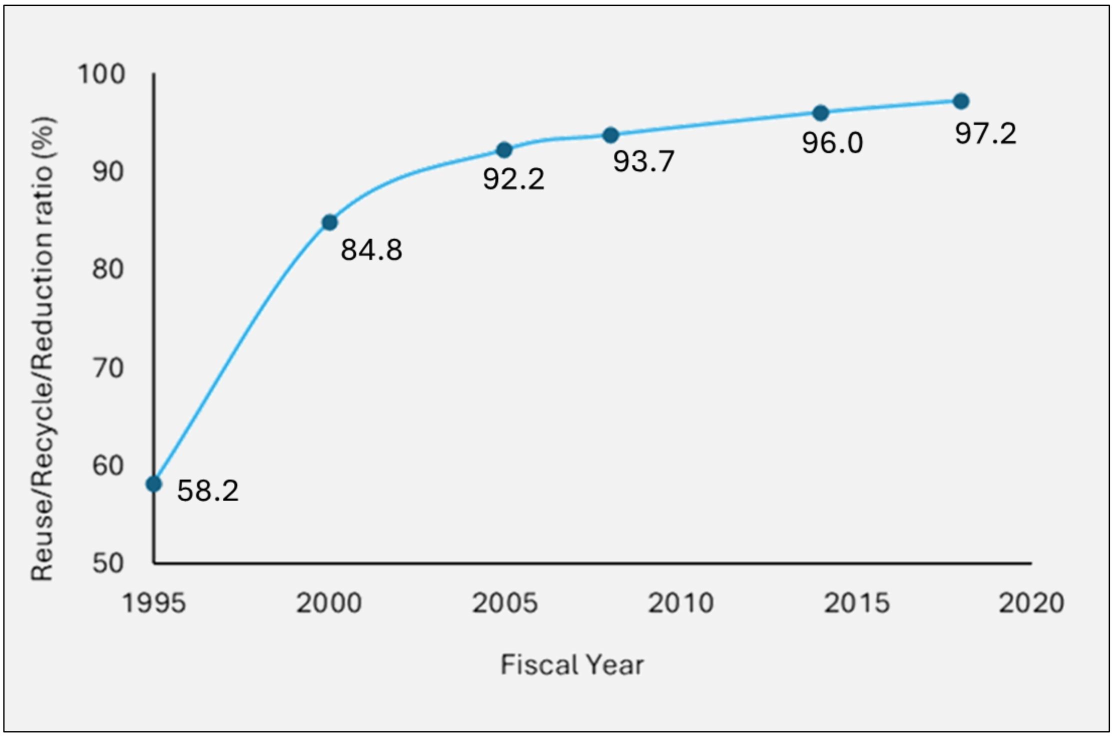

Figure 7: Reuse/recycle/reduction ratio of the wastes from construction works in Japan (adapted from Sumikura and Katsumi, 2022).

New Zealand: there are a number of government incentive schemes to encourage sustainable construction, and all were met with a high level of interest and a willingness from contractors to try to achieve more sustainable practices (Perkins and McDonagh, 2012). Whilst there was some reduction in waste production (Ginga et al., 2020), there was a low implementation rate across authorities, with many blaming the lack of financial and human resources, and a "lack of integrated sustainability policies across different levels of the Government" (Perkins and McDonagh, 2012, p.1). Whilst these initiatives can be successful, Ginga et al. (2020) argued that deterrents (e.g., higher landfill taxes) over sustainability schemes would force construction companies to either lower their waste production or face lower profits. From Environmental Performance Reviews, it can be seen that countries with higher landfill taxes have lower landfill rates (OECD, 2019). Whilst Figure 8 refers to municipal waste, the principle is still applicable to CDW.

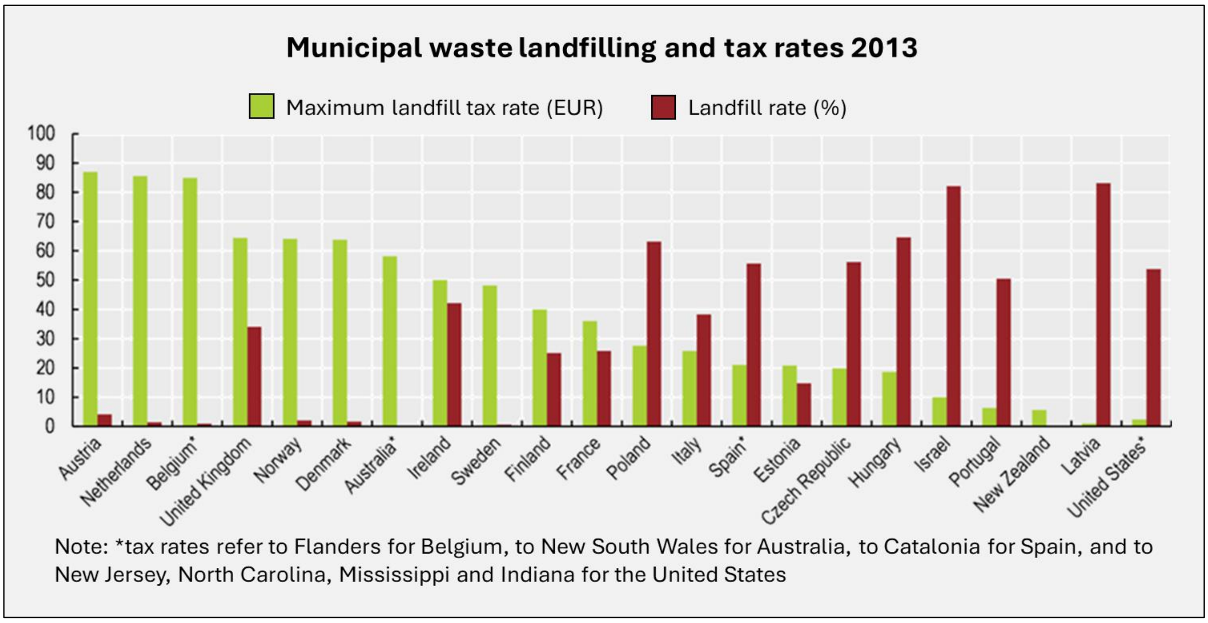

Figure 8: Countries with high landfill taxes often have lower landfill rates (adapted from OECD, 2019)

From the literature, it is clear that if given a choice companies will take the more profitable route, and so ensuring circularity is the cheaper option and supporting this with policy (ensuring this includes soils within the definition of waste) can shift the construction industry's approach towards sustainability.

8 Conclusion

It is clear from the available literature that a transition from a linear to a circular economy is needed to achieve sustainable waste management in the construction industry. This review identified current regulations relating to waste, and the current LE approach adopted by the construction industry. The reasons why a LE approach is preferred need to be fully understood.

It highlighted benefits arising from the implementation of a CE approach, together with the challenges experienced by those in the sector. It further identified that waste regulation in the UK often undermines the waste hierarchy and that one of the greatest challenges to implementing a CE in the construction industry is a lack of knowledge and interest to make the switch, as well as concerns over the financial impact of implementing the relevant practices.

The dissertation this review is intended to inform will highlight the areas/gaps within current regulations and policies which are discouraging circularity within the UK construction industry. It will then make suggestions for improvements, whilst acknowledging both government (environmental) and industry (economic) priorities.

Ginga et al. (2020) identified that most research and studies over the last few decades have focused upon recycling of CDW into new construction applications, with little focus on the reuse of construction waste. This review identifies that the greatest opportunity for promoting a CE is the reuse of CDW (including soil), instead of disposal in landfill, and the resulting carbon savings. Therefore, the dissertation will focus upon the carbon savings available from sustainable CDW management, and the new technologies being explored within the construction industry.

References

Adams, K.T., Osmani, M., Thorpe, T. and Thornback, J., 2017, February. Circular economy in construction: current awareness, challenges and enablers. In *Proceedings of the institution of civil engineers-waste and resource management* (Vol. 170, No. 1, pp. 15-24). Thomas Telford Ltd.

Ajayi, S.O., Oyedele, L.O., Bilal, M., Akinade, O.O., Alaka, H.A., Owolabi, H.A. and Kadiri, K.O., 2015. Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. *Resources, Conservation and Recycling*, *102*, pp.101-112.

Akhtar, A. and Sarmah, A.K., 2018. Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. *Journal of Cleaner Production*, *186*, pp.262-281.

Baldassarre, B., Schepers, M., Bocken, N., Cuppen, E., Korevaar, G. and Calabretta, G., 2019. Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives. *Journal of cleaner production*, *216*, pp.446-460.

Bardos, P., Shao, X., Lal, J. and Yong, R., 2021. The regulatory policy and guidance regime for the management of land contamination in England. *Remediation Journal*, *31*(4), pp.71-82.

Benachio, G.L.F., Freitas, M.D.C.D. and Tavares, S.F., 2020. Circular economy in the construction industry: A systematic literature review. *Journal of cleaner production*, *260*, p.121046.

BERR, 2008. ‘Strategy for Sustainable Construction June 2008’ Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20121212135622/http://www.bis.gov.uk/files/file46535.pdf (Accessed: 2nd May 2024)

BREEAM, 2024. Available at: https://breeam.com/ (Accessed: 12th May 2024)

Chen, K., Wang, J., Yu, B., Wu, H. and Zhang, J., 2021. Critical evaluation of construction and demolition waste and associated environmental impacts: A scientometric analysis. *Journal of Cleaner Production*, *287*, p.125071.

Chittoori, B., Puppala, A.J., Reddy, R. and Marshall, D., 2012. Sustainable reutilization of excavated trench material. In *GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering* (pp. 4280-4289).

Circular., 2024. 'Circular economy could reduce construction emissions by 75% by 2050' Available at: https://www.circularonline.co.uk/news/circular-economy-could-reduce-construction-emissions-by-75-by-2050/#:~:text=A%20new%20report%20reveals%20the,establishment%20of%20a%20circular%20economy(Accessed: 12th May 2024)

CL:AIRE., 2011. The Definition of Waste: Development Industry Code of Practice. Available at: https://www.claire.co.uk/component/phocadownload/category/8-initiatives?download=212:definition-of-waste-development-industry-code-of-practice (Accessed: 12th May 2024)

Construction Leadership Council, 2021. 'Launch of the Green Construction Board Zero Avoidable Waste Routemap' Available at: https://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2021/07/ZAW-Routemap-launch-22.7.21-FINAL.pdf (Accessed: 12th May 2024)

Coronado, M., Dosal, E., Coz, A., Viguri, J.R. and Andrés, A., 2011. Estimation of construction and demolition waste (C&DW) generation and multicriteria analysis of C&DW management alternatives: A case study in Spain. *Waste and Biomass Valorization*, *2*, pp.209-225.

Defra., 2009. 'Construction Code of Practice for the Sustainable Use of Soils on Construction Sites' Available at: https://assets.publishing.service.gov.uk/media/5b2264ff40f0b634cfb50650/pb13298-code-of-practice-090910.pdf (Accessed: 12th May 2024)

Defra., 2011 'Guidance on applying the Waste Hierarchy' Available at: https://assets.publishing.service.gov.uk/media/5a795abde5274a2acd18c223/pb13530-waste-hierarchy-guidance.pdf (Accessed: 12th May 2024)

Defra., 2013. 'Proposed repeal of construction Site Waste Management Plan Regulations (2008) Summary of responses and Government response' Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/237398/site-waste-manage-consult-sum-resp-20130830.pdf (Accessed: 12th May 2024)

Defra., 2021. 'Waste Management Plan for England' Available at: https://assets.publishing.service.gov.uk/media/60103f71d3bf7f05bc42d294/waste-management-plan-for-england-2021.pdf (Accessed: 12th May 2024)

Defra., 2023. 'Environmental Improvement Plan 2023' Available at: https://assets.publishing.service.gov.uk/media/64a6d9c1c531eb000c64fffa/environmental-improvement-plan-2023.pdf (Accessed: 12th May 2024)

DTU, n.d. 'Circular Construction' Available at: https://baeredygtighed.dtu.dk/en/teknologi/cirkulaert-byggeri (Accessed: 2nd May 2024)

EEA, 2020. 'Construction and demolition waste: challenges and opportunities in a circular economy' Available at: https://www.eea.europa.eu/publications/construction-and-demolition-waste-challenges (Accessed: 9th May 2024)

EEA., 2023. 'Waste Recycling in Europe' Available at: https://www.eea.europa.eu/en/analysis/indicators/waste-recycling-in-europe (Accessed: 12th May 2024)

Environment Act 2021. Available at: https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted (Accessed: 12th May 2024)

Environment Agency., 2019. 'The state of the environment: soil' Available at: https://assets.publishing.service.gov.uk/media/5cf4cbaf40f0b63affb6aa55/State_of_the_environment_soil_report.pdf (Accessed: 12th May 2024)

Environment Agency., 2021a 'Waste Classification Technical Guidance WM3' Available at: https://assets.publishing.service.gov.uk/media/6152d0b78fa8f5610b9c222b/Waste_classification_technical_guidance_WM3.pdf (Accessed: 12th May 2024)

Environment Agency., 2021b. 'Construction and demolition sites - Do you know what's in your waste?' Available at: https://environmentagency.blog.gov.uk/2021/03/28/construction-and-demolition-sites-do-you-know-whats-in-your-waste/ (Accessed: 12th May 2024)

Environmental Protection Act 1990. Available at: https://www.legislation.gov.uk/ukpga/1990/43/contents (Accessed: 12th May 2024)

European Commission, 2015. 'Construction and Demolition Waste management in Austria' Available at: https://ec.europa.eu/environment/pdf/waste/studies/deliverables/CDW_Austria_Factsheet_Final.pdf (Accessed: 9th May 2024)

European Commission., 2011. 'SOIL: the hidden part of the climate cycle' Available at: https://climate.ec.europa.eu/system/files/2016-11/soil_and_climate_en.pdf (Accessed: 12th May 2024)

Ghaffar, S.H., Burman, M. and Braimah, N., 2020. Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of cleaner production*, *244*, p.118710.

Ghufran, M., Khan, K.I.A., Ullah, F., Nasir, A.R., Al Alahmadi, A.A., Alzaed, A.N. and Alwetaishi, M., 2022. Circular economy in the construction industry: A step towards sustainable development. *Buildings*, *12*(7), p.1004.

Ginga, C.P., Ongpeng, J.M.C. and Daly, M.K.M., 2020. Circular economy on construction and demolition waste: A literature review on material recovery and production. *Materials*, *13*(13), p.2970.

Hale, S.E., Roque, A.J., Okkenhaug, G., Sørmo, E., Lenoir, T., Carlsson, C., Kupryianchyk, D., Flyhammar, P. and Žlender, B., 2021. The reuse of excavated soils from construction and demolition projects: Limitations and possibilities. *Sustainability*, *13*(11), p.6083.

Hartley, K., Schülzchen, S., Bakker, C.A. and Kirchherr, J., 2023. A policy framework for the circular economy: Lessons from the EU. *Journal of Cleaner Production*, *412*, p.137176.

Hernandez-Soriano, M.C. and Junod, M. F., 2019. 'Soil: the foundation of life on Earth' Available at: https://www.jic.ac.uk/advances/soil-the-foundation-of-life-on-earth/#:~:text=In%20optimum%20conditions%20and%20a,in%20a%20mere%20200%20years. (Accessed: 12th May 2024)

Hiete, M., Stengel, J., Ludwig, J. and Schultmann, F., 2011. Matching construction and demolition waste supply to recycling demand: a regional management chain model. *Building Research & Information*, *39*(4), pp.333-351

Horodytska, O., Kiritsis, D. and Fullana, A., 2020. Upcycling of printed plastic films: LCA analysis and effects on the circular economy. *Journal of Cleaner Production*, *268*, p.122138.

Hossain, M.U., Ng, S.T., Antwi-Afari, P. and Amor, B., 2020. Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable and Sustainable Energy Reviews*, *130*, p.109948.

Husgafvel, R. and Sakaguchi, D., 2021. Circular economy development in the construction sector in Japan. *World*, *3*(1), pp.1-26.

Ibrahim, M.I.M., 2016. Estimating the sustainability returns of recycling construction waste from building projects. *Sustainable Cities and Society*, *23*, pp.78-93.

ICEC-MCM, 2023. 'Policy Brief – Landfill Tax - December 2023'

Liu, J., Li, Y. and Wang, Z., 2023. The potential for carbon reduction in construction waste sorting: A dynamic simulation. *Energy*, *275*, p.127477.

Low, J.K., Wallis, S.L., Hernandez, G., Cerqueira, I.S., Steinhorn, G. and Berry, T.A., 2020. Encouraging circular waste economies for the New Zealand construction industry: Opportunities and barriers. Frontiers in Sustainable Cities, 2, p.35.

Marino, A. and Pariso, P., 2016. From linear economy to circular economy: research agenda. *International Journal of Research in Economics and Social Sciences*, *6225*(6), pp.2249-7382.

Munaro, M.R. and Tavares, S.F., 2023. A review on barriers, drivers, and stakeholders towards the circular economy: The construction sector perspective. *Cleaner and Responsible Consumption*, *8*, p.100107.

Nasir, M.H.A., Genovese, A., Acquaye, A.A., Koh, S.C.L. and Yamoah, F., 2017. Comparing linear and circular supply chains: A case study from the construction industry. *International Journal of Production Economics*, *183*, pp.443-457.

Noor, T., Javid, A., Hussain, A., Bukhari, S.M., Ali, W., Akmal, M. and Hussain, S.M., 2020. Types, sources and management of urban wastes. In *Urban ecology* (pp. 239-263). Elsevier.

OECD, 2019. 'Waste Management and the Circular Economy in Selected OECD Countries' Available at: https://doi.org/10.1787/a2dde1e8-en (Accessed: 10th May 2024)

Ogunmakinde, O.E., 2019. A review of circular economy development models in China, Germany and Japan. *Recycling*, *4*(3), p.27.

Ogunmakinde, O.E., Egbelakin, T. and Sher, W., 2022. Contributions of the circular economy to the UN sustainable development goals through sustainable construction. *Resources, Conservation and Recycling*, *178*, p.106023.

O'Riordan, R., Davies, J., Stevens, C., Quinton, J.N. and Boyko, C., 2021. The ecosystem services of urban soils: A review. *Geoderma*, *395*, p.115076.

Panjwani, A., 2023. 'Industries in the UK' Available at: https://commonslibrary.parliament.uk/research-briefings/cbp-8353/ (Accessed: 12th May 2024)

Papamichael, I., Voukkali, I., Loizia, P. and Zorpas, A.A., 2023. Construction and demolition waste framework of circular economy: A mini review. *Waste Management & Research*, *41*(12), pp.1728-1740.

Perkins, M.A. and McDonagh, J., 2012. New Zealand local government initiatives and incentives for sustainable design in commercial buildings.

Plimmer, M., 2023. New Guidance on Classification of Waste Soil from Construction. Available at: https://www.gea-ltd.co.uk/blog/detail/new-guidance-on-classification-of-waste-soil-from-construction.html (Accessed: 12th May 2024)

Purchase, C.K., Al Zulayq, D.M., O'Brien, B.T., Kowalewski, M.J., Berenjian, A., Tarighaleslami, A.H. and Seifan, M., 2021. Circular economy of construction and demolition waste: A literature review on lessons, challenges, and benefits. *Materials*, *15*(1), p.76

Rose, C.M. and Stegemann, J.A., 2018. From waste management to component management in the construction industry. *Sustainability*, *10*(1), p.229.

Sáez, P.V. and Osmani, M., 2019. A diagnosis of construction and demolition waste generation and recovery practice in the European Union. *Journal of Cleaner Production*, *241*, p.118400.

Soils in Planning and Construction Task Force., 2022 'Building on soil sustainability: Principles for soils in planning and construction'. Available at: https://wp.lancs.ac.uk/sustainable-soils/files/2022/09/Soils-in-Planning-and-Construction-Sept-22.pdf (Accessed: 12th May 2024)

Soto-Paz, J., Arroyo, O., Torres-Guevara, L.E., Parra-Orobio, B.A. and Casallas-Ojeda, M., 2023. The circular economy in the construction and demolition waste management: A comparative analysis in emerging and developed countries. *Journal of Building Engineering*, p.107724.

Stelzer, V.B., da Silva, A.A., Penteado, C.S.G. and Cristale, J., 2023. Organophosphate esters in inert landfill soil: A case study. *Waste Management & Research*, p.0734242X231190813.

Sumikura, Y. and Katsumi, T., 2022. Material reuse and recycling in construction works in Japan. *Journal of Material Cycles and Waste Management*, *24*(4), pp.1216-1227.

Tafesse, S., Girma, Y.E. and Dessalegn, E., 2022. Analysis of the socio-economic and environmental impacts of construction waste and management practices. *Heliyon*, *8*(3).

The Environmental Permitting (England and Wales) Regulations 2016. Available at: The Environmental Permitting (England and Wales) Regulations 2016 (legislation.gov.uk) (Accessed: 12th May 2024)

The Site Waste Management Plans Regulations 2008. Available at: https://www.legislation.gov.uk/uksi/2008/314/contents/made (Accessed: 12th May 2024)

The Waste (Circular Economy) (Amendment) Regulations 2020. Available at: https://www.legislation.gov.uk/uksi/2020/904/contents/made (Accessed: 12th May 2024)

The Waste (England and Wales) Regulations 2011. Available at: https://www.legislation.gov.uk/uksi/2011/988/contents/made (Accessed: 12th May 2024)

The Waste Framework Directive 2008/98/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705 (Accessed: 12th May 2024)

Van Ewijk S, Stegemann JA. Limitations of the waste hierarchy for achieving absolute reductions in material throughput. Journal of Cleaner Production. 2016 Sep 20;132:122-8.

Walsh, D., McRae, I., Zirngibl, R., Chawla, S., Zhang, H., Alfieri, A., Moore, H., Bailey, C., Brooks, A., Ostock, T. and Pong, S., 2019. Generation rate and fate of surplus soil extracted in New York City. *Science of the total environment*, *650*, pp.3093-3100.

Yu, B., Wang, J., Li, J., Lu, W., Li, C.Z. and Xu, X., 2020. Quantifying the potential of recycling demolition waste generated from urban renewal: A case study in Shenzhen, China. *Journal of cleaner production*, *247*, p.119127.

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X. and Tukker, A., 2022. An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. *Science of the Total Environment*, *803*, p.149892.

Zhang, C., Hu, M., Yang, X., Miranda-Xicotencatl, B., Sprecher, B., Di Maio, F., Zhong, X. and Tukker, A., 2020. Upgrading construction and demolition waste management from downcycling to recycling in the Netherlands. *Journal of Cleaner Production*, *266*, p.121718.

Appendix 2: Focus Group participant information, , including number identifiers and relevant sector each participant was from.

Focus Group	Participant (P) Number	Participant Sector
1	Facilitator 1	Soil Research
	Facilitator 2	Soil Research
	Facilitator 3	Research
	P1	Industry
	P2	Local Authority
	P3	Local Authority
	P4	Planning
	P5	Local Authority
	P6	Industry
	P7	Planning Authority
	P8	Local Authority
2	Facilitator 1	Soil Research
	Facilitator 2	Soil Research
	Facilitator 3	Research
	P9	Regulator (Environment Agency)
	P10	Industry
	P11	Water company
	P12	Local Authority
	P13	Soil Research
	P14	Planning
	P15	Charity (CL:AIRE)
	P16	Local Authority
3	Facilitator 1	Soil Research
	Facilitator 2	Soil Research
	Facilitator 3	Research
	P17	Local Authority
	P18	Local Authority
	P19	Planning Authority
	P20	Industry
	P21	Local Authority
	P22	Industry
	P23	Local Authority
	P24	Wrye River Trust
	P25	Land Manager

Appendix 3: Figure 8 carbon calculations

For soil sent to landfill:

1 ton soil carbon = 3.67 tons of CO_2 *(Eurofins Agro, n.d.)*

Assuming an average 2% SOC per ton of soil, the lowest percentage stated by DAF, 2022.

3.67 x 0.02 = 0.07 tons

- Total CO_2 emitted per year from natural aggregate production:

0.046 x 210,602,241= 9,687,703

(Tam et al., 2018; Mineral Products Association, 2023)

- Total CO_2 emitted per year from soil landfilling:

0.07 x 31,967,000 = 2,237,690

(Eurofins Agro, n.d.; Mineral Products Association, 2023)

- Total CO_2 sequestered per year from using recycled aggregates:

Note: tonne from Mineral Products Association, 2023 converted to ton

0.01 x 76,685,976 = 766,860

(Kaliyavaradhan and Ling, 2017; Mineral Products Association, 2023)

- Total CO_2 emitted per year from recycled aggregate production

Note: tonne from Mineral Products Association, 2023 converted to ton

0.0024 x 76,685,976 = 184,046

(Tam et al., 2018; Mineral Products Association, 2023)

- Total CO_2 saved per year from reusing soil:

Note: tonne from ICEC-MCM, 2023 converted to ton

0.015 x 31,967,000 = 479,505

(Magnusson et al., 2015; ICEC-MCM, 2023)

Total CO_2 (in tons) emitted per year following Linear Economy model:

9,687,703 + 2,237,690 = 11,925,393

Total CO_2 (in tons) saved and sequestered per year following Circular Economy model:

766,860 - 184,046 + 479,505 = 1,062,319

Appendix 4: Further Information of Case studies for Figure 10

Country	Project	Recycling/Reuse Aspect	Economic Implications
UK	Newport Southern Distributor Road	— Maximised use of project derived excavated materials — 95% of aggregates used were recycled — RA used: 452,500 tonnes	— Direct savings: , £1,034,135 — Indirect savings: £941,360 (avoiding waste disposal charges and landfill tax)
UK	Channel Tunnel Rail Link	— Reuse of tunnel spoil for development of platforms and motorway embankments — Clients saw waste as a priority issue from outline of design phase	— Saving for Channel Tunnel Rail Link project: upwards of £100 million — Savings for Highway Agency: ~ £10 million
UK	A34 Chieveley/M4 junction 13 improvement	— NA reduced by over 50,000 tonnes — RA used: 56,000 tonnes — Soil stabilised: 7,350 tonnes — NA limited to 16,650 tonnes	— Savings to client of ~£70,000