Development of an Analytical Framework to Facilitate the Transition Towards a Circular Construction Economy

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ABSTRACT

The Anthropocene has redirected global economic development toward sustainable models to avoid destabilising Earth's natural systems. Major contributing industries have been identified as a target for innovation; the largest of which is the construction industry. A leading innovation advocated by researchers and policymakers to address the problem is the Circular Economy (CE), which aims to create circular (as opposed to linear) material flows and enhance the economic potential of virgin materials entering the system. By circulating materials within an economy, the sustainability of its systems is improved; however, material thermodynamics will persist, and the CE will only delay the inevitable generation of waste. Due to the size, lifespan, and socio-economic importance of buildings developed by the construction industry, minor circular innovations can produce a considerable impact on the sustainability of the wider economy.

A core problem within the existing development of the CE within the construction industry is a lack of clarity and cohesiveness amongst policymakers, practitioners, and researchers. The development of the CE within the construction industry is trailing other industries, such as car manufacturing. CE practices within the construction industry are being applied on an ad hoc basis, reducing or mitigating the benefits of holistic applications. Although CE scholarship in construction has grown rapidly, United Kingdom (UK) based studies and syntheses remain comparatively few, and the international knowledge base is fragmented. Studies that seek to coalesce the CE's practices are incomplete and lack cohesiveness with the wider body of knowledge. The fragmentation within studies identifying and categorising the practices of the CE insinuates a lack of holistic and comprehensive research to synthesise and standardise the approach of the CE within the construction industry. Furthermore, research into the drivers and barriers of implementing CE practices is in its infancy and faces similar impediments. Overall, the fragmentation and early-stage development of the Drivers, Barriers and Practices (DBPs) of the literature highlight a gap in knowledge towards the holistic, comprehensive, standardised, and systematic adoption of the CE within the UK construction industry. Therefore, this research aims to encapsulate the CE's DBPs into a comprehensive framework to facilitate a systematic transition within the UK construction industry to a Circular Construction Economy (CCE).

This research adopts a pragmatist philosophy to identify and adopt methods to generate action within the construction industry to facilitate the UK's transition to a CE. The study employs an abductive approach consisting of deductive and inductive stages. The DBPs of the CE were

identified through a systematic literature review for the development of a theoretical framework in the form of a comprehensive taxonomy, which was then deductively and inductively investigated within the empirical studies. Two supply chains were identified as case studies to conduct semi-structured interviews. A snowball sample was used, following the purposive selection of highly experienced and influential practitioners within each supply chain, resulting in 27 participants. The data on the practices of the CE were collected qualitatively and analysed using discourse, comparative, and content analyses, which were later used to generate quantitative data to be analysed through descriptive statistics. The drivers and barriers of the CE were collected and analysed quantitatively using measures of central tendency and descriptive statistics, which were subjected to a discourse and comparative analysis.

The findings of the empirical studies found that both supply chains had different levels of development and faced different drivers and barriers. Commonalities between DBPs that were present throughout each group and supply chain were: laws and regulations, guidance/best practices, frameworks, and business models. These commonalities suggest that, above all, the supply chains require guidance through a model that can assess their circular needs and prescribe practices that can assist them to develop in a tailored fashion to achieve their organisational targets, resulting in the development of the Analytical Circular Construction Economy (ACCE) framework. The ACCE framework was then evaluated and validated in two focus groups, one within each supply chain, and through two external specialist interviews.

There are several contributions to knowledge and practice within this PhD study. Firstly, the bibliometric and scientometric analyses of the extant literature provide a cross-sectional view of the current body of knowledge surrounding the CE within the construction industry. From the fragmented literature, a comprehensive taxonomy was developed to coalesce the identified DBPs into one unified theoretical framework. This contribution to theory can establish a baseline for future research and empirical studies into the DBPs of the CE and provide guidance to practitioners investigating the potential options for developing their practice. The development of the ACCE framework presents a novel and structured list of DBPs that can be systematically compared to support a comprehensive analysis of CE development. Its simplicity and analytical structure make it scalable across various sample sizes, such as disciplines, organisational divisions, companies, supply chains, or entire industries, allowing it to effectively inform both practice and the advancement of CE theory. The findings of the ACCE framework's application developed a foundational benchmark for the advancement of the CE within its respective supply chain. Although the findings are non-parametric case studies and cannot be generalised for the construction industry, the empirical findings provide a case for the development and guidance of the CE within other projects, academic or practical. Additionally, the proof of concept of the ACCE framework allows for future benchmarks to be developed in practice for the comparison of projects or the collection of generalisable industry-wide data for a holistic assessment of the construction industry.

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ABBREVIATIONS

- AR6 – Assessment Report 6
- BCU – Birmingham City University
- BIM – Building Information Modelling
- CCE – Circular Construction Economy
- CDE – Construction, Demolition, and Excavation
- CDW – Construction and Demolition Waste
- CE – Circular Economy
- DBPs – Drivers, Barriers, and Practices
- EC – European Commission
- EMF – Ellen MacArthur Foundation
- EU – European Union
- FG1 - Focus Group 1
- FG2 – Focus Group 2
- GHG – Green House Gasses
- GSCM – Green Supply Chain Management
- IoT – Internet of Things
- IPCC – International Panel on Climate Change
- IPD – Integrated Project Delivery
- NDRC – National Development and Reform Commission
- PSS – Product Service Systems
- R&D – Research and Development
- SC1 – Supply Chain 1
- SC2 – Supply Chain 2
- SCM – Supply Chain Management
- SDG – Sustainable Development Goal
- UK – United Kingdom
- UKEA – United Kingdom Environmental Agency
- UN – United Nations
- US – United States
- USEPA – United States Environmental Protection Agency

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DEDICATION

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To my family, I dedicate all my achievements in life.

To my wife, your dedication has no bounds. Your unconditional love and support have helped me to strive through every adversity that I have faced.

To my son, let this thesis and all that follows show my dedication to you and your future.

CHAPTER 1: INTRODUCTION

1.1 Background

The Anthropocene's capitalistic use of linear economic consumption (take-make-waste), coupled with the thermodynamic finality of the Earth's resources, has created an unsustainable and infinitely more complex geological future for humankind (Crutzen, 2006; Steffen et al., 2007; Rockström, 2009; IPCC, 2023). The International Panel on Climate Change (IPCC) has predicted a 2.25-fold increase in raw material consumption by 2050, indicating a massive increase in the impact of the Anthropocene and a significant demand for a sustainable solution (IPCC, 2023).

Climate scientists underscore the urgency of systemic change to the existing unsustainable model. The IPCC's Sixth Assessment (2023) confirms the planet is tracking the former "worst-case" emissions pathway and is likely to exceed the 1.5 °C threshold within the next decade. In response, governments have embedded resource efficiency into the UN Sustainable Development Goals (SDG) (e.g. SDG 12) and national climate plans; the IPCC explicitly recommends integrating waste and resource management measures, namely the CE or reduce, reuse, recycle, into mitigation pathways because material efficiency can deliver substantial reductions in Green House Gasses (GHG) (IPCC, 2023). Together, environmental limits and policy commitments require an economic transition that decouples prosperity from resource depletion.

Anthropogenic impacts are concentrated in a handful of sectors, and transition strategies prioritise construction alongside agriculture and energy (IPCC, 2023). Construction is one of the world's most resource-intensive industries: it consumes roughly 50 % of all raw materials in the EU and generates 20 – 35 % of global solid waste (European Commission (EC), 2020). In the UK, the figure is starker—construction, demolition and excavation (CDE) waste constituted 64 % (120.4 million tonnes) of all national waste in 2016 (UK Environmental Agency (UKEA), 2021). Hence, small efficiency gains in construction can yield outsized environmental and economic dividends.

A leading strategic response is the CE, typically defined as "an industrial system that is restorative or regenerative by intention and design" in which materials circulate at their highest value (Ellen MacArthur Foundation (EMF), 2013; IPCC, 2023). The CE combines environmental benefits (e.g. reduced resource extraction, lower emissions) with economic incentives (e.g. cost savings, new revenue streams) and is now widely framed as the prime pathway to sustainable, resilient growth. Despite the high stakes, CE adoption in construction lags behind other industries. Academic output on CE in construction did not accelerate until the mid-2010s (whereas manufacturing studies date back to the 1990s) (Benachio et al., 2020; Munaro et al., 2020; Çetin et al., 2021). Implementation is hampered by the sector's fragmentation: each project involves a transient network of clients, designers, contractors and suppliers, making system-wide change difficult (Latham, 1994; Farmer, 2016). As a result, few projects address circularity across all life-cycle stages: design, procurement, manufacturing, logistics, construction, operation, and demolition.

The development of the CE within the construction industry is currently between theory development and application (Adabre et al., 2023; Williams, 2022). At present, the construction industry is transitioning to a recycling economy that recovers waste instead of reducing or reusing it, meaning the industry has not yet achieved full circularity (Adabre et al., 2023; Williams, 2022). Governments are beginning to respond with their own action plans for the CE; however, specific applications are vague and provide little to no direction (EC, 2020; National Development and Reform Commission (NDRC), 2021; United States Environmental Protection Agency (USEPA), 2021). Although the CE's practice remains embryonic, firms report progress mainly in waste segregation and recycling; only isolated pilots explore preventative practices that reduce the level of material consumption and waste generation (Adabre et al., 2023; Williams, 2022).

Existing studies focus narrowly on single materials or operational energy (e.g. Bherwani et al., 2022; Finch et al., 2021; Litleskare and Wuyts, 2023; Marey et al., 2024), providing little insight into whole-life circularity. Empirical evidence on real-world drivers and barriers is also sparse (e.g. Ababio and Lu, 2023; Munaro and Tavares, 2023; Shooshtarian *et al.*, 2023), leaving policymakers and firms without robust data on what enables or inhibits the circular transition. Investigations into the DBPs of the CE within the construction industry are in their initial stages of identification and contextualisation, which are posing a barrier to the adoption of CE practices (e.g. Wuni, 2022; Wuni, 2023; Wuni and Shen 2022). More empirical studies on the DBPs within the construction industry are required to understand the development and presence of such factors in practice. Evidence of the DBPs is imperative to increase the development of the CE as it motivates practitioners, guides their application of the CE, and overcomes barriers that could discourage them (Amarasinghe et al., 2024; Shooshtarian et al., 2023).

1.1.1 Gap in Knowledge

Various studies have identified lists of potential circular DBPs for CE in construction (e.g. Ababio and Lu, 2023; Adams et al., 2017; Domenech et al., 2019; Huang et al., 2018). That is, the majority of the literature focuses on either the drivers (e.g. Wuni, 2023), barriers (e.g. Wuni, 2022), or practices (e.g. Wuni and Shen, 2022), and there are rarely publications that combine each element. Even in the attempts that have tried to present the DBPs comprehensively (e.g. Akinade et al., 2020; Arora et al., 2020; Azcárate-Aguerre et al., 2018; Daly, 2023), these elements remain dispersed across different disciplines, lifecycle stages, and types of construction projects, and have not been unified into a single, coherent schema. A comprehensive understanding of the CE's DBPs is imperative for the development of the CE within the construction industry to provide a holistic and informed approach to transitioning to a CE, to ensure the overall economic and environmental aspirations are fully achieved.

Furthermore, the studies on the CE's drivers, barriers, or practices lack empirical data to thoroughly understand their presence within the construction industry (Ababio and Lu, 2023; Çimen, 2023; Gálvez-Martos et al., 2018; Ginga et al., 2020). The lack of empirical data on the CE's DBPs in construction limits the ability of researchers and practitioners to understand what is being implemented, what the motivations for implementation are, and what hindrances have been encountered during applications (e.g. Ababio and Lu, 2023; Munaro and Tavares, 2023; Shooshtarian *et al.*, 2023). Additionally, due to the lack of cohesive studies on the DBPs, the dynamics between the three elements are unknown. Understanding the dynamics between the DBPs could enable the successful implementation of the CE across different disciplines, building types, and organisational structures through an informed and tailored approach.

In addition, publications exist on the DBPs from different regions, such as Asia (e.g. Hassan et al., 2023, Hishammuddin et al., 2018, Huang et al., 2018, Wu et al., 2019, Wuni and Shen, 2022), Australasia (e.g. Jahan et al., 2022, Shooshtarian et al., 2023), and the Nordics (e.g. Knoth et al., 2022, Zu Castell-Rüdenhausen et al., 2021) with different perspectives and findings. A similar pattern is observed in government policies: literature originating from the United States (US) (e.g. USEPA, 2021) tends to view the CE primarily as a commercial strategy with environmental benefits; literature from the European Union (EU) (e.g. EC, 2020) frames the CE mainly as an environmental strategy with commercial benefits; and literature from China (e.g. NDRC, 2021) presents the CE largely as a strategy for national security of the economy and environment. The uneven development of the CE globally suggests that context matters; that is, solutions in one country may not be directly transferable to another, suggesting that without UK-specific studies, crafting effective strategies for construction is difficult. The situation is exacerbated as researchers, regardless of geographical location, are constrained in their inability to compare findings or build cumulative knowledge (since each study may define CE factors differently), and practitioners are left without clear guidance on how to systematically implement CE beyond ad hoc measures (Wu et al., 2019; Campbell-Johnston et al., 2019; Ghisellini et al., 2018; Knoth et al., 2022).

Moreover, a key shortcoming in the existing literature is the absence of a holistic, standardised framework for the CE in the construction sector to guide and measure developmental progress (Mhatre et al., 2023; Wuni, 2022). This means stakeholders lack a common reference model: there is no widely accepted roadmap that a construction company can consult to evaluate how circular its operations are, nor a standard toolkit to guide improvements. In essence, firms cannot measure or benchmark how circular their current practices are in operation, as highlighted by Womack, Jones, and Roos (1990) in their study on Lean development, meaningful improvement begins with effective measurement. This gap hampers both research and implementation. The effect on practitioners is amplified by the lack of interactive tools for the assessment of the CE in practices (Munaro and Tavares, 2023; Oluleye et al., 2023; Mhatre et al., 2023). Existing frameworks, business models, and circular tools are often static conceptual models that provide a level of education on the theory of the CE in practice (e.g. Ababio et al. 2023, Abadi et al. 2021, Amarasinghe et al. 2024, Çimen 2023, Hossain et al. 2020), but do not adapt to the context of the practitioner's project and scope to measure and guide the development of the CE.

Addressing this gap will support the UK construction industry in assessing CE maturity within businesses more rigorously and in implementing CE principles in a consistent, scalable way. Providing a shared structure for understanding what the circular economy means for construction, a holistic taxonomy of DBPs, and an accompanying framework for the assessment of current level of CE maturity within construction businesses, will enable stakeholders to align their efforts, measure progress, and learn from each other, thereby accelerating the transition to a truly circular construction industry. Without it, the risk is that CE in construction remains a buzzword with isolated successes, rather than a transformative and standard practice across the industry. Filling this gap is therefore essential to bridge the current knowledge deficits and to support the UK construction sector in catching up to global circular economy leaders.

1.2 Aim of Research

This research aims to encapsulate the CE's DBPs into a comprehensive framework to facilitate a systematic transition to a CCE within organisations of the UK's construction industry.

1.2.1 Objectives

O1: To identify the DBPs of the CE in the construction industry from the literature for the development of a comprehensive taxonomy.

O2: To explore the presence and level of development of DBPs of CE in the UK construction industry.

O3: To develop a framework based on the findings from the literature review and empirical studies for the assessment of CE's DBPs within and across construction supply chains and businesses to facilitate the incorporation of the CCE.

O4: To validate the framework and evaluate the applicability and appropriateness of the proposed framework through UK-based case studies in assessing their transition to a CCE.

1.3 Research methods

In this section, the research methods will be outlined and discussed (Figure 1.2). The overall philosophy of the thesis is pragmatism. Pragmatism investigates that which is only relevant to actionable practice (Saunders et al., 2019). A pragmatist believes in multiple perspectives and the complexity of actions, which create consequences that make up reality (Cameron and Price, 2009). Therefore, mixed-methods and multiple philosophies are utilised to understand the diverse range of criteria within this study to develop actionable practice within the construction industry. The methods used within this thesis are split into four stages. The stages of the methodology are as follows:

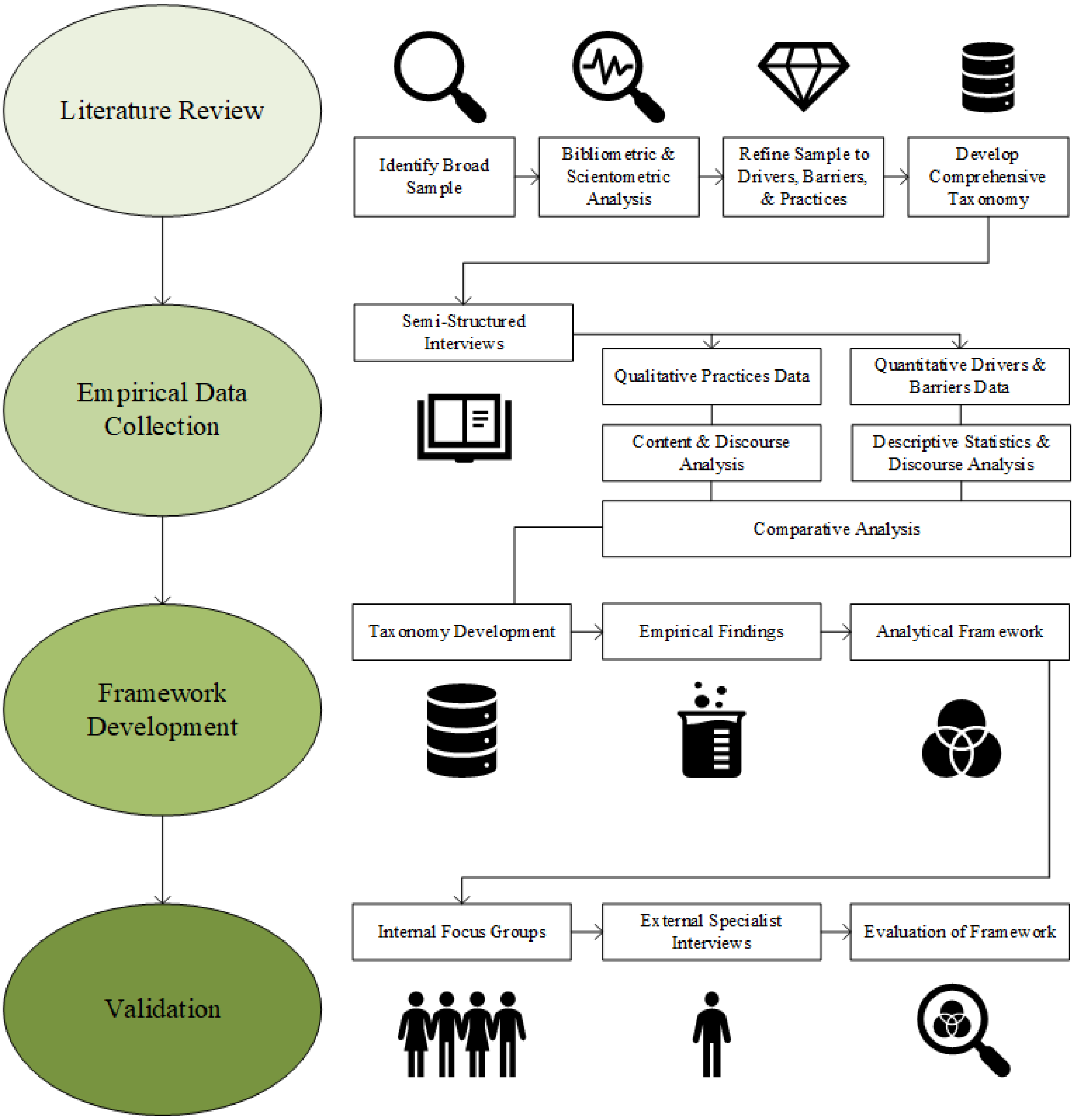

Figure 1.2: Research methods flow

1.3.1 Stage 1 - Systematic Literature Review

The first stage of the research conducted was in the form of a systematic literature review, in which data was collected using Scopus by using keywords to search for the titles, abstracts, and keywords of extant literature. An initial exploratory literature review defined the problem domain and set keywords. The following keyword strings were used; **String 1 (CE):** ("Circular Econom*" OR "Circular Practice" OR "circular manage*"); **String 2 (Construction):** ("construction industry" OR "construction"); **String 3 (Specific)** ("Circular Econom*" OR "Circular Practice" OR "circular manage*") AND ("construction industry" OR "construction") AND (Driver OR Enabler OR Barrier); **Or String 4 (Specific):** ("Circular Econom*" OR "Circular Practice" OR "circular manage*") AND ("construction industry" OR "construction") AND ("Best practice* OR Practice* OR "Practice-based" OR Guidance) AND (Framework or "Business model"). The first sample was collected through strings 1and2 to identify a broad overview of the CE within the construction industry. The sample provided an excess of 5000 journal articles for review. To gain an overview of the sample, bibliometric and scientometric analyses were conducted to understand the landscape of the CE in the construction industry and view the shortfalls in the extant literature. The second sample provided 50 journal articles for string three and 117 for string four. Through a manual review, 44 in string three and 72 in string four were identified as relevant. In the final review, 34 journal articles were included in the sample for string three and 58 were included in string four. An interpretivist philosophy and deductive reasoning guided this stage to review and compare the synergies within the literature (Saunders *et al.*, 2019). The second sample of literature enabled the identification of DBPs for the development of a holistic theoretical framework in the form of a taxonomy. The taxonomy contained four themes derived from categories in the extant literature: economic, institutional, social-cultural, and technological.

1.3.2 Stage 2 - Empirical Data Collection

The DBPs of the theoretical framework were addressed within the semi-structured interviews to explain the phenomenon through the interpretations of managers in the construction industry (Cameron and Price, 2009). The use of semi-structured interviews for this study allowed for follow-up questions to be asked to probe into the initial answer given to gain abductive qualitative data to measure and explore the practices (Patton, 2014). Interviews are recorded and transcribed to analyse the discourse between disciplines and supply chains (Saunders *et al.*, 2019). The collection of qualitative data was crucial to exploring and explaining the knowledge and experiences of industry professionals (Cameron and Price, 2009). The qualitative data was analysed using NVivo to conduct a content and discourse analysis (Gray, 2019). The content analysis coded and cross-analysed participants' answers to identify findings (e.g. commonalities and differences) and compare the discourse between different supply chains and disciplines.

In addition, a structured section was included within the interview with the option to elaborate. The structured section was measured on a Likert scale of one to four; the drivers and barriers were ranked from strongly disagree to strongly agree. A structured design was better suited for the understanding of the drivers and barriers of the chosen topic, which sought to understand and gauge the opinions and experiences of industry professionals. The participants are given the option to expand on their rationale and express any drivers or barriers that they have experienced. The quantitative data collected from the structured section of the interview were analysed with descriptive statistics and measures of central tendency. The use of descriptive statistics is best suited for the analysis of non-parametric quantitative data on a Likert scale, as it visually represents the data (Saunders *et al.*, 2019). The use of positivism for the measurement of the drivers and barriers follows previous research, such as that by Chan et al. (2019), who used a positivist philosophy to measure barriers between different disciplines.

The sampling method used for the identification and selection of participants was the volunteer snowball design (Saunders *et al.*, 2019). Initially, organisations were purposefully sampled for their characteristics. Characteristics of the supply chains that were deemed desirable were residential buildings with supply chains that were established and connected. The initial network of participants and cases was limited but information-rich and therefore provided the opportunity to contact key participants and snowball the study throughout the organisation/network to infiltrate the supply chain (Patton, 2014; Saunders *et al.*, 2019). Twenty-seven participants were interviewed across two supply chains, a range of disciplines, ages, and levels of experience within the construction industry. Supply Chain 1 (SC1) is a high-rise residential developer that controls large amounts of the construction process in its supply chain (Figure 2.5). The design, mechanical, electrical, and plumbing (MEP), construction management, commercial management, sustainability, demolition and some suppliers are all controlled within one umbrella. Supply Chain 2 (SC2) is a residential housing developer that controls large amounts of its supply chain to improve the logistical performance and management of its developments (Figure 2.6). However, they subcontract several areas of both construction and management practices which they cannot facilitate. Their main group includes the construction management, commercial management, logistical management, sustainability, procurement, and design groups. Their external working groups are their suppliers and waste management.

1.3.3 Stage 3 - Framework Development

The synergy of DBPs identified within the sample of literature was condensed and developed into a holistic theoretical and analytical framework summarising the CE within academic literature, with the findings from the empirical data collection. The identified DBPs were presented within the analytical framework for the analysis of the maturity within selected supply chains based in the UK. Instructions for the use of the analytical framework were divided into six stages, which instruct the user on the correct procedure to apply the analytical framework in practice. The analytical framework contains all of the DBPs contained within the theoretical framework for analysis on a Likert scale of 1 to 4. Drivers and barriers were on a scale of strongly disagree (1) to strongly agree (4). Practices were on a scale from below standard (1) to above standard (4). The tool can be adjusted to have a wider Likert scale for more detailed analysis, and the DBPs can be selected or added based on the users' needs and findings.

1.3.4 Stage 4 – Validation and evaluation

The validation stage of this study relies on the interpretations of peers within industrial practice to determine the final product's usefulness (Cameron and Price, 2009). Due to the reliance on industrial acceptance of the research, focus groups and specialist interviews were selected for the validation stage to determine the opinion of industry practitioners and experts and gain feedback. Two focus groups and two specialist interviews were used to determine the validity of the study. Two focus groups were conducted internally within the supply chains to determine the internal validity of the study. Two specialist interviews were conducted external to the study with an expert consultancy within the CE field to gain external validity. All participants were asked the same set of questions to demonstrate the utility of the analytical framework within their business and the wider construction industry. Each of the two supply chains which participated in the study was shown its own results. The external consultancy was shown the results from both supply chains that were merged together to provide an example of use (Tremblay, et al., 2010). The validation was split into two tasks: one to test the use of the framework and its practicality, efficiency, and flexibility. The second was to validate the results of the study in accordance with the perception of CE maturity within the supply chains to see if the results were accepted, applicable, and if the tool was effective.

1.4 Research scope

The initial review of literature has a deliberately broad focus that reviews journal articles on an international basis to understand the landscape of the literature focused on the CE in the construction industry. Based on the findings of the broad literature sample, the study was refined to frameworks and business models that contain drivers, practices, or barriers of the CE in the construction industry. The business models and frameworks span the whole lifecycle of construction projects (cradle-to-grave) and through the perspective of different disciplines and roles within the construction industry, capturing the sequence of collective decision making and communication from early concept through to completion.

Based on the findings of the scientometric analysis (section 3.2.1) of the broad sample of literature on the CE, a large focus on the measurement or optimisation of specific materials was identified as saturated. Additionally, from an initial pilot study into the available material data within UK-based construction companies, a lack of material data for analysis was seen, the collection of which, would be unfeasible during the timeframe of this PhD study. Therefore, the focus of the study does not include the performance of materials and or waste generation. The research does not directly investigate CE practices at the material level or performance level. It therefore does not attempt to optimise specific materials, nor does it quantify indicator level metrics such as the amount of waste or CO_2 emissions. The focus of the study is purely on the presence and level of development of the CE's DBPs.

The focus of the empirical studies looks at residential buildings to allow for a comparable medium between the two supply chains. The empirical studies compare housing and high-rise residential projects in their respective supply chains through the experiences and opinions of practitioners. The project does not compare materials or waste between housing and high-rise projects. The empirical studies do compare like-for-like disciplines categorised into 'working groups'. The comparison focuses on the participants' knowledge, experience, understanding, and opinion of the CE's DBPs within their respective supply chains.

1.5 Thesis structure

This thesis covers seven chapters, each of which meets the aim of the research and one or more objectives (Figure 1.1). The thesis chapters are as follows:

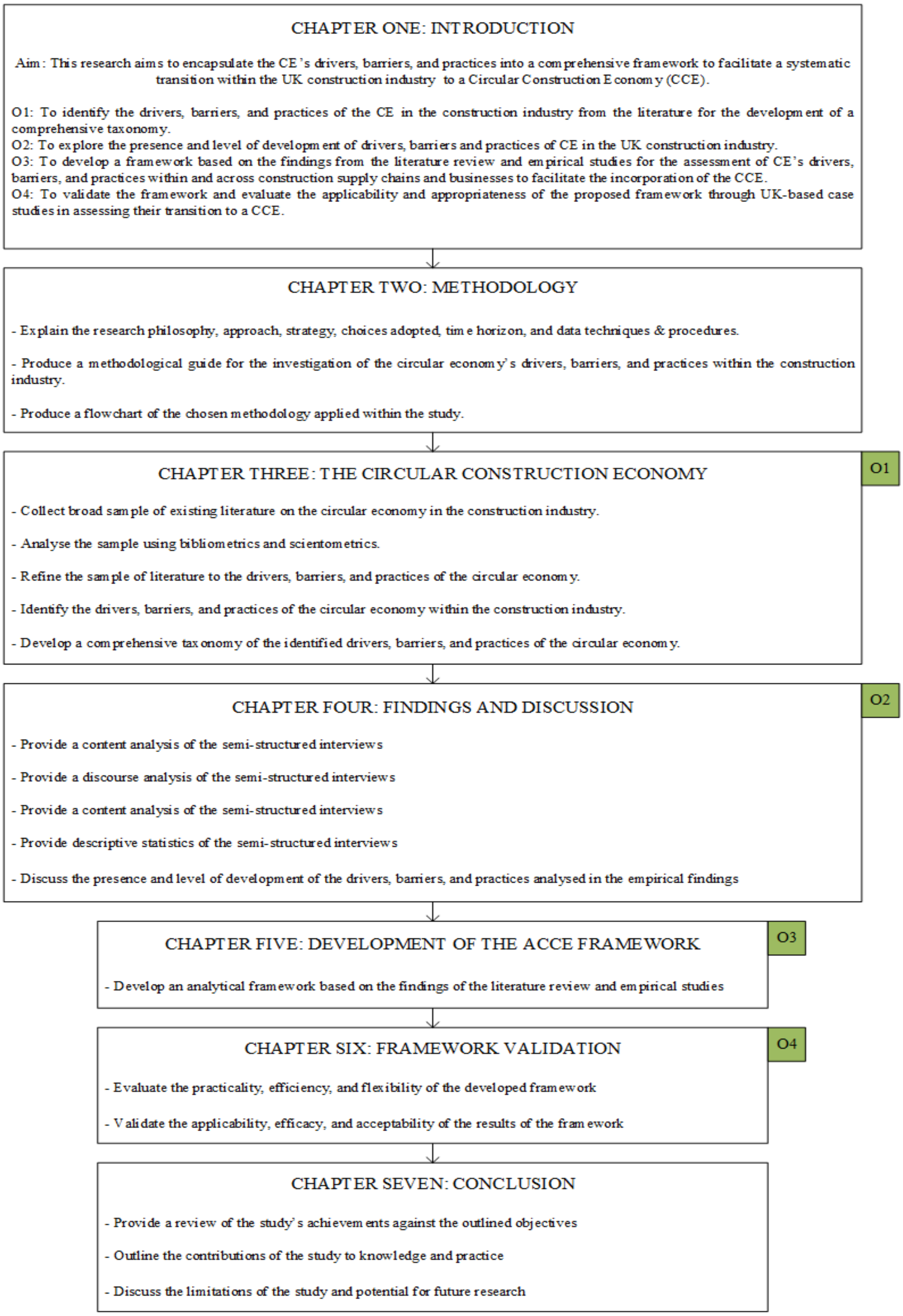

Figure 1.1: Thesis structure

1.5.1 Chapter One – Introduction

This chapter outlines the context and structure of the thesis on the CE. The chapter also highlights the identified gap in knowledge, aim and objectives, focus, and methodological approach of the research.

1.5.2 Chapter Two – Methodology

This chapter provides details on the methodological approach of the PhD study. The chapter looks at the adopted philosophies, approaches, data collection strategies, structural choices, time horizons, and techniques and procedures for analysis. Each section details the methodological choice of the study and its application within the PhD thesis. The adopted methodological approach for the study includes pragmatism, abduction, case studies, surveys, mixed-methods, a cross-sectional timeframe, and a bibliometric, scientometric, content, discourse, comparative analysis, and descriptive statistics.

1.5.3 Chapter Three – The Circular Construction Economy

This chapter provides a review of the extant literature on the CE within the construction industry. The chapter utilises a systematic literature review to collect a sample of the DBPs for the development of a holistic theoretical framework. Bibliometric and scientometric analyses were also conducted for the identification of the gap within the current body of knowledge to refine the keywords used within the systematic literature review of the CE. This chapter was summarised with the development of a theoretical framework in the form of a taxonomy, which included a holistic categorisation of the DBPs of the CE identified within the review of the literature.

1.5.4 Chapter Four – Findings and Discussion

This chapter analyses the results of the empirical data collection for discussion against the existing literature on the DBPs of the CE. A mixture of qualitative and quantitative data was analysed using content, discourse, and comparative analysis, and descriptive statistics. The empirical data was analysed based on disciplines, supply chains, and as a complete sample to gain both granular and holistic results. The variance between samples was also reviewed to understand the difference between supply chains. This chapter is summarised by the lack of guidance and framework for the CE within the construction industry and the suggested characteristics for the development of a framework identified within the empirical studies.

1.5.5 Chapter Five – Development of the Analytical Circular Construction Economy (ACCE) Framework

This chapter reviews the findings from the extant literature and empirical studies to develop a framework suited to the needs of practitioners within the construction industry and the development of the CE in practice. The initial theoretical framework is reviewed based on the findings of the empirical data collection to understand the required adaptations for practitioners within the construction industry. From the theoretical framework, an analytical framework was developed to be simple, measurable, prescriptive, scalable, adaptable, and holistic. The use of the analytical framework is then discussed with examples before summarising with a plan for proof of concept and validation of both frameworks.

1.5.6 Chapter Six – Framework validation and evaluation

This chapter investigates the validity of the empirical studies and evaluates the developed theoretical and analytical frameworks. The chapter commences with the stages of the designed validation/evaluation process and the questions constructed for the assessment of the empirical data collection and framework's use. Two focus groups were conducted, one with each supply chain, and two structured interviews were conducted with specialists in the CE. The results were discussed based on the approval of each question or recommendations for improving one or both of the frameworks. The chapter is summarised by the improvements and future research required for the use of the frameworks in practice.

1.5.7 Chapter Seven – Conclusion

This chapter concludes the PhD thesis by reviewing the aim and objectives of the research to gauge the success of the chosen approach. The limitations of the study will also be identified and reviewed to understand the potential improvements for future research. Finally, the opportunities for future research will be identified and discussed to provide direction for the advancement of the research field.

CHAPTER 2: METHODOLOGY

This chapter discusses the methodological choices and structure of the research. The research process and design are key to the production of quality research and a deeper understanding of the reality around us. The structure of the PhD's methodology follows Saunders et al. (2019) 'Research Onion' (Figure 2.1). Saunders et al. (2019) devised the research onion to guide and structure research in businesses, and since this research closely scrutinises business practices in relation to CE, its use was judged as appropriate. Furthermore, the research onion was selected as a methodological structure as it is more comprehensive compared to other structures, such as that of Cameron and Price (2009) and Gray (2019), which were also considered to guide the research methodology and, in parts, drawn on to supplement Saunders et al. (2019). A commonality between research structures is that they start with the philosophical views of the researcher and end with the granular analysis of the data. The different layers of the research onion are stratified from the outside inward to decide and organise the research process. Proceeding from the choice of philosophy is the research approach, whether the research is inductive, deductive or abductive, and its focus is exploratory, descriptive, explanatory or experimental. Depending on the specific choices made, a single method, multiple methods, or mixed methods would then be chosen and inform specific strategies and methods. There are a number of strategies, the most common are the case study, survey, action research, and grounded theory methods. The time horizon of the methods of data collection will also be determined, whether the study is longitudinal or cross-sectional.

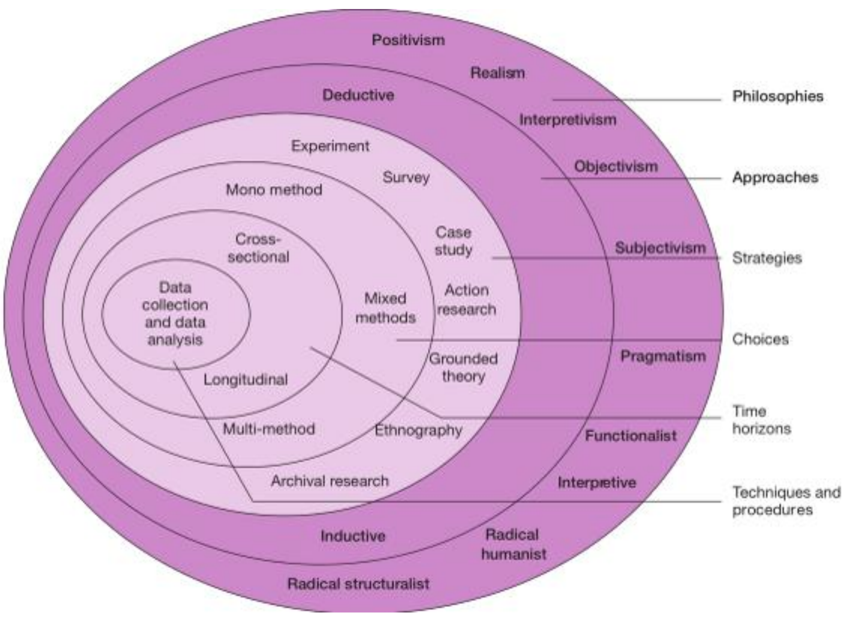

Figure 2.1: 'Research Onion' (Saunders et al., 2019)

The methodology of this PhD research adopted a pragmatic abductive sequential mixed-method approach that utilised interviews and focus groups to gain a cross-sectional view of the topic (Figure 2.2). The use of a mixed-method design for this study allowed for the cross-comparison of the results to refine the findings and gain insights into the dynamics within the construction industry in the context of extant academic literature. Similar methodological designs have been used within literature to study the CE (e.g. Ghaffar et al., 2020), to explain phenomena that comprise industrial performance and management (e.g. Schöggl et al., 2020), to assess and develop the CE (e.g. Bao and Lu, 2020), and to compare practice and opinion/experience in UK construction (e.g. Dey et al., 2020). Using the results of the literature review and previous studies on the CE, the following methodology was devised.

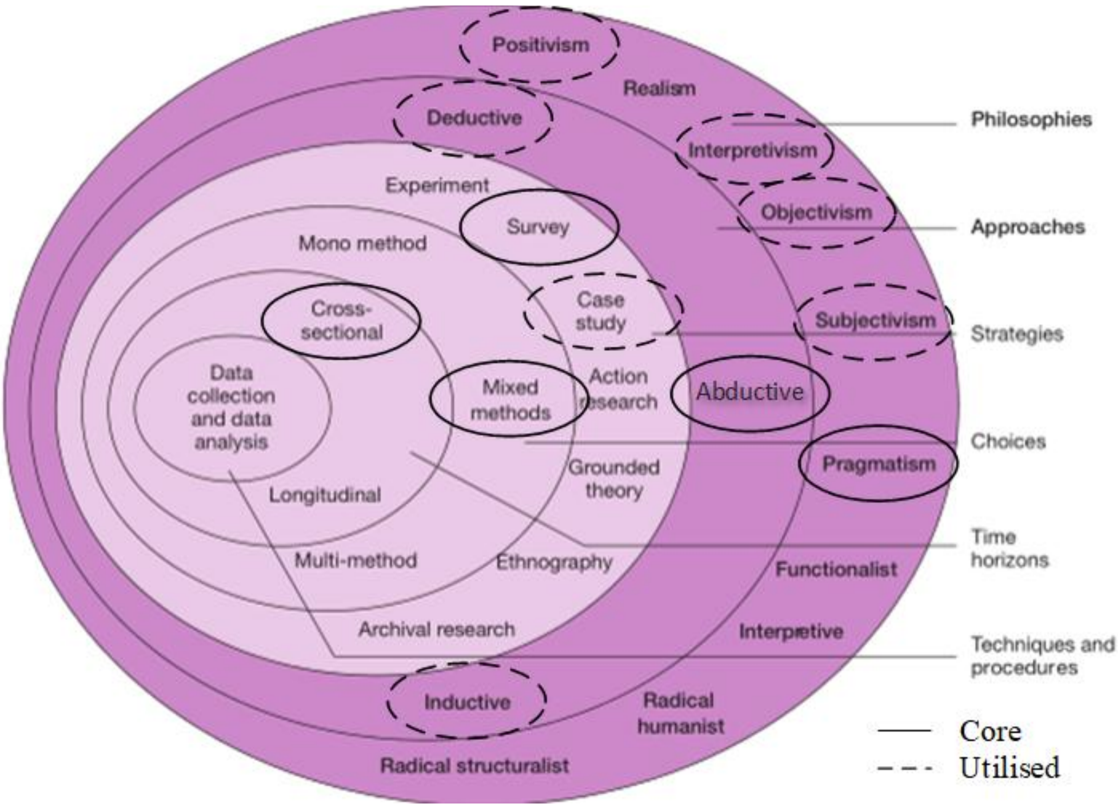

Figure 2.2: Annotated 'Research Onion' (Saunders et al., 2019)

2.1 Philosophical Perspectives

The philosophical perspective is the underpinning of the research and how the researcher views the reality in which they measure and analyse (Crotty, 1998b; Saunders et al., 2019). A pragmatist perspective was chosen for this PhD study to create practical action within the construction industry as it transitions to a CE. Pragmatism as a philosophy can utilise a mixture of qualitative and quantitative methods, which hold different philosophical properties (Cameron and Price, 2009). The use of pragmatism and a mixture of methods within this PhD study has led to the use of aspects of positivism and interpretivism (Figure 2.3). In this section, the philosophical perspective of the research will be discussed.

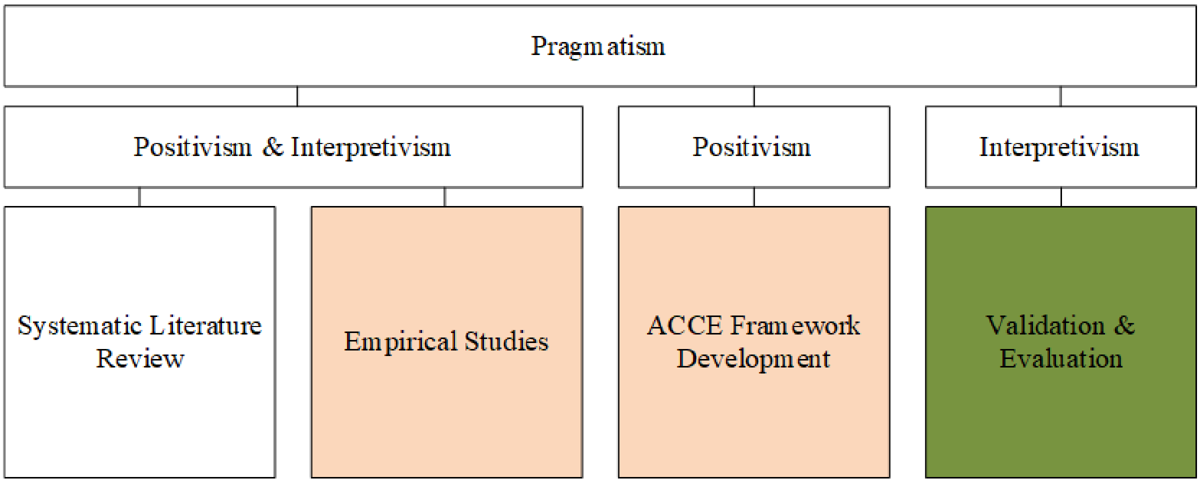

Figure 2.3: Philosophical perspectives of the PhD thesis

2.1.1 Pragmatism

The chosen philosophy for this study is pragmatism. Pragmatism regained popularity in the 1970s as it provides insights into management and organisational research (Gray, 2019). Pragmatism investigates that which is only relevant to actionable practice (Saunders et al., 2019). Pragmatism is the stance of action, and the focus of the pragmatist is on the impact of the phenomenon (Saunders, 2019). In pragmatic research, theory and knowledge enable doing, and consequently, actions (Cameron and Price, 2009). Pragmatism's interpretation of reality is the consequences of ideas, systems, and processes (Crotty, 1998); hence, these elements need to be investigated using the appropriate methods. Pragmatism is often used as a justification for the use of mixed-method research designs and views mixed-method research as legitimate; however, in some cases, it is absolutely necessary (Gray, 2019). For this study, the lack of a holistic taxonomy of the CE for the construction industry means that there is a requirement for the consolidation of theory to enable actionable practice by any means necessary. Therefore, mono-method philosophies are not suitable for the study due to the size and different characteristics of each topic identified within the literature, which requires a mixture of different methods for exploration and explanation.

A pragmatist believes in multiple perspectives and the complexity of actions, which create consequences that make up reality (Cameron and Price, 2009). Research starts with a problem and then aspires to achieve a practical solution, which may require multiple methods of data collection utilising multiple philosophies to gain a solution to achieving action (Saunders, 2009). Ultimately, pragmatism's concern with multiple perspectives increases the overall knowledge of the phenomenon, which allows for better action (Cameron and Price, 2009). Due to the diverse aspects of the topic under investigation (DBPs of the CE), a mixture of methods is best suited in this study to investigate different elements of the research using the best perspective to view, collect, and analyse data to understand the phenomenon. Therefore, topics are investigated using either qualitative or quantitative forms of data collection to explore or explain the problem using the method that will enable action through the development of a theory. The mixed method approach aligns with adopting multiple philosophies to view the problem and results, aligning ontology, epistemology, and axiology (Cameron and Price, 2009). The investigation into the extant literature utilises an interpretivist philosophy to identify and categorise the DBPs of the CE into a taxonomy. In the empirical studies, the drivers and barriers of the CE were investigated quantitatively with a positivist lens due to a lack of understanding within the literature of their presence, which requires explanation. Whereas, the practices of the CE had little evidence of the level of development within the construction industry, which required exploration through qualitative methods and an interpretivist lens. Furthermore, when developing models, systems, or policies that require testing, pragmatism and mixed-method research designs are suited to allow for multiple forms of data collection and testing to understand the effectiveness and use of the developed output (Clark and Creswell, 2008). In this PhD study, interpretivism and positivism are used for the understanding, exploration, and explanation of the existing theory before the final output is evaluated and tested. Bell et al. (2022) stated that pragmatism is best suited to abductive research, which aims to develop and then test a research output. This further supports the philosophical selection of this study, as it seeks to develop and validate a framework of the CE's DBPs for the use of practitioners. The ontological perspective of pragmatism within this study views the nature of the research focus as a complex and rich reality that is the consequence of experiences and opinions (Saunders et al., 2019) of the managers within the construction industry, which creates actions and consequences. The epistemological perspective of pragmatism states that the practical meaning of knowledge and truth is contextual (Saunders et al., 2019) and that the problems faced by the construction industry when seeking to develop a CE can be investigated, contextualised, and solved through the generation of knowledge and theory that enables practice. Therefore, the application of the pragmatist's perspective within this study enables the investigation of a complex reality, whereby the problems faced by practitioners can be investigated through the researcher's axiological doubts and beliefs to understand the problem and develop knowledge to create actionable practice.

Critical realism was also considered for this purpose. Critical realism investigates the underlying structures that create the reality we perceive (Saunders et al., 2019). The objective and the subjective are stratified and layered to understand the complex picture of reality (Saunders et al., 2019). The critical realist looks at the empirical, actual and real and gauges the differences between the former two aspects with the real (Alvesson and Sköldberg, 2017). As a mixed-method philosophy, critical realism would also enable the use and comparison of multiple mixed-methods for the exploration of multiple topics of varying characteristics within different layers of the sample and research focus. However, the key difference between pragmatism and critical realism in this study is the outcome of the research, for which pragmatism seeks to create impact, and the timeframe of this study and the quantity of DBPs limit the ability to understand the 'real' aspect of critical realism for comparison with the empirical and actual domains.

2.1.1.1 INTERPRETIVISM

Interpretivism emphasises that everyone has different subjective perceptions and experiences, which alter the perceived reality (Patton, 2014). The different experiences humans have created different meanings or interpretations of reality that can differ from the sciences that quantitatively analyse reality (Saunders et al., 2019). Interpretivists studying the social sciences believe the socially constructed realities are fundamentally different to natural processes and therefore require different methods of measurement (Bell et al., 2022). Interpretivists believe in a constructionist ontology of society that is built up of human action and experience (Bell et al., 2022). Thus, these different interpretations require collection and analysis to understand the range of different conceptions (Bell et al., 2022). Interpretivism concerns itself with the investigation and discussion of these different experiences and their meaning by collecting data that focuses on narratives, stories, perceptions, and interpretations (Saunders et al., 2019). Interpretivism aims to understand the different causes and effects perceived by different participants to understand the root and stem of the phenomenon (Bell et al., 2022). The interpretation of the reviewed literature provided the themes and structure of the theoretical framework based on the interpretations of other researchers, their identified DBPs, and categorisation. Themes already identified within the literature were compared, and the core themes were interpreted by the researcher from existing categorisations to assign the DBPs to their designated theme based on their characteristics. Furthermore, empirical data on the practices of the CE were ranked based on the researcher's interpretation of the qualitative response of the participant using a content analysis for a positivist comparison with the quantitative data collected on the drivers and barriers for use within the analytical framework. This use of interpretivism for qualitative results to produce quantitative data was also used by Oesterreich and Teuteberg (2016) to compare data sets for a positivist comparison of data to reinforce their final analysis. The final evaluation and validation of the PhD study also employs an interpretivist lens to analyse and understand the responses provided by participants for the review of the research output and potential future research.

2.1.1.2 POSITIVISM

Positivism observes reality through measurable data, whilst working in an observable social reality (Saunders et al., 2019). Positivism's objectivist stance to research forms one true reality that can be measured through numerical values (Bell et al., 2022). Positivism is the observation of the natural world whilst working within an observable social reality to form law-like generalisations (Saunders, 2009). Positivism is typically deductive and quantitative in nature (Crotty, 1998). Positivism is used within this study to measure the drivers and barriers of the CE to understand their relevance and impact on the sample of participants. The use of positivism for the measurement of the drivers and barriers follows previous research, such as that of Chan et al. (2019), who used a positivist philosophy to measure barriers between different disciplines. The use of positivism to understand the presence and severity of the drivers and barriers within the empirical studies was to deduce law-like generalisations within the sample of participants within their social reality, as suggested by Saunders (2009) and Crotty (1998). However, positivism can also be used in the identification of a phenomenon (Bell et al., 2022). Within this study, the positivist quantification of the drivers and barriers deduced their presence and severity whilst inductively providing direction for the identification of the sample's needs for development. The final analytical framework also adopts a positivist perspective to measure the development of practices and the presence of drivers and barriers within the selected sample. This approach for the analytical framework was rationalised by the desires of the participants in the empirical data collection, who requested a prescriptive and measurable guide to understand their development towards a CE.

2.2 Approach to Theory Development

In this section, the types of research approaches and design that have been used for the PhD research will be discussed, and how these were expected to aid theory development. Overall, an abductive approach was chosen to deductively identify and describe the CE's DBPs, abductively explore and explain the CE's DBPs, and deductively evaluate the final output of the PhD (Figure 2.4).

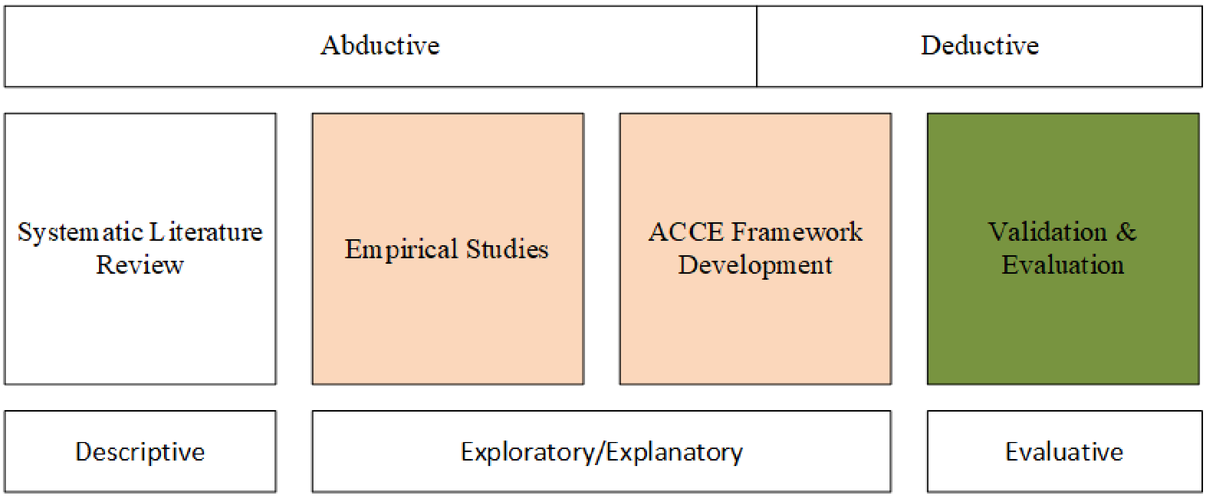

Figure 2.4: Approach to theory development

2.2.1 Research Approach

This PhD study follows a mixture of inductive and deductive approaches, creating an overall abductive approach. Since the start of the 21st century, it has been more common to follow an abductive approach to research in business (Bell et al., 2022). This is due to the nature of businesses, which draw on data from both qualitative and quantitative means, as well as the presence of many known and unknown phenomena in organisations (Bell et al., 2022). Bell et al. (2022) proposed the use of abduction within business research with a pragmatic philosophy to identify the problem in literature or through organisational engagement to gain empirical data on the phenomenon. Saunders et al. (2019) state that abductive approaches are common in the development of management strategies. A mixed approach can be conducted by initially understanding the available knowledge and developing a hypothesis (Gray, 2019). Following the inductive development of a hypothesis, the hypothesis is deductively tested alongside the working theory (Gray, 2019). An abductive approach, however, identifies a problem in theory or from empirical means and seeks to explain the phenomenon, to simplify, or to solve it (Bell et al., 2022). Based on the gap in knowledge and the output of the study, an abductive approach is used, where the theory informs the development of a taxonomy, which is investigated empirically to deduce the presence of drivers, barriers, or practices within the construction industry and inductively identify the requirements of practitioners. The findings of the empirical studies were then developed into a framework, which was then evaluated and validated to deduce the performance of the framework in practice. A similar study was conducted on the CE by Mies and Gold (2021) to understand the social dimensions of the CE for the inductive development of a framework, which was then deductively tested.

2.2.1 Research Design

In this section, the different types of research designs will be discussed, and the chosen design for this PhD explained and justified. Overall, the PhD study includes descriptive, exploratory, explanatory, and evaluative sections of its design.

2.2.2.1 DESCRIPTIVE

The literature review of the study follows a descriptive approach to develop a theoretical framework of the DBPs of the CE. Descriptive studies seek to describe a phenomenon that is well-known but requires further detail (Neuman Lawrence, 2014). Descriptive research is based on rich theory for the comparison with empirical data to improve the body of knowledge (Cameron and Price, 2009). Descriptive studies aim to collect a profile of situations, persons, or events to further understand and contextualise them (Saunders et al., 2019). Descriptive research can be a catalyst for exploratory research or a prelude to explanatory research (Saunders et al., 2019). The use of descriptive research within this study enabled the later exploration and explanation of the CE by extracting DBPs from the literature to develop a theoretical framework which defines and describes each topic. This method was required by the lack of a comprehensive taxonomy of DBPs within the extant literature, which limited the ability of informed investigations on the development of the CE specifically within the UK construction industry.

2.2.2.2 EXPLORATORY and EXPLANATORY

Following the descriptive part of the study, the study followed an exploratory and explanatory phase, investigating the described DBPs. Exploratory research is completed when there is little theory or knowledge on the problem (Neuman Lawrence, 2014). Exploratory studies are used to collect enough initial data on a phenomenon to be able to form a more detailed study in the future (Neuman Lawrence, 2014). An exploratory study rarely provides conclusive answers, merely clues and hints (Neuman Lawrence, 2014). Exploratory research is aimed at uncovering what is occurring, to achieve insight, and to identify novel ideas for future research (Cameron and Price, 2009). An exploratory study is a valuable tool to ask open questions and uncover insights about a given topic using methods such as (semi-structured) interviews and focus groups to explore topics and gain qualitative data (Saunders et al., 2019). Exploratory studies have the advantage of being flexible and adapting to the topics and themes that emerge from the study (Saunders et al., 2019).

Explanatory research, on the other hand, aims at identifying and drawing comparisons between relationships that are informed by existing theory/theories (Cameron and Price, 2009). Explanatory research builds on exploratory and descriptive studies and goes on to find the reasoning for the occurrence of phenomena (Neuman Lawrence, 2014). Explanatory research looks for causes and reasons to explain a phenomenon (Neuman Lawrence, 2014). Explanatory studies can use a wide range of methods and techniques and can start with the development of a novel theory or the extraction of one from existing theory, and provide empirical evidence to support or refute said theory (Neuman Lawrence, 2014). Explanatory designs can also be used to compare two theories to identify the more prominent (Neuman Lawrence, 2014). In business research, explanatory research will likely be concerned with the effectiveness of a strategy, policy, initiative, or practice (Saunders et al., 2019). Explanatory studies allow the researcher to determine the knowledge of the topic, performance, and follow up with 'Why?' to compare the answer with the pre-existing knowledge (Saunders et al., 2019).

The empirical data collection in this PhD utilised an explanatory approach to understand the identified DBPs described in the theoretical framework and to explain their development and presence. However, due to the infancy of the CE in research, the empirical data collection was designed to include exploratory elements to gain new insights into existing DBPs and identify new drivers, barriers, or practices by asking open-ended questions and using unstructured elements to explore new phenomena.

2.2.2.3 EVALUATIVE

The evaluative section of this study focuses on the drivers and barriers identified within the literature, as well as the developed theoretical and analytical frameworks and their use in practice. Evaluative studies seek to identify how well something works (Saunders et al., 2019). The main goal of evaluative studies is to assess the value of something in terms of the outputs and outcomes of its use (Clark et al., 2021). In business research, these may include business strategies, policies, programmes, processes, or even groups, events, situations, or changes/performance over time (Saunders et al., 2019; Clark et al., 2021). The evaluation itself seeks to understand how effective something is and why (Saunders et al., 2019; Clark et al., 2021). Evaluative research is normally carried out as a process of identifying areas for improvement within an organisation or sector (Clark et al., 2021). The ranking of the drivers and barriers within the empirical studies of the research provided a level of evaluation as to their presence within each supply chain and discipline. This provided an evaluation of the events or situations within each supply chain (Saunders et al., 2019; Clark et al., 2021). The developed frameworks were later evaluated within interviews and focus groups to understand how effective they are at measuring and guiding the CE's development and why they are useful to practitioners in the construction industry for their wider acceptance. This was used to evaluate the framework and empirical studies within the original supply chains and by specialists external to the study.

2.3 Methodological Choice

Saunders et al. (2019) state that defining the nature of the methodology and types of methods is key to any research. However, in business research, qualitative and quantitative data collection and analysis methods are often combined (Saunders et al., 2019). In this section, the different types of methodological choices will be discussed.

2.3.1 Mono-Method, Multiple Method, and Mixed-Method

This PhD employs a mixed method design due to the requirement of the study to investigate different types of topics and processes (e.g. probing into what is being done/has happened, as well as why and how). Mixed method uses a mix of qualitative and quantitative methods as opposed to purely one or the other (multi-method) (Saunders et al., 2019). Patton (2014) notes that the strongest forms of data collection use mixed-method designs. The practices of the CE required exploration to understand their development and, therefore, required qualitative forms of data collected; the drivers and barriers of the CE required explanatory research. One of the research designs discussed by Clark and Creswell (2008) utilises an exploratory and explanatory mixed-method design to generate and test a model. This design utilised a mixed-methods approach to generate a model with qualitative data and test it quantitatively. A similar approach was utilised for this study, where the initial data collection consisted of qualitative and quantitative methods to generate an analytical framework, which was consequently evaluated with qualitative methods. The use of mixed methods within the initial data collection provided rich qualitative data and exploration to understand the requirements of the framework, whilst the quantitative data provided an explanation of the drivers and barriers of the CE. When analysed, the two data sets provided an understanding of the requirements and the best mechanism for the framework to evaluate CE knowledge, interpretations, and its application in the construction industry.

2.4 Strategies for Data Collection

This section discusses the different types of strategies considered and explains and justifies the choices made. The core method of data collection for the empirical studies chosen was the survey strategy, consisting of semi-structured interviews. The sample of participants for the empirical studies was selected from two supply chains used as case studies. A systematic literature review was also utilised to collect a sample of bibliometric data for both bibliometric and scientometric analyses. The final data collection stage was used to evaluate and validate the study and consisted of two focus groups and two structured interviews.

2.4.1 Unit of Analysis

The initial unit of analysis within this study resides within the systematic literature review, whereby extant literature was analysed to understand the existing landscape of the knowledge within the field and refine the scope of the study through the identification of novel areas. The main unit of analysis for this study was determined to be holistic supply chains in the UK construction industry. Out of five potential supply chains identified, two were selected for the study. Within each supply chain, disciplines were also analysed and compared through the participation of expert practitioners with management roles within their respective supply chains.

2.4.2 Case-Studies

Case study research is useful in studies that want or require interaction with the problem in focus (Cameron and Price, 2009). A case study is the investigation of a series of phenomena with multiple methods to provide a rich picture (Yin, 2009). Case studies require multiple methods of data collection to fully analyse the processes behind the case (e.g. the management style) (Cameron and Price, 2009). This allows the researcher to immerse themselves in the problem domain, whereas other strategies aim to detach themselves from the problem (Cameron and Price, 2009). A case study can be performed on one project, organisation, or across multiple of either (Cameron and Price, 2009). The use of multiple cases allows the researcher to draw comparisons between the studies (Cameron and Price, 2009). These characteristics constituted the reasons for adopting a case study approach for this PhD, even though case study findings cannot be generalised externally to the studied case (Bell et al., 2022; Cameron and Price, 2009; Gillham, 2000; Saunders et al., 2019; Yin, 2009). The specific insights and data gained from one or more chosen case studies can help in painting a picture of what may be more generally pertinent and relevant. Multiple case studies are becoming more common in business research as a tool to compare cases for more rigorous analysis (Bell et al., 2022). This PhD study purposively selected two supply chains after the consideration of five separate entities. The use of multiple cases can be beneficial in bridging the gap between the unique nature of case study research and achieving the generalisability of the results (Saunders et al., 2019). A pilot case study was conducted to understand the available data within UK construction companies to refine the scope of the study. The pilot case study determined that there is a lack of reporting on material data and practices, which limited the ability of the researcher to conduct practice and material performance studies. 2.4.3 Survey Strategy (Survey method, interviews, focus groups)

The survey strategy is useful for the analysis of relationships between variables to develop models or frameworks (Saunders et al., 2019). The survey method is one of the most widely used methods in social research (Neuman Lawrence, 2014). The survey strategy is often related to deductive reasoning in explanatory or descriptive research (Saunders et al., 2019). The most common data collection methods within the survey strategy are questionnaires, interviews, and focus groups (Saunders et al., 2019). Surveys can collect data for multiple variables by asking a number of questions (Neuman Lawrence, 2014). This enables the use of descriptive statistics to cross-reference variables (Neuman Lawrence, 2014). Surveys commonly start with a hypothesis, develop and test the chosen questions, select a target population and sample, and collect data for analysis (Neuman Lawrence, 2014).

When forming questions for a survey, researchers should avoid slang, vagueness and emotional language, and avoid questions being double-barrelled, leading, expressing future intentions, being double negatives, creating unbalanced categories, and false pretences (Neuman Lawrence, 2014). Researchers often find that the survey method is limited by the participants' willingness and availability, which can delay or prolong the data collection stage (Saunders et al., 2019). Another limitation of surveys is the number of questions that can be asked, as the respondent's time is valuable and not limitless (Saunders et al., 2019). Without care, structured surveys can provide misleading results due to the population's familiarity with performing them (Neuman Lawrence, 2014). To avoid any of the former, three pilot interviews were conducted to assess the interview questions and identify any misleading, vague, or unbalanced questions.

2.4.3.1 SEMI-STRUCTURED INTERVIEWS

At the core of interviewing is the desire to understand and interpret the experiences and narratives of others (Gray, 2019). One-on-one interviews are useful to make the participant feel comfortable in a confidential environment, which enables open conversation (Gray, 2019). In comparison to questionnaires, interviews allow for the probing of answers, which can increase the clarity and quality of the data collected (Gray, 2019). In this PhD study, semi-structured interviews were conducted to allow for exploratory and explanatory approaches. Semi-structured interviews use a set list of open-ended questions with prompts to guide and discuss a given topic (Bao and Lu, 2020; Patton, 2014; Saunders et al., 2019). This allows for comparable themes and topics within the interview whilst enabling the researcher to improvise and further investigate emergent topics (Patton, 2014). The method of interviewing allows for rich qualitative data to be collected and compared to view answers to the predefined themes and unveil new themes and concepts (Saunders et al., 2019).

Semi-structured interviews were selected for this study to explore and explain the knowledge and experience of participants on a set list of open-ended questions determined from the extant literature (Patton, 2014; Saunders *et al.*, 2019). Semi-structured interviews were judged to be the best-suited method of data collection for this research because they allow the exploration and explanation of current practices in industry qualitatively, while measuring the drivers and barriers for a circular economy quantitatively. As the themes were developed from extant literature, the approach will largely be deductive and aim to test the existing theory (Saunders et al., 2019). By following this approach, there needs to be consistency between the themes in the theory and within the interviews to be able to produce comparable results (Saunders et al., 2019), which further justifies the creation of a comprehensive taxonomy from the existing literature. This process, when utilised for explanatory deduction, can create an abductive design where the existing theory is inductively developed and then compared in a deductive manner to produce explanations (Saunders et al., 2019). The choice of an abductive approach for the empirical studies allowed for the inductive development of the ACCE framework through the deductive explanation of the CE's DBPs.

Twenty-seven participants were interviewed across two supply chains, a range of disciplines, ages, and levels of experience within the construction industry (Tables 2.2 and 2.3). Themes were identified within the literature and developed into a theoretical framework. The DBPs of the theoretical framework were addressed within the semi-structured interviews to explain the phenomenon through the interpretations of managers in the construction industry (Cameron and Price, 2009). The use of semi-structured interviews for this study allowed for follow-up questions to be asked to probe into the initial answer given to gain exploratory qualitative data to identify novel topics (Patton, 2014). The collection of qualitative data was crucial to the understanding of the industry professionals' knowledge and experiences to be understood (Cameron and Price, 2009). In addition, a structured section was included within the interview with the option to elaborate. The structured section consisted of drivers and barriers measured on a Likert scale of one to four, ranging from 'strongly disagree' to 'strongly agree', and practices were ranked from 'far below standard' to 'far above standard' (Table 2.1). A four-point Likert scale was selected to ensure positive or negative data was collected to avoid null responses, as identified within the pilot interviews conducted. A structured design was better suited for the understanding of the drivers and barriers of the chosen topic, which sought to understand the opinion of industry professionals. The participants were given the option to expand on their rationale and express any specific details about drivers or barriers that they have experienced.

Table 2.1: Interview themes, questions, and prompts

Theme	Question	Practices for Prompts
Control Questions	Age? (Opt-out option)	N/A
	Job Role?	
	Job Description?	
	Years of Experience?	
Information Management	Are Sustainable Waste Management Plans (SWMPs) used to plan for and evaluate waste management practice?	• Waste management • Data collection and communication
	Is information regarding material consumption and waste shared between parties?	• Establishing communication and information sharing • Knowledge management and education
	Are digital technologies used to enhance management strategies?	• Building Information Modelling (BIM) • Internet of Things (IoT) • Circularity tools • Cost modelling tools • Collaboration tools

Design Management	Are closed loops for waste recovery considered in the design stage?	• Design for closed loops • Design for longevity • Design for deconstruction • Material specification • Operational impacts
	Are processes and activities simplified, standardised, or prefabricated to reduce waste? (VE, TQM)	• Modularisation • Best practices • Material standards
	Is the infrastructure to recover and reuse or recycle waste planned or designed for?	• Take-back systems • Supervision
Supply-Chain Management	Is material consumption and waste tracked and evaluated?	• Information management and tracking • Benchmarking • Blockchain • LCA • Material passports
	Is waste segregated and reused or recycled?	• Upcycling/Downcycling • Urban mining • 3-12Rs of the CE • Secondary material innovations
	Are designers, suppliers, and or contractors managed to identify and reduce waste?	• Understanding the product, process, and consumer • Top-down management • Bottom-up management • IPD • Networking
	Is procurement used to manage levels of consumption and waste?	• Extended responsibilities • Product as a service
Drivers and Barriers (Likert Scale)	**Drivers (1-4)**	**Barriers (1-4)**
	New Economic and Environmental Opportunities for Businesses	Complexity of Construction
	Industrial Competition	Profitable Linear Market
	Secondary Material Production/Supply	The Stigma Surrounding Secondary Materials
	Raw Material Volatility	Lack of Short-term Benefits
	Reduced Environmental Impact	Risk of Innovating

	Servitisation/PSS	Cost of Innovating
	Take-back Schemes	High Cost of Secondary Products
	Recovery and Reuse Infrastructure	Lack of Infrastructure for Recovery and Reuse
	Standardisation	Lack of Standardisation
	Waste Reduction	Lack of Time
	Cost and Time Efficiency	Quality of Secondary Materials
	Improved Product Quality	Lack of Segregation
	Circular Laws and Legislation	Low value Recovered Materials
	Taxes (Relief and Penalties)	Immature Secondary Market
	Goals and Targets	Lack of Financial Support
	Supervision and Inspections	Lack of Supporting Laws and Legislation
	Financial Incentives	Lack of Taxes (Relief and Penalties)
	Procurement Strategies	Lack of Goals and Targets
	Frameworks/Business Models	Lack of Supervision
	Guidance and Best Practice	Lack of Incentives and Penalties
	Secondary Material Standards	Lack of Procurement Strategy
	Integrated Project Delivery (IPD)	Lack of Frameworks/Business Models
	Responsibility and Recognition	Lack of Guidance and Best Practice
	Marketing and Awareness Campaigns	Lack of Government Support
	Education Programs	Lack of Industry Adoption
	Data sharing	Lack of Integrated Project Delivery (IPD)
	Society's Opinion of Unsustainable Practice	Lack of Responsibility and Recognition
	Research and Development (R&D)	Lack of Marketing and Awareness of the CE
	New networks	Lack of Knowledge and Education

	Lack of Life Cycle Analysis (LCA) and Benchmarking	Lack of Management
	Material Database	Lack of Consumer Demand
	Case Studies	Lack of R&D
	BIM(BIM)	Lack of Life Cycle Analysis (LCA) and Benchmarking
	Circularity tools	Lack of Material Data
	Design tools	Lack of Case Studies
	Collaboration tools	Lack of Information
	Material Tracking	Lack of Circular Tools
	New Methods of Construction and Deconstruction	Lack of Design Tools
	New Materials	Lack of Collaboration Tools
		Lack of Material Tracking
		Lack of Transparency
		Lack of Material Technology
		Lack of Material Classification

Table 2.2: Participants of the semi-structured interviews (SC1)

No.	Role	Experience (years)	Working Group
P1	Construction Director	15	Construction Management
P2	Commercial Director	13	Commercial Management
P5	Construction Manager	26	Construction Management
P7	Senior Design Manager	13	Design Management
P11	M&E Regional Director	35	MEP Management
P12	Commercial Director	24	Commercial Management
P13	Regional Commercial Director	25	Commercial Management
P15	Façade Director (Supplier)	13	Supplier
P16	Demolition CEO	35	Demolition Management
P17	Sustainability	4	Sustainability Management
P19	Commercial Director	20	Commercial Management
P21	Director of Sustainability	8	Sustainability Management

Table 2.3: Participants of the semi-structured interviews (SC2)

No.	Role	Experience (years)	Working Group
P3	Site Manager	16	Construction Management
P4	Senior Designer and Planner	35	Design Management
P6	Site Waste Liaison Officer	13	Waste Management
P8	Project Manager	30	Construction Management
P9	Senior Designer and Planner	35	Design Management
P10	Engineer	11	Design Management
P14	Quantity Surveyor	6	Commercial Management
P18	New product development PM	8	Supplier
P18	New product development	24	Supplier
P22	Sustainability	2	Sustainability Management
P23	Logistics account manager	20	Logistical Management
P24	Head of Sustainability	8	Sustainability Management
P25	Head of Procurement	18	Procurement Management
P26	Head of Logistics	26	Logistical Management
P27	Design Director	35	Design Management

2.4.3.2 EVALUATORY AND VALIDATORY STRUCTURED FOCUS GROUPS AND INTERVIEWS

A focus group is a small group of specifically selected participants who discuss selected topics for approximately two hours (Patton, 2014). If multiple focus groups are conducted, the results and discussions can be compared to identify themes (Patton, 2014). The validation stage of this study relies on the interpretations of participants with practical industry or specialist expertise to determine its usefulness and effectiveness (Cameron and Price, 2009). Due to the reliance of the framework on the empirical findings and the study's requirement for industrial acceptance, focus groups and specialist interviews were selected for the validation stage to determine the opinion of industry practitioners and gain feedback. Two focus groups and two specialist interviews were used to evaluate and determine the validity of the study (Table 2.6, 2.7, and 2.8). Two focus groups were conducted internally within the supply chains to evaluate and determine the internal validity of the study. Two specialist interviews were later conducted externally to the study with independent expert consultants within the CE field to gain external evaluation and validation. All participants were asked the same set of questions in a structured format to evaluate the utility of the analytical framework within their business and the empirical results of the study. Each of the two supply chains which participated in the study was shown its own results and the theoretical and analytical frameworks in a summary report. The external consultants were shown the results from both supply chains merged together to provide an example of use (Tremblay et al., 2010). The development of reports to summarise the results of the empirical studies and the development/use of the theoretical and analytical frameworks provided participants the ability to review and evaluate the study before the focus group/interview.

The validation was split into two tasks, one to test the use of the framework and its practicality, efficiency, and flexibility (Table 2.4). The second was to validate the results of the study in accordance with the perception of CE maturity within the supply chain sample and the CE specialists to see if the results were accepted, applicable, and if the tool was effective (Table 2.5). The attributes of the questions in Tables 2.4 and 2.5 were derived from Tzortzopoulos' (2004) study, which utilised a combination of sources to develop the structure of the attributes (i.e. Bresnen and Marshall (2001), Cooper (2006), Kagioglou (1998), Smith and Morrow (1999)). Similarly, a thesis authored by Talebi et al. (2016) adapted Tzortzopoulos' (2004) framework for the validation and evaluation of a model developed for the construction industry.

Table 2.4: Validation Questions (Task 1)

Attributes	Corresponding questions
Practicality	In terms of clarity and practicality, is the framework easy to use and interpret?
Efficiency	Do the resources required (e.g. time) to use the framework outweigh the potential benefits of understanding the path towards a circular economy in your organisation?
Flexibility	Is the framework adaptable and generalisable for different scales (macro, meso, micro), project sizes, types of businesses or projects, and working teams (e.g. national/local, companies, business units, and disciplines).

Table 2.5: Validation Questions (Task 2)

Attributes	Corresponding questions
Applicability	Do the results of the framework reflect the current state of circular transition within your team, business unit, supply chain, or organisation?
Efficacy	Does the framework help you to understand the maturity of the circular economy within your team, business unit, supply chain, or organisation?
	Does the framework help to guide you to implement the circular economy within your team, business unit, supply chain, or organisation?
Acceptability	Does the proposed framework have the potential to be accepted by practitioners and be used in the industry?

Table 2.6: Participants of focus group one (SC1)

Role	Experience (years)
Construction Manager	26
Senior Design Manager	13
MandE Regional Director	35
Regional Commercial Director	25

Table 2.7: Participants of focus group two (SC2)

Role	Experience (years)
Construction Director	15
Commercial Director	13
Site Manager	16
Senior Design and Planner	35

Table 2.8: Participants of specialist structured interviews

Role	Experience (years)
Circular Economy Consultant	20
Circular Economy Consultant	17

2.4.4 Sampling

In this section, the use of purposive and snowball sampling within the PhD study is explained and justified.

2.4.4.1 PURPOSIVE/SELECTIVE

Purposive sampling typically utilises a small sample of information-rich participants or cases (Patton, 2014). The sample is selected specifically for its value to the research (Patton, 2014). Purposive sampling is sometimes known as judgement sampling due to the nature in which the researcher selects the sample (Saunders et al., 2019). The researcher has to decide what participants or cases are included within the study based on their knowledge of the subject and what is relevant to the study (Saunders et al., 2019). This form of sampling cannot be used to create statistical generalisations of the wider population (Saunders et al., 2019). Purposive sampling is best used on small samples or in case-study research (Saunders et al., 2019). The weakness of purposive sampling is the lack of probability in the selection of the sample, which could suggest researcher bias (Patton, 2014). The size of the sample is determined once the researcher has determined that the saturation of the research has been met or the available opportunities have been exhausted (Patton, 2014).

Two out of five of the identified supply chains were selected based on specific characteristics: the strength and depth of their connection. Furthermore, the supply chains were purposively selected based on their project type for a comparable medium: supply chain one working on high-rise structures and supply chain two working on residential dwellings. Once the main developer was contacted for participation, a key director within the developer was contacted for participation in the initial interview based on their experience and connections within the supply chain. The selection of the initial interview mitigated researcher bias in the selection of the participant. After the initial interviews were conducted, snowball sampling proceeded thereafter. This was the best-suited option for the study, as a holistic collection of data throughout the supply chain was required, which relied on the connection between independent organisations. Moreover, the use of snowball sampling following the initial purposive interviews limits the level of researcher bias present within the sample. However, participant bias could increase due to the natural social connections between employees who may recommend participants based on connection instead of expertise.

Within the validation focus groups, participants from the original interviews were invited to participate. The participants were purposively selected based on their discipline to gain a diverse range of professions within the evaluation and validation process. Within the discipline groupings, one participant from each group was accepted to participate after volunteering. Four participants from each supply chain were present within the validation focus groups. An even distribution from each discipline was not possible due to participant availability. Furthermore, the validation interviews with CE specialists were purposively selected based on their knowledge and experience of the CE within the construction industry. The specialists were selected from two independent organisations external to the study.

2.4.4.2 SNOWBALL

Snowball sampling begins with identifying and approaching key informants or cases and asking questions such as 'Who should I talk to?' (Patton, 2014). The outcome of asking such questions expands the sample size and identifies valuable participants or cases for the study (Patton, 2014). Snowball sampling is commonly used when it is difficult to identify participants or the available sample upfront (Saunders et al., 2019). Snowball sampling includes a volunteer-based selection (Saunders et al., 2019). Where the initial participants are chosen and then asked to identify new potential participants for the study (Saunders et al., 2019). Potential shortfalls of snowball sampling surround the context in which participants or cases are recommended (Patton, 2014). Unknown bias can form within the sample as recommendations could include like-minded individuals, not solely the best-suited participants for the study

(Patton, 2014). The snowball sample was a necessity to identify participants with experience and knowledge within the supply chain. The participant network was not known before the study and required identification for rigorous data collection through the selection of knowledgeable participants. Therefore, the use of a snowball sample was key to identifying the participants of the sample through the referral of purposively selected participants. The saturation point was then identified by the level of penetration within the supply chain and the number of participants sampled from each discipline (e.g. 2-3 per supply chain).

2.5 Time Horizon

There are two main time horizons for research projects, cross-sectional and longitudinal (Saunders et al., 2019). Cross-sectional research takes a snapshot of the phenomenon, whereas longitudinal research measures variables over time (Saunders et al., 2019).

Longitudinal designs are used to map changes in performance over time (Bell et al., 2022). The main use of longitudinal studies is to monitor the changes of variables over time (Saunders et al., 2019). Ongoing surveys can provide key data on the opinion of respondents over time (Saunders et al., 2019). Quantitative measurement can also be monitored to view the performance of variables over time and their change when experimenting (Saunders et al., 2019). Longitudinal studies are far more costly than cross-sectional; however, they provide far richer information (Neuman Lawrence, 2014). A limitation of longitudinal studies is the cost, both financially and in terms of time for businesses and studies (Bell et al., 2022).

Cross-sectional design focuses on a specific time period in which data is collected (Bell et al., 2022; Saunders et al., 2019). Cross-sectional research analyses multiple cases for quantifiable comparison to be explored (Bell et al., 2022). Research methods that adopt a cross-sectional design often utilise surveys as a method of exploring the patterns identified within the case-studies (Bell et al., 2022). Cross-sectional designs are primarily quantitative to determine changes in variables at differing cross-sections (Bell et al., 2022). Cross-sectional research can be exploratory, explanatory, or descriptive, but is best suited to the latter (Neuman Lawrence, 2014). Cross-sectional data collection is not always completed in one instance and can occur over weeks or months; however, the individual points of data collection take a snapshot (Neuman Lawrence, 2014). A cross-sectional time horizon was selected for this study as the scope does not look at the performance or development of the CE over time and seeks to gain a foundational knowledge of the CE in current practice. This was identified as a gap in the current literature, which lacked a holistic understanding of the current level of CE development within the construction industry and requires development before longitudinal studies can be performed in a comprehensive and systematic manner.

2.6 Methods of Analysis

In this section, qualitative and quantitative methods of analysis are discussed and how they have been applied in this research.

2.6.1 Qualitative Methods of Analysis

Qualitative methods chosen for analysis of the literature were bibliometric, scientometric, thematic, content, and discourse analyses. For the analysis of the interviews and focus groups, a content, discourse, and comparative analysis was selected.

2.6.1.1 BIBLIOMETRIC AND SCIENTOMETRIC ANALYSIS

From the advancement of the body of knowledge on a universal database, bibliometric analysis has been growing in popularity (Donthu et al., 2021). A bibliometric analysis studies the quantitative aspects of the creation, communication, and record of information (Hood and Wilson, 2001; Donthu et al., 2021). The most common databases used are Scopus and Web of Science (Donthu et al., 2021), hence, the use of Scopus for this study, offering the right range of disciplinary coverage for CE. The most frequently used software to perform a bibliometric or scientometric analysis is VosViewer, Leximancer, and Gephi (Donthu et al., 2021); Scopus' built-in bibliometric analysis tool was used for the publication frequency analysis, and VosViewer was selected for the scientometric analysis based on its rigour, detail, and flexibility when performing analyses.

Bibliometric methods also contain traces of scientometric and informetric analyses (Donthu et al., 2021). A scientometric analysis looks at the quantitative data of the science of economic activity within the data (Tague-Sutcliffe, 1992; Hood and Wilson, 2001). The Informetric analysis focuses on quantitative data surrounding information in any form (Tague-Sutcliffe, 1992; Hood and Wilson, 2001). A bibliometric and scientometric analyses provide reflections on the body of knowledge through the handling of large quantities of data (Donthu et al., 2021). This analysis can uncover trends within the literature, patterns of collaboration and the saturation of topics within the body of knowledge (Donthu et al., 2021). Furthermore, a bibliometric or scientometric analysis can be used for the identification of gaps within the literature, for the creation of novel topics, and for the justification of the research scope/artefact (Donthu et al., 2021). Both forms of analysis require a sample of quantitative data, which is commonly collected via a systematic literature review (Donthu et al., 2021). A systematic literature review requires the sample to be systematically refined with strings of keywords related to the research scope (Donthu et al., 2021). The analysed sample can show the frequency of occurrences of topics, journals, authors, keywords, and more (Donthu et al., 2021). The analysis of these factors provides useful insights into the geometry of the body of knowledge, the age of the knowledge, and the links that form the knowledge (Donthu et al., 2021).

A bibliometric analysis was conducted to view the literature's development on the topic of the CE in the construction industry. A sample of literature was gained from Scopus using search strings to gain an international sample of literature for analysis. This analysis provided evidence of novelty and direction for the gap in knowledge, which refined the literature selection and review process. The bibliometric analysis provided a publication frequency scale to identify the rate of publication since 2005. The country of origin for the publications also provided useful information, drawing on the geographical location of publications to understand the relevance within the UK construction industry. The sample of bibliometric data was then used to create a scientometric analysis through VosViewer, which produced a network analysis of keywords. Keywords required a minimum of 10 occurrences within the sample to be included in the network map. No method of normalisation was used. This provided an overview of the most discussed topics and their connection within the literature to identify the newest topics for investigation. The analysis of the keyword network map developed through a scientometric analysis on VosViewer identified an infant and fragmented knowledge of the DBPs of the CE in construction, which directed the investigation towards consolidating the existing knowledge.

2.6.1.2 THEMATIC ANALYSIS

A thematic analysis aims to identify themes or patterns that occur within qualitative data (Saunders et al., 2019). It is systematic in nature as it aims to order and apply logic to qualitative data by coding text passages and constructs into themes (Saunders et al., 2019). A thematic analysis is not limited to one particular philosophy, although it is heavily used within interpretivism to analyse subjective qualitative data sets (Saunders et al., 2019). Similar to content analysis, thematic analysis can also be used to analyse qualitative data quantitatively (e.g. using descriptive statistics) (Saunders et al., 2019). A thematic analysis is beneficial for several reasons, namely, the analysis of large amounts of qualitative data, the comparison of constructs against a uniform set of themes, developing theoretical connections to test explanations, and drawing and verifying conclusions (Saunders et al., 2019). A thematic analysis can be inductive or deductive. An inductive approach will identify novel emergent themes, whereas a deductive approach will use predefined themes for testing (Saunders et al., 2019). Thematic analysis is a largely undefined process of identifying themes within source data (Clark et al., 2021). It is shared amongst research designs and approaches to organise concepts and content into categories (Clark et al., 2021). Such themes can be used as codes for other types of analysis and comparisons (Clark et al., 2021). A thematic analysis was used within this PhD study to define themes within the literature review in order to assign the identified DBPs of the CE within the construction industry. A thematic analysis was best suited to analyse the literature, as the sample was large (Saunders et al., 2019), the DBPs required to be deduced in a uniform and comprehensive categorisation (Clark et al., 2021), and would later be used for deductive testing (Saunders et al., 2019), which required a comparison that was assisted by the use of coding (Clark et al., 2021). The development of the theoretical framework in the form of the taxonomy was derived from existing themes within the sampled literature. The commonalities between DBPs and themes within the existing literature were combined to categorise the DBPs into the appropriate themes of the taxonomy to create a theoretical framework based on existing theory.

2.6.1.3 CONTENT ANALYSIS

Content analysis aims to draw quantitative data from qualitative means such as text or audio (Bell et al., 2022). It thus aims for analytical categorisation and coding of audio and visual qualitative data (Saunders et al., 2019). Qualitative content is systematically analysed and attributed to themes to measure the composition of the sample and the presence of themes (Bell et al., 2022). The content can be words, meanings, pictures, symbols, ideas, themes, or anything communicated (Neuman Lawrence, 2014). This method initially begins with the coding of the qualitative data, followed by either the qualitative analysis of common terms or phrases or the quantitative analysis of keywords or themes and their occurrences (Saunders et al., 2019). In a quantitative content analysis, the content is compared against predetermined criteria to produce a numerical description of the content (Neuman Lawrence, 2014). After gathering the quantitative data, the researcher can apply statistical analyses like that of a survey study (Neuman Lawrence, 2014). The unit of analysis can vary heavily within a content analysis, for example, a theme, phrase, word, plot, article or character, depending on the type of source and content (Neuman Lawrence, 2014). The unit of analysis is coded similarly to that of a survey to form relationships between units (Neuman Lawrence, 2014). The process of a content analysis is as follows: the formulation of a research question, the creation of the units of analysis, the development of the sample, construct coding categories, and finally, data collection and analysis (Neuman Lawrence, 2014). Some disadvantages of content analysis are the quality of the initial data and the fact that the coding process relies on the researcher's interpretations, which are subjective by nature (Bell et al., 2022). In this PhD study, the DBPs of the CE in the construction industry were subjected to a content analysis for the purpose of coding within the thematic analysis and to enable cross-comparison within the results of the empirical findings. Later, within the empirical studies, a content analysis was used to quantify the qualitative responses of participants towards the practices of the CE for the purpose of summarising the findings of the semi-structured interviews (Bell et al., 2022). The quantified summaries of the practices were used to understand the number of practices identified and the level of development of practices based on the knowledge, understanding, and examples of practice provided by the participant. The content analysis was ranked quantitatively on a Likert scale of 1-4, from far below standard to far above standard. Far below standard would be determined by a complete lack of knowledge by the participant. Far above standard would be determined by examples of full application within their role or project. The quantitative interpretation of the qualitative data on the practices of the CE provided a comparative medium for analyses alongside the drivers and barriers.

2.6.1.4 COMPARATIVE ANALYSIS

A comparative analysis was conducted to understand the differences between supply chains and disciplines within the study. A comparative analysis involves the use of two or more data sets collected with identical methods for the comparison of results (Bell et al., 2022). A comparative analysis can be conducted on qualitative and/or quantitative data to provide insights into the differences between quantitative values or the differences between and similarities with qualitative responses (Patton, 2014). The comparative analysis can also be conducted as a cross-sectional or longitudinal study (Bell et al., 2022). A comparative analysis is useful for contrasting case studies, surveys, nations, and cultures (Bell et al., 2022). This method was used to contextualise the different opinions and experiences of construction professionals and characterise the supply chains; together, this helped to explore the use and understanding of the CE in different samples (i.e. supply chains or disciplines). A comparative analysis provided key insights into the differences between disciplines within and between supply chains to understand the practices relevant to their profession, as well as the drivers and barriers present within their role. Furthermore, the comparison between supply chains provided insights into the differences between supply chains and residential building types.

2.6.1.5 DISCOURSE ANALYSIS

Discourse analysis covers a variety of different approaches with the aim to analyse the differing use of language (e.g. in narratives) and its social impacts (Clark et al., 2021). By analysing the socially constructed reality, discourse analysis aims to draw conclusions from the differing realities experienced and expressed by audio or text (Saunders et al., 2019). Discourse analysis is useful within organisational research to determine similar and differing underlying values/mindsets, opinions and perceptions to understand the social reality as communicated or performed (Saunders et al., 2019). Interviews and other survey-based methods of data collection are the most commonly analysed to understand the discourse between participants (Clark et al., 2021). To understand the discourse about a particular phenomenon, the participants must be questioned in a uniform manner within a similar context to understand the differing perceptions of the phenomenon (Saunders et al., 2019). A discourse analysis was conducted to understand the differences within and between the various disciplines of the sampled supply chains. This allowed for the understanding of perceptions within specific working groups, such as commercial managers, to determine if select disciplines had unified opinions on the DBPs of the CE. This was important for two reasons: the understanding of the opinions, experiences, and needs within and between each discipline, and to verify if the findings were consistent within disciplines or varied to provide a level of validation to the results.

2.6.2 Quantitative Methods of Analysis

In this section, quantitative methods of analysis will be discussed.

2.6.2.1 MEASURES OF CENTRAL TENDENCY

The measurement of the central tendency aims to identify the quantitative average of numerical values with three main methods: the mean, median, and mode (Saunders et al., 2019). The central tendency measures the centre of the sample’s distribution (Bell et al., 2022). The mean average measures the collective average of the sample (Saunders et al., 2019). This is achieved by adding together the collective values and dividing the total by the number of values (Saunders et al., 2019). The mean method of measuring the central tendency is useful for analysing the collective average of a sample and can be split over several categories to describe multiple responses (Saunders et al., 2019). The median method of measurement requires the ranking of values in an ascending numerical order (Saunders et al., 2019). Once ranked the value in the middle of the ranking is selected as the average. This method allows for the identification of the middle of a spectrum of results (Saunders et al., 2019). The median average is useful when determining an average amongst mixed responses to determine a more accurate result than the mean, which includes both extremes of the spectrum (Saunders et al., 2019). The mode method of measurement is one of the most accurate forms of descriptive statistics, as it measures the quantity of the values (Saunders et al., 2019). The mode method quantifies the number of occurrences of each value to determine the most common response (Saunders et al., 2019). This method of central tendency allows for the identification of the most popular category (Saunders et al., 2019). When multiple categories are used, the mode average can be used to compare the frequency of categories (Saunders et al., 2019).

The mean average was used for the analysis of the quantitative data due to the requirement of the study to understand the central tendency of the collective. Participants were assigned to groups based on supply chain, discipline, and then compared based on their average response. The mean average was the best-suited method to gain granular detail on the collective response for comparison. The median and mode measures of central tendency would provide whole numerical values, which would limit the diversity and granularity of results when ranking the DBPs of the CE. Furthermore, the use of distributions and bell curves provided a level of detail which was too detailed for analysis within this study due to the quantity of DBPs under investigation, as well as the size of the analysis.

2.6.2.2 DESCRIPTIVE STATISTICS

Descriptive statistics are used to analyse and describe quantitative data through the comparison of values derived from non-parametric data sets (Saunders et al., 2019). Descriptive statistical analyses fall into two main categories: measurement of the central tendency and the measure of dispersion (Saunders et al., 2019). Non-parametric statistics are designed to contrast values with categories (Saunders et al., 2019). Often, the first analysis conducted when using descriptive statistics is to determine the recorded frequency and distribution of responses in context to their category (Bell et al., 2022). Responses can be summarised and converted into percentages to measure the frequency of responses (Bell et al., 2022). Viewing responses in the form of percentages also incorporates a self-check of the data set to identify errors (Bell et al., 2022).

Descriptive statistics fall into three categories: univariate, bivariate, or multivariate (Neuman Lawrence, 2014). Univariate descriptive statistics look at one variable, bivariate, and so on (Neuman Lawrence, 2014). When looking at a univariate analysis, a frequency distribution measure is most appropriate to understand the responses in more detail (Neuman Lawrence, 2014). Descriptive statistics were best suited for the analysis of the drivers and barriers, as the data set was non-parametric and did not require the granular detail of Kruskal-Wallis or chi-squared forms of analysis. Descriptive statistics using line graphs, bar graphs, and histograms provided a visual representation of the drivers and barriers to summarise and compare results from both supply chains and different disciplines. A combined line-bar graph was created to analyse the frequency of identified practices by discipline against the mean identified level of development by discipline. Descriptive statistics were also coupled with a content analysis to quantify the qualitative responses of participants when discussing the practices. After responses were quantified based on the knowledge, understanding, and examples of practice provided, a combination of bar and line graphs was used to compare the mean average of both supply chains. The use of descriptive statistics was core to the comparison between drivers, barriers, or practices within both supply chains, each discipline, and overall to understand the presence and level of development of the CE.

2.6.3 Types of Frameworks

Within this PhD study, a theoretical framework was developed to comprehensively categorise the identified DBPs into a holistic taxonomy to structure their measurement within the final analytical framework. The requirement for the development of a theoretical framework was identified within the scientometric analysis of the review of literature. The need for an analytical framework was identified by participants within the empirical studies of this PhD. This section provides a review of the types of frameworks and how/why they were developed.

2.6.3.1 CONCEPTUAL

Conceptual frameworks take a graphical or narrative form that highlights the core themes or categories of a topic and any presumed relationships between them (Miles et al., 2014). Conceptual frameworks develop from the early exploration of the extant literature and shape how data will be collected and analysed (Miles et al., 2014). A conceptual framework is inductive by nature and incorporates case-specific variables, contexts, concepts, or participants (Miles et al., 2014). Conceptual frameworks are a mechanism to structure questions and strategies for exploration (Ravitch and Riggan, 2016). Leshem and Trafford (2007) found that conceptual frameworks model relationships, create links between theories, and provide a theoretical basis to design, interpret, and collect empirical data. A conceptual framework was not developed within this study due to the quantity and scale of the DBPs identified. Due to the quantity of DBPs, the connections and relationships could not be measured and presented accurately within a singular conceptual framework.

2.6.3.2 THEORETICAL

Although there are some similarities between conceptual and theoretical frameworks, which can cause confusion amongst researchers, they have distinct differences (Miles et al., 2014). In their study of researchers and students, Ravitch and Riggan (2016) found that the individuals' perceptions of conceptual and theoretical frameworks largely depend on one's definition of theory. However, it is commonly accepted within the literature that conceptual frameworks seek to identify relationships between theories, cases, concepts or participants; whereas theoretical frameworks seek to extract the elements of theories found within the literature (Miles et al., 2014). The collected theories within a theoretical model create a structure for investigation to collect and analyse data (Miles et al., 2014). According to Varpio et. al., 2020, a theoretical framework structures concepts from one or more theories to ground investigations through logical connections. A theoretical framework was developed from the sample of literature to identify the DBPs of the CE in construction. DBPs were coded and assigned to themes within a global theme (Saunders et al., 2019). The themes of the analyses were derived from the systematic literature review, which broke down practices into four themes: economic, institutional, social-cultural, and technological. The selected themes were identified as the common denominator across the sampled literature where previously categorised.

2.6.3.3 ANALYTICAL

The identified DBPs were then developed from a theoretical framework into an analytical framework for the analysis of the maturity within selected supply chains based in the UK. An analytical framework structures theories and concepts to enable the analysis of data and problem-solving (Creswell and Plano Clark, 2017). Analytical frameworks are mixed-method and can analyse qualitative and quantitative data (Creswell and Plano Clark, 2017). The approach used in this PhD is similar to Long (1990), who proposed an early form of analytical framework, which was created from a theoretical framework. The framework sought the analysis of concepts and theories that were developed from the structure of a theoretical framework (Long, 1990). Analytical frameworks are a critical tool for developing a comprehensive understanding of theories that can be directly analysed against empirical data for data-led decision making (Creswell and Plano Clark, 2017). The synergy of DBPs identified within the sample of literature was condensed and developed into a holistic analytical framework summarising the CE within academic literature. The analytical framework contains all of the DBPs contained within the theoretical framework for analysis, rated using a Likert scale of 1 to 4. Drivers and barriers were rated on a scale ranging from strongly disagree (1) to strongly agree (4). Practices were evaluated on a scale ranging from far below standard (1) to far above standard (4). The tool can be adjusted to have a wider Likert scale (e.g. 1-10) for more detailed analysis, and the DBPs can be selected or added based on the users' needs. This information is useful for the application CE practices to determine their maturity.

2.7 Ethical considerations and practice

For all data collection methods, a consent forms were used to explicitly stipulate that all personal and professional information (such as company/organisation names) collected will remain strictly confidential and will not be disseminated or divulged willingly or otherwise. Survey-based data collection methods will use online tools such as 'MSTeams' and 'Online Survey' (BCU's approved approach), which uses a university email and account to collect and store data. Emails to multiple participants are to be 'discouraged', unless a supervisor approves this means of collecting data, provisions will be made to ensure that: intended participants are blind copied (BCC-ed) into the email; a consent form that describes the work, the name and contact details of the supervisor is included; and the email clearly states how data will be handled, protected, and that the anonymity of participants is guaranteed. Additionally, coding and interpreting any sensitive data (such as the names of participants or contractors), all personal and company details are to be excluded in the final report and will be referred to as Company A, B, C, etc. or Participant 1, 2, 3, etc.

When storing data, BCU's secure 'OneDrive' was used for the storage of sensitive data since it is managed (and secured) by the University. In the event of paper copies, data will be stored in a locked cupboard and securely shredded at the end of the research period as per the data termination specification provided. If a participant wishes to stop participating, withdraw their data, or lose the capacity to consent, their details and any information collected will be immediately and securely destroyed with no further contact made. Furthermore, all the details of a participant who wishes to withdraw from the study will be efficiently deleted from the folders on BCU's OneDrive. After a certain degree of analysis, data may not be feasibly removed from the research, which will be noted in the 'Consent Form' and 'Information Sheet' for participants to agree to before participating.

2.8 Risk

The research was conducted remotely through online means such as 'MSTeams' and therefore entailed minimal physical risk to participants. Possible psychological risks do not extend beyond what is normally encountered during the course of a normal working day. Respondents may elicit an emotional response whilst reading the open-ended questions. If a respondent is uncomfortable during an interview, they can elect to withdraw from that portion of the data collection/analysis. Furthermore, the topic is considered 'safe' as it entails no discussion on sensitive subjects or personal questions.

2.9 Critical Appraisal

When critically appraising the methodological selection of this PhD study, the chosen route met the needs of the literature, the availability of data, and the requirements of practitioners who participated in the empirical studies. However, some improvements could be made to increase the rigour of the final results. Firstly, due to the exploratory and explanatory nature of the study, mixed methods were used to collect data in the most impactful way to analyse the DBPs. However, this limited the ability of the research to run statistical analyses on the DBPs in unison to determine correlations. On reflection, the use of purely quantitative data could have increased the quality of the data analysis for the review of causal relationships between DBPs and allowed for the analysis of correlations between the datasets.

Moreover, a wider sample of the construction industry could have been collected to develop generalisable data. The available network at the start of the study was minimal. This hampered the ability of the researcher to commence data collection with the knowledge of and access to the sample. Due to the lack of an available network of participants, organisations and supply chains were identified and contacted for participation. The process of identifying and enrolling supply chains into the study was time-consuming and limited the progress of the research. Once a company that met the research requirements were enrolled, a snowball sample was selected to identify participants for data collection. This method limited the speed of data collection and increased the potential for bias within the study, as participants would recommend other participants based on experience and or opinion. In the future, an increased sample size would enable random sampling and parametric data collection to increase the validity of the results for a generalisable set of guidance for the CE. The use of random sampling would have also enabled the use of parametric forms of analysis to gain granular detail on the development of the CE's practices, and the presence of the drivers and barriers.

Additionally, the lack of practical information within the literature on the UK precluded a wider narrative literature review on the DBPs of the CE with more examples of the CE in practice. However, due to the scope of the research, a narrative explanatory literature review would have exceeded the size of the project and or reduced the scope for feasible data collection.

Finally, the case studies used within the study could have been investigated in more detail to provide a level of triangulation of the results from the participants, which would have formed a foundation for the 'actual' dimension of critical realism. This was also not feasible due to the lack of available data identified within the initial investigation into the case studies. Overall, the chosen approach was the best suited for this PhD study; however, the aforementioned alternatives could be conducted in future research projects to provide alternative results to progress industrial practice and the body of knowledge.

CHAPTER 3: THE CIRCULAR CONSTRUCTION ECONOMY (CCE)

This chapter investigates the existing literature on the CE within the construction industry to understand the current landscape of the CE's development. Firstly, the section looks at the background of the CE to understand the context for further investigation. Following the initial investigation into the background of the CE, a broad systematic literature review was conducted to understand the current landscape of the CE within the construction industry to identify areas for development. In this effort, a bibliometric and scientometric analysis was conducted to understand the direction of the CE's development within the literature. The findings of the scientometric and bibliometric analyses were then used to refine the scope of the sample of literature to the DBPs of the CE within the construction industry. The resulting sample was then reviewed to identify and delineate the DBPs of the CE for the development of a holistic and comprehensive taxonomy of the CCE.

3.1 Background

The 'Paris Agreement' or the 'Paris Accords' set out to reduce GHG emissions to avoid a global temperature rise of 1.5-2°C by the end of the century, support developing countries to enhance their abilities to mitigate climate change, and review countries' commitments every five years (IPCC, 2022). The IPCC periodically provides reports on impacts and solutions to the anthropogenic changes within the Earth's climate system (IPCC, 2022). These reports have been used as the largest and most reliable review of research on climate change (IPCC, 2022). The IPCC has completed six assessment reports, starting in 1988, with their most recent in 2022 (IPCC, 2023). The IPCC Assessment Report Six (AR6) in 2022 highlighted a stark future for the Anthropocene, stating that the global temperature is predicted to rise above 3°C (IPCC, 2023). The main areas in which the IPCC suggests reducing the impact of the Earth's climate system are based on the management of land, air, water, and biodiversity (IPCC, 2023). The main quantifiable target within each mitigation strategy is the overall reduction of GHG concentrations in the atmosphere to stay below a 1.5-2°C increase in global temperature (IPCC, 2023).

The Anthropocene, marked by an industrial, capitalist-driven, linear model of economic activity—characterized by the extractive cycle of take, make, and dispose—has, in conjunction with the thermodynamic limitations of Earth's finite resources, produced an increasingly unsustainable and complex geological trajectory for human societies (Crutzen, 2006; Steffen et al., 2007; Rockström, 2009; IPCC, 2023). Projections by the IPCC estimate a 2.25-fold increase in global raw material consumption by 2050, reflecting a significant intensification of anthropogenic pressures and underscoring the critical need for sustainable intervention (IPCC, 2023). In response, policy frameworks such as the United Nations (UN) SDGs—particularly SDG 12—have integrated resource efficiency as a core objective. The IPCC explicitly advocates for embedding resource and waste management strategies, including reduction, reuse, and recycling, within climate mitigation pathways. These strategies are especially pertinent in sectors such as construction and infrastructure, where improvements in material efficiency can lead to substantial reductions in GHG emissions (IPCC, 2023). The convergence of environmental constraints and international policy imperatives thus necessitates a systemic economic transformation that decouples material throughput from economic prosperity.

Anthropogenic environmental impacts are predominantly concentrated within a limited number of high-intensity sectors, prompting transition strategies to prioritise construction, agriculture, and energy (IPCC, 2023). Among these, construction stands out as one of the most resource- and waste-intensive industries, accounting for approximately 50% of raw material consumption in the EU and generating between 20–35% of global solid waste (EC, 2020). In the UK, the scale is particularly pronounced: construction, demolition, and excavation (CDE) waste represented 64%—or 120.4 million tonnes—of total national waste output in 2016 (UKEA, 2021). Consequently, even marginal gains in construction sector efficiency hold the potential to deliver disproportionately large environmental and economic benefits.

3.2 The state of the global construction industry

The construction industry produces the lion's share of waste in developed and developing economies, termed Construction and Demolition Waste (CDW) (USEPA, 2021; EC, 2020; IPCC, 2022; Salemdeeb et al., 2016; Gallego-Schmid et al., 2020). The Ellen MacArthur Foundation (EMF) identified 26% of the waste produced by the US in 2008 was from CDW (MacArthur, 2013). The USEPA's figures for 2018 identified that 600 million tons of CDW were generated, equating to double that of municipal waste (USEPA, 2021). The EU, through the EC, identified the construction industry as the consumer of 50% of all extracted resources, and the industry accounts for 35% of waste generated (EC, 2020). Similarly, around the globe, in governments' waste management and reduction strategies, CDW is highlighted as a primary target due to its significant contribution to the problem of consumption and waste in the economy (Aslam et al., 2020; Luciano et al., 2022). The CDW from developed and developing countries have highlighted the implications of waste on the natural environment. New economic plans aspire to counteract this linear CDW using strategies such as the CE (USEPA, 2021; EC, 2020; NDRC, 2021). However, the construction industry has been wasteful and difficult to manage throughout history due to its size and complexity involving multiple stakeholders, companies, disciplines, designs, and materials (Latham, 1994; Farmer, 2016). The adoption of manufacturing strategies has been attempted several times in history and seldom finds equal results (e.g. Lean Construction) (Alarcón, 1997). However, in comparison to the application of other management strategies, there are imminent drivers for the CE within the construction industry (IPCC, 2023).

3.2 A systematic review of the extant literature on the CE in the construction industry

A systematic literature review was conducted, in which data was collected using Scopus by identifying and using keywords from key sources on the CE to search for the titles, abstracts, and keywords of extant literature (Figure 2.5). According to Bell, E., et al. (2022), systematic literature reviews are more transparent due to a methodical process, which enables replicability and reduces the potential for researcher bias. Bell, E. et al. (2022) and Saunders et al. (2019) have identified four stages to a systematic literature review: 1. Define and review the research scope and key words, 2. Collect a sample of relevant studies, 3. Assess the sampled studies for relevance to the research scope through inclusion and exclusion criteria, and 4. Analyse and synthesise the results of the sampled literature. Saunders et al. (2019) suggested the formation of a panel to review the scope of the research and keywords to ensure replicability, which was undertaken during this study. Furthermore, they suggested a two-stage review of the sample, initially reviewing the titles and abstracts for relevance, then a full review of the study.

An initial exploratory literature review defined the problem domain and set keywords. The following keyword strings were used; **String 1 (CE):** (“Circular Econom*” OR “Circular Practice” OR "circular manage*"); **String 2 (Construction):** ("construction industry" OR "construction"); **String 3 (Specific)** (“Circular Econom*” OR “Circular Practice” OR "circular manage*") AND ("construction industry" OR "construction") AND (Driver OR Enabler OR Barrier); **Or String 4 (Specific):** (“Circular Econom*” OR “Circular Practice” OR "circular manage*") AND ("construction industry" OR "construction") AND (“Best practice* OR Practice* OR “Practice-based” OR Guidance) AND (Framework or “Business model”). The sample of strings one and two provided an excess of five thousand journal articles. The sample was sufficient to conduct bibliometric and scientometric analyses of publication frequencies, geographical locations, and keywords to refine the study. However, the sample was too large to review in detail. A narrative review of the literature was deemed unfeasible due to the size of the initial searches. Therefore, a systematic review was selected to refine the available journal articles for the identification of the CE’s DBPs through pre-existing compilations (i.e frameworks, business models, and thematic analyses). As illustrated in Figure 2.4, the refined sample provided 50 journal articles for string three and 117 for string four. Through a manual review, 44 in string three and 72 in string four were identified as relevant based on the focus and content of the sources. In the final round of review, 34 journal articles were included in the sample for string three and 58 were included in string four based on the presence of drivers, barriers, and or practices.

An interpretivist philosophy and abductive reasoning guided this study to review and compare the synergies within the literature (Saunders *et al.*, 2019). The systematic review of the DBPs was key in establishing the developed theoretical framework through the comparison of DBPs and their assigned themes in the extant literature. The identified DBPs in the extant literature were categorised into economic/financial, social/cultural, technological, governmental/institutional. The DBPs were therefore assigned to the common themes derived from existing studies. In the case that one of the DBPs was not already categorised, the influence and characteristics of the DBP were interpreted by the researcher and assigned to a theme.

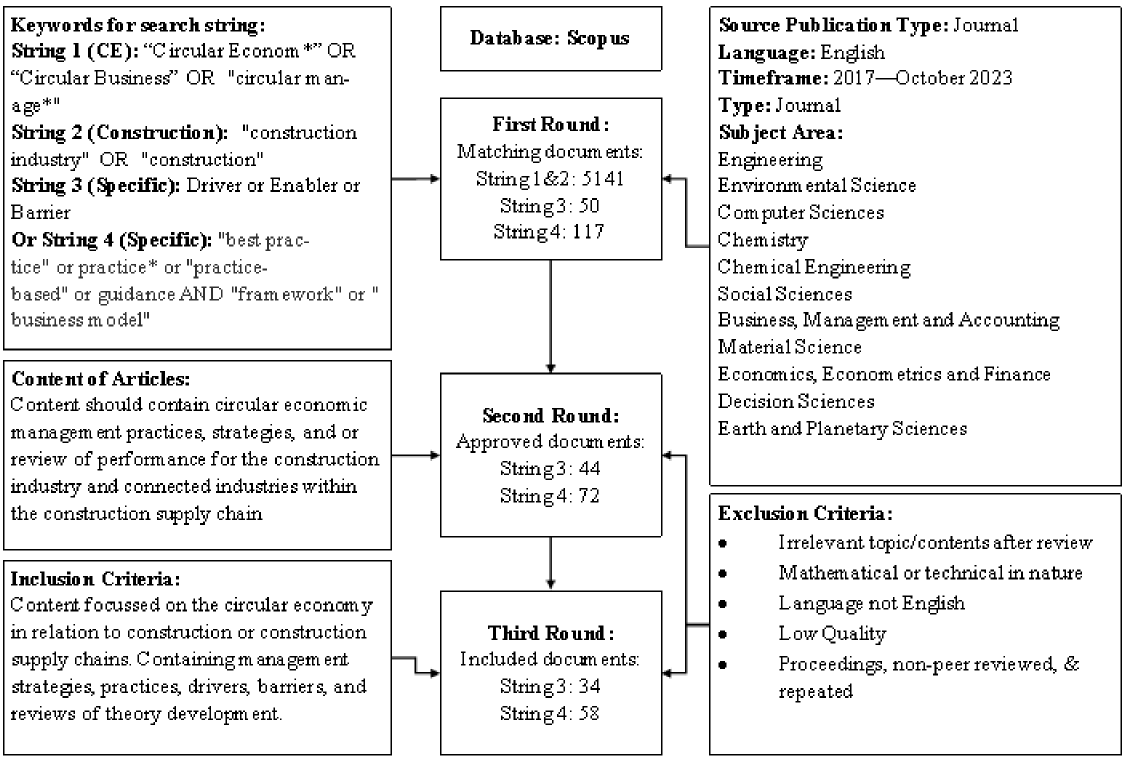

Figure 2.5: Systematic literature review selection criteria and process

The strings were analysed through several methods to determine key factors of the extant literature. Firstly, the sample from string two was analysed to identify key characteristics such as publication frequency over time and publication by geographical location. Secondly, a keyword analysis on string two was conducted on the sample to identify common terms and syntax. A scientometric analysis was conducted using VosViewer to further analyse the occurrence of keywords within the literature and understand their connection in more depth with a network map analysis. This process assisted the identification of the gap in knowledge and the terms and keywords for strings three and four. Strings three and four were analysed independently through a content analysis to identify the current DBPs of the CE within the extant literature for the construction industry for the development of a taxonomy of the CE.

The CE, as with manufacturing, has become a focus for research into waste and consumption mitigation in the construction industry. Within the sample of 5141 journal article publications, the publication frequency of CE research relating to the construction industry has rapidly increased since 2017 (Figure 3.1). Figure 3.1 highlights the demand, requirement, or interest in the research community for a less wasteful system within the industry, as well as insight into the extent of literature development. Both points suggest an overall demand for CE research in the construction industry and a young body of knowledge, posing a gap for researchers to explore and develop the concept further. In a review of the literature, the CE within the context of the construction industry can be sampled and reviewed systematically due to the size and infancy of the available knowledge, allowing the sampling of the literature for a bibliometric analysis using scientometric methods of analysing themes and keyword occurrences.

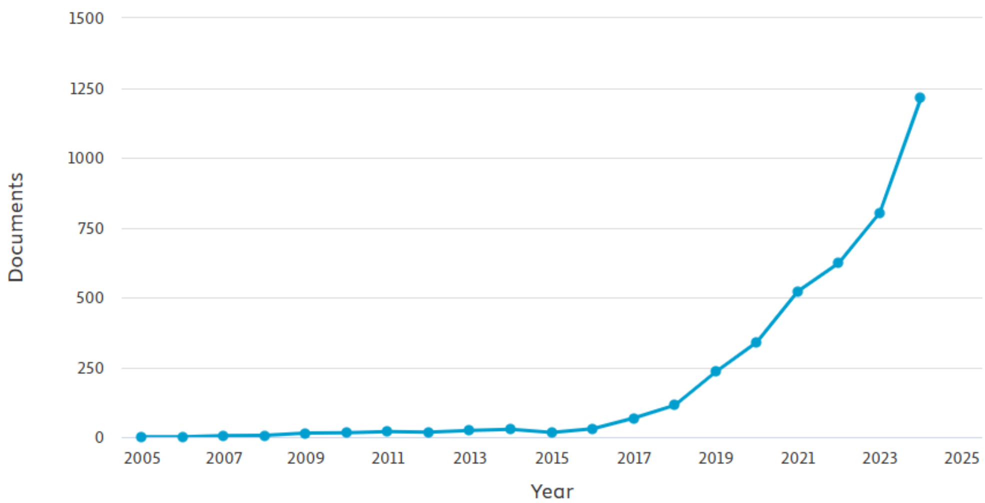

Figure 3.1: Literature frequency of CE documents via Scopus

Figure 3.2 shows the frequency of CE publications relating to the construction industry by country or territory. Leading countries have been identified as China, Italy, the UK, Spain, and Australia. Two clear trends have been determined upon the examination of countries' CE publication frequency. Firstly, the three largest governing bodies are in the top 15 countries or territories: the United States, China, and members of the European Union. Secondly, members not within the aforementioned governing bodies are less developed countries aiming to reduce the waste generated or imported to their territory without the correct infrastructure to manage and remove the waste (Liu et al., 2018). More developed countries have commonly exported waste to less developed countries, creating a hierarchy in which the developed countries show little responsibility for their waste, whilst underdeveloped countries are flooded with waste materials, causing squalor and a need for waste innovation (Liu et al., 2018).

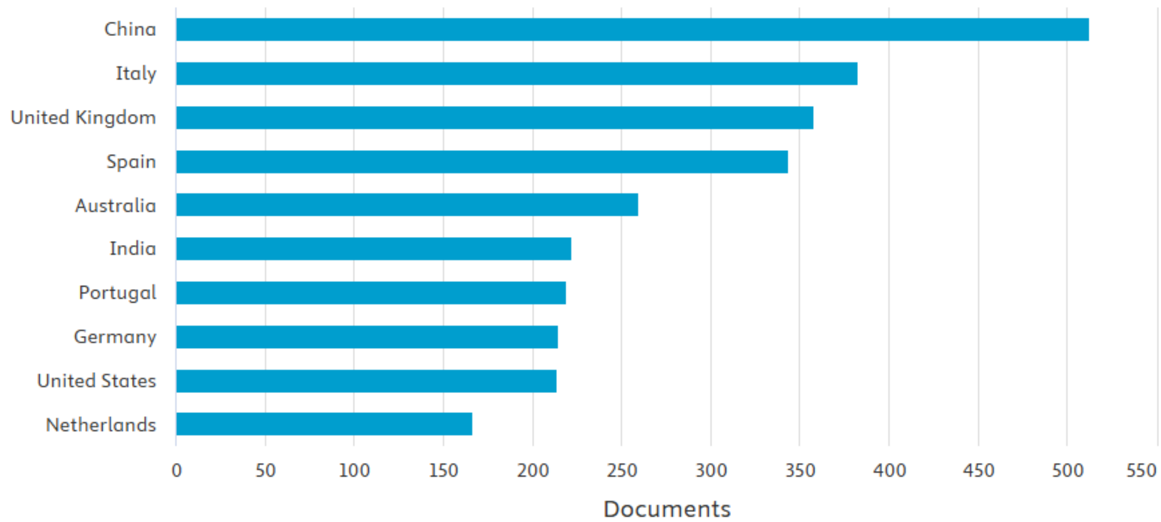

Figure 3.2: Literature frequency of CE documents and publications by country or territory via Scopus

3.2.1 Scientometric Analysis

The scientometric network analysis of the bibliometric data from the sample of literature (5141 publications) highlighted common themes and keywords used (Figures 3.4 and 3.5). There are four main clusters, namely 'materials' (red), 'technology' (yellow), 'processes' (blue), and 'environmental' (green). The 'CE' nodes are central within the network, and each node's links span the diagram.

The red cluster, which focuses on material innovations, is the largest cluster. The size of the cluster shows that there is a growing focus on circular materials to change the composition of the construction industry. This also shows that the direction of the existing body of knowledge is on the development of materials to replace existing raw and linear materials while creating outputs for waste materials. This is further shown by the core node that the materials stem from, recycling. The materials cluster has connections with the environmental cluster and the technology cluster. This suggests that the development of recycled materials is improving the environmental performance of the construction industry and that technology is a key factor in the development and or implementation of recycled materials. Due to the size of the materials cluster, the R&D of materials is the most saturated portion of the body of knowledge in the existing literature.

The green cluster, which focuses on the environmental aspect of the CE, is the second smallest cluster. This shows that, although important, it is not the driving factor for research within the construction industry. The environmental cluster stems from the waste management node. The link between the environmental focus of the CE and waste management suggests that the environmental practices in the construction industry are focused on waste management and mitigation strategies. This is reflected by nodes such as 'material flow analysis' and 'GHG', which show a focus on reduction strategies through the analysis of metrics.

The yellow cluster, which focuses on technologies, contains modern innovations such as '3D printing' and 'artificial intelligence'. This shows that new innovations in technology are being utilised as a catalyst to assist the CE in its development and application within the construction industry. The yellow nodes stem from 'life cycle analysis' and 'building materials', suggesting that the new technologies assist in the analysis and application of the CE in the construction industry. The nodes are also lighter and smaller than the majority of the network, suggesting that their investigation is more novel and still under exploration.

The blue cluster, which focuses on the processes of the CE, focuses on the social-cultural and institutional aspects of the CE. Key nodes within the cluster focus on design, disciplines, processes, and decision-making. The cluster opposes the red (materials) cluster, suggesting that it seeks to investigate the dynamics of the construction industry in a more holistic and systematic way. The cluster is linked to the green (environmental) and yellow (technological) clusters, suggesting that the cluster on processes is linked to the analysis of waste and the implementation of new technologies for the enhancement of practice. Nodes that are closely connected to the green cluster are SCM, which links the analysis of materials with social and institutional processes. Similarly, nodes linked with the technology cluster focus on BIM and design, suggesting the development of technological systems for the analysis and improvement of construction processes. Outlying nodes within the blue cluster are the drivers and barriers of the CE, which are in their infancy compared to other keywords within the network.

Overall, the clusters provide a visual representation of the literature, its foci and gaps. It has assisted in the interpretation of the literature and identified key gaps. One of the main gaps identified is the lack of connection between the CE's practices within the literature, which span the scientometric network and each cluster. Secondly, a majority of nodes represent individual material innovations and lack holistic and comprehensive strategies for implementation. Furthermore, the drivers and barriers of the CE are on the periphery of the network, showing a lack of connection with the practices and investigation within the body of knowledge.

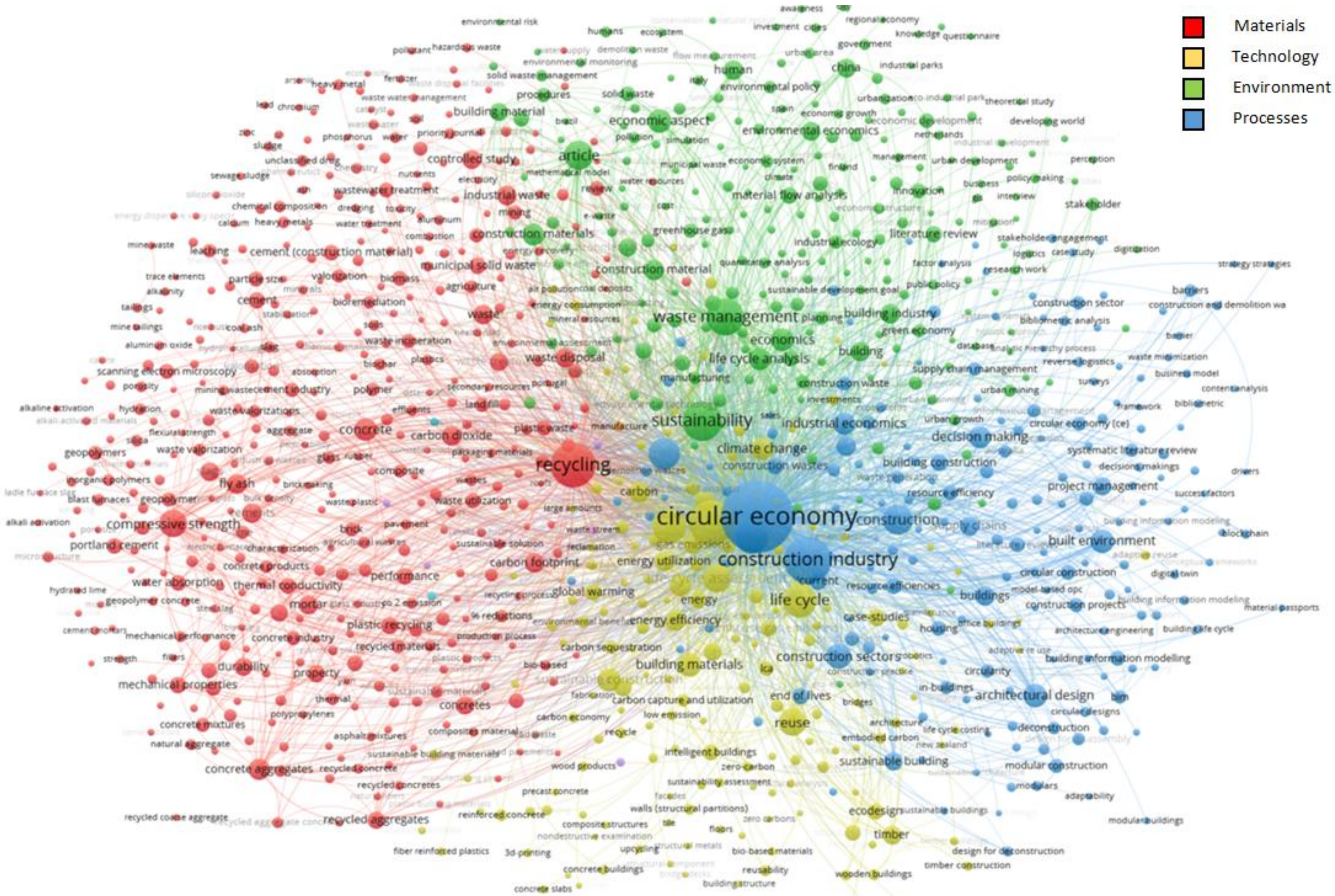

Figure 3.4: Scientometric analysis of keyword occurrences

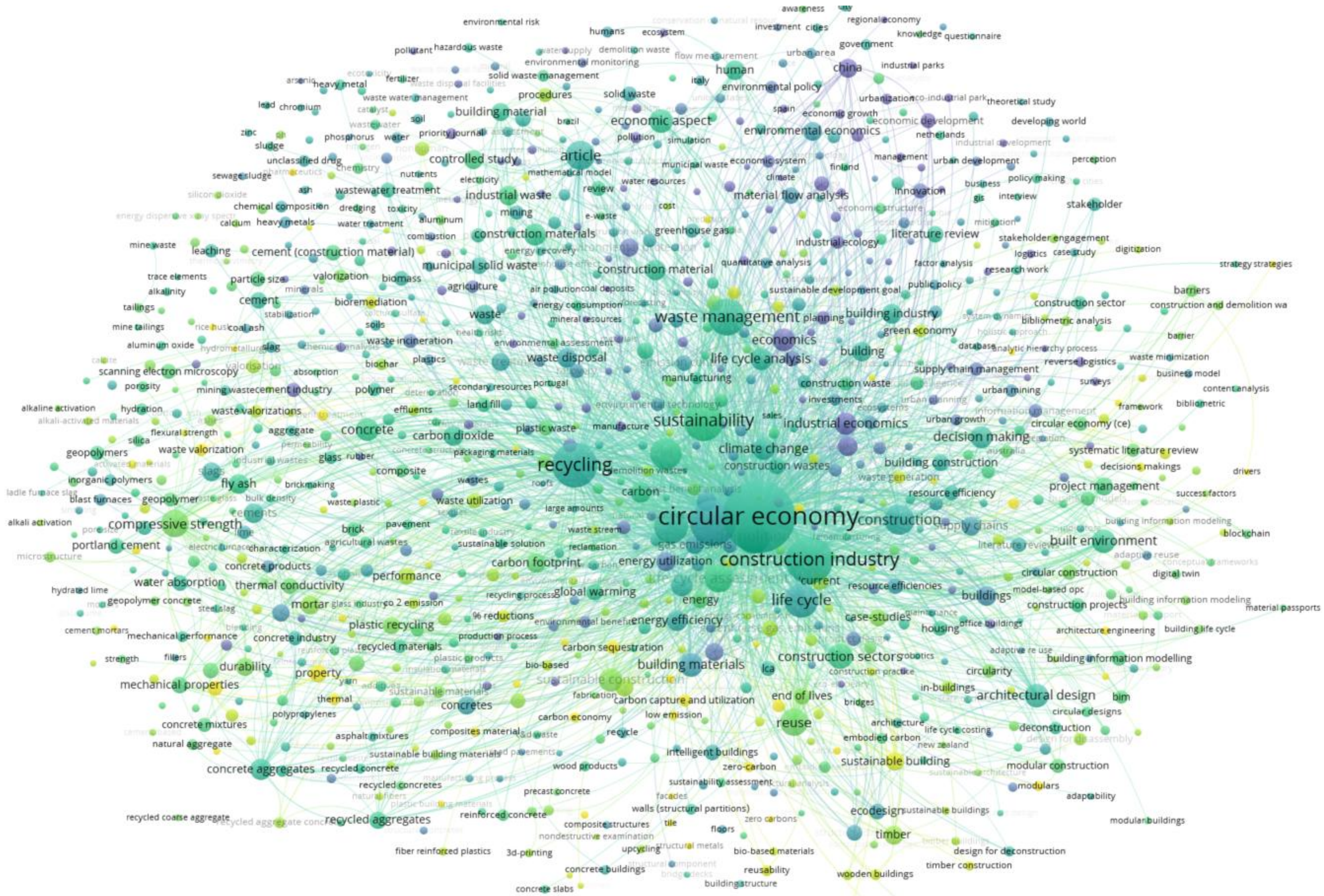

Figure 3.5: Scientometric analysis of keyword occurrences through a time lens (blue = mature, yellow = immature)

3.4 Drivers

This section looks at the drivers of the CE that have been identified within the literature. Overall, 39 drivers were identified and categorised within 4 global themes: economic, institutional, social-economic, and technological (Appendix A.1).

3.4.1 Global Theme 1: Economic

The CE is primarily an economic model used to improve value generation from the original input of resources. This section reviews the economic drivers associated with operational practices that improve or assist the financial value of the construction industry.

D1: New economic and environmental opportunities for businesses

In relation to business economics, new opportunities are a common driver of innovations to achieve profit and remain competitive. The case is no different within the CE, as the secondary materials market develops new closed-loop supply chains and materials are creating a new industry of reuse and recovery. This then creates new market opportunities for companies to expand into and improve their return on investment from their original material input. Chen et al. (2022) produced a systematic literature review which highlighted key drivers of the CE within the construction sector. They identified that new market opportunities (e.g. waste-to-wealth) are a driver for construction companies, including Small and Medium Enterprises (SMEs). In a similar study conducted by Gue et al. (2020), new financial opportunities that stem from collaboration were identified as a prime driver for organisations to transition to a CE. Furthermore, Domenech et al. (2019) investigated the levels of industrial symbiosis in Europe. The study found that new opportunities from the CE were a key driver in businesses to improve their economic and environmental performances. The study found that the CE provided new opportunities to reduce the overall environmental and economic cost of operation whilst providing social benefits (Domenech et al., 2019).

D2: Industrial Competition

Similar to economic opportunities, competition within the construction industry is key to driving innovation (e.g. Adam Smith's invisible hand). Adabre et al. (2023) identified that competition within the construction industry is a leading driver for the CE, which can also drive collaboration. As the CE is developing, the ability for companies to innovate and reap the rewards of closed-loop material efficiency increases, creating a competitive new market for companies. Furthermore, the core benefits of the CE provide a competitive edge for organisations to outdo their competitors (Adabre et al., 2023). Luciano et al. (2022) also identified the benefits of competition in the development of a CE. Furthermore, Luciano et al. (2022) identified that the competition in the CE could increase the overall competitiveness of the industry to inspire the development of the CE through new markets and sectors. Rakhshan et al.'s (2020) investigation into the drivers of the CE found that the savings from selective reuse and recovery of structures provide cost savings for the project, thus allowing for higher levels of profit or project quality (Rakhshan et al., 2020). Competition in industry is one of the prime drivers for the development of (new/revised) practice and products, is key in the development of the CE.

D3: Secondary material production/supply

Munaro and Tavares (2023) proposed that secondary materials are a key driver for the CE for several reasons: primarily, the diversion of waste from landfill, the creation of value from low-value goods, the supplementation of the materials market, the creation of new materials, and the reduction of raw resource use. Overall, the commercial aspect of secondary materials and the CE is the key driver of the practice (Munaro and Tavares, 2023). Adams et al. (2017) found that a key enabler of the CE was the production of high-quality secondary goods. New innovative materials derived from secondary goods are still being tested and investigated, which means the overall standard is low (Adams et al., 2017). By developing high-quality secondary goods, the secondary market will be driven to match raw material supplies (Adams et al., 2017).

Ababio and Lu (2023) discussed secondary resources as a driver for the industry to be able to increase the material types and varying performances to diversify the market. Domenech et al. (2019) identified that secondary materials and their value vary significantly depending on the geographical location. Furthermore, Domenech et al. (2019) proposed that correct waste management and secondary material supply would drive the CE resource efficiency. Adabre et al. (2023) discussed the need for quality secondary materials and their use within the design and construction of structures. They proposed that as the quality and standardisation of secondary materials continue, the implementation and use of them will increase. Luciano et al. (2022) also discussed the use of waste management as a key driver to developing the secondary materials market. As attention to waste management increases, the ability to identify recoverable and reusable materials increases substantially, increasing the ability to utilise the CE in practice and gain the benefits of it (Luciano et al., 2022).

D4: Raw material volatility

Charef et al. (2022) drew attention to the reduction of raw resource availability and increases in price as a core driver of the CE and the substitution with secondary resources. By reducing the input of raw resources into the process, the process overall is more flexible and secure from virgin material fluctuations (Charef et al., 2022). Adabre et al. (2023) also identified that one of the key drivers of the CE is the resource security of closed loops and secondary materials as opposed to raw material supply chains that are experiencing shortfalls in supply. By creating a diverse material market of raw resources and associated secondary uses, the overall dependence on raw materials is reduced. Adabre et al. (2023) identified that material security through implementing secondary materials is a key driver for the CE. Luciano et al. (2022) reviewed the raw material market in Italy, where secondary material substitutions are increasing. Furthermore, Luciano et al. (2022) identified the environmental and economic benefits of substituting raw materials with secondary resources. They also suggested that the trend of increased cost and volatility for raw materials should help grow the secondary market as a stabilising force (Luciano et al., 2022). Finally, Wuni (2023) proposed schemes, such as tax levies, to reduce organisations' dependence on raw materials to drive the CE.

D5: Reduced environmental impact

Adabre et al. (2023) found that there is a strong sense among consumers towards environmentally correct decisions due to the ongoing climate impacts faced by developed and developing countries alike. With the environmentalist movement continuing to gain momentum, the economic impact on the environment is becoming more costly for businesses as it destabilises the status quo (i.e. financially, socially, organizationally). Wuni (2023) found that the CE's environmental drivers stemmed from the increased level of education within society and a better understanding of the negative impacts of industrial processes on the environment at macro, meso, and micro levels. The global impact of climate change is increasing the awareness of the need for a different economic system, hence the attention to CE and industrial symbiosis as a driving force for change (Wuni, 2023). Domenech et al. (2019) identified that industrial symbiosis, and the CE can impact the levels of consumption within businesses, which has a mitigating effect on the environmental cost of production. Charef et al. (2022) found that servitisation also has environmental benefits, and consideration for the CE can assist in the mitigation of operational impacts on the environment. Furthermore, the maintenance of materials and components improves the durability and the quality of the material during recovery (Charef et al., 2022). Rakhshan et al.'s (2020) study on the reuse of components within the construction sector found that the reuse of materials and components significantly reduces environmental impact. Rakhshan et al. (2020) discussed the increased environmental benefits of reuse over recycling and how both reduce the industrial impact on the environment more than linear methods, as they circulate materials instead of returning man-made materials into the natural environment. Luciano et al.'s (2022) findings in the EU identified that the CE could benefit the environment in multiple ways to reduce the impact of industrial activities. Primarily, the reduction of disposal and raw material extraction (Luciano et al., 2022).

D6: Servitisation, Product-Service-Systems (PSS), and maintenance

Adabre et al. (2023) proposed that the promotion of servitisation could incentivise and enable the CE through financial means. Ababio and Lu (2023) proposed financial incentives through CE practices such as servitisation to create market opportunities. Charef et al.'s (2022) investigation of the CE found that servitisation or PSS improve the quality of the product through a higher level of consideration for operational maintenance. By considering the lifecycle and maintenance of the product, the consumers' needs are considered, creating a higher level of quality for the consumer.

D7: Take-back schemes

Adams et al. (2017) and Shooshtarian et al. (2023) proposed that take-back schemes are viable to improve the return of materials into the economy and provide contractual assurances. Wuni (2023) theorised that the use of mandatory take-back schemes for hazardous materials and incentivising take-back schemes in industry can have a profound impact on the CE's transition and make it more financially viable for organisations. Shooshtarian et al. (2023) also identified take-back schemes as a prime driver for the CE within the Australian construction industry.

D8: Recovery and reuse infrastructure

Ghufran et al. (2022) identified the development of supportive infrastructure as an enabler of the CE. Wuni (2023) identified several drivers for recovery and reuse infrastructure. Firstly. the availability of technology and equipment, which is required to process materials (Wuni, 2023). Secondly, supportive infrastructure for organisations to channel materials and avoid landfill (Wuni, 2023). Finally, the development of reverse logistics and supply chain networks enables consistent closed-loop material flows (Wuni, 2023). Overall, at present, there is a demand for infrastructure to recover and reuse materials in Nordic countries, as well as to establish communication infrastructure of a digital and physical nature between different organisations in the supply chain (Knoth et al., 2022).

D9: Standardisation

Standardisation is also a big enabler of the CE, as it provides a quality standard for materials and standard methods in which to operate (Mignacca and Locatelli, 2021). This process of standardisation simplifies the number of variables that businesses have to manage (Mignacca and Locatelli, 2021).

D10: Waste reduction

Waste reduction is a primary objective and driver of the CE strategy, accompanied by value creation. The literature surrounding the drivers and barriers of the CE, however, rarely states waste reduction explicitly as a driver (probably due to its blatancy). Domenech et al. (2019) found that within the EU, waste reduction through the CE is increasing and improving the value of the initial input of raw resources. The drivers associated with waste reduction and improved value, such as new market opportunities, reduced operational costs, and environmental impacts, are more commonly discussed within studies than the benefits and motivational factors of reducing waste in practice. This suggests that the reduction of waste is not widely discussed as a driver due to its apparent driving factor in businesses.

D11: Cost and time efficiency

Domenech et al.'s (2019) investigation of the CE and industrial symbiosis in the EU found that member countries have been saving millions of euros since CE practices were first incorporated. In terms of cost efficiency, the new CE transition provides better cost efficiency than the previous linear model (Domenech et al., 2019). While the CE requires more consideration and time to be implemented within operations, overall, the extra use of time for the application of the CE eventually produces higher levels of value within a process (Domenech et al., 2019). Thus, it could be argued that the extra use of time to retain value within a process does not necessarily negatively impact the efficiency of time and in fact can improve the overall cost/time ratio. Additionally, Charef et al.'s (2022) study found that by utilising BIM's tools for material databases, scheduling, and simulation, the development of the CE can be enhanced to reduce operational time and cost.

D12: Improved product quality

Charef et al.'s (2022) investigation of the CE found that the practice of servitisation or PSS improved the quality of the product through a higher level of consideration for operational maintenance. By considering the lifecycle and maintenance of the product, the consumers' needs are considered, creating a higher level of quality for the consumer.

3.4.2 Global Theme 2: Institutional

Institutions are the backbone of the economy and society and a major driving force for standards and change, for example, guiding best practice and regulating innovations. In this section, the institutional drivers are reviewed.

D13: Circular laws and legislation

Ababio and Lu (2023) proposed that the policies and guidelines established by legislators are key in encouraging and enabling the CE. They commented that legislation is at the core of the CE transition and assists in the development of circular procurement. Furthermore, the development of CE laws and legislation can provide a benchmark for whole supply chains to conform to, which will assist in overcoming barriers linked to collaboration (Ababio and Lu, 2023). Chen et al. (2022) also discussed the requirement of legislation within the construction industry for the selection and regulation of designs and materials, arguing that without the laws and regulations to govern decision making in design, there are difficulties with ensuring performance and assurances. Ghufran et al. (2022) analysed the dynamics created by policies and legislation on businesses within the economy, stating that policies create an ecosystem for businesses to collaborate and form new alliances. The creation of new policies to encourage and guide the CE is key in fostering a new CE model within the linear economy. At present, the majority of global policies favour the linear economic model and continue to drive unsustainable methods (Ghufran et al., 2022). Munaro and Tavares (2023) found that legislation in the current climate is both a driver and a hindrance. Current linear legislation contradicts the goals and aspirations of the CE and therefore poses a barrier to the transition (Munaro and Tavares, 2023). However, as legislation evolves and stimulates green and circular policies, legislation will become a prime driver of the transition (Munaro and Tavares, 2023).

D14: Taxes (relief and penalties)

Adabre et al.'s (2023) study on the drivers of the CE in the construction industry found that taxation (e.g. taxes on natural resources, linear disposal, and CE products) is a key driver for economic change. Cruz Rios et al. (2021) also discussed the use of taxes in two ways: penalties and incentives. Penalties include taxes on virgin resources, landfill, and demolition; and incentives include tax deductions for CE models, innovation funding, materials, and refurbishment/reuse to encourage the use of CE practices (Cruz Rios et al., 2021). Ghufran et al. (2022) also identified tax levies as an incentive for driving the CE, and Wuni (2023) similarly identified the use of tax as a driver to incentivise organisations to move towards CE models.

Munaro and Tavares (2023) identified the use of landfill tax as a tool to drive organisations to implement waste management. They also discussed the use of taxes to reduce the cost of CE activities and innovations, as well as reliefs for companies in the process of transitioning. A further mechanism that Munaro and Tavares (2023) covered is the use of taxes to target products with no recycled content, which is an issue that has not been thoroughly discussed within the extant literature. The use of high landfill taxes in EU countries has increased the level of materials entering the secondary market and has driven innovation to avoid disposal expenses (Luciano et al., 2022). Rakhshan et al. (2020) proposed that the UK taxes on landfill have driven the transition to a CE but have also pushed some organisations to illegally dispose of waste, subverting all end-of-life processing. Similarly, Gillott et al. (2022) discussed the potential of taxes in driving the CE and how the current model of taxation hinders the use of circular methods and materials. For instance, new-build projects have 0% value-added tax, whereas refurbishments are taxed at 5-20% (Gillott et al., 2022).

D15: Goals and targets

According to Ababio and Lu (2023), a clear vision and ambitious goals are key to guiding organisations and advising them on the direction of governance. Chen et al. (2022) discussed the impact of government goals and targets on the transition to a CE, arguing that without clear targets and goals, the transition to a CE would be a long process. Cruz Rios et al. (2021) features a list of enablers for the CE within the construction industry, targets and goals are at the core of establishing levels of waste, recovery, and overall consumption of materials. They further stated that goals and targets drive and guide practitioners to avoid penalties and achieve financial benefits. Munaro and Tavares (2023) discuss the use of goals at all levels of the lifecycle and argue that global, national, and local-level goals, targets, and plans are required to drive the CE and guide organisations throughout the transition. Adabre et al.'s (2023) study on the CE also picks up on this theme and stresses the importance of common goals within organisations, more so in the transition between models, such as transitioning from a linear economic model to a CE. Furthermore, to increase consensus within business on the importance and relevance of the CE, the government's goals and targets are key to establish guidance and direction for the economy (Adabre et al., 2023).

D16: Supervision and inspections

Huang et al. (2018) proposed implementing stricter punishments for linear practices and conducting inspections and supervision to identify and enforce penalties. Similarly, Adabre et al. (2023) proposed enforcing compliance with inspections and penalties. Once CE laws are in place, there needs to be a robust governance system, including legal procedures, to ensure compliance (Adabre et al., 2023). Furthermore, Shooshtarian et al. (2023) identified that within the Australian construction industry, enforcement of legislation was a key enabler.

D17: Financial incentives

Adabre et al. (2023) identified the use of finances to incentivise the CE transition within the construction industry. Cruz Rios et al. (2021) also identified financial incentives as an enabler to improve the business case of the CE within the build environment and financially incentivise companies. Increasing the availability of funds for innovations and support of organisations' transitioning to circular models (Adabre et al., 2023) is particularly important for SMEs who may otherwise lack the capacity to invest in innovation (Chen et al., 2022; Cruz Rios et al., 2021). Ababio and Lu's (2023) investigation found that there are multiple financial risks for companies to innovate that pose a barrier to the CE and that financial incentives through CE practices, such as servitisation, could create market opportunities to drive change. Knoth et al. (2022) found that companies ranked financial incentives high on the list of enablers. Participants stressed that they needed to be incentivised to change in some manner and that financial incentives are the most effective in businesses (Knoth et al., 2022). Similarly, Adams et al. (2017) results on the enablers for the CE found that financial incentives to use secondary materials could enable the CE within the construction industry. Furthermore, the use of examples to create a financial business case has been proposed to incentivise companies by increasing their confidence in the strategy. Wuni (2023) found that financial incentives are important in two ways to enable the CE. Firstly, to develop a strong financial case, strategy or model to guide practitioners to financial benefits; and secondly, to develop and use secondary materials (Wuni, 2023).

Ghufran et al. (2022) proposed government financial support as an enabler of the CE. In their results, government financial support and assistance were ranked as the strongest enabler as they provide structure and guidance to companies (Ghufran et al., 2022). Furthermore, they discussed the benefits of government financial support on the development of the CE, such as developing case studies and regulations for national implementation. Huang et al. (2018) included regulations from the National Development and Reform Commission in China that provide financial support for recycling and waste management projects, including the specification of materials. Shooshtarian et al. (2023) found that within the Australian construction sector, financial incentives were ranked sixth on their list of twelve enablers. This shows that financial incentives are commonplace within multiple studies and across sectors. However, Shooshtarian et al. (2023) found that there has been a transition from financial concerns being the prime driver/barrier towards technical and regulatory aspects becoming a prime focus of attention. This suggests that the CE is developing at more practical levels now within industry.

D18: Procurement strategies

Wuni (2023) found that procurement is a key driver of collaboration within the supply chain. By establishing the CE within the contractual links between companies of the supply chain, companies are required to meet specific requirements for the design, maintenance, and recovery of materials (Wuni, 2023). Adabre et al. (2023) proposed higher regulations on the types of materials that can be used within the construction industry to reduce the main contributors to the problem. They also identified that procurement is a key practice to enforce performance. Specifically, they proposed procurement as a tool for the establishment of practices and regulations before they are enforceable by law. Procurement was also suggested by Ababio and Lu (2023) as a key enabler of the secondary market by providing assurances and responsibility for companies to mitigate risk. Cruz Rios et al. (2021) further discussed the use of procurement to instil practices and penalties for the CE. Procurement could integrate the CE into the project’s requirements, ensure circular design, and establish targets for recovery and reuse (Cruz Rios et al., 2021). Knoth et al. (2022) identified that regulations were key in enforcing the CE; however, where such regulations are lacking, procurement can be a substitute for regulation. This was also noted by Munaro and Tavares (2023) in their review of political drivers.

D19: Business models and frameworks

In their study, Adams et al. (2017) identified business models and frameworks as a key enabler amongst practitioners to guide and structure CE practices. Adams et al. (2017) identified that there are variants of CE models for businesses; however, existing models are not attuned to industry needs and have little evidence to support their usefulness as they lack empirical testing or use by practitioners. Therefore, new business models attuned to the needs of the industry could assist in driving the transition (Adams et al., 2017). Knoth et al. (2022) also identified amongst practitioners the requirement of specific business and legal frameworks from governing bodies to guide and structure the CE within organisations. According to Knoth et al. (2022) study, business models and frameworks drive organisational development and are required to organise the process amongst practitioners and within supply chains. Furthermore, Wuni (2023) discussed the correlation between frameworks and organisation; specifically, the need for regulatory and institutional frameworks to clarify and drive the CE.

D20: Guidance and best practice

Wuni (2023) identified a gap in knowledge between theory and practice, which suggests that providing guidance on the application of the CE model would help drive its implementation. Ababio and Lu (2023) discussed the importance of guidance and best practices for the construction industry, which comprises practices and challenges covering all levels and domains within it (i.e. macro, meso, micro and social-cultural, technological, institutional, and economic). Munaro and Tavares (2023) also stressed the need for collaboration to develop best practice and examples for practitioners. A key driver identified by Munaro and Tavares (2023) is the disclosure of data and information to collaborate and identify not only best practice but also opportunities for the CE. Knoth et al. (2022) discussed the demand from practitioners and policymakers for guidance and examples of the CE and best practice. Furthermore, they stress the need for collaboration between companies to collect said examples (Knoth et al., 2022).

D21: Secondary material standards

Shooshtarian et al. (2020) discussed the need for quality within the secondary material market. Regulations and standards for best practice and performance qualities could assist in the increase of reliability and trust in the material quality of the secondary material market (Shooshtarian et al., 2020). Wuni (2023) also discussed the use of standards within the CE to improve the assurances of methods and materials. With increased levels of standards and regulations on the CE, organisations can be assured of the quality and performance of the product (Wuni, 2023).

3.4.3 Global Theme 3: Social-Cultural

The social-cultural environment within a business is a core aspect of how the business is managed and how decision-making is conducted. In order to implement change within the management of a business, significant social-cultural changes are required. In this section the social-cultural drivers are therefore reviewed.

D22: Integrated Project Delivery (IPD)

Ababio and Lu (2023) stressed the importance of collaboration to enable the CE throughout the lifecycle in a holistic manner. This collaboration is key to enabling information exchanges between the companies within a supply chain to actively manage and track materials and opportunities to help develop the CE and the secondary materials market (Ababio and Lu, 2023). Cruz Rios et al. (2021) furthermore highlighted that collaboration is a key enabler as it assists in overcoming social-cultural barriers. Their study found that practitioners desire closer collaboration between the design and construction stages, and incentives such as joint venture funding initiatives may help. Adabre et al. (2023) discussed the need for integration within the supply chain to create collaboration over the information and application of the CE. Ding et al. (2023) discussed the benefits of companies collaborating with the government, other organisations, SMEs, and universities. Firstly, collaboration strengthens organisational communication and information (Ding et al., 2023). Secondly, it provides information to R&D for the creation of regulations, guidelines, educational resources, market opportunities, case studies, and new technologies (Ding et al., 2023). Knoth et al. (2022) concluded that collaboration is a key enabler of practice and knowledge generation. More collaboration is needed to drive the CE, specifically between manufacturing industries to develop material knowledge (Knoth et al., 2022).

D23: Responsibility and recognition

Gue et al. (2020) identified that organisations are beginning to incorporate social responsibility into their business models. This sense of social responsibility is driving higher levels of consideration for the environment and consumers, overall improving the quality of products and processes (Gue et al., 2020). Additionally, receiving recognition for incorporating social responsibility and environmental considerations further drives organisations to apply the CE and other practices. Ultimately, this creates a self-regulating dynamic between organisations and society to enact and manage changes to industry. Overall, by stating responsibility within the lifecycle, organisations and stakeholders can be held accountable for their practices (Wuni, 2023). Knoth et al. (2022) identified in Norway that extended producer responsibilities could drive the CE by enforcing design and end-of-life considerations into organisations.

D24: Marketing and awareness campaigns

Adams et al.'s (2017) study found that amongst practitioners, awareness raising was a prime driver for their transition. In lieu of this, they proposed awareness campaigns to support collaboration between large companies and SMEs on CE projects within supply chains. Cruz Rios et al. (2021) discussed awareness in three key areas: institutions, governments, and academia. In each area, CE practices, benefits and challenges are to be discussed to inform policymakers, practitioners, and consumers (Cruz Rios et al., 2021). Cruz Rios et al. (2021) proposed that government awareness campaigns for stakeholders and consumers can increase the demand for environmental and CE methods of construction. Munaro and Tavares (2023) discussed the use of marketing, social media, events, and awareness campaigns to improve the availability of information and encourage collaborative research projects.

Adabre et al. (2023) proposed that producers of CE products should better market their products to increase consumer awareness and their contribution to a CE. Chen et al. (2022) discussed the use of awareness schemes to increase levels of training amongst practitioners and diffuse difficulties between education and application. Furthermore, Wuni (2023) found that awareness is key for driving interest and understanding of the CE within the industry and among consumers; the consumers' demand drives stakeholders and practitioners to change their products.

D25: Education programmes

Ababio and Lu (2023) discussed the importance of education at multiple levels within the lifecycle to develop and drive a CE within the construction industry. Initially, there is a lack of education within the construction industry, which requires addressing at a micro level to create a foundation for operational applications (Ababio and Lu, 2023). Secondly, the requirement of governments and higher education to push CE resources and teachings on students and industry to drive the transition (Ababio and Lu, 2023). Ghufran et al. (2022) suggested that through education of the CE, awareness and application levels will increase, driving the transition. Gillott et al. (2022) results showed that education and training was a prime enabler amongst participants. Specifically, the need for engineers and designers to be informed and trained in CE methods (Gillott et al., 2022).

Wuni (2023) proposed that education within the sector could increase adoption by increasing awareness and demand amongst clients and stakeholders. However, there is also the need to educate and train the workforce to support the demands of stakeholders (Wuni, 2023). Cruz Rios et al. (2021) discussed the need to educate not only practitioners but clients and stakeholders. Furthermore, Cruz Rios et al. (2021) proposed the use of consultants to increase the level of circularity within the design of structures. Knoth et al. (2022) found that education and information drivers are inextricably linked to the social-cultural change within industry and, therefore, are core drivers of the CE transition. However, in order to achieve this, more integration of CE practices is required in higher education and academia (Knoth et al., 2022).

D26: Data sharing

Gue et al. (2020) found that the availability of data was a key barrier and driver to a CE. Practitioners state that information on the CE and closed loops would be a top enabler to their transition (Gue et al., 2020). In order to establish a CE, Ababio and Lu (2023) suggested that tools for data sharing and collaboration are needed. To fully understand the whole process and the impacts of decision-making, data and information need to be shared within and between companies and across the stages within the lifecycle (Ababio and Lu, 2023). Munaro and Tavares (2023) identified integrated data systems within supply chains to be a leading driver of the CE, especially for practitioners and suppliers. Furthermore, the development of CE information would mitigate or remove barriers associated with design and recovery within the industry (Munaro and Tavares, 2023).

D27: Society's opinion of unsustainable practice

Gue et al. (2020) discussed the importance of society and social responsibility as a driver for organisations. When given recognition from consumers and society more generally, practitioners feel rewarded and desire further recognition for their good work (Gue et al., 2020). As the concern within society for the environment grows, so does the weight of their opinion on wasteful industries and organisations. A positive societal opinion of an organisation can also drive economic benefits for organisations, creating a secondary driver (Rakhshan et al., 2020). Wuni (2023) discussed at length the increased levels of social responsibility within organisations as the impact of social opinions and pressure increases within the construction industry. In other words, organisations are becoming more focused on the impacts of their products on society and in doing so, are creating a dynamic in which the consumer has influence on industry practices (Wuni, 2023).

D28: R&D

Adabre et al. (2023) discussed the benefits of R&D at the business level to provide case studies to guide practice. Furthermore, governments should inspire bottom-up R&D within the construction industry (Adabre et al., 2023). Ding et al. (2023) identified the importance and the lack of R&D within SMEs. To drive the CE within the construction industry, Ding et al. (2023) proposed that SMEs should be encouraged to participate in R&D with wider groups. Munaro and Tavares (2023) highlighted that more academic research needs to be conducted to inform guidelines, and secondly, the level of government funding initiatives for R&D needs to increase to incentivise research (Munaro and Tavares, 2023).

D29: New networks

Wuni (2023) identified the development of reverse logistics and supply chain networks as an enabler of consistent closed-loop material flows. Similarly, Domenech et al.'s (2019) discussion on the difficulties of the CE in relation to supply chain networks promotes new networks as a driver of the CE. As the CE is dependent on collaboration within the supply chain, the creation and collaboration with new networks and partners provide a driving force for the industry to transition to a CE model. Without such networks, there are significant barriers to the development of a CE (Domenech et al., 2019).

3.4.4 Global Theme 4: Technological

Technology is a supporting factor in any business or industry. In this section, the drivers associated with technology will be reviewed.

D30: Life Cycle Analysis (LCA) and benchmarking

Adams et al. (2017) stated that the cost-related benefits of the CE are a big driver for the CE, which needs highlighting. Furthermore, the construction industry desires more detailed financial performance information from practice, and Adams et al. (2017) proposed an analysis of the lifecycle. Chen et al. (2022) noted the difficulty in completing an LCA, as it requires multiple companies to participate and significant amounts of time and resources. However, facilitating this process through BIM can increase the speed and accuracy of the analysis (Chen et al., 2022). In fact, BIM-based lifecycle costing could benefit the decision-making process for most circular materials or methods and create a strong business case for the CE (AlJaber et al., 2023). Munaro and Tavares (2023) proposed LCA and lifecycle costing as a mandatory practice within industry to collect data and actively consider CE opportunities. By enforcing LCA and lifecycle costing, organisations would become aware of the opportunities and costs of the CE, and this would also increase the awareness of practitioners and stakeholders (Munaro and Tavares, 2023).

D31: Material databases

Ghufran et al. (2022) listed big data as an enabler of the CE. AlJaber et al. (2023) discussed the importance of databases as an enabler of collaboration and communication. Furthermore, it is a prime element of material tracking and passports (AlJaber et al., 2023). Wuni (2023) also noted that the availability of data is a key enabler of the CE and provides information to support circular decision-making. Chen et al.'s (2022) discussion on databases focused on BIM and IoT, which are both seen as leading enablers of the CE in construction. CE design and material performances are key to a successful CE; both rely on databases and information to function effectively (Chen et al., 2022). Furthermore, Chen et al. (2022) discussed the importance of databases in creating predictions and simulations. In the US, Cruz Rios et al. (2021) found that material databases were a key enabler as well as a list of components suited to be reused in their end-of-life period. Furthermore, the importance of data in understanding costs, environmental impacts, performance, quality, time, and applications of reuse was highlighted by Knoth et al. (2022), who concluded that the use of big data has the potential to inform guidance.

D32: Case studies

Gillott et al. (2022) discussed the need for case studies to enable technical applications of the CE, such as design guidance. Adams et al. (2017) found that case studies are one of the key enablers amongst practitioners. Furthermore, a key driver of the CE amongst practitioners was a financial case for transitioning. Cruz Rios et al. (2021) also discussed the need for case studies to improve the financial case of the CE and to encourage businesses to transition. Knoth et al. (2022) found that designers, manufacturers, consultants, and public institutions require and rely on case studies for best practice. Furthermore, case studies and pilots are key for regulatory development (Wuni, 2023).

D33: BIM

Charef et al. (2022) investigated the synergy between using BIM and enabling the CE. By utilising BIM's tools for material databases, scheduling, and simulation, the development of the CE can be enhanced to reduce operational time and cost (Charef et al., 2022). Ababio and Lu (2023) discussed BIM as a tool for enabling CE practices such as material passports and design for the CE. As a driver, Chen et al. (2022) proposed that BIM can improve information management, utilise the IoT, manage scheduling and waste production, inform design, conduct LCA, and perform predictive simulations. AlJaber et al. (2023) found that there are multiple benefits to costing through the use of BIM, specifically, collaboration, data tracking, simulations, databases, design, standardisation, lifecycle costing, and circularity assessments. Munaro and Tavares (2023) also proposed the use of BIM to simplify the process of material tracking and information storage.

D34: Circularity tools

Ababio and Lu (2023) proposed several types of tools for the CE: reporting, financial, and information to drive the CE. Adams et al. (2017) found design and guidance tools to be a key driver amongst industry professionals. Ghufran et al. (2022) touched upon the requirement of CE tools to guide practitioners and policymakers. Munaro and Tavares (2023) found that CE tools and technologies are a key driver in enabling and promoting the CE within organisations. Furthermore, Munaro and Tavares (2023) highlighted that guidance and design tools are key to establishing CE practices. Cruz Rios et al. (2021) discussed the need to integrate LCA and design tools into decision-making for integrating CE practices, materials, or designs.

D35: Design tools

Munaro and Tavares (2023) stressed the importance of design and designers in developing and applying the CE to the construction industry. They argued that incorporating the CE within design allows for other stages to apply aspects of the CE and overcome common barriers. Ababio and Lu (2023) also discuss the need for design in multiple forms, specifically, the need for a design framework to guide practice. They asserted that design for the CE provides a multitude of options for later applications of CE principles and that without such design, the CE's benefits are severely limited. AlJaber et al. (2023) discussed the multiple benefits of integrating the CE within BIM to enable the optimisation of structural design and spaces for the CE.

D36: Collaboration tools

AlJaber et al. (2023) discussed the use of BIM to enable interdisciplinary collaboration through a shared digital environment, thus allowing information exchanges and collaboration between disciplines and stages within the lifecycle. Munaro and Tavares (2023) identified integrated data systems within supply chains to be a leading driver of the CE, especially for practitioners and suppliers.

D37: Material tracking

One of the biggest difficulties of the CE is managing the material information and tracking resources. AlJaber et al. (2023) proposed the use of BIM and other digital technologies to manage material information and track resources throughout the lifecycle and varying stages. Ensuring the traceability of materials and their information is a key driver of the CE (AlJaber et al., 2023). Munaro and Tavares (2023) proposed that material tracking is essential to mapping and working in a secondary CE market similar to that of the current linear market. Developing integrated tracking and information systems enables material passports and lifecycle analysis of performance data (Cruz Rios et al., 2021).

D38: New methods of construction and deconstruction

Wuni (2023) discussed the need for supporting technology and equipment for recovery infrastructure, recovery technology, and closed-loop material technology. Moreover, Munaro and Tavares (2023) discussed and proposed new methods of construction to improve the feasibility and quality of reuse and recovery measures in the deconstruction stage. This suggests that new methods of construction and deconstruction focus on the innovation of designs and processes to enable the recovery and reuse of materials and components. Furthermore, Knoth et al. (2022) proposed new methods of reuse as an enabler of the CE by providing quality materials for the secondary material market. Additionally, Ababio and Lu (2023) commented that to overcome technological barriers, innovations in technology for materials and digitalisation are required to drive operational applications of the CE. Overall, the focus of new methods of construction and deconstruction requires new technologies for application to develop a material stock for the recovery and reuse of building elements and materials.

D39: New materials

Ababio and Lu (2023) stated that a core piece of technology needed to drive the CE are material and process technology to manage raw material inputs and wastes to develop a flow of materials to the secondary market. Furthermore, they commented that the information about new materials is also paramount to understand their likely or potential uses and implications. In their study, Wuni (2023) identified the need for new material technologies as well as the information and infrastructure to develop closed-loop material flows. Ding et al. (2023) suggested that by diversifying the material market, more waste can be utilised within the economy to develop new products. Thus, driving the CE by creating new opportunities and value streams for companies to expand into (Ding et al., 2023).

Table 3.1: References associated with the drivers of the CE

Theme	Sub-Theme (Drivers)	Source
Economic	New Economic and Environmental Opportunities for Businesses	Domenech et al. (2019), Chen et al. (2022), Gue et al. (2020), Charef et al. (2022)
	Industrial Competition	Rakhshan et al. (2020), Luciano et al. (2022), Adabre et al. (2023)
	Secondary Material Production/Supply	Munaro and Tavares (2023), Ding et al. (2023), Ababio and Lu (2023), Adams et al. (2017), Luciano et al. (2022), Wuni (2023), Adabre et al. (2023), Domenech et al. (2019), Chen et al. (2022)
	Raw Material Volatility	Ababio and Lu (2023), Adams et al. (2017), Luciano et al. (2022), Wuni (2023), Adabre et al. (2023), Charef et al. (2022)
	Reduced Environmental Impact	Rakhshan et al. (2020), Luciano et al. (2022), Wuni (2023), Adabre et al. (2023), Domenech et al. (2019), Charef et al. (2022)
	Servitisation/PSS	Adabre et al. (2023), Charef et al. (2022)
	Take-back Schemes	Adams et al. (2017), Shooshtarian et al. (2023), Wuni (2023)
	Recovery and Reuse Infrastructure	Ghufran et al. (2022), Wuni (2023), Knoth et al. (2022)
	Standardisation	Mignacca and Locatelli (2021)
	Waste Reduction	Wuni (2023), Domenech et al. (2019), Charef et al. (2022)
	Cost and Time Efficiency	Wuni (2023), Domenech et al. (2019), Charef et al. (2022)
	Improved Product Quality	Domenech et al. (2019), Charef et al. (2022)
Institutional	Circular Laws and Legislation	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Ghufran et al. (2022), Wuni (2023), Adabre et al. (2023), Chen et al. (2022), Shooshtarian et al. (2020), Knoth et al. (2022)

	Taxes (Relief and Penalties)	Munaro and Tavares (2023), Cruz Rios et al. (2021), Ghufran et al. (2022), Rakhshan et al. (2020), Luciano et al. (2022), Wuni (2023), Gillott et al. (2022), Adabre et al. (2023), Knoth et al. (2022)
	Goals and Targets	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Adabre et al. (2023), Chen et al. (2022), Knoth et al. (2022)
	Supervision and Inspections	Shooshtarian et al. (2023), Huang et al. (2018), Adabre et al. (2023)
	Financial Incentives	Knoth et al. (2022), Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Adams et al. (2017), Shooshtarian et al. (2023), Ghufran et al. (2022), Huang et al. (2018), Wuni (2023), Adabre et al. (2023), Chen et al. (2022), Knoth et al. (2022)
	Procurement Strategies	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Wuni (2023)
	Frameworks/Business Models	Adams et al. (2017), Huang et al. (2018), Wuni (2023), Knoth et al. (2022)
	Guidance and Best Practice	Munaro and Tavares (2023), Ababio and Lu (2023), Shooshtarian et al. (2023), Wuni (2023), Adabre et al. (2023), Gue et al. (2020), Knoth et al. (2022)
	Secondary Material Standards	Ghufran et al. (2022), Wuni (2023), Shooshtarian et al. (2020)
Social-Cultural	Integrated Project Delivery (IPD)	Ding et al. (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Shooshtarian et al. (2023), Ghufran et al. (2022), Adabre et al. (2023), Mignacca and Locatelli (2021), Chen et al. (2022), Knoth et al. (2022)
	Responsibility and Recognition	Wuni (2023), Gue et al. (2020), Knoth et al. (2022)
	Marketing and Awareness Campaigns	Munaro and Tavares (2023), Cruz Rios et al. (2021), Adams et al. (2017), Wuni (2023), Adabre et al. (2023), Chen et al. (2022), Shooshtarian et al. (2020), Knoth et al. (2022)
	Education Programmes	Ababio and Lu (2023), Cruz Rios et al. (2021), Shooshtarian et al. (2023), Ghufran et al. (2022), Wuni (2023), Gillott et al. (2022), Shooshtarian et al. (2020), Knoth et al. (2022)
	Data sharing	Munaro and Tavares (2023), Ababio and Lu (2023), Gue et al. (2020)

	Society's Opinion of Unsustainable Practice	Rakhshan et al. (2020), Wuni (2023), Domenech et al. (2019), Gue et al. (2020), Knoth et al. (2022)
	R&D	Munaro and Tavares (2023), Ding et al. (2023), Shooshtarian et al. (2023), Adabre et al. (2023), Knoth et al. (2022)
	New networks	Domenech et al. (2019)
Technological	Lack of Life Cycle Analysis (LCA) and Benchmarking	Munaro and Tavares (2023), Adams et al. (2017), AlJaber et al. (2023), Chen et al. (2022), Knoth et al. (2022)
	Material Database	Cruz Rios et al. (2021), Ghufran et al. (2022), Wuni (2023), AlJaber et al. (2023), Chen et al. (2022), Gue et al. (2020), Knoth et al. (2022)
	Case Studies	Munaro and Tavares (2023), Cruz Rios et al. (2021), Adams et al. (2017), Shooshtarian et al. (2023), Wuni (2023), Gillott et al. (2022), Knoth et al. (2022)
	BIM(BIM)	Chen et al. (2022), Shooshtarian et al. (2020), Knoth et al. (2022)
	Circularity tools	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Adams et al. (2017), Ghufran et al. (2022), Huang et al. (2018), Wuni (2023), Adabre et al. (2023), Shooshtarian et al. (2020), Knoth et al. (2022)
	Design tools	Munaro and Tavares (2023), Ababio and Lu (2023), Ghufran et al. (2022), Huang et al. (2018), Gillott et al. (2022), Adabre et al. (2023), AlJaber et al. (2023), Mignacca and Locatelli (2021)
	Collaboration tools	AlJaber et al. (2023)
	Material Tracking	Munaro and Tavares (2023), Cruz Rios et al. (2021), AlJaber et al. (2023), Knoth et al. (2022)
	New Methods of Construction and Deconstruction	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Wuni (2023), Adabre et al. (2023), Shooshtarian et al. (2020), Knoth et al. (2022)
	New Materials	Ding et al. (2023), Ababio and Lu (2023), Wuni (2023), Adabre et al. (2023), Knoth et al. (2022)

3.5 Practices

This section looks at the practices of the CE that have been identified within the literature. Overall, 41 practices were identified within the literature within 4 themes: economic, institutional, social-cultural, and technological (Appendix A.2).

3.5.1 Global Theme 1: Economic

The CE is primarily an economic model used to improve value generation from the original input of resources. In this section, the practices associated with the economy are reviewed.

P1: Design for Closed Loops

Adams et al. (2017) suggested considering closed loops within the design stage to identify potential options for materials and develop networks to lower and avoid wastes before they are generated. Abadi et al. (2021) discussed the requirement for closed loops within the construction industry to foster biomimicry and the need to design closed-loop systems to optimise their effectiveness in practice. Amarasinghe et al. (2024) found that designing a structure for closed-loop recovery and reuse reduces the environmental impact of material consumption and develops networks that promote industrial symbiosis. Christensen et al. (2022) discussed the benefits of designing closed-loop material processes within the construction industry. They asserted that by returning materials back into the industry, the economic cost of material supplies would be lowered, as long as there are recipients and processes available to ensure secondary material production and quality control. Similarly, Eray et al. (2019) discussed the requirement of the design stage to consider closed loops for the construction industry operational stage to increase the return of energy and materials within systems.

Asante et al. (2022) viewed design for closed loops as a process to improve the construction, operation, and deconstruction of structures through recovery and reuse. Benachio et al. (2020) focused on the impact when designing for closed loops; specifically, the improved value of materials and products, as well as the increased lifespan of the product. Çimen (2021) discussed the need for design to sustain closed loops within the construction industry and enable later recovery and reuse of materials and components. In their later study, Çimen (2023) elaborated further on the requirement of closed-loop consideration within the design stage to transition the current recycling economy to a proactive CE which can operate in every stage of the building lifecycle instead of purely the deconstruction stage. Guerra et al. (2021) stated that the design for closed loops enables manufacturers to recover and reuse materials and components effectively, mitigating expenses and environmental impacts. Alternatively, Köhler et al. (2022) discussed the influence of designing for deconstruction on the overall implementation of closed loops at every stage of the building lifecycle due to the consideration of material recovery. Çetin et al. (2021) discussed the need to foster closed loops within the Australian construction industry and the impact of design to enable their effective implementation. Çetin et al. (2021) focused on several strategies for closed-loop designs within systems: narrowing the loop, slowing the loop, closing the loop, and regenerating the loop. They also emphasised that the design for closed loops should focus on the design for durability, material lifecycles, adaptable products, and the reuse of products. Ababio and Lu (2023) stated that more information is required on materials used within closed loops to fully acquire the benefits of material circularity and to develop digital tools to enhance the identification and incorporation of CE designs and materials.

Iyer-Raniga et al. (2023) De Silva et al. (2023) noted the difference between applications of the CE within developing and developed nations. From this comparison, De Silva et al. (2023) identified that the marginally higher level of consideration for waste within the design stage of developed countries improves the ability of the industry to apply the CE and foster closed loops. Overall, there are, however, to date, few studies on the actual application of designing for closed loops, hence making the practice difficult to apply.

P2: Design for Longevity

Abadi et al. (2021) discussed the need for longevity within the design of structures to retain value and reduce the creation of waste in the lifecycle. Ginga et al. (2020) and Eray et al. (2019) stated that design for longevity increases the product and material value, creates a longer lifecycle, and retains the quality of the material for future lifecycles. Benachio et al. (2020) discussed the use of design to implement longevity within the composition of structures and extend the timeframe between closed loops within the CE, effectively extending its economic use. Ababio et al. (2023) commented that due to the long life of structures, the design for a long life reduces the need for material replacements and repairs, thereby limiting the amount of waste generated over the lifecycle. Finch et al. (2021) discussed the need for longevity in the design of structures and components to withstand repeated use and mitigate the need for repairs or replacement, and thus their concurrent production of waste. Medina et al. (2021) stated that the longevity required in design focuses on several outcomes, multi-purpose spaces, reusable components, and long-term economic investments to retain value. Tokazhanov et al. (2022)

identified several actions in order to increase the longevity of buildings, long-life design, long-life materials, appropriate maintenance, and appropriate urban planning. Guerra et al. (2021) stated that product life extension can increase the value of the structure, create a higher level of quality, and ensure the structure stays in use for a longer duration. Joensuu et al. (2020) discussed the value of the maintenance and durability of components generated by designing for longevity. Furthermore, they discussed the design for long-term agreements for closed loops to increase the ability to recover and reuse waste. Marzouk et al. (2019) focused on Lean and BIM in relation to a CE and provided various solutions to designing for longevity. Marzouk et al. (2019) stated that the long-term focus of the CE aligns with the Lean Economy's promotion of long-term value and networks.

Hossain et al. (2020) stated the need for long-life design by discussing the benefits for the service of the building and the longevity of the materials and components, which can be recovered within the CE and maintained to extend operational use and value. Furthermore, Eberhardt et al. (2022) discussed the use of CE principles for closed loops through the design for longevity within components to increase the time between cycles through durable and or high-quality materials. Perotti et al. (2023) stated that structures need to be designed with long-lasting and easily recyclable materials. Furthermore, the materials selected should be harvested from recycled materials to avoid the use of raw materials. Kręt-Grześkowiak and Baborska-Narożny (2023) discussed designing for adaptability as a strategy to increase the longevity of structures throughout the serviceable use of the structure and its changes in use. Çetin et al. (2021) identified the requirement of designers to consider the incorporation of durable materials, the ease of maintenance, and the consumers' perspective of the operational use and maintenance of the structure over the lifecycle. Cerdá-Suárez et al. (2023) discussed the need for designers to consider the materials and components of structures over a longer timeframe to facilitate the CE throughout the lifecycle and into future uses of the structure.

P3: Design for Disassembly

Ababio and Lu (2023) proposed being proactive and introducing early (new) considerations within the design stage for the deconstruction and disassembly of structures to recover materials and components for reuse. Furthermore, Ababio and Lu (2023) suggested enhancing the process with data collection methods, information banks, BIM, and material passports. Amarasinghe et al. (2024) discussed the alignment between circular principles and design for disassembly, stating that such a strategy enhances the ability of deconstruction to recover materials and components in a usable state. Papamichael et al. (2023) found that the inclusion of disassembly considerations within the design of structures will mark a critical step for enabling the recovery and reuse of building elements. Similarly, in their study, Asante et al. (2022) identified that designing for disassembly provides the potential to support the recovery of materials in their end-of-life state. Furthermore, designing for disassembly should be encouraged within the early stages of planning. Moreover, Eberhardt et al. (2022) discussed the benefits of design for disassembly for the reuse of materials and components, transcending from the simple recovery of materials, and Incelli et al. (2023) discussed in depth the benefits of design considerations for disassembly to enable closed-loop recovery and reuse. Incelli et al. (2023) stated that disassembly considerations enable the collection of usable waste throughout the lifecycle.

In their study, Kręt-Grześkowiak and Baborska-Narożny (2023) found that design for disassembly increases the reuse probability of materials due to the consideration of the end-of-life recovery. Joensuu et al. (2020) discussed the market benefits of design for disassembly through the consideration of materials that can work within closed loops, whilst avoiding those that return little value for use within the CE. Quashie et al. (2024) found that the design for disassembly enables the refurbishment and reuse of building materials and components which leads to the reduction in the environmental impact of the construction industry. Wong et al. (2024) found that the design for disassembly increases the flexibility and adaptability of the structure throughout the lifecycle, enabling multiple closed loops. Similarly, Zhuang et al. (2023) discuss the benefits of design for disassembly for the ease with which components can be repaired or retrofitted, as well as the ease of recovering materials. Fernandes and Ferrão (2023) delve deeper into designing for disassembly, focusing on the ability to recover the components of the structure whilst retaining the core structure for reuse. Fernandes and Ferrão’s (2023) suggestions could alleviate the concerns highlighted by Eray et al. (2019), who discussed the limitations of existing structures to recover and reuse materials due to the inability to effectively disassemble them, stating the importance of designing for disassembly in new buildings.

P4: Closed-loop Material Specification

Eberhardt et al. (2022) stated that the environmental performances of buildings heavily rely on the decision-making regarding material specification in the design stage; material specification is key to improving circular economics by avoiding reactionary implementations of the CE in the end-of-life stage, which are less effective and more costly. Adams et al. (2017) identified that a key enabling strategy of the CE within the construction industry is the specification of materials that work well within closed loops or are recyclable. They also discussed the increase in value of materials within their end-of-life stage when they are selected for recycling and reuse in the design stage, a point also covered by Appendino et al. (2021) in a more recent study. Ababio et al. (2023) discussed the need for material specification to reduce consumption, remove toxic materials, include environmentally friendly and secondary materials, and specify materials that are compatible with a closed-loop system. Asante et al. (2022) further promoted the practice of material specification in the design stage to optimise the use of environmentally friendly and secondary materials (i.e. materials compatible with closed-loop recovery). Moreover, Incelli et al. (2023) discussed the need for material specification for the implementation of design for deconstruction and the recovery of materials and components in a circular manner. Kręt-Grześkowiak and Baborska-Narożny (2023) discussed the need for materials to be specified within the design stage for circularity within the lifecycle. Moreover, Kręt-Grześkowiak and Baborska-Narożny (2023) focused on the specification of materials to a standardised size to reduce waste produced by the cutting of materials. Maher et al. (2023) discussed the need for regulations to specify circular and secondary materials within the design of structures. Guerra et al. (2021) highlighted the importance of manufacturers to specify materials that can be recovered within their own systems and products to establish circular economics. Gálvez-Martos et al. (2018) discussed the specification of materials that are functional within the CE and that can be facilitated by prefabrication, standardisation, reuse, and the possibility of contracts such as product as a service. Jahan et al. (2022) found that the consideration placed within the design for prefabricated and modularised components increases the level of consideration for the material waste and recovery. Furthermore, the increased use of BIM in manufacturing increases the ability of manufacturers to consider different materials and their performance.

Amarasinghe et al. (2024) discussed three types of material specifications to enable the CE: the use of high-quality materials; secondly, the use of secondary, innovative, or reused materials; and finally, the avoidance of hazardous materials. Via a survey, they found that academics favour the use of secondary materials, contractors favour the avoidance of hazardous materials, and consultants prefer innovative materials, which shows that material specifications are in development within the construction industry but lack the full integration of secondary materials, limiting the CE's full potential. The need for low-impact innovative materials was examined by Abadi et al. (2021), highlighting secondary materials to reduce the environmental impact of the construction industry. Furthermore, they suggested the use of BIM in the design stage to measure the circularity of material specifications for their optimisation throughout the lifecycle in closed loops. Benachio et al. (2020) proposed the specification of durable materials that work within closed loops to increase the possibility of recovery and reuse. Furthermore, they suggested the creation of material banks within BIM technologies to analyse the best material specifications for the CE within the construction industry, which would help practitioners to identify the most circular materials. Çetin et al. (2021) also proposed the use of BIM to increase the ease with which renewable and secondary materials are specified within the design stage for the increased levels of recovery and reuse at the end-of-life stage.

P5: Reduced Operational Impact

Consideration of a circular lifecycle in the construction industry has a significant effect on the operational impacts of buildings in use; impacts to be considered are carbon emissions, energy consumption, and waste production (Abadi et al., 2021). Tokazhanov et al. (2022) discussed the lifecycle impact in terms of two dimensions, economic impact and environmental/energy impacts. The aim of organisations is to improve the former whilst reducing the latter. Similarly, Appendino et al. (2021) discussed several benefits of circular economic considerations on the operation of buildings, also including economic and environmental aspects. Firstly, the consideration for reuse and recycling mitigates the consumption of materials and the need for extracting virgin materials. Secondly, the refurbishment of structures extends the lifecycle and reduces the need for demolition and new developments. Finally, the analysis of lifecycles allows for higher levels of decision-making for the management in companies to increase the operational efficiency of buildings. Eberhardt et al. (2022) discussed the correlation between material selection and environmental impact reduction, stating that the selection of less impactful, benign materials significantly improves the environmental performance of structures. Çimen (2021) found that the consideration of less impactful materials does not reduce the durability of structures. Furthermore, the implementation of circular practices for the disassembly of structures minimises the impact of deconstruction and benefits new projects that utilise recovered materials. Moreover, these considerations reduce the amount of waste produced in the lifecycle, thereby mitigating the impacts of waste generation. While there is a lack of information to fully understand the impacts of the existing material stock within the construction industry to employ reduction strategies from the CE, Joensuu et al. (2020) found that emerging CE practices, such as the sharing economy, show early signs of reducing the environmental and economic impacts of existing practices. They therefore suggest that more environmentally friendly and secondary materials are utilised within new projects to help mitigate the impacts of construction, and, furthermore, to develop links between industrial systems to create a symbiotic network of material sharing.

Perotti et al. (2023) found that companies striving to reduce their environmental impact look at implementing CE practices to reduce both material consumption and operational resources such as water and energy. In India, for example, the application of the CE to the construction industry reduced impacts related to climate change, such as the carbon and material footprint of structures (Bherwani et al., 2022). Moreover, Han et al. (2024) found that the creation of information systems such as BIM can empower designers to identify circular materials and construction processes to be designed out of the construction industry. Çetin et al. (2021) noted that the use of BIM with the CE can benefit designers investigating material and system performances within the construction industry to reduce the overall impact of structures.

P6: Servitisation/Product-Service-Systems (PSS)

Ababio et al. (2023) discussed the effects of servitisation within the construction industry, stating that it highlights the potential reuse value of materials, components, and structures. They found that PSS are gradually gaining momentum within circular procurement; however, organisations are cautious of it due to its novelty within the construction industry. Similarly, Azcárate-Aguerre et al. (2018) commented on PSS as a new and complex concept within the construction industry with several challenges to its implementation (i.e. uncertainty of legal ownership, unfamiliarity with the novel concept, and the need for long-term collaboration). However, there are also potential benefits of PSS as they can potentially create longer service lifecycles, incur lower maintenance costs, enable recovery/reuse, and increase potential avenues for profit among construction companies (Azcárate-Aguerre et al., 2018). Ploeger et al. (2019) also discussed the radical changes required in ownership to enable PSS within the construction industry. While ownership of property has been present since the Roman Empire, specific components which require servicing could benefit from service contracts, which maintain and reuse components for improved longevity, reuse, and recycling. Zhuang et al. (2023) argued that PSS provides long-term environmental impact reduction, reduces costs, and extends the product lifecycle. Furthermore, PSS provides shared value between the consumer and the producer and the potential to develop a collaborative system.

Medina et al. (2021) discussed the benefits of PSS as it transitions the construction industry from a consumption of products model to a consumption of services model that reduces the overall number of products consumed. Çimen (2021) discussed the potential of PSS as an enhancement to a CE to maintain and recover material and components, whereas Hossain et al. (2020) discussed the correlation between design for the CE and PSS and commented that the design should account for the service life off the structures and therefore there should be minimal risk for companies implementing a PSS. Joensuu et al. (2020) found that PSS could reduce the overall material consumption of the construction industry by extending the current building stock through maintenance and value retention. They discussed using PSS as a facilitator for a range of design functions relating to maintenance, disassembly, adaptive reuse, and remanufacturing. Tokazhanov et al. (2022) proposed service contracts instead of warranties to disincentivise replacement and create proactive maintenance throughout the lifecycle. Moreover, Guerra and Leite (2021) found that PSS has potential applications within building facades and steel structures to maintain, reuse, and recycle components throughout the lifecycle. Wong et al. (2024) suggested that PSS provides organisations with financial circularity to enable the development of material circularity.

P7: Take-back Systems

Joensuu et al. (2020) found that take-back systems foster reuse and are key features of PSS. They stated that take-back systems need to be considered within each stage of a building's lifecycle, especially procurement. Ploeger et al. (2019) identified that take-back and buy-back systems are developing within the construction industry, especially within the concrete and gypsum industries, due to their inert properties and recyclability. Moreover, Ploeger et al. (2019) found that take-back systems can be mutually beneficial for clients and producers as clients do not have the cost of processing waste and producers regain materials for re-entry into their products. Adams et al. (2017) came to similar conclusions, arguing that take-back systems are a viable practice for material and component recovery and act as a positive enabler for clients, contractors, and suppliers. Take-back systems already exist and are on the increase, according to Perotti et al. (2023). They help recover lost value within supply chains. Perotti et al. (2023) furthermore found that those systems, and the recovery of materials and components more generally, can be enabled by digitalisation and traceability.

P8: Recovery and Reuse Infrastructure

Alite et al. (2023), Maher et al. (2023), and Torgautov et al. (2022) discussed the need for infrastructure for the processing and treatment of materials to enable the CE. Similarly, Amarasinghe et al. (2024a) commented on the current lack of infrastructure as stifling the reuse and recycling within the construction industry. Joensuu et al. (2020) proposed circular infrastructure as a symbiotic practice to recover, reuse, and recycle materials, water and energy. Current recovery processes seem largely limited to purely linear or recycling activities rather than extending to the reuse of materials and components more generally. Ramos et al. (2023) suggested that improved infrastructure for the CE would mitigate illegal dumping and incentivise the use of reuse and recycling facilities.

P9: Standardisation

Asante et al. (2022) found that the standardisation of designs was one of the key practices to enable the CE in the construction industry to extend lifecycles and increase the ability of companies to recover resources. Eberhardt et al. (2022) also noted the importance of standardisation, stating that it will maximise the potential for recovery, reuse, and recycling. Similarly, Hossain et al. (2020) suggested that the standardisation of materials and secondary products would ensure their ability to function within closed loops and to enable consistent reuse and recycling. Guerra and Leite (2021) found that the use of standardisation is applicable in multiple building types to enable the CE; however, tailored projects benefit less from standardisation due to the unique use of materials and components. Furthermore, the standardisation of materials, components, and building designs allows for the reuse of structures with minimal rework. Kręt-Grześkowiak and Baborska-Narożny (2023) stated that standardisation fully supports the CE; however, effective and consistent standardisation of materials, components, and practices has not yet been fully recognised. With a specific focus on modularisation, Tokazhanov et al. (2022) discussed the benefits of standardisation to simplify components for the application of modularisation and to reap the benefits of prefabricated and repetitive work construction industry. Eberhardt et al. (2022), Guerra and Leite (2021), and Hossain et al. (2020) also discussed the benefits of modularisation when coupled with standardised materials and components with similar findings.

Marzouk et al. (2019) discussed the benefits of standardisation within the construction industry to reduce the complexity of structures for the application of strategies such as the CE. They found that standardisation requires three processes to improve its application: firstly, transparency and the visualisation of processes to develop standards; secondly, BIM to measure and design material dimensions and components to incorporate standardised structures; and thirdly, the use of a BIM database to monitor resources and inform maintenance and the deconstruction of structures to understand standardisable activities and those of a unique and uncertain nature. Fernandes and Ferrão (2023) highlighted standardisation practices as crucial for the success of CE frameworks, as well as the construction industry's contribution to the EC's policies to improve the application of the CE's principles within the EU. Adams et al. (2017) found that respondents classified standardisation as an important practice for designing for the CE, especially in the deconstruction stage.

P10: Prefabrication

Prefabricated components are preferred within a CE as they facilitate deconstruction and reuse within the construction industry (Appendino et al., 2021). Torgautov et al. (2022) identified that prefabrication is one of the most important practices within the construction industry to reduce waste generation and to enable the CE. Guerra and Leite (2021) also found that prefabrication was one of the more common practices implemented within the construction industry to reduce waste created from on-site construction processes. Tokazhanov et al. (2022) found that the use of prefabrication not only reduces waste due to factory conditions but also reduces the cost and time of construction. Hossain et al. (2020) stated that the use of prefabricated components to reduce the challenges associated with reuse, recovery, and deconstruction assists the adoption of CE practices within the construction industry. Wong et al. (2024) discussed the use of prefabrication to facilitate the reuse and repair of materials as well as the minimisation of waste, all of which were found to increase the lifespan of structures.

Eberhardt et al. (2022) discussed the benefits of concrete structures that use prefabricated concrete, stating that there are potential reductions of carbon emissions due to the reduction of waste caused by natural phenomena such as the weather. Amarasinghe et al. (2024) discussed the practical implications of CE practices, stating that prefabrication can profoundly reduce waste in timber and concrete elements. Furthermore, Amarasinghe et al. (2024a) stated that prefabrication assists in the ease with which materials and components can be recovered and reused within the supply chain. Finch et al. (2021) found that the use of prefabrication for frames and claddings can extend the lifecycle of the elements due to the improved quality of manufacturing in factory conditions. In Europe, Gálvez-Martos et al. (2018) found that prefabricated concrete produces less waste than in-situ works. They also commented that prefabricated modules are one of the most common practices to reduce waste within the construction industry. In the Australian construction industry, Jahan et al. (2022) found that many participants in their study were in direct contact with manufacturers that specialise in prefabrication and view prefabrication as an enabling practice to reduce waste and simplify processes on site. However, for the housing sector, prefabrication was less favourable due to the limited ability to tailor the components to the client's satisfaction (Jahan et al., 2022).

P11: Modularisation

Adams et al. (2017) identified modularisation as a key practice to simplify designs for deconstruction and recovery practices. Furthermore, modularisation assists the development of standardised materials and components to develop best practice for the CE in the construction industry. Torgautov et al. (2022) also highlight prefabricated modules as one of the most effective practices to reduce the generation of construction and demolition waste within the construction industry. Furthermore, Wong et al. (2024) found that modularisation is not just a key enabler of disassembly and reuse but also enables the extension of the building lifecycle. Similarly, Çimen (2021), Medina et al. (2021), and Eberhardt et al. (2022) found that modularisation facilitates flexibility and adaptability within structures to enable dismounting, disassembly, replacement, reconfiguration, reuse, recycling, lean applications, and produces a cost-effective structure for long-term economic gains. Finch et al. (2021) found that the use of modularisation for building elements allows designers to consider more innovative designs to reduce waste and implement standardisation to reduce the complexity of structures for the recovery and reuse of materials. In addition, Hossain et al. (2020) discussed the higher levels of reuse and recycling of modular components as opposed to in-situ works, stating that modular sections have a simple disassembly process and can be transported for repair and reuse within new projects. Tokazhanov et al. (2022) found that the use of modularisation within the construction industry increases the quality of components due to the factory conditions in which they are produced. Furthermore, modularisation promotes the standardisation of structures and materials for the CE, and the transfer of information throughout the lifecycle due to the QR codes and other information packets provided with modular sections, which can promote material passports, correct use of structures, and proactive maintenance to increase the lifespan of products. Similarly, Benachio et al. (2020) found that modularisation allows for LCA measurements to be conducted on components and materials to understand the potential for CE applications in the lifecycle.

P12: Waste Management

Amarasinghe et al. (2024) discussed the benefits of waste management in construction, stating that the generation of waste and the associated costs were reduced. According to Çimen (2021) waste management includes five stages: installation, storage, on-site segregation, waste transfer, and final storage for reuse and recycling. Moreover, waste management can be enhanced with digital tracking technologies to provide transparency to the system and identify causes and opportunities (Çimen, 2021). Hossain et al. (2020) found that effective waste management within the construction industry is heavily influenced by the design of the structure. Furthermore, as CE-style waste management develops, the secondary market will have an abundance of materials for reuse and recycling back into industries. However, Abadi et al. (2021) found that this may not be so straightforward and that effective waste management requires supply chain collaboration to understand the production and opportunities for reuse and recycling. Additionally, they highlight that the classification of waste and proactive management assists the recovery process. Condotta and Zatta (2021), on the other hand, focused on waste management in the demolition stage, stating that a pre-demolition waste management plan should be created to identify materials and components for reuse and recycling. Similarly, Papamichael et al. (2023) stated that LCA could improve waste management by identifying wastes and opportunities for reuse and recycling. Furthermore, the design and tracking of materials and their generation of waste could improve the effectiveness of waste management practices.

P13: Upcycling/Downcycling

Guerra and Leite (2021) identified recycling (downcycling) or upcycling as a key CE strategy to recover and remanufacture materials for reuse. Ababio et al. (2023) found that an indicator of the CE is the ability of industries to upcycle or downcycle materials and/or components. Hossain et al. (2020) stated that for a CE, closed loops are required and that upcycling is better than downcycling for value and environmental impact reduction, as upcycling retains the value of a more complex product, which replaces the chain of manufacturing process to create it. Medina et al. (2021) proposed that upcycling concrete, steel, and asphalt has positive impacts, whilst downcycling can also have positive impacts for the same materials, plus granite. Importantly, Perotti et al. (2023) found that organisations have begun to shift attention from downcycling to upcycling and are establishing upcycling strategies for the development of secondary materials. De Silva et al. (2023) also emphasised the benefits of upcycling over downcycling, and the need for the construction industry to transition from downcycling to upcycling to increase the value retention of the CE in the construction industry.

P14: Urban Mining

Condotta and Zatta (2021) described the construction industry as a massive urban stockpile of materials and components that can be mined for new projects once the existing structure has reached its end-of-life stage. Williams (2021) discussed landfill mining and urban mining as a source of materials to reuse and recycle for the construction industry. Arora et al. (2020) identified that urban mining is a feasible strategy to increase the supply of secondary goods and reusable components. However, Arora et al. (2020) highlight that the identification and estimation of reusable and recyclable components needs to occur before demolition. Joensuu et al. (2020) discussed the need for more recycling and reuse facilities to accommodate urban mining and reclaim the value lost in current linear demolition processes by the construction industry. Giorgi et al. (2022) found that there is currently little collaboration between manufacturers and demolition contractors, which limits the ability for manufacturers to tap into the urban stock to supplement their supply of materials. Despite this, Çetin et al. (2021) found multiple cases of urban mining that provided the construction industry with a significant number of materials for the creation of secondary goods, suggesting that it is possible to address the concerns identified in Giorgi et al.'s (2022) study, however, practice requires further development and application.

P15: Financial Support

Hassan et al. (2023) found that the construction industry needs financial support to mitigate the risks of innovation, especially in developing countries that lack the capital to innovate. Azcárate-Aguerre et al. (2018) found that financial incentives are key to maintaining stakeholder interest throughout the lifecycle and highlight the enabling role that banks are playing by developing new financial packages for innovation towards a CE. Adams et al. (2017) found that financial support for the use of secondary materials could improve the secondary market and mitigate the risk to organisations looking to employ them. Moreover, Wong et al. (2024) discussed the development of a financial model to support organisations in understanding the financial benefits of the CE to incentivise transitioning. Similarly, Maher et al. (2023) found that without government support or incentives, the CE remains a low priority for businesses and therefore argued that financial support from the government to enable the development of the CE within the construction industry was necessary. Financial support would allow organisations, particularly SMEs, to prioritise the CE and mitigate losses from resources and labour that are being utilised for CE innovations instead of other streams of income.

Christensen et al. (2022) found examples of governments developing deconstruction funds to support organisations to avoid demolition. Furthermore, Tokazhanov et al. (2022) also proposed that governments should provide financial incentives for the use of secondary materials within the construction industry. Additionally, Fernandes and Ferrão (2023) highlight that support from policymakers is key to the development of the CE, for example, the EU's initiatives to support the CE through financial incentives for organisations. In comparison, for China, Huang et al. (2018) proposed government subsidies to support reuse and recycling facilities and to develop the CE within the construction industry. Alternatively, in Australia, Iyer-Raniga et al. (2023) proposed tax levies to financially support the CE and incentivise reuse and recycling over linear methods. Also in Australia, Shooshtarian et al. (2022) proposed tax levies and incentives to provide financial support for companies trying to justify the transition to a CE. Finally, in Norway, Litleskare and Wuyts (2023) proposed the need for financial punishments, incentives, and support from the government to support and drive the CE within the construction industry.

3.5.2 Global Theme 2: Institutional

Institutions are the backbone of the economy and society. Institutions are, therefore, a major driving force for standards and change. Guiding best practice and regulating innovations. In this section, the institutional practices will be reviewed.

P16: Laws and Regulations

Köhler et al. (2022) found that one of the main enabling factors of the CE in the construction industry is regulatory measures. Similarly, Ababio et al. (2023) found that policy implementation and laws increase the adoption of the CE within the construction industry and establish lifecycle collaboration. Gembali et al. (2024) found that the regulations developed for recycling have increased the adoption of recycling practices within the construction industry. The same, however, cannot be said for reuse, which has seen little regulatory development. Han et al. (2024) found that regulations alongside government schemes to financially support businesses in China promoted privately owned recycling facilities and innovations within businesses to develop a CE. Maher et al. (2023) found that laws and regulations can assist SMEs and remove or reduce barriers to the implementation of a CE in a linear economy.

Furthermore, they can provide guidance for organisations through associated standards and classifications for CE-relevant processes.

In China, Cheng et al. (2023) found that the continuously developing legal system is providing structure for organisations transitioning to a CE as well as assurances. Furthermore, strict punishments for illegal activities deter organisations from deviating from waste management regulations. In Australia, Iyer-Raniga et al. (2023) found that the leadership and guidance from the government and their regulations had an evident impact on the development of the CE within the construction industry. Iyer-Raniga et al. (2023) proposed expanding the existing CE regulations in Australia to incorporate more practices for reduction and reuse as opposed to simply recycling activities. Also in Australia, Shooshtarian et al. (2022) found that participants commented that current material and waste regulations hinder the promotion of the CE strategy within practice and impede the creation of end-of-life markets for waste. Shooshtarian et al. (2022) proposed expanding the regulatory framework of the CE to increase the uptake of the CE within the construction industry and to develop recycling markets. In the Nordics, Zu Castell-Rüdenhausen et al. (2021) found that the regulations stipulating the need for product information for the CE have driven the CE by providing the necessary data for its implementation.

P17: Taxation

Gálvez-Martos et al. (2018) found that tax increases for landfill and raw material extraction, as well as levies for the circular market, provide regulators with an incentive tool to drive the CE within the construction industry. Joensuu et al. (2020) found that taxes on non-renewable materials increase the adoption of circular and secondary materials through tax competition within the economy. Fernandes and Ferrão (2023) discussed tax levies for refurbishment projects to increase the attractiveness of refurbishment over reconstruction. Shooshtarian et al. (2022) also discussed the driving force of taxes on raw materials and non-renewable practices coupled with levies for secondary and recyclable goods as a commercial incentive to transition.

P18: Goals and Targets

Gembali et al. (2024) discussed the need for governments to develop goals for organisations to aspire towards. Furthermore, Gembali et al. (2024) proposed that the CE operates at the macro level above any individual company, making the strategy difficult to visualise for individual companies and hence may need a national vision and goals. Ababio and Lu (2023) discussed the need for governments to implement more detailed targets for the CE that are focused on more than the diversion of waste. Torgautov et al. (2022) found that once organisations are provided with goals and guidance, they can analyse their performance and develop action plans to alter their business model. Han et al. (2024) discussed the need to identify, and measure wastes to quantify them and set recycling and reuse targets. Furthermore, Han et al. (2024) proposed using BIM to enhance the process. Ababio et al. (2023) proposed the use of circular procurement to implement targets within the construction industry for the CE.

Iyer-Raniga et al. (2023) found that the Australian construction industry is driven by targets and goals set by the EU in its sustainable development goals framework that structures and defines goals for innovation. In their study, Shooshtarian et al. (2022) recorded a participant stating that they did not clearly know the goals of the Australian government and the process to achieve them, stating that there needs to be clear and direct advice for organisations to follow. Papamichael et al. (2023) found that the EU's CE goals focus heavily on optimising waste management but rarely focus on reducing or reusing materials. In the Nordics, Zu Castell-Rüdenhausen et al. (2021) found several cases of policies providing goals for the construction industry, such as recycling targets, including specific targets for certain materials. Furthermore, Zu Castell-Rüdenhausen et al. (2021) found that national policies and regional goals developed a sense of responsibility within organisations to meet national targets.

P19: Supervision

In China, Huang et al. (2018) proposed increasing the supervision of waste management in the construction industry arguing that this would increase the knowledge generation of CE practices, establish communication among stakeholders, strengthen adherence to waste management regulations, and track materials and waste for case studies.

P20: Incentives

Amarasinghe et al. (2024a) proposed the use of financial incentives to mitigate the initial cost of innovating and transitioning to a CE business model. Adams et al. (2017) identified that financial incentives would encourage practitioners, academics, and clients to employ the CE within the construction industry, specifically, in the design stage. Huang et al. (2018) found that most of the economic incentives for the CE are within the end-of-life stage, where value is recovered, suggesting more incentives are needed for the earlier stages of the lifecycle and provided the example of loans for innovation. Maher et al. (2023) proposed the use of financial incentives such as grants and loans coupled with taxes on landfill and virgin resources, as well as levies for recycling and reuse. Alternatively, in Australia, Iyer-Raniga et al. (2023) proposed the use of taxes to create financial incentives for organisations to recycle and reuse materials instead of sending them to landfills.

P21: Circular Procurement

Adams et al. (2017) and Bao et al. (2019) found that procurement is a key enabler of the CE as it establishes the framework for the criteria and responsibilities of the construction industry, which can mitigate barriers such as the ownership of materials and the waste generated. Maher et al. (2023) proposed the use of circular procurement to establish end markets for materials to provide circular mechanisms for recovery and reuse. Ababio and Lu (2023) stated the need for procurement to harness the secondary materials market and establish a CE within construction supply chains, whilst maintaining controls to establish responsibilities and monitor cash flows to mitigate corruption from opportunistic behaviours. In their later study, Ababio et al. (2023) found that public procurement could develop a foundational practice for the development of circular indicators for the wider application of the CE in the construction industry. Moreover, Ababio et al. (2023) stated that circular procurement can enable supply chain collaboration, material tracking, resource allocation, and could establish the requirements and criteria for the CE in the design stage for the lifecycle. Jahan et al. (2022) discussed the process of procurement and how it creates the characteristics of the supply, logistics, quantities, and responsibilities of the supply chain. Therefore, Jahan et al. (2022) highlighted that procurement can be used to estimate and plan the logistics for waste produced within the system. Wuni and Shen (2022) proposed the use of collaborative circular procurement to establish circular principles within modular construction practices.

P22: Frameworks/Business Models

Ramos et al. (2023) discussed the development of a legal CE framework to guide and enforce waste management and the application of the CE within the design stages. Wong et al. (2024) proposed enhancing BREEAM certificates with CE principles to develop a CE framework that includes CE indicators for construction projects to standardise the approach to a CE. Medina et al. (2021) developed a framework of CE practices that includes more specific activities that they proposed as an elaboration on the 3R principles to provide more specific identification of potential solutions. In their framework, Hossain et al. (2020) proposed utilising BIM for the application of modular and prefabricated methods of construction to apply the CE.

P23: Top-down/Bottom-up Management

In China, Huang et al. (2018) proposed implementing a top-down system of regulations to standardise the CE within the construction industry. Furthermore, the incorporation of CE teams, supervision of practice, and penalties for malpractice. Joensuu et al. (2020) proposed the development of a top-down system of management for the CE involving regulations for the CE and catalysts for collaboration. However, Joensuu et al. (2020) suggested that the top-down approach should not hinder bottom-up innovations and should encourage organisations to procure novel adaptations of practices. Moreover, Joensuu et al. (2020) discussed the benefits to latecomers to a CE as it guides and enforces innovation through tested and developed practices. In Malaysia, Sinoh et al. (2023) proposed government reforms to implement relevant CE legal frameworks to establish top-down management of the construction industry, noting that centralised policies and incentive schemes driven by the EU and UK governments have seen positive results. Joensuu et al. (2020) discussed the benefits of bottom-up innovations as a competitive strategy for organisations to outperform their counterparts. LCA is a common bottom-up strategy to understand the product, process, and supply chain for the investigation and application of CE innovations (Joensuu et al., 2020). A tailored approach can then be taken by the organisation to measure the inputs and outputs of the system to be tested accordingly for later adjustment to be shared with the wider organisation (Joensuu et al., 2020).

P24: Material Standards/Classification

Maher et al. (2023) proposed the enhancement of standards and regulations for secondary materials to increase the confidence of the construction industry towards the secondary materials market. Wong et al. (2024) found that creating standards for secondary materials and their performances for the CE allowed stakeholders to understand their qualities and provided certainties for their use. Jahan et al. (2022) found that a lack of material standards deters stakeholders from selecting secondary materials and therefore propose the creation of secondary material standards to increase the level of secondary materials being incorporated in construction. Marey et al. (2024) found that the classification of secondary materials for concrete provides manufacturers with a set list of potential concrete types utilising secondary materials and standardising the process for efficiency. Alite et al. (2023) discussed the need for standardised practices for materials recovery in disassembly to regulate the quality of materials inputted into the secondary market. Appendino et al. (2021) proposed classifying wastes into four categories: energy, water, waste, and other to manage each based on the processes required to reuse or recycle them. Furthermore, Joensuu et al. (2020) proposed the classification of reused materials into in-situ reuse or relocated reuse to clarify the market for reused materials.

Fonseca et al. (2023) identified several pieces of European legislation that aim to classify waste using segregation codes to identify the quantity and potential of recovered materials. Fonseca et al. (2023) found that when enforced, the classification of waste and secondary materials significantly increased the quantity and quality of recovered materials. Gálvez-Martos et al. (2018) found that the classification of crushed concrete into aggregates in the EU provides manufacturers with green concrete options and assurances of the recovered materials. In China, Huang et al. (2018) found that the lack of material classification hinders segregation activities and proposed the development of classes from materials to improve the recovery and reuse of construction waste. Litleskare and Wuyts (2023) discussed the classification of materials for reuse within the Norwegian construction sector as an enabling factor for the identification and documentation of reusable materials and components.

P25: The 3-12Rs of the Circular Economy

Ababio et al. (2023) discussed the use of the 3Rs (reduce, reuse, recycle) in the demolition sector to manage waste generation and increase material recovery. Asante et al. (2022) discussed the 6Rs (reduce, reuse, recycle, recover, remanufacture, redesign) in regard to the lifecycle analysis of the construction industry to identify practices for CE implementation. Hassan et al. (2023) created a figure displaying their interpretation of the 3Rs, which included some of the 6Rs, such as remanufacturing, to contextualise their risk assessment for CE practices. Papamichael et al. (2023) stated that the 3R principles are a positive approach to CE thinking, but need to be used together rather than individually to enable practitioners to incorporate reduction strategies to mitigate consumption, the reuse of materials and components within a supply chain, and the effective recycling of materials to recover value within the construction industry. De Silva et al. (2023) stated that the 3R principles are not sufficient on their own to mitigate waste generation, but they help to develop a culture for the development of CE practices in every stage of the lifecycle. Gembali et al. (2024) found that the 3R principles are beneficial to developing the EU’s SDGs.

P26: The Lean Philosophy

Ababio et al. (2023) stated that the lean philosophy assists in optimising the construction process for the application of the CE. Kręt-Grześkowiak and Baborska-Narożny (2023) found that the design for a lean process in construction was identified within the extant CE literature as a key practice. Quashie et al. (2024) found that the lean philosophy, specifically those for design and construction, are key competencies for industry practitioners to attain a developing CE within the sector. Moreover, Marzouk et al. (2019) found that the use of lean in designing for the construction industry can improve the operational feasibility of deconstruction activities to improve the performance of reuse and recycling activities in the end-of-life stage of structures. Furthermore, Ababio et al. (2023) found that procurement specification for a lean model enables the CE in practice. Additionally, Maher et al. (2023) found that the implementation of lean within the construction industry was a key indicator of the application of reduction strategies linked to a CE. Perotti et al. (2023) proposed lean production as a strategy for slowing, narrowing, and closing loops within the construction industry to develop a CE. Similarly, Wuni and Shen (2022) stated that lean production principles have the ability to make valuable contributions to the design and cleaner production of the construction industry through the use of modular construction for the development of a CE.

3.5.3 Global Theme 3: Social-Cultural

The social-cultural environment within a business is a core aspect of how the business is managed and how decision-making is conducted. In order to implement change within the management of a business, significant social-cultural changes are required. In this section, the social-cultural practices will be reviewed.

P27: SCM and IPD

Ababio and Lu (2023) found that SCM was a key practice to implement the CE and integrate practices within the construction industry. Quashie et al. (2024) stated that a core practice for integrating CE practices in the supply chain is supply chain collaboration and stakeholder management. Çetin et al. (2021) and Giorgi et al. (2022) found that integrated project delivery can reduce a wealth of inefficiencies within traditional construction by establishing information sharing and collaborative design to mitigate errors in the design composition of structures and waste generation in the construction stage. Furthermore, Wuni and Shen (2022) stated that many of the critical success factors of the CE rely on the client’s involvement, stakeholder collaboration, and SCM to understand and holistically apply the CE in practice. Tosi et al. (2024) proposed using incentives and common goals to establish these close relationships and integrate cohesion within construction supply chains for the CE. Moreover, Joensuu et al. (2020) discussed the benefits of SCM to enable cross-sector integration of closed loops through networking, knowledge management, and information platforms. Maher et al. (2023) proposed that policymakers could have a large influence on the implementation of circular supply chains by improving the secondary market and promoting collaboration.

P28: Extended Responsibilities

Fernandes and Ferrão (2023) identified a lack of responsibility among manufacturers that needs to be extended into the operational stage of the lifecycle to ensure considerations for the CE. Gembali et al. (2024) identified shared responsibility as a strategy to incorporate the CE within the construction industry and to increase the consideration for the impacts of decision-making among stakeholders. Fonseca et al. (2023) found that governments need to instil responsibility within the construction industry for the production of waste and should establish schemes through procurement to extend the period of responsibility among stakeholders in the construction industry. In Australia, Shooshtarian et al. (2022) found that manufacturers do not responsibly consider waste generation and therefore, the use of extended responsibility strategies would hold manufacturers to CE criteria.

P29: Marketing and Awareness of the CE

Adams et al. (2017) found that the awareness of stakeholders and professionals in the construction industry was one of the most important aspects of the transition to a CE to increase the desire to implement CE practices and increase its demand. Amarasinghe et al. (2024) stated that the awareness of the CE is imperative to its application to ensure that professionals understand the CE and its importance. Ababio and Lu (2023) stressed the importance of stakeholders having an awareness of the CE, which can be facilitated through education schemes. Ababio et al. (2023) discussed the increased awareness of the CE through government schemes and public sector procurement, implementing circular procurement strategies. In this effort, Medina et al. (2021) proposed that innovative marketing provides awareness of the benefits of a CE among consumers and industry professionals to expand the potential opportunities and benefits gained from utilising the CE. Moreover, marketing can expand industry networks to further develop and gain from CE practices (Medina et al., 2021). However, Hassan et al. (2023) identified a lack of awareness as a risk to implementing the CE and completing their responsibilities, which can be combated with awareness campaigns and educational schemes. Maher et al. (2023) discussed the dynamic between awareness and marketing both within organisations and among consumers. Maher et al. (2023) state that awareness of the CE within an organisation can assist in its application and the benefits of implementing CE practices. Additionally, the awareness of consumers can increase demand for products and their use within a CE (Maher et al., 2023).

P30: Knowledge Management and Education

Ababio and Lu (2023) discussed the requirement of education policies within the construction industry, especially within the private sector, to encourage the adoption of the strategy on a macro level. Torgautov et al. (2022) found that the generation and sharing of knowledge within organisations is of a high priority to enable the CE through data-led decision-making. Torgautov et al. (2022) also found that education is one of the most effective strategies for enabling the CE waste management within the construction industry due to the provision of information about the application of waste management and the associated benefits.

Wuni and Shen (2022) found that the generation of knowledge, its management, and the sharing of knowledge among the top five most significant critical success factors for the application of the CE. Joensuu et al. (2020) discussed knowledge management as a relationship between private organisations, public sectors, and education to develop a body of knowledge comprehensively for the guidance of the circular transition within the construction industry. Köhler et al. (2022) found that the development and management of knowledge within supply chains and across organisations provide benefits when innovating through trade-off relationships such as those developed within a CE. To reinforce this, Guerra et al. (2021) found that participants in their study with formal education had a higher level of awareness of the CE than those without, suggesting that there are benefits of education in the transition to a CE. Moreover, in Australia, Jahan et al. (2022) found that participants with formal or additional education had a higher awareness of the CE, though it was found that it had little effect on practice.

P31: Establishing Communication and Information Sharing

Ababio et al. (2023) found that communication is a crucial component of success in the construction process by providing details on processes for procurement. Ababio et al. (2023) suggested this process could be enhanced with information technologies. In their study, Torgautov et al. (2022) found that knowledge and information sharing were one of the highest priorities to inform the employees of the situation and direction of the circular transition. Eray et al. (2019) proposed interface management systems to improve communication and information generation between projects and stakeholders to manage the complexities of construction projects and implement circularity within the process. Additionally, Köhler et al.

(2022) discussed the benefits of communication platforms and knowledge sharing to promote innovation within the construction industry for the development of the CE. In the analysed case studies, Köhler et al. (2022) found that there are numerous benefits and trade-offs from knowledge sharing and communication platforms. Furthermore, Marzouk et al. (2019) found that centralised information through electronic means like BIM provides a platform for communicating lean and CE functions within the construction industry throughout the lifecycle. Giorgi et al. (2022) proposed the use of digital communication and information-sharing technologies such as material passports and BIM to increase communication within the lifecycle and improve the circularity potential of the construction industry.

P32: Understanding the Product, Process, and Consumer

Ababio and Lu (2023) stated that it is imperative that the products, processes, and consumers are understood in their current state in order to innovate and improve the system using the CE. Moreover, Ababio et al. (2023) proposed understanding and innovating the process, optimising material use, extending the processes over the lifecycle, detailing the materials during the design and procurement, incentivising product as a service, substituting linear and hazardous materials for circular and sustainable ones, and transferring materials and waste products to other organisations. Additionally, Medina et al. (2021) discussed the changes required to the process, specifically, the need for authorities to supervise and enforce CE processes within the construction industry. Furthermore, Medina et al. (2021) proposed information services and databases to collect and analyse products while informing consumers of their use in a CE, such as PSS contracts. Finally, they proposed monitoring and altering consumer behaviours to consider their use of products and the potential expenses they may incur.

P33: R&D

Adams et al. (2017) found that there is a lack of R&D to clarify CE applications in the construction industry and therefore proposed further research on technologies which can collect and store CE data for its wider application. Amarasinghe et al. (2024) stated that the lack of R&D stems from the lack of collaboration and sharing in the construction industry, suggesting that researchers and stakeholders should collaborate to understand material circularity in construction for future applications. Medina et al. (2021) identified a need for R&D into material properties and circular principles to update technology and procedures for the creation of best practices which can be applied across the construction industry. On the other hand, Ababio and Lu (2023) noted that R&D requires significant investment, which would explain the reluctance of organisations to conduct it into a CE. Similarly, Guerra and Leite (2021) recorded an example of R&D developing from industrial and academic collaboration to create a network of partnerships for the application and development of the CE in practice; however, the case was not fully discussed. Moreover, Tokazhanov et al. (2022) tested elements of the CE in different types of buildings, finding that R&D is a significant factor required across the sector.

3.5.4 Global Theme 4: Technological

Technology is a supporting factor in any business or industry. In this section, the practices associated with technology will be reviewed.

P34: Life Cycle Analysis (LCA) and benchmarking

Foster et al. (2020) state that LCA embodies the core concepts of the CE as it is grounded in the identification and reduction of material use and wastage. Moreover, they state that LCA is the foremost practice to inform decision-making for the application of the CE within systems. Çimen (2023) states that LCA can identify opportunities and risks that are associated with the product, process, or services provided throughout the lifecycle and to which stakeholders they are attributed. They discussed several forms of LCA, such as cradle to grave, cradle to gate, gate to gate, as well as different types of LCA, such as cost, information, lifecycle health, frameworks, and for products and buildings. Furthermore, Fernandes and Ferrão (2023) proposed that LCA should be more widely applied within the construction industry to understand the environmental impact of buildings and construction. Joensuu et al. (2020) discussed the benefits and difficulties when using LCA on buildings. Firstly, buildings are often tailor made which limits the capacity for comparison and benchmarking. Secondly, the lifespan of buildings differs, with some being designed for a limited lifespan, which makes analysis and improvement difficult. However, LCA in the construction industry has identified the most wasteful aspects of construction and the construction industry to assist in prioritising the most impactful strategies. Furthermore, it has helped to assess the most optimal service plan for components within the construction industry to prolong the operational lifespan.

Quashie et al. (2024) proposed LCA for the design stage to understand the potential circularity before construction to make adjustments and improve the circularity of the building before construction commences. Han et al. (2024) discussed different types of LCA that have been coupled with BIM, the extraction of the bill of quantities for use in LCA software, automatic links between the collected data and LCA software, or linking data points and parameters within BIM for a BIM-based LCA. However, Han et al. (2024) stressed that there is still a need for BIM to be linked to LCA databases for the autonomous analysis of geometric and material information within models to simplify the process. Moreover, Quashie et al. (2024) discussed the use of benchmarking to understand the linear performances of buildings to seek circular innovations to improve the design of the building, the material circularity, and the potential for refurbishments in line with the CE. Ababio and Lu (2023) noted that benchmarking is a key practice for understanding their level of growth and transition to a CE. Wong et al. (2024) discussed the use of sustainable accreditations and frameworks to benchmark performances against circular and sustainable criteria. This would allow for the comparison of projects against standardised measurements to structure the industry's transition to a CE. Abadi et al. (2021) proposed a tool for benchmarking to understand areas that consist of good practices and those that need improvement to become more circular.

P35: Data Collection and Communication

Ababio and Lu (2023) discussed the need for databases to be increased to inform technological innovations and data-driven decisions. In their study, Condotta and Zatta (2021) addressed the development of interactive tools containing databases of products and components that can be reused. Joensuu et al. (2020) proposed that there is a need to develop databases for material reduction, reuse, and recycling in the CE, as well as the associated costs, to understand the potential impacts when performing an LCA. However, this needs to come from industry collaboration to gain holistic and accurate data collection (Joensuu et al., 2020). Medina et al. (2021) proposed the collection of data surrounding waste generated in the construction industry and the materials used within the construction industry to create an index database of material information for LCA methods. Zhuang et al. (2023) summarised by stating that a large database of construction data is needed to investigate circular designs, business models, and innovations to understand how to optimise and improve the construction industry.

P36: Case Studies

Adams et al. (2017) found that practitioners and academics desire case studies to better understand and apply the CE to their organisations. In Australia, Shooshtarian et al. (2022) found that case studies increase practitioners' confidence in the CE and would assist in the development and application of practices.

P37: BIM

Çimen (2021) briefly discussed BIM as a tool for the calculation and optimisation of construction designs to reduce the embodied carbon in structures and provide assistance to apply multiple objectives to a project. In their later study, Çimen (2023) stated that although BIM is not used throughout the construction industry, it is proposed that its use could consolidate and integrate data for the application of the CE throughout the lifecycle. Çetin et al. (2021) discussed the use of BIM to lead the design for a CE using simulations, collect data during the construction and operation lifecycles for the tracking of performances and materials, and provide details on the CE aspects of the building for the demolition stage. Furthermore, Marzouk et al. (2019) proposed using BIM with an integrated Lean element to design and manage buildings for end-of-life deconstruction. Moreover, Marzouk et al. (2019) stated that the use of BIM assists project collaboration and understanding for complex projects. Benachio et al. (2020) identified multiple sources seeking to integrate whole life assessments into BIM to understand building performances for the application of waste reduction strategies within the CE concept. Giorgi et al. (2022) discussed the use of BIM to enable lifecycle thinking in the design stage and the implementation of material passports to transfer the CE strategy throughout the lifecycle. Medina et al. (2021) discussed the uses of BIM to perform analyses of buildings and their systems to understand the whole-life performance and aid the progress of circular strategies. Torgautov et al. (2022) proposed the use of BIM to quantify the material usage, potential waste, and the corresponding strategies for the minimisation and management of waste. Fernandes and Ferrão (2023) proposed using BIM for the assessment and collection of data for the existing building stock to understand the history of structures and their future use within the CE, which can be collected with laser scanning and photogrammetry to develop material passports. Han et al. (2024) discussed the use of BIM, which has been linked with LCA databases for the assessment of demolition projects. Han et al. (2024) looked at several case studies to understand the potential of BIM-based assessments within demolition projects and found that BIM can enhance the interoperability, visibility of design guidance, and benchmarking of different approaches.

P38: Circularity Tools

Ababio and Lu (2023) discussed the need for tools to map the circular economy within the construction industry to understand the current state of the art and the potential improvements that can be made through the CE. Furthermore, Marey et al. (2024) stressed that circularity tools are needed for informed decision-making during the design and planning phase. Additionally, Benachio et al. (2020) proposed the use of circular tools within the early stages of the construction lifecycle to maximise the potential application of the CE. Tools could then assist in the understanding of potential cost savings from reuse and recycling metrics (Medina et al., 2021). Perotti et al. (2023) discussed the use of digital tools as an enabler of circular performance tracking, stating that the use of digital tools for optimising designs and processes in the construction industry can act as circular tools. Çimen (2021) identified several conceptual tools in the extant literature that look at material circularity and reusability values in their review of circular tools and assessments. Tokazhanov et al. (2022) found that circularity tools use existing tools that were developed for sustainability assessments, such as LCA tools. Tokazhanov et al. (2022) found that circular tools often focus on four areas: waste management, environmental impacts, material/products and building design. Tokazhanov et al. (2022) proposed the development of a tool specifically designed for the CE, which covers more indicators of circularity than those of sustainable assessment tools. Kręt-Grześkowiak and Baborska-Narożny (2023) found reference to a circularity and demountability assessment tool for the construction industry, but failed to discuss it in-depth. Kręt-Grześkowiak and Baborska-Narożny (2023) state that the process for a circularity assessment is clear, but the criteria are less so.

De Silva et al. (2023) addressed the use of LCA software such as One-Click as a tool for implementing circularity into construction designs to quantify and then optimise material consumption over the lifecycle. For envelope systems in construction, Finch et al. (2021) state that there are only theoretical tools for assessing the circularity potential, which limits the design potential of the systems. However, there is a lack of clarity on the indicators that are to be assessed. In regard to LCA, there are multiple tools available with a multitude of dimensions to be considered, which makes the process complicated. In the Nordics, Litleskare and Wuyts (2023) found that diagnosis and guidance tools are still in the early stages of development. Litleskare and Wuyts (2023) also found examples of digital tools that seek to apply reuse and recycling principles to design; however, Litleskare and Wuyts (2023) state that access to databases for the tools is still unknown. In their study, Adams et al. (2017) found that practitioners found circular tools for design are seen as a high priority to guide CE innovations within the construction industry. Wong et al. (2024) concluded that there are tools that possess the ability to assess the performance of the CE; however, they also stated that there is little use of them and a lack of developed circular-specific tools for CE-focussed design, collaboration, information management, and the assessment of circular metrics.

P39: Cost Modelling Tools

Ababio and Lu (2023) discussed the need for tools to understand the financial implications of circular methods and materials to reinforce the benefit to specific stages or the lifecycle as a whole. Kręt-Grześkowiak and Baborska-Narożny (2023) noted life cycle costing as a form of assessment but did not discuss its applications. Marey et al. (2024) proposed that circular tools would not only help with the selection of circular materials and systems but also with the selection of cost-effective items. Medina et al. (2021) recommended developing a circular tool that can holistically assess the building lifecycle to oversee opportunities for cost savings as well as connections with supply chains and secondary markets to reuse and recycle elements of the building. Litleskare and Wuyts (2023) discussed the costs of demolition contractors when assessing structures for valuable materials, stating that the cost analysis performed on the structure can provide a model to reclaim the value of existing structures. It suggests that if cost modelling tools were provided from the design stage, the cost to deconstruction contractors would be minimised.

P40: Collaboration Tools

Ababio et al. (2023) proposed using circular procurement as a tool for collaboration in the lifecycle between contractors, designers, stakeholders, and regulators. Köhler et al. (2022) developed a collaboration framework to contextualise the benefit of collaboration when innovating towards the CE. The relationships within the framework proposed collaborations within the construction industry for knowledge sharing, fostering relationships to complement resources and capabilities, and effective governance of the sector (Köhler et al., 2022). All of which aim to establish collaborative open innovations and dynamic capabilities when transitioning towards the CE (Köhler et al., 2022). Perotti et al. (2023) discussed the commonality within the literature towards the use of digital platforms for the collection of data, communication among stakeholders, and the resulting collaboration of the centralised environment. Cerdá-Suárez et al. (2023) proposed platforms and centralised information as a tool for collaboration between stakeholders within the construction industry to increase the application and performance of the CE. Marzouk et al. (2019) proposed the use of BIM as a collaborative platform for stakeholders, designers, and contractors to inform and communicate their decisions as well as to record the as-built performance of the building.

P41: Material Passports (MP)

Benachio et al. (2020) discussed MPs as a tool that can store important data on building materials and components for the transition from the design stages through to their end-of-life stage to ensure circular practices are applied. Ababio et al. (2023) stated that MPs are a useful tool that enables information continuity and integration along the lifecycle and its infrastructure. Kręt-Grześkowiak and Baborska-Narożny (2023) suggested the use of MPs and BIM to transfer knowledge on the designed circular strategy for materials and components from the design and construction stages to the operational and deconstruction stages for long-term applications of the CE. Fernandes and Ferrão (2023) address the link between BIM and MPs as a tool for storing material data and the circular practices for reuse and recycling to facilitate the CE in the end-of-life stage. Fernandes and Ferrão (2023) also noted their importance for developing databases on building materials and components for the future of the CE in the construction industry. Giorgi et al. (2022) proposed that MPs should be mandatory within the construction industry to inform practitioners and private owners of the composition of their structure and the potential circular applications. Furthermore, Giorgi et al. (2022) suggested that the link between MPs and BIM could develop detailed systems and databases that can store material information to encourage the flow of knowledge on a large scale for better asset management. Wong et al.'s (2024) study on circularity assessments within case studies found that MPs are included in some pioneering projects. However, the benefits of MPs are yet to be fully investigated within practice.

P42: Information Management and Transparency

Guerra et al. (2021) stated that information management and transparent data are key enablers of making informed decisions when applying the CE to the construction industry. Bao et al. (2019) discussed a lack of transparent information for the client as a leading barrier to their decision-making surrounding the incorporation of CE practices within their projects. Ababio and Lu (2023) found that information and collaboration lead to transparency between organisations within the construction supply chain, which was identified as a key enabler of the CE. In another study, Ababio et al. (2023) found that transparency is a key indicator for the development of circular procurement, and it relies on information, documentation, and the sharing of knowledge. Litleskare and Wuyts (2023) found that there is insufficient infrastructure for the collection and transfer of information within the construction industry to correctly govern the transition to a CE. Therefore, they suggest implementing standards and rules for collaboration, the exchange of information, and the tracking of data to improve transparency. Similarly, Köhler et al. (2022) proposed that governance of the construction industry requires freedom to access information within the supply chain and wider industry to innovate and allow transparent information to flow to the most valuable actors.

P43: New Secondary Material Developments

Domenech et al. (2019) proposed innovation within the secondary market to increase the quality of products and concurrently increase the economic strength of the secondary materials market. Perotti et al. (2023) discussed the recovery of materials that can be converted into raw materials, which can then be processed into secondary goods. Such materials as plastic are already known to be recycled, which allows the construction industry to learn from manufacturing and innovate the process for the construction industry. Amarasinghe et al. (2024) proposed innovating the secondary materials industry with quality standards to provide assurances to the construction industry as to their performance. Adams et al. (2017) proposed innovating secondary materials through assurance schemes, incentives to innovate, and the development of higher-quality materials from the secondary market to increase their utilisation within the construction industry. In their developed CE calculator, Medina et al. (2021) identified the reuse of secondary materials as a positive scoring factor. From this, Medina et al. (2021) identified concrete, steel, and granite as circular materials fit to become secondary products.

P44: Digitalisation

Amarasinghe et al. (2024) discussed the use of digitalised technologies that can be integrated within the construction industry lifecycle to manage and inform circular practices and their performances. Such technologies include BIM, material banks, material passports, and blockchain technology to track, store, utilise and manage material data for the circular construction industry. Litleskare and Wuyts (2023) discussed the use of BIM, material banks, and data collection of both waste and design/construction processes to inform future designs and to increase the industry's understanding of the reuse and recycling potentials of building stocks. Marzouk et al. (2019) stated that digital information held within documents or BIM models is essential for the correct deconstruction of structures in their end-of-life stage. Zu Castell-Rüdenhausen et al. (2021) proposed that digitalisation is a key enabling factor of the CE once stakeholders accept it within their practice to trace materials, store information in a central system, and understand the flow of waste and how to treat it. Wong et al. (2024)

discussed the use of digital technologies to track operational performances (e.g. water, energy) of buildings to achieve metrics within sustainability frameworks such as BREEAM. In their study, Perotti et al. (2023) found that 14 out of 16 organisations that were investigated contributed digital technologies as a significant factor in their successes when applying the CE. Such digitalisation included cloud systems, information sharing, centralised planning, the IoT, and blockchain.

P45: IoT

Guerra and Leite (2021) state that IoT provides a database for material tracking, traceability, and information management. The IoT can provide a database of material and component circularity performances for the design of buildings and systems (Çetin et al., 2021). Çetin et al. (2021) discussed IoT as an enabling technology that can assist service systems and maintenance by providing a database of material and component information. Furthermore, IoT technology can be linked with blockchain technology to track materials and components throughout the lifecycle (Çetin et al., 2021). Additionally, tracking technologies such as material passports can be linked to the IoT to make information readily available to practitioners (Çetin et al., 2021). Çetin et al. (2021) suggested that IoT can provide a much-needed platform to enable other practices of the CE within the construction industry and simplify the analysis of information. Perotti et al. (2023) proposed IoT as a tool to improve supply chain communication and coordination through information sharing and data collection.

P46: Blockchain

Çimen (2021) proposed that blockchain could benefit the construction industry's ability to manage and track materials. Çetin et al. (2021) discussed the benefits of blockchain technology when working with complex supply chains to trace material information and potential material passports. Ababio et al. (2023) discussed the use of blockchain to manage access to information and the flow of materials throughout the lifecycle.

Table 3.2: References associated with the practices of the CE

Theme	Sub-Theme (Practices)	Source
Economic	Design for Closed Loops	Ababio and Lu (2023), Ababio et al. (2023), Abadi et al. (2021), Adams et al. (2017), Amarasinghe et al. (2024), Asante et al. (2022), Benachio et al. (2020), Cerdá-Suárez et al. (2023), Çetin et al. (2021), Christensen et al. (2022), Çimen (2021), Çimen (2023), De Silva et al. (2023), Eray et al. (2019), Finch et al. (2021), Gálvez-Martos et al. (2018), Ginga et al. (2020), Guerra and Leite (2021), Guerra et al. (2021), Hossain et al. (2020), Incelli et al. (2023), Iyer-Raniga et al. (2023), Köhler et al. (2022), Tokazhanov et al. (2022), Torgautov et al. (2022), Tosi et al. (2024), Zhuang et al. (2023), Zu Castell-Rüdenhausen et al. (2021)
	Design for Longevity	Ababio et al. (2023), Abadi et al. (2021), Benachio et al. (2020), Cerdá-Suárez et al. (2023), Çetin et al. (2021), Eberhardt et al. (2022), Eray et al. (2019), Finch et al. (2021), Ginga et al. (2020), Guerra and Leite (2021), Guerra et al. (2021), Hossain et al. (2020), Joensuu et al. (2020), Kręt-Grześkowiak and Baborska-Narożny (2023), Marzouk et al. (2019), Medina et al. (2021), Papamichael et al. (2023), Perotti et al. (2023), Tokazhanov et al. (2022), Wong et al. (2024), Wuni and Shen (2022)
	Design for Disassembly	Ababio and Lu (2023), Abadi et al. (2021), Adams et al. (2017), Amarasinghe et al. (2024), Asante et al. (2022), Benachio et al. (2020), Çimen (2021), Condotta and Zatta (2021), De Silva et al. (2023), Eberhardt et al. (2022), Eray et al. (2019), Fernandes and Ferrão (2023), Finch et al. (2021), Guerra and Leite (2021), Hossain et al. (2020), Incelli et al. (2023), Joensuu et al. (2020), Kręt-Grześkowiak and Baborska-Narożny (2023), Marzouk et al. (2019), Papamichael et al. (2023), Quashie et al. (2024), Wong et al. (2024), Zhuang et al. (2023)
	Closed-loop Material Specification	Ababio et al. (2023), Abadi et al. (2021), Adams et al. (2017), Amarasinghe et al. (2024), Appendino et al. (2021), Asante et al. (2022), Benachio et al. (2020), Bherwani et al. (2022), Cerdá-Suárez et al. (2023), Çetin et al. (2021), Çimen (2021), Eberhardt et al. (2022), Fernandes and Ferrão (2023), Finch et al. (2021), Gálvez-Martos et al. (2018), Ginga et al. (2020), Guerra and Leite (2021), Guerra et al. (2021), Incelli et al. (2023), Jahan et al. (2022), Kręt-Grześkowiak and Baborska-Narożny (2023), Maher et al. (2023), Marey et al. (2024)
	Reduced Operational Impact	Abadi et al. (2021), Appendino et al. (2021), Bherwani et al. (2022), Çetin et al. (2021), Çimen (2021), Eberhardt et al. (2022), Han et al. (2024), Joensuu et al. (2020), Perotti et al. (2023), Tokazhanov et al. (2022)

	Servitisation/PSS	Ababio et al. (2023), Azcárate-Aguerre et al. (2018), Benachio et al. (2020), Cerdá-Suárez et al. (2023), Çimen (2021), Giorgi et al. (2022), Guerra et al. (2021), Hossain et al. (2020), Joensuu et al. (2020), Medina et al. (2021), Ploeger et al. (2019), Tokazhanov et al. (2022), Wong et al. (2024), Zhuang et al. (2023)
	Take-Back Systems	Ababio et al. (2023), Adams et al. (2017), Joensuu et al. (2020), Perotti et al. (2023), Ploeger et al. (2019)
	Recovery and Reuse Infrastructure	Ababio et al. (2023), Alite et al. (2023), Amarasinghe et al. (2024a), Cheng et al. (2023), Fernandes and Ferrão (2023), Gálvez-Martos et al. (2018), Joensuu et al. (2020), Litleskare and Wuyts (2023), Maher et al. (2023), Ramos et al. (2023), Shooshtarian et al. (2022), Torgautov et al. (2022), Williams (2021)
	Standardisation	Adams et al. (2017), Asante et al. (2022), Eberhardt et al. (2022), Fernandes and Ferrão (2023), Guerra et al. (2021), Hossain et al. (2020), Kręt-Grześkowiak and Baborska-Narożny (2023), Marzouk et al. (2019), Tokazhanov et al. (2022)
	Prefabrication	Amarasinghe et al. (2024), Amarasinghe et al. (2024a), Appendino et al. (2021), Eberhardt et al. (2022), Finch et al. (2021), Gálvez-Martos et al. (2018), Guerra et al. (2021), Hossain et al. (2020), Jahan et al. (2022), Tokazhanov et al. (2022), Torgautov et al. (2022), Wong et al. (2024)
	Modularisation	Adams et al. (2017), Amarasinghe et al. (2024), Benachio et al. (2020), Bherwani et al. (2022), Çimen (2021), Eberhardt et al. (2022), Finch et al. (2021), Hossain et al. (2020), Incelli et al. (2023), Medina et al. (2021), Tokazhanov et al. (2022), Torgautov et al. (2022), Zu Castell-Rüdenhausen et al. (2021), Wuni and Shen (2022)
	Waste Management	Abadi et al. (2021), Amarasinghe et al. (2024), Çimen (2021), Condotta and Zatta (2021), Fonseca et al. (2023), Gálvez-Martos et al. (2018), Hossain et al. (2020), Marey et al. (2024), Papamichael et al. (2023), Shooshtarian et al. (2022), Torgautov et al. (2022), Zu Castell-Rüdenhausen et al. (2021)
	Upcycling/Downcycling	Ababio et al. (2023), De Silva et al. (2023), Guerra et al. (2021), Hossain et al. (2020), Medina et al. (2021), Perotti et al. (2023)
	Urban Mining	Arora et al. (2020), Çetin et al. (2021), Condotta and Zatta (2021), Giorgi et al. (2022), Joensuu et al. (2020), Williams (2021)
	Financial Support	Adams et al. (2017), Azcárate-Aguerre et al. (2018), Christensen et al. (2022), Fernandes and Ferrão (2023), Hassan et al. (2023), Huang et al. (2018), Iyer-Raniga et al. (2023), Litleskare and Wuyts (2023), Maher et al. (2023), Shooshtarian et al. (2022)

Institutional	Laws and Regulations	Ababio and Lu (2023), Cheng et al. (2023), Gembali et al. (2024), Han et al. (2024), Iyer-Raniga et al. (2023), Köhler et al. (2022), Maher et al. (2023), Shooshtarian et al. (2022), Zu Castell-Rüdenhausen et al. (2021)
	Taxation	Amarasinghe et al. (2024a), Appendino et al. (2021), Fernandes and Ferrão (2023), Gálvez-Martos et al. (2018), Huang et al. (2018), Joensuu et al. (2020), Shooshtarian et al. (2022), Sinoh et al. (2023), Torgautov et al. (2022), Zu Castell-Rüdenhausen et al. (2021)
	Goals and Targets	Ababio and Lu (2023), Ababio et al. (2023), Gembali et al. (2024), Han et al. (2024), Iyer-Raniga et al. (2023), Papamichael et al. (2023), Shooshtarian et al. (2022), Torgautov et al. (2022), Zu Castell-Rüdenhausen et al. (2021)
	Supervision	Huang et al. (2018)
	Incentives	Adams et al. (2017), Amarasinghe et al. (2024a), Huang et al. (2018), Iyer-Raniga et al. (2023), Köhler et al. (2022), Maher et al. (2023)
	Circular Procurement	Ababio and Lu (2023), Ababio et al. (2023), Adams et al. (2017), Bao et al. (2019), Jahan et al. (2022), Maher et al. (2023), Torgautov et al. (2022), Wuni (2023), Zu Castell-Rüdenhausen et al. (2021)
	Frameworks/Business Models	Hossain et al. (2020), Medina et al. (2021), Ramos et al. (2023), Wong et al. (2024)
	Top-down/Bottom-up Management	Ababio and Lu (2023), Huang et al. (2018), Joensuu et al. (2020), Sinoh et al. (2023)
	Material Standards/Classification	Ababio and Lu (2023), Alite et al. (2023), Appendino et al. (2021), Fonseca et al. (2023), Gálvez-Martos et al. (2018), Huang et al. (2018), Jahan et al. (2022), Joensuu et al. (2020), Litleskare and Wuyts (2023), Maher et al. (2023), Marey et al. (2024), Wong et al. (2024)
	The 3-12Rs of the Circular Economy	Ababio et al. (2023), Asante et al. (2022), De Silva et al. (2023), Gembali et al. (2024), Hassan et al. (2023), Papamichael et al. (2023)
	The Lean Philosophy	Ababio et al. (2023), Kręt-Grześkowiak and Baborska-Narożny (2023), Maher et al. (2023), Marzouk et al. (2019), Perotti et al. (2023), Quashie et al. (2024), Wuni and Shen (2022)
Social-Cultural	Integrated Project Delivery (IPD)	Ababio and Lu (2023), Çetin et al. (2021), Giorgi et al. (2022), Joensuu et al. (2020), Maher et al. (2023), Perotti et al. (2023), Quashie et al. (2024), Shooshtarian et al. (2022), Sinoh et al. (2023), Tosi et al. (2024), Wuni and Shen (2022)

	Extended Responsibilities	Fernandes and Ferrão (2023), Fonseca et al. (2023), Gembali et al. (2024), Shooshtarian et al. (2022)
	Marketing and Awareness of the CE	Ababio and Lu (2023), Adams et al. (2017), Amarasinghe et al. (2024), Hassan et al. (2023), Maher et al. (2023), Medina et al. (2021)
	Knowledge Management and Education	Ababio and Lu (2023), Guerra et al. (2021), Jahan et al. (2022), Joensuu et al. (2020), Köhler et al. (2022), Torgautov et al. (2022), Wuni and Shen (2022)
	Establishing Communication and Information Sharing	Ababio et al. (2023), Çetin et al. (2021), Eray et al. (2019), Giorgi et al. (2022), Köhler et al. (2022), Marzouk et al. (2019), Perotti et al. (2023), Torgautov et al. (2022), Wuni and Shen (2022)
	Understanding the Product, Process, and Consumer	Ababio and Lu (2023), Ababio et al. (2023), Medina et al. (2021)
	R&D	Ababio and Lu (2023), Adams et al. (2017), Amarasinghe et al. (2024), Guerra and Leite (2021), Medina et al. (2021), Tokazhanov et al. (2022)
Technological	Lack of Life Cycle Analysis (LCA) and Benchmarking	Çimen (2023), Fernandes and Ferrão (2023), Foster et al. (2020), Han et al. (2024), Joensuu et al. (2020), Kręt-Grześkowiak and Baborska-Narożny (2023), Quashie et al. (2024), Benachio et al. (2020), Sinoh et al. (2023), Ababio and Lu (2023), Abadi et al. (2021), Cheng et al. (2023), Esguícero et al. (2021), Quashie et al. (2024), Wong et al. (2024)
	Data Collection and Communication	Ababio and Lu (2023), Condotta and Zatta (2021), Han et al. (2024), Joensuu et al. (2020), Zhuang et al. (2023)
	Case Studies	Adams et al. (2017), Shooshtarian et al. (2022)
	BIM(BIM)	Çetin et al. (2021), Çimen (2021), Çimen (2023), Fernandes and Ferrão (2023), Giorgi et al. (2022), Han et al. (2024), Jahan et al. (2022), Kręt-Grześkowiak and Baborska-Narożny (2023), Marzouk et al. (2019), Medina et al. (2021), Torgautov et al. (2022)
	Circularity Tools	Ababio and Lu (2023), Adams et al. (2017), Benachio et al. (2020), Çimen (2021), De Silva et al. (2023), Finch et al. (2021), Kręt-Grześkowiak and Baborska-Narożny (2023), Litleskare and Wuyts (2023), Marey et al. (2024), Medina et al. (2021), Perotti et al. (2023), Tokazhanov et al. (2022), Wong et al. (2024)

	Cost Modelling Tools	Ababio and Lu (2023), Kręt-Grześkowiak and Baborska-Narożny (2023), Litleskare and Wuyts (2023), Marey et al. (2024), Medina et al. (2021)
	Collaboration Tools	Ababio et al. (2023), Cerdá-Suárez et al. (2023), Köhler et al. (2022), Marzouk et al. (2019), Perotti et al. (2023)
	Material Passports	Ababio et al. (2023), Benachio et al. (2020), Fernandes and Ferrão (2023), Giorgi et al. (2022), Kręt-Grześkowiak and Baborska-Narożny (2023), Tokazhanov et al. (2022), Wong et al. (2024)
	Information Management and Transparency	Ababio and Lu (2023), Ababio et al. (2023), Bao et al. (2019), Çetin et al. (2021), Guerra et al. (2021), Köhler et al. (2022), Litleskare and Wuyts (2023), Marzouk et al. (2019), Wuni and Shen (2022)
	New Secondary Material Developments	Adams et al. (2017), Amarasinghe et al. (2024), Domenech et al. (2019), Medina et al. (2021), Perotti et al. (2023), Shooshtarian et al. (2022), Zu Castell-Rüdenhausen et al. (2021)
	Digitalisation	Amarasinghe et al. (2024), Litleskare and Wuyts (2023), Marzouk et al. (2019), Perotti et al. (2023), Wong et al. (2024), Zu Castell-Rüdenhausen et al. (2021)
	IoT (IoT)	Perotti et al. (2023), Çetin et al. (2021), Guerra and Leite (2021)
	Blockchain	Ababio et al. (2023), Çetin et al. (2021)

3.6 Barriers

This section looks at the barriers to the CE that have been identified within the literature. Overall, 48 barriers were identified within the literature within 4 themes: economic, institutional, social-cultural, and technological (Appendix A.3).

3.6.1 Global Theme 1: Economic

The CE is primarily an economic model used to improve value generation from the original input of resources. In this section, the barriers associated with the economy will be reviewed.

B1: The complexity of construction

Adams et al. (2017) found that the design and composition of buildings are a leading barrier to the implementation of the CE due to its complexity. Mahpour (2018) found that buildings are inherently complex, which poses a barrier to the application of strategies, especially those like the CE, which impact both the physical structure and the management of the industry. Charef et al. (2021) discuss building complexity as a barrier to a CE in multiple contexts. Initially, the unique nature of each project produces a level of complexity that cannot be fully replicated. Secondly, the incorporation of new secondary materials creates a secondary level of complexity due to their novel and unique performances. Finally, the replacement of materials during the operational lifecycle would require consistent updating of the building's information to ensure that the materials are maintained and used at their highest utility. In their later paper, Charef et al. (2022) discussed the complexity of a building in comparison to a manufactured product. Stating that the buildings consist of multiple products that each have different lifespans creates complexity within the industry. However, Charef et al. (2022) suggest that it is a potential benefit to view a building as a set of different but associated systems that can be individually managed with suppliers over the lifecycle.

Munaro and Tavares (2023) found that the construction industry is complex in several ways that pose barriers to a CE. Firstly, the materials used within buildings are required to perform in multiple ways compared to those of individual manufactured products (e.g. thermally, structurally, acoustically, etc). Secondly, throughout the lifecycle, a building will require maintenance, which changes the consistency of the structure and its overall performance. And finally, the complexity of the supply chain, which utilises multiple manufacturing supply chains for the compilation of materials into one building or structure. All of these factors create a complex dynamic within the construction industry, posing a barrier to the development of a CE.

B2: Profitable linear market

Huang et al. (2018) discussed multiple barriers related to the profitability of linear methods over the CE counterparts. Mainly, due to the underdevelopment of the CE, which limits the financial benefits of transitioning from wasteful linear methods (Huang *et al.*, 2018). In their analysis of case studies, Campbell-Johnston et al. (2019) discussed the barrier as a linear 'lock-in'. Campbell-Johnston et al. (2019) categorised the profitability of the linear market as a cultural barrier that overlaps with regulations and business models. The ease and simplicity of linear methods 'lock-in' traditional practices and make CE practices unfeasible for practitioners (Adabre *et al.*, 2023). Liu et al. (2021) discussed a multitude of barriers that ultimately make linear methods more profitable, such as high recycling costs, low disposal costs, and an immature market for recovery and reuse. Luciano et al. (2022) also identified the differences in cost for the linear and CE methods of waste management as a leading barrier. Stating that waste diversion is more expensive and intensive than linear methods of disposal (Luciano *et al.*, 2022).

Mignacca and Locatelli (2021) discussed the use of economics as a business driver and that the CE option may not be the cost-effective choice at present, posing a barrier to the CE's development. Additionally, Gue et al. (2020) proposed that in order to drive the CE within the construction industry, linear methods and materials need to be equal to or less than the CE market. At present, the linear market is far superior and therefore, the CE and secondary market cannot compete (Gue *et al.*, 2020). Furthermore, Ababio and Lu (2023) found that the raw material market and linear methods of wasting materials vastly outperform that of the secondary market and CE. Due to the profitability of the linear market, the circular market will consistently face market-based barriers (Ababio and Lu, 2023). Wuni (2023) also discussed the impact of familiarity with linear profit as a barrier to a CE, as companies are "entrenched" in cheaper linear practices.

B3: The stigma surrounding secondary materials

Densley Tingley et al. (2017) identified a stigma surrounding secondary and recovered materials, as well as the need for performance guarantees. Wu et al. (2019) found that participants had concerns regarding the cost of secondary materials and the information provided about their performances, leading to a perception barrier within the construction industry. Akinade et al. (2020) found that there was a negative perception of secondary materials amongst participants. This could be due to a lack of standards or information about products (Akinade *et al.*, 2020). Rakhshan et al. (2020) found that participants had a negative perception towards the performances and quality of secondary materials. Wuni (2022) found that participants have a perception that secondary materials and products are of poor quality and value. Additionally, by providing examples and information, practitioners and clients can be reassured to overcome the perception barrier.

B4: Lack of short-term benefits

Wu et al. (2019) found that a lack of short-term benefits poses a severe barrier to a CE as there is little incentive for organisations to transition. Especially, organisations that work within the short term, such as SMEs (Wu *et al.*, 2019). Akinade et al. (2020) discussed the long-term nature of the CE, posing a barrier to the design stage, as there are few benefits for the extra time and consideration committed by the organisation. Furthermore, the durability of construction projects and materials means that standards and methods will have changed once the components reach their end-of-life stage (Akinade *et al.*, 2020). Wuni (2022) found that participants' perceptions were split when ranking a lack of short-term benefits as a barrier. Some found the CE had few unjustifiable short-term economic benefits; the barrier did not impact those who benefited from long-term strategies. However, participants who worked within the short term saw it as a core barrier.

B5: Risk of innovating

Adams et al. (2017) noted the risks of organisations expanding into new sectors and the natural fear of the unknown that comes with new enterprises within business. Mahpour (2018) stated risk aversion as a barrier to a CE, as companies naturally try to avoid risk. Domenech et al. (2019) found that the risk associated with the CE was largely due to uncertainty and a lack of information. Similarly, Gillott et al. (2022) found that the uncertainty surrounding the CE and secondary materials plays a key role in creating risk, specifically, financial risk for organisations that pose barriers to CE development. Charef et al. (2021) found that deconstruction creates higher risks for companies compared to demolition, which poses a barrier to a CE. It can also increase the chances of health and safety risks due to potential contaminants within the materials (Charef *et al.*, 2021).

B6: Cost of innovating

Adams et al. (2017) found that the upfront cost was a leading barrier to a CE, and it could be offset by government support and the availability of loans to reduce the impact and risk of transitioning. Wuni (2022) found that the cost of innovating was ranked in the top quartile of barriers, and it presents a clear obstacle to organisations transitioning to a CE. Furthermore, Mahpour (2018) discussed the cost of innovation in terms of the cost to transition and the potential value from transitioning. Ababio and Lu (2023) found that the initial cost of innovation is too high compared to the perceived return on investment. Ding et al. (2023) found that the construction industry already struggles with financial barriers such as material, labour, and equipment costs, making CE funding more difficult. Luciano et al. (2022) found that the selective demolition is expensive and labour-intensive. Moreover, the additional costs for transportation and management mitigate potential financial benefits (Luciano *et al.*, 2022). Mhatre et al. (2023) state that organisations require capital for new technologies and mechanisms for the CE, as well as storage, labour, and equipment for operational management, all of which cost time and money with little proof of financial benefits. Rakhshan et al. (2020) state that there are additional costs for recovery due to longer and more selective methods of deconstruction, storage and processing of components, performance testing, and the cost of design incorporating reused components and materials. Munaro and Tavares (2023) have attributed three core costs to that of circular innovation. The cost of new technologies and methods, the cost of waste management, and the cost of developing certificates for secondary products (Munaro and Tavares, 2023). Overall, these costs pose a barrier to companies aspiring to transition to a CE, especially when coupled with the profitability of linear means (Munaro and Tavares, 2023). Charef et al. (2021) investigated the cost of innovation to the different stages of the lifecycle and found that designers are impacted the most by the cost of innovating. Construction professionals, however, face fewer costs and reap benefits from higher levels of waste management (Charef *et al.*, 2021). Charef et al. (2021) also found that clients are becoming concerned with the costs of increased waste management and regulations on-site. Akinade et al. (2020) found that in design, it is costly and time-consuming to apply the CE. Furthermore, the return on investment is limited for designers (Akinade *et al.*, 2020).

B7: High cost of secondary products

Wuni (2022) discusses the high cost of secondary and green products, posing a barrier to their use within the construction industry. Munaro and Tavares (2023) also discussed the cost of secondary products as a key barrier to the economic angle of the CE. Munaro and Tavares (2023) found that the cost of innovating secondary products increases the sale price, dissuading consumers from selecting secondary products based on their cost.

B8: Lack of infrastructure for recovery and reuse

Charef et al. (2021) identified a lack of infrastructure and recovery facilities within the construction industry, posing a barrier to a CE. Mahpour (2018) found that the current infrastructure for the recovery and reuse of materials is inadequate for the effective application of CE strategies. Furthermore, the lack of technology and knowledge of circular supply chains increases the difficulty of developing infrastructure to support the CE (Mahpour, 2018). Knoth et al. (2022) found that stakeholders view infrastructure as the key change required to enable the CE, but it is also a costly structure to change. Additionally, they stressed the lack and importance of knowledge and digital infrastructure to enable physical applications. Ding et al. (2023) found a lack of infrastructure as a leading barrier, specifically, the lack of storage, sorting, screening, crushing, and specialised methods. Oluleye et al. (2023) identified the lack of infrastructure and other related barriers as the most significant barriers to the development of the CE due to its enabling role within the supply chain.

B9: Lack of standardisation

Mahpour (2018) identified non-standardised practices as a key barrier to the CE within the construction industry. Mahpour (2018) proposed that waste reporting and CE practices should be standardised to mitigate barriers that stem from a complex and diverse range of materials and methods in the construction industry. Akinade et al. (2020) identified a lack of standardisation for recovered materials as a barrier for the CE within the construction industry. A lack of standardisation increases the complexity of the industry and hinders the categorisation of materials. Mhatre et al. (2023) identified a lack of standardisation for the CE in the design stage of construction projects as a leading barrier to the adoption of the CE within the construction industry. Additionally, Wuni (2022) identified a lack of standardisation in regulations and the recording of data as a barrier to the construction industry's transition to a CE. Moreover, Munaro and Tavares (2023) identified a lack of standardised reporting (i.e. EPDs) as a barrier to the implementation of the CE within the design stage. Furthermore, Munaro and Tavares (2023) discussed the lack of standardised geometries for products within the construction industry as a barrier to the implementation of the CE. The lack of standardised geometries creates more waste due to the trimming and adjustments of products, as well as an increased number of product types. Finally, AlJaber et al. (2023) identified a lack of standardisation as a barrier to the categorisation and creation of datasets for the CE in the construction industry. AlJaber et al. (2023) proposed the use of standardisation to simplify processes and record performances in construction to develop circular BIM tools and other data-driven technologies.

B10: Lack of time

Mahpour (2018) found that companies prioritise time and cost over waste management. Domenech et al. (2019) discussed time as a crucial barrier for companies to transition to a CE. The initial time required to alter the existing business model is the prime obstacle, followed by the continued time required to maintain the circular model (Domenech *et al.*, 2019). Akinade et al. (2020) found that the increase in time could mitigate potential financial benefits from incorporating the CE. Densley Tingley et al. (2017) discussed the dynamic between the selection of demolition or deconstruction. Densley Tingley et al. (2017) found that demolition is still favourable due to the time and concurrent cost savings, which pose a major barrier to organisations transitioning.

B11: Quality of secondary materials

In their study, Gillott et al. (2022) found that practitioners have concerns about material information, quantity, and quality regarding recovered materials and secondary products. Campbell-Johnston et al. (2019) discussed the quality of secondary materials in terms of two key themes of barriers, technological and financial. Firstly, Campbell-Johnston et al. (2019) investigate the quality of secondary materials, their source, availability, associated technologies, and the consistency of circular supply chains as opposed to their linear counterparts. Secondly, the financial barriers associated with the former are discussed and how each poses uncertainties and risks to businesses that create financial barriers and dissuade organisations from using new materials (Campbell-Johnston *et al.*, 2019). Charef et al. (2021) state that the material recovery and reuse are inconsistent in quality and supply to make consistent secondary products. Furthermore, in construction, the materials have a low value, which limits the financial business case for transitioning to a CE (Charef *et al.*, 2021). Akinade et al. (2020) discussed the relationship between the need for quality assurance and the market for recovered components. Without quality assurance and standards for secondary and recovered materials, there is a stigma and uncertainty amongst consumers that pose a barrier to the circular market (Akinade *et al.*, 2020).

B12: Lack of segregation

Mhatre et al. (2023) found that a lack of segregation poses a barrier to closing the loop and the secondary good market by limiting the ability to recover materials. Mhatre et al. (2023) identified several causes for the lack of segregation in the construction industry. Primarily, the extra costs incurred, the increased time for deconstruction, a lack of classification for segregation, and a lack of education or training.

B13: Low-value recovered materials

Adams et al. (2017) found that construction materials are primarily of low value in their end of life, and this poses a barrier to a CE. Adabre et al. (2023) also discussed the uncertainty of the value of materials and components when recovering or reusing them within the secondary market as a barrier to their application within the CE. Domenech et al. (2019) identified that the value generated by construction materials in their end-of-life phase was of low value and provided little incentive for organisations to recover or reuse them. Liu et al. (2021) state that construction materials have few applications in their end-of-life period, which poses a barrier to the application of the CE in construction.

B14: Immature secondary market

Adams et al. (2017) found that a lack of market mechanisms to enable the secondary market posed a barrier to organisations. Additionally, the lack of recovered materials is posing a barrier for the secondary materials market that relies on the supply of waste materials (Adams *et al.*, 2017). Moreover, addressing the volatility of the secondary market could overcome market barriers to the transition of the CE (Adams *et al.*, 2017). Adabre et al. (2023) found that the secondary market was immature, and therefore is volatile and risky, lacking support from governing bodies. Chen et al. (2022) also identified that although the secondary market is a driver for companies, it is immature and volatile, which deters investment. Similarly, the study conducted by Gue et al. (2020) identified barriers surrounding the supply/demand dynamic within the secondary market, which makes investment risky and sometimes futile. and macro levels, stemming from the interrelationships between organisations and countries. In their study, Wu et al. (2019) found that practitioners ranked an immature secondary market as a leading barrier to a CE. Rakhshan et al. (2020) found that market barriers are the most significant and that the lack of competitiveness with linear methods is a key challenge to developing a secondary market. Mignacca and Locatelli (2021) found that organisations face multiple barriers related to the secondary market and its instability or availability. In their analysis of case studies, Campbell-Johnston et al. (2019) found that a lack of secondary material markets and mechanisms in which to utilise the reuse of components posed a significant and consistent barrier to a CE. Campbell-Johnston et al. (2019) state that supporting the development of the secondary market is key to overcoming barriers to a CE.

B15: Lack of financial support

Adams et al. (2017) found that there is a lack of financial support or benefits to assist organisations in transitioning to a CE. Munaro and Tavares (2023) found that a lack of financial aid and assurances for innovations were among the most prevalent barriers to transitioning to a CE. Without a financial plan or assurances, organisations are open to various risks while innovating, dissuading them from employing a CE model. Mhatre et al. (2023) also discussed the financial burden of transitioning on organisations and discussed government support as a solution to entice the development of the CE. Mahpour (2018) focused on the government and policymakers when discussing financial support as a barrier. Stating that governments need to financially support the transition to act as a catalyst for the early development of the CE (Mahpour, 2018).

3.6.2 Global Theme 2: Institutional

Institutions are the backbone of the economy and society. Institutions are a major driving force for standards and change. In this section, the institutional barriers will be reviewed.

B16: Lack of supporting laws and legislation

Adabre et al. (2023) state that national laws pose a barrier to a CE as they still favour linear models. Furthermore, on the local level, regulations are determined by the local council, causing variations in practice and creating a barrier to national application. Gillott et al. (2022) found that a lack of regulation to track and manage waste was a key barrier to the CE and promoted linear methods. Mignacca and Locatelli (2021) also found that current regulations favour linear methods and hinder the repair and reuse of components. Furthermore, the current CE regulations, coupled with linear methods, create a complex environment for the reuse of materials and components (Mignacca and Locatelli, 2021). In Norway, Knoth et al. (2022) concluded that regulation is a key enabler for the CE, and the current lack of CE laws and legislation poses a significant barrier to the development of the CE. Furthermore, Cruz Rios et al. (2021) identified that current linear laws in the US hinder the repair and reuse industry by making the business case unfeasible in comparison to linear means.

Charef et al. (2021) found that there is a clear lack of regulations and supportive policies to develop and incorporate the CE into the construction industry. Ababio and Lu (2023) found that laws and legislation are a key enabler of the CE. However, the lack of supporting laws and legislation, as well as the inconsistency of CE laws, creates a barrier for CE development and application (Ababio and Lu, 2023). Gillott et al. (2022) also found that a lack of CE regulations poses a barrier to the application of the CE within the construction industry. Gillott et al. (2022) proposed the use of regulation to enforce material tracking and waste management. Adabre et al. (2023) found that there is a lack of national laws for the CE that poses a barrier to the application of the CE. Mahpour (2018) discussed the lack of supporting policies and laws for the CE as well as a lack of supervision that poses a barrier to its application. Mahpour (2018) stressed the need for stricter policies and mechanisms to monitor their application. Moreover, Liu et al. (2021) found that there is a lack of mature laws and legislation to support the CE. Moreover, Liu et al. (2021) found that laws and legislation are key for establishing quality within the secondary materials market. Mignacca and Locatelli (2021) found that the barriers caused by a lack of supporting laws and legislation affect the processes of policymakers and designers the most. The lack of laws and legislation for these early stages vastly limits the application of the CE within product development and use (Mignacca and Locatelli, 2021). Munaro and Tavares (2023) discussed the lack of regulatory instruments, taxes, and goals for the CE within policies and laws. Wuni (2022) identified that this lack of regulations and policies impacts the industry's mindset by inadvertently suggesting that the CE and waste management isn't important to policymakers, and it is therefore not an immediate problem.

B17: Lack of taxes (relief and penalties)

Gillott et al. (2022) stressed the importance of taxes to incentivise organisations. Moreover, they found that the linear structure of taxes hinders the CE and secondary market by making the circular model financially unfeasible. Adabre et al. (2023) discussed the role of taxes on the development of the CE and how a linear mindset to taxes can pose a barrier to a CE. Adabre et al. (2023) stated that there is a dynamic between taxes on virgin and secondary materials that creates a barrier for the CE. The low taxes on raw resources and the high taxes on secondary products cause an economic environment that is inhospitable to the development of a CE (Adabre *et al.*, 2023). Luciano et al. (2022) identified in their study of the Italian CE that the taxes on raw materials and their extraction are almost non-existent and are a key barrier to the secondary materials market. Secondary materials have a high processing cost and, therefore are more expensive than raw materials (Luciano *et al.*, 2022). This, coupled with low costs of raw materials, means that the secondary market isn't able to compete with the raw material market (Luciano *et al.*, 2022).

B18: Lack of goals and targets

Mahpour (2018) found that a lack of clear targets is causing a barrier due to the uncertainty that it instils within businesses, which demotivates organisations attempting to innovate. Ababio and Lu (2023) found that a lack of political and legislative targets poses serious barriers to a CE. This is due to the lack of guidance and targets it establishes within the construction industry, creating a distorted path of development (Ababio and Lu, 2023). Wuni (2022) found that a lack of national vision for the CE creates a significant barrier to the development of a circular culture and strategy within private corporations. Moreover, Ghisellini et al. (2018) found that China has achieved some success by establishing ambitious goals for the CE. However, within the construction industry, more goals and targets for the 3Rs are required to guide and inspire organisations (Ghisellini *et al.*, 2018). Furthermore, Huang et al. (2018) found that the targets set by the Chinese government focus more on treating waste as opposed to reducing and reusing resources, which is currently posing a barrier for the CE.

B19: Lack of supervision

Adabre et al. (2023) proposed supervision within the early stages of the project's design and specification to incorporate CE knowledge within the core of the project. Secondly, supervisors require training to guide and support regulatory development and to facilitate the inspection of its implementation. Overall, this could assist the development of the CE within the construction industry. Munaro and Tavares (2023) found that a lack of government supervision, experienced supervisors, and monitoring poses a barrier to monitoring the application of the CE. Liu et al. (2021) also suggested increasing supervision of waste management within the construction industry to 'crack down' on illegal behaviours and instil correct waste management. Furthermore, Ghisellini et al. (2018) looked at the use of supervision within prefabricated construction elements to implement quality standards as an example of its benefits for the application of the CE. They found that a lack of supervision poses a barrier to the enforcement of laws and the correct application of the CE in practice. Huang et al. (2018) proposed several steps to improve supervision: a top-down regulatory system by appointing a body to administer regulations, a process monitoring system to monitor resources throughout the lifecycle, and strict punishments for deviating from regulations and the illegal dumping of materials.

B20: Lack of incentives and penalties

Ababio and Lu (2023) found that current policies and regulations have a lack of incentives to drive organisations towards a circular business model. Liu et al. (2021) also found that there is a lack of incentives in governing policies and that current financial schemes would not facilitate long-term application of the CE. Adams et al. (2017) and AlJaber et al. (2023) proposed financial incentives to mitigate any increased costs to the design team. Munaro and Tavares (2023) discussed the link between a lack of incentives and the lack of end-of-life design, reuse, recovery, and the financial case of the secondary material market. Rakhshan et al. (2020) found that a lack of incentives, both regulatory and financial, poses a significant barrier to a CE. Wuni (2022) found several incentives and disincentives that are lacking within the construction industry, posing a barrier to a CE. Initially, incentives such as innovation funding, short-term benefits, and the availability of secondary materials are lacking (Wuni, 2022). Other dynamics disincentivise organisations, such as the low price of virgin resources, the low cost of linear methods of wasting materials, and the high cost of secondary materials (Wuni, 2022). Furthermore, in their study of stakeholder perspectives, Luciano et al. (2022) found that incentives would overcome several barriers to the application of the CE. Primarily, it would enable design for the CE and its lifecycle by mitigating constraints (Luciano *et al.*, 2022). Moreover, Mahpour (2018) found that a lack of incentives for organisations pushes companies to use more complicated methods, such as off-site sorting and recovery plants or linear methods, such as landfill.

B21: Lack of procurement strategy

Ababio and Lu (2023) identified current methods of procurement as a barrier to a CE due to the linear design of the processes. They also discuss the importance of procurement in developing a CE within private organisations, as the development of procurement for the CE could mitigate other barriers. Furthermore, they discuss the potential of innovative procurement methods to facilitate funding for the development and application of CE practices. Adabre et al. (2023) identified a lack of procurement within public projects as a barrier to a CE. The lack of CE procurement within public projects could further cause barriers to its adoption within the private sector due to a lack of examples. Liu et al. (2021) also found that CE procurement methods were scarce within public projects, limiting the number of successful examples available to guide the private sector. Wuni (2022) found that a lack of procurement methods and strategies was a key barrier to a CE within the construction industry. Moreover, in their study on stakeholder perception, Luciano et al. (2022) found that more CE procurement methods are required to improve the development of a CE within the construction industry.

B22: Lack of business models and frameworks

Ababio and Lu (2023) coalesced several barriers under the theme of frameworks. They identified a lack of holistic frameworks within the industry and a series of specific frameworks that lack coherence and consideration for other stages of the lifecycle or industrial sectors. Charef et al. (2021) identified a lack of common frameworks to simplify CE practices and considerations across the construction industry and construction industry. Furthermore, due to the lack of a common framework for the construction industry, studies aiming to understand and record CE approaches are not consistent with the overall holistic structure of the CE. In the Norwegian construction industry, Knoth et al. (2022) identified a lack of business and regulatory frameworks for the CE. Furthermore, participants found that a clear business framework and CE consultants would assist the transfer of knowledge within the construction industry. Additionally, a legal framework for the CE would mitigate barriers that stem from current regulations, which hinder the CE in practice and structure the procurement process.

B23: Lack of best practice

Charef et al. (2021) found that there is a lack of best practices for the application of the CE within the construction industry. However, Charef et al. (2021) stated that it was not due to best practices being non-existent but non-disclosed to other organisations and institutions. The lack of examples and sharing of best practice is therefore the true barrier to the establishment of CE best practice within the construction industry. Wuni (2022) discusses a significant gap between the theory of the CE and its practices and physical application which poses a barrier to the development of a CE within the construction industry. Additionally, Wuni (2022) discusses a lack of technological knowledge to implement best practices from the CE. Furthermore, Wuni (2022) identified a lack of best practices surrounding CE planning and procurement, which poses a barrier to the establishment of the CE within the construction industry. Knoth et al. (2022) found that there is no established best practice for the CE within the construction sector and that actors across the supply chain require more knowledge on practices for the CE. They proposed the development of case studies to understand the process and methods available for the CE to develop best practices for the recovery and reuse of buildings.

B24: Lack of government support

In their study, Adams et al. (2017) found that there is insufficient support from governments to spread awareness and incentivise the construction industry to develop a CE. Campbell-Johnston et al. (2019) found that there is a lack of government support to facilitate the development of the CE. The support proposed is in the form of financial, educational, regulatory, and in the form of CE infrastructure (Campbell-Johnston *et al.*, 2019). In China, Ghisellini et al. (2018) found that a lack of government support was a key barrier, along with regulatory supervision. Moreover, Huang et al. (2018) found that in China, there is a lack of regulation and policies for construction and demolition waste, which limits the available support for the CE. Wu et al. (2019) also found that China has a lack of government support caused by immature regulations and limited financial opportunities. In Norway, Knoth et al. (2022) found that there is a severe lack of regulation to support the CE within the construction sector. Also, Knoth et al. (2022) found that there is insufficient support from governments in the form of finances and subsidies for organisations transitioning to a CE.

B25: Lack of industry adoption

Liu et al. (2021) found that the construction industry has the most potential for the CE due to its socio-economic impacts and diverse use of materials. However, the construction industry has seen minimal adoption of the CE, which has limited its development. In China, Ghisellini et al. (2018) found that there is a lack of industry adoption of the CE within the construction industry. Specifically, the reduction of material consumption and waste during the construction stage. They found a general reluctance from industry when adopting environmental strategies such as the CE and waste management. Moreover, Ghisellini et al. (2018) found a clear correlation between the adoption of waste management practices and a reduction in the quantity of waste being sent to landfill.

3.6.3 Global Theme 3: Social-Cultural

The social-cultural environment within a business is a core aspect of how the business is managed and how decision-making is conducted. In order to implement change within the management of a business, significant social-cultural changes are required. In this section, the social-cultural barriers will be reviewed.

B26: Lack of Integrated Project Delivery (IPD)

Ababio and Lu (2023) found that a lack of integration and collaboration across the supply chain poses a significant barrier to a CE within the construction industry due to its complexity, diversity, policymaking, and education. Mahpour (2018) found that there is a lack of integration in terms of waste management strategies between the different lifecycle stages and throughout the levels of the hierarchy. The lack of integration within the supply chain reduces communication and collaboration and, therefore, reduces the chance of identifying CE opportunities, resulting in the use of linear methods. Wuni (2022) identified a lack of integration of the CE strategy within construction supply chains, which was exacerbated by the lack of communication between stakeholders. Ultimately, the lack of collaboration within the supply chain hinders the ability to develop industrial symbiosis and closed loops within supply chains (Adabre *et al.*, 2023). Moreover, integration between the stages of the construction industry is needed to implement circular design considerations, ensure its application within the construction process, transfer the strategy's information throughout the operational lifecycle, and inform deconstruction in the end-of-life stage. Munaro and Tavares (2023) also identified the need for a regulatory framework to integrate the CE within the construction industry. Rakhshan et al. (2020) proposed the integration of reuse and recovery practices into design codes and procurement routes to mitigate the barriers linked to integration and collaboration in later stages of the lifecycle.

B27: Lack of responsibility and recognition

Mahpour (2018) identified a lack of producer-based responsibility within the construction industry; however, it possessed a low priority compared to other barriers of the CE. Charef et al. (2021) identified a lack of responsibility among key players within the construction industry, especially among suppliers. Mhatre et al. (2023) found that the lack of responsibility within the supply chain is consistent with the lack of understanding surrounding the ownership of products and materials when subject to CE practices. On the other hand, Liu et al. (2021) discussed the dynamics surrounding the recovery and recycling of materials from the construction industry into the secondary market. Liu et al. (2021) state that the responsibility for facilitating the transfer of deconstructed material into the secondary good market is solely on demolition and waste management facilities. Cruz Rios et al. (2021) also identified a lack of responsibility as a barrier to the development of a CE. Participants in their study identified policymakers as the leading responsibility to enable the CE, followed by stakeholders within the supply chain.

B28: Lack of marketing and awareness of the CE

The study conducted by Adams et al. (2017) found that there is a general awareness of the CE but there is a lack of awareness of its practical application, especially among clients and designers. Charef and Emmitt (2021) found that increasing awareness among stakeholders is key to driving the development of the CE within private businesses. Additionally, Rakhshan et al. (2020) found that the reluctance within the construction industry could be in part due to the lack of awareness among stakeholders. Wuni (2022) found that there is a lack of awareness across stakeholders, construction supply chains, and the client base of the industry, which poses a significant barrier to the uptake of the CE. Ababio and Lu (2023) identified a lack of awareness as a leading barrier to the social-cultural aspect of the CE within the construction supply chain. Furthermore, Ababio and Lu (2023) suggested it is key for the stakeholders to have an awareness of the CE to enable its adoption within the industry. Mhatre et al. (2023) identified a lack of awareness among stakeholders, policymakers, and those who are decision makers in the industry, which limits the most impactful applications of the CE before work commences on site.

Munaro and Tavares (2023) identified that the lack of marketing for the CE and secondary materials is posing a significant barrier to a CE. This is due to the lack of awareness and stigmatisation of secondary goods, which limits the consumer's desire or perception of the CE (Munaro and Tavares, 2023). Wuni (2022) found that there are several barriers to the market of the CE. Initially, the lack of competition within the market for organisations to drive one another. Secondly, a lack of knowledge on the supply and demand of secondary materials and goods. Finally, the lack of established, regulated, and standardised secondary materials provides confidence among practitioners to the quality and performance of the products. Ding et al. (2023) found that a lack of marketing strategy, product development, and closed loops poses a barrier to a CE’s secondary material market. Ding et al. (2023) proposed improving marketing research and strategies to increase the awareness of the benefits of the secondary market.

B29: Lack of knowledge management and education

Adams et al. (2017) found that practitioners feel as though they lack the knowledge to apply the principles of the CE to their businesses, especially in SMEs. Adabre et al. (2023) found that there is a lack of knowledge on the CE amongst politicians and within industry on the technical applications of the CE and the quality of secondary materials that form a barrier to a CE.

Munaro and Tavares (2023) found that there is a lack of knowledge among policymakers and designers that is impeding design for deconstruction. Furthermore, a lack of knowledge sharing within the supply chain poses a further barrier to reducing the gap in knowledge. Campbell-Johnston et al. (2019) found that knowledge poses a significant barrier to the recovery and reuse of materials, and that consistent and comparable data is difficult to obtain. Furthermore, Campbell-Johnston et al. (2019) stated that the gap in knowledge prevents the effective application of the CE within the construction industry. Knoth et al. (2022) found that all participants identified a lack of knowledge as a barrier, especially architects, consultants, and public institutions. Shooshtarian et al. (2020) found that there is a lack of information among clients towards the CE, which is limiting its application within the construction industry. Furthermore, there is a lack of knowledge among the policymakers of Australia, limiting its inclusion within laws and legislation.

Ababio and Lu (2023) commented on the lack of education at the macro level as a barrier to organisations at the meso level who are willing or seeking to transition to a circular model. Ababio and Lu (2023) proposed that education is a critical activity to engage and unify the supply chain. Liu et al. (2021) found that a lack of education surrounding the CE and its application poses a barrier to collaboration, knowledge generation, and accessing circular markets. Rakhshan et al. (2020) proposed CE education for the stakeholders within the construction industry to increase the top-down push for its application within the industry and mitigate barriers that stem from a lack of stakeholder knowledge. Moreover, AlJaber et al. (2023) proposed the use of BIM as a supplement for the lack of knowledge and education within the construction industry towards the CE. Ultimately, Wu et al. (2019) found that the lack of education among stakeholders poses a barrier to innovation and adoption of the strategy.

B30: Lack of management

Mahpour (2018) identified several barriers surrounding the lack of management for the CE within the construction industry. Initially, a lack of guidance and regulation for managers to adhere to and apply to their practice. Secondly, a lack of supervision from regulatory bodies to ensure CE practices are conducted in accordance with best practice. Furthermore, a lack of knowledge among managers impedes their ability to apply the CE correctly and effectively. Additionally, a lack of management across the supply chain to integrate the CE in a holistic manner. And finally, a lack of willingness among managers to implement the CE due to a negative perception of its worth. Mahpour (2018) found that the barriers linked to management ranked highest in their study and are a key focus to improve the adoption and effectiveness of the CE strategy within the construction industry. Huang et al. (2018) also identified that a lack of management in the design stage was due to a lack of standardised regulations and practices for designers to adhere to. Furthermore, Mhatre et al. (2023) identified a lack of support from top management towards the adoption and implementation of the CE within the construction industry. AlJaber et al. (2023) identified a lack of knowledge among the managers of the construction industry, which poses a significant barrier to the application and supervision of the strategy.

B31: Lack of consumer demand

Akinade et al. (2020) found that the demand of consumers in the secondary materials and reuse markets is a complex dynamic. Furthermore, Mhatre et al. (2023) identified that consumers have negative perceptions of secondary or reused materials that stem from both irrational stigmas and experience with recovered goods. This is largely due to the supply as well as the demand from consumers, but is largely contributed to by the inconsistency of the supply of materials alongside the niche demands of consumers. Wuni (2022) identified two barriers linked to consumer demand. Initially, the uncertainty of the secondary market's supply and demand. Secondly, there is a lack of demand for environmental technologies within the construction industry. Adabre et al. (2023) found that policymakers and academics are required to stimulate the market and increase consumer demand through education and regulations. Oluleye et al. (2023) found that the lack of consumer demand is more prevalent in developing countries due to the commercial difference between cheaper virgin materials and costly secondary products.

Mhatre et al. (2023) found that consumers prefer to use virgin materials and new products due to their consistency and known performance. Adabre et al. (2023) found that consumers have a hesitancy towards new products and their performances, which contributes to their preference for virgin materials over secondary goods. Adabre et al. (2023) also suggested that a lack of knowledge, high levels of customisation, and the perceived low value of secondary products contribute to the consumer's demand for virgin materials. Wuni (2022) found that the client or consumer is often ignorant of the CE and its benefits and therefore rejects the strategy in favour of traditional materials and methods. Wuni (2022) discussed the business-as-usual mindset within the construction industry, which hinders the use of materials that are not widely known or used. Akinade et al. (2020) found that design guidance and codes often specify virgin materials, which limits the ability for the incorporation of secondary materials.

B32: Lack of R&D

Charef et al. (2021) found that the research on the CE within the construction industry is still in its infancy and requires academic interest to reduce the gap in research. Adams et al. (2017) found that there has been limited research conducted on the CE that is posing a barrier to the CE within the construction industry. More importantly, the lack of research is hindering the ability of designers to consider the CE, further delaying the application of the CE within the construction industry. Liu et al. (2021) found that there is a lack of research on the CE within the construction industry on plant and machinery for material recovery, new secondary materials, and construction and demolition waste management. Furthermore, there is a lack of research and innovation funding available. Ding et al. (2023) found that only a minuscule number of companies have invested in research and innovation to develop a CE. Therefore, there are only a few technologies that have been developed for the operational application of the CE. This is largely due to the lack of time and finances available to companies looking to transition to a circular model. Ababio and Lu (2023) found that the lack of R&D for the CE within the construction industry could be attributed to the upfront cost of innovation, which is also a barrier to the development of the CE.

3.6.4 Global Theme 4: Technological

Technology is a supporting factor in most modern businesses or industries. In this section, the barriers associated with technology will be reviewed.

B33: Lack of Life Cycle Analysis (LCA) and benchmarking

Wuni (2022) discussed the lack of benchmarking for the CE as a barrier to informed decision-making among managers of the construction industry who lack incentives and information on the CE in the construction industry. In Australia, Shooshtarian et al. (2020) discussed a lack of benchmarking as a barrier to the construction industry's development of a CE and to the improvement of the current performance of the industry. Oluleye et al. (2023) identified a lack of benchmarking in the construction industry for the CE as a barrier to understanding the current state of development and identifying key goals and targets to improve the performance of the strategy. Oluleye et al. (2023) found that benchmarking was a larger barrier to a CE within developing countries, suggesting a lack of availability or tools to benchmark. Furthermore, Oluleye et al. (2023) suggested that developing countries can outperform developing countries in their transition to a CE by benchmarking performances against more developed countries.

B34: Lack of material data

Wuni (2022) identified a lack of data on construction materials, products, and methods, along with a lack of transparency and standardisation of data. Wuni (2022) identified the lack of data as a key barrier to the identification of opportunities and the application of the CE. Furthermore, the lack of data exacerbates the barriers surrounding decision making among designers and stakeholders. Such a lack of data is a barrier to facilitating the CE (Munaro and Tavares, 2023). Munaro and Tavares (2023) also questioned the quality of the available data and proposed the development of datasets and tools to improve decision-making and the availability of data. Moreover, Gillott et al. (2022) discussed the lack of material data for existing structures in the urban stock, which poses a barrier to deconstruction and recovery of materials. Participants stated that there is not enough data and information on existing structures to selectively deconstruct buildings in line with the CE without incurring extra costs to collect the necessary information. Finally, Ababio and Lu (2023) identified a lack of material databases and information to inform decision-making and innovations within the construction industry for the CE. Mahpour (2018) found that data on materials and waste management were inaccessible or unique, mitigating the opportunity to learn and adapt from examples. Charef et al. (2021) identified a lack of material data as a leading barrier for the design and deconstruction stages, which require an in-depth knowledge of the building's constitution to employ considerations from the CE.

B35: Lack of case studies

Ababio and Lu (2023) identified a lack of ‘convincing’ case studies for the CE in the construction industry which is posing a barrier to the adoption of the CE. Ababio and Lu (2023) discussed the importance of case studies to improve the practical and financial case for the CE within the construction industry. Akinade et al. (2020) discussed the lack of case studies as a barrier in the context of the design for deconstruction. Akinade et al. (2020) found that the length of the lifecycle poses a significant barrier to the collection of data for the creation of case studies to inform the methodological and financial aspects of design for deconstruction. In the Norwegian construction and manufacturing sectors, Knoth et al. (2022) identified the demand for case studies to inform innovation and the application of the CE within the construction industry. In Australia, Shooshtarian et al. (2023) identified a lack of case studies and demonstrations as a barrier within the construction industry. However, participants ranked a lack of case studies as the least significant barrier compared to barriers such as incentives, regulations, knowledge, and collaboration.

B36: Lack of information

Akinade et al. (2020) identified a lack of information for circular design, disassembly, and the identification of recoverable materials. Charef et al. (2021) also identified a lack of information to inform circular design within construction. However, Charef et al. (2021) discussed the information barrier in a wider context, stating a lack of information management throughout the supply chain, which is hindering each stage by sustaining division within the lifecycle. Alternatively, Gillott et al. (2022) identified the lack of information for existing buildings to be disassembled and recovered within the CE, posing a barrier to its application. Wuni (2022) identified a lack of information towards construction materials, products, and services as well as a lack of information systems to track and trace materials for recycling. Luciano et al. (2022) identified a lack of information sharing throughout the lifecycle that presents a barrier to knowledge generation and informed decision-making. Munaro and Tavares (2023) identified a lack of information and an information management system, which is posing a barrier to the CE and collaboration within the lifecycle. AlJaber et al. (2023) identified a lack of information to apply circular design considerations to new buildings and for the recovery of materials from existing structures. Furthermore, AlJaber et al. (2023) identified a lack of systems to exchange data and information about the CE, proposing the incorporation of BIM technology to mitigate the barrier.

B37: Lack of circular tools

Akinade et al. (2020) discussed the lack of tools to identify materials in the end-of-life stage for their recovery and reuse within the CE. Adabre et al. (2023) discussed the lack of tools to forecast the end of life and the financial benefits of the CE. Mhatre et al. (2023) discussed the lack of circular tools as two barriers: a lack of circular tools available to assist the application of strategies and a lack of finances to source circular tools. Munaro and Tavares (2023) found that there is a lack of circular tools for the implementation and assessment of the CE within the construction industry. Furthermore, they discussed the lack of knowledge within the construction industry about the tools available.

In China, Wu et al. (2019) proposed the use of circular tools by governing bodies to incentivise organisations to implement the CE. Furthermore, in China, Ghisellini et al. (2018) proposed the use of circular tools to map and balance economic and environmental performances to assist decision-making within the construction industry and among legislators. Oluleye et al. (2023) discussed the infancy of circular tools for the management of resources within the construction industry. In their study, Oluleye et al. (2023) found little difference between developed and developing countries, which both ranked the lack of circular tools as a prime barrier, but not the most or least significant. Moreover, Oluleye et al. (2023) noted the lack of information for circular deconstruction as a significant barrier, adding to the requirement for circular management tools.

B38: Lack of design tools

Adams et al. (2017) identified a lack of design tools for the CE within the construction industry as a key barrier to the application of the CE. Moreover, Ababio and Lu (2023) discussed a lack of CE tools to inform the design and planning stages of the construction industry. Specifically, the need for information and communication systems to inform users of the designed strategy for the CE. Wuni (2022) identified a lack of circular design tools as a barrier to the implementation of CE strategies and frameworks. Oluleye et al. (2023) discussed the infancy of circular tools for the design of structures within the construction industry. Oluleye et al. (2023) found that the lack of design tools for the CE impacts developing countries more than developed countries. Akinade et al. (2020) also discussed the lack of CE tools for the prediction of end-of-life outcomes to improve the ability to design and plan for deconstruction. Moreover, Akinade et al. (2020) found that the design for deconstruction tools are not BIM compliant, limiting their use within the architectural profession.

B39: Lack of collaboration tools

Ababio and Lu (2023) discussed a lack of CE tools for the collection of information and communication throughout the lifecycle to increase the transfer of knowledge and the collection of data.

B40: Lack of material tracking

Wuni (2022) discussed a lack of material tracking for the recovery and reuse of materials within the construction industry. Wuni (2022) identified a lack of information systems to track materials as a prime barrier to the application of the CE. AlJaber et al. (2023) identified material tracking and traceability as a barrier to the CE within the construction industry. AlJaber et al.

(2023) proposed BIM as a solution to the difficulties of recording, tracking, and sharing information.

B41: Lack of transparency

Mhatre et al. (2023) and Wuni (2022) discussed the lack of transparency within the supply chain as a significant barrier to understanding the characteristics of the supply chain and quantifying the benefits of applying CE practices. AlJaber et al. (2023) proposed the use of BIM to mitigate the lack of transparency within the design, delivery, and operation of the building lifecycle. Wuni (2022) found that a lack of transparency and information sharing among stakeholders within the supply chain was an incremental barrier to applying the CE to the construction industry.

B42: Lack of material technology

Wuni (2022) identified several technological barriers to the recovery and reuse of materials. Initially, a lack of technology within the infrastructure for the construction industry to identify and extract materials from structures. Secondly, a lack of methods and equipment to recover materials and components to a good quality for their use within secondary materials. Finally, a lack of digital technology to track materials and inform decision-making. Additionally, Mhatre et al. (2023) identified a lack of technology within the construction supply chain to segregate and recover materials for use within the CE. Technologies proposed by Mhatre et al. (2023) include material testing, methods of deconstruction, and the reuse or recycling potential of materials and components. Moreover, Ding et al. (2023) identified a lack of technology surrounding methods of creating high-quality products from recovered materials to compete with virgin resources. At present, it is common to create aggregates from recovered materials, but organisations lack the technology to produce more complex products. Campbell-Johnston et al. (2019) identified a lack of technology to identify the quality of waste materials for their reuse or incorporation into secondary products. Densley Tingley et al. (2017) identified a lack of technology to identify the quantity, quality, and potential reuse of steel members.

B43: Lack of material classification

Akinade et al. (2020) discussed the lack of classification of raw and secondary materials as a barrier to the CE. 0Liu et al. (2021) found that organisations fail to classify their materials on site, which leads to mixed waste posing a barrier to recovery practices. Furthermore, Liu et al. (2021) discussed the lack of classification as a barrier to the deconstruction and recycling stages, which require information on the material's properties and its uses. Munaro and Tavares (2023) discussed the repercussions of unclassified materials on deconstruction companies, recovery facilities, and the secondary materials market.

Table 3.3: References associated with the barriers of the CE

Theme	Sub-Theme (Barriers)	Source
Economic	Complexity of Construction	Munaro and Tavares (2023), Oluleye et al. (2023), Charef et al. (2021), Adams et al. (2017), Gillott et al. (2022), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Charef et al. (2022), Densley Tingley et al. (2017), Charef and Emmitt (2021)
	Profitable Linear Market	Munaro and Tavares (2023), Oluleye et al. (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Charef et al. (2021), Huang et al. (2018), Luciano et al. (2022), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), Wuni (2022), Mignacca and Locatelli (2021), Campbell-Johnston et al. (2019)
	The Stigma Surrounding Secondary Materials	Cruz Rios et al. (2021), Rakhshan et al. (2020), Luciano et al. (2022), AlJaber et al. (2023), Wuni (2022), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020)
	Lack of Short-term Benefits	Wuni (2022), Wu et al. (2019), Akinade et al. (2020)
	Risk of Innovating	Ababio and Lu (2023), Adams et al. (2017), Gillott et al. (2022), AlJaber et al. (2023), Domenech et al. (2019), Mahpour (2018), Densley Tingley et al. (2017), Charef and Emmitt (2021), Knoth et al. (2022)
	Cost of Innovating	Munaro and Tavares (2023), Ding et al. (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Charef et al. (2021), Mhatre et al. (2023), Adams et al. (2017), Shooshtarian et al. (2023), Rakhshan et al. (2020), Luciano et al. (2022), Gillott et al. (2022), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), Domenech et al. (2019), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	High Cost of Secondary Products	Munaro and Tavares (2023)
	Lack of Infrastructure for Recovery and Reuse	Oluleye et al. (2023), Ding et al. (2023), Mhatre et al. (2023), Rakhshan et al. (2020), AlJaber et al. (2023), Domenech et al. (2019), Wuni (2022), Mignacca and Locatelli (2021), Mahpour (2018), Densley Tingley et al. (2017), Akinade et al. (2020), Charef and Emmitt (2021), Knoth et al. (2022)

	Lack of Standardisation	Munaro and Tavares (2023), Mhatre et al. (2023), Wuni (2022), Mahpour (2018), Akinade et al. (2020)
	Lack of Time	Cruz Rios et al. (2021), Shooshtarian et al. (2023), Liu et al. (2021), Domenech et al. (2019), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Wu et al. (2019), Akinade et al. (2020), Knoth et al. (2022)
	Quality of Secondary Materials	Charef et al. (2021), Gillott et al. (2022), Shooshtarian et al. (2020), Akinade et al. (2020), Campbell-Johnston et al. (2019)
	Lack of Segregation	Munaro and Tavares (2023), Mignacca and Locatelli (2021), Mahpour (2018), Akinade et al. (2020)
	Low value Recovered Materials	Adams et al. (2017), Liu et al. (2021), Adabre et al. (2023), Wuni (2022), Mignacca and Locatelli (2021), Shooshtarian et al. (2020)
	Immature Secondary Market	Munaro and Tavares (2023), Ababio and Lu (2023), Charef et al. (2021), Mhatre et al. (2023), Adams et al. (2017), Rakhshan et al. (2020), Huang et al. (2018), Luciano et al. (2022), Ghisellini et al. (2018), Adabre et al. (2023), AlJaber et al. (2023), Wuni (2022), Mignacca and Locatelli (2021), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	Lack of Financial Support	Munaro and Tavares (2023), Oluleye et al. (2023), Mhatre et al. (2023), Adams et al. (2017), Wuni (2022), Mahpour (2018), Wu et al. (2019), Campbell-Johnston et al. (2019), Knoth et al. (2022)
Institutional	Lack of Supporting Laws and Legislation	Cruz Rios et al. (2021), Gillott et al. (2022), Adabre et al. (2023), Mignacca and Locatelli (2021), Akinade et al. (2020), Knoth et al. (2022), Munaro and Tavares (2023), Oluleye et al. (2023), Ababio and Lu (2023), Charef et al. (2021), Mhatre et al. (2023), Shooshtarian et al. (2023), Huang et al. (2018), Luciano et al. (2022), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), Wuni (2022), Mignacca and Locatelli (2021), Mahpour (2018), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	Lack of Taxes (Relief and Penalties)	Luciano et al. (2022), Gillott et al. (2022), Adabre et al. (2023)
	Lack of Goals and Targets	Oluleye et al. (2023), Ababio and Lu (2023), Huang et al. (2018), Ghisellini et al. (2018), Wuni (2022), Mignacca and Locatelli (2021), Mahpour (2018), Densley Tingley et al. (2017)
	Lack of Supervision	Munaro and Tavares (2023), Huang et al. (2018), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), Wuni (2022), Wu et al. (2019)

	Lack of Incentives and Penalties	Munaro and Tavares (2023), Oluleye et al. (2023), Ababio and Lu (2023), Adams et al. (2017), Shooshtarian et al. (2023), Rakhshan et al. (2020), Luciano et al. (2022), Liu et al. (2021), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Akinade et al. (2020), Knoth et al. (2022)
	Lack of Procurement Strategy	Ababio and Lu (2023), Rakhshan et al. (2020), Luciano et al. (2022), Liu et al. (2021), Adabre et al. (2023), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Knoth et al. (2022)
	Lack of Frameworks/Business Models	Mhatre et al. (2023), Wuni (2022)
	Lack of Guidance and Best Practice	Charef et al. (2021), Wuni (2022), Charef and Emmitt (2021), Knoth et al. (2022)
	Lack of Government Support	Adams et al. (2017), Huang et al. (2018), Ghisellini et al. (2018), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	Lack of Industry Adoption	Ghisellini et al. (2018), Liu et al. (2021)
Social-Cultural	Lack of Integrated Project Delivery (IPD)	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Mhatre et al. (2023), Shooshtarian et al. (2023), Rakhshan et al. (2020), Adabre et al. (2023), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Knoth et al. (2022)
	Lack of Responsibility and Recognition	Cruz Rios et al. (2021), Mhatre et al. (2023), Liu et al. (2021), Wuni (2022), Mahpour (2018), Charef and Emmitt (2021), Knoth et al. (2022)
	Lack of Marketing and Awareness of the CE	Ababio and Lu (2023), Cruz Rios et al. (2021), Charef et al. (2021), Mhatre et al. (2023), Adams et al. (2017), Shooshtarian et al. (2023), Rakhshan et al. (2020), Ghisellini et al. (2018), Liu et al. (2021), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Charef and Emmitt (2021), Knoth et al. (2022), Ding et al. (2023), Wuni (2022), Densley Tingley et al. (2017)
	Lack of Knowledge and Education	Munaro and Tavares (2023), Ababio and Lu (2023), Cruz Rios et al. (2021), Charef et al. (2021), Mhatre et al. (2023), Adams et al. (2017), Shooshtarian et al. (2023), Rakhshan et al. (2020),

		Huang et al. (2018), Luciano et al. (2022), Charef and Emmitt (2021), Ghisellini et al. (2018), Adabre et al. (2023), AlJaber et al. (2023), Domenech et al. (2019), Wuni (2022), Mahpour (2018), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022), Oluleye et al. (2023), Ababio and Lu (2023), Charef et al. (2021), Rakhshan et al. (2020), Luciano et al. (2022), Liu et al. (2021), AlJaber et al. (2023), Wuni (2022), Mahpour (2018), Wu et al. (2019), Knoth et al. (2022)
	Lack of Management	Oluleye et al. (2023), Mhatre et al. (2023), Huang et al. (2018), AlJaber et al. (2023), Mahpour (2018)
	Lack of Consumer Demand	Oluleye et al. (2023), Cruz Rios et al. (2021), Charef et al. (2021), Mhatre et al. (2023), Adams et al. (2017), Adabre et al. (2023), Wuni (2022), Mahpour (2018), Akinade et al. (2020)
	Lack of R&D	Liu et al. (2021), Campbell-Johnston et al. (2019), Knoth et al. (2022)
Technological	Lack of Life Cycle Analysis (LCA) and Benchmarking	Oluleye et al. (2023), Adabre et al. (2023), Wuni (2022), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	Lack of Material Data	Munaro and Tavares (2023), Oluleye et al. (2023), Ababio and Lu (2023), Charef et al. (2021), Gillott et al. (2022), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), AlJaber et al. (2023), Domenech et al. (2019), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Akinade et al. (2020), Campbell-Johnston et al. (2019), Charef and Emmitt (2021)
	Lack of Case Studies	Ababio and Lu (2023), Shooshtarian et al. (2023), Akinade et al. (2020), Campbell-Johnston et al. (2019), Charef and Emmitt (2021), Knoth et al. (2022)
	Lack of Information	Munaro and Tavares (2023), Oluleye et al. (2023), Cruz Rios et al. (2021), Rakhshan et al. (2020), Luciano et al. (2022), Gillott et al. (2022), Ghisellini et al. (2018), AlJaber et al. (2023), Domenech et al. (2019), Wuni (2022), Akinade et al. (2020), Campbell-Johnston et al. (2019), Charef and Emmitt (2021)
	Lack of Circular Tools	Munaro and Tavares (2023), Oluleye et al. (2023), Ding et al. (2023), Ababio and Lu (2023), Mhatre et al. (2023), Ghisellini et al. (2018), Adabre et al. (2023), Wuni (2022), Mahpour (2018), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Campbell-Johnston et al. (2019), Knoth et al. (2022)
	Lack of Design Tools	Ababio and Lu (2023), Adams et al. (2017), Huang et al. (2018), Ghisellini et al. (2018), Liu et al. (2021), Adabre et al. (2023), Wuni (2022), Mahpour (2018), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Wu et al. (2019), Akinade et al. (2020), Knoth et al. (2022)

	Lack of Collaboration Tools	Ababio and Lu (2023)
	Lack of Material Tracking	Munaro and Tavares (2023), AlJaber et al. (2023), Wuni (2022), Densley Tingley et al. (2017), Charef and Emmitt (2021)
	Lack of Transparency	Cruz Rios et al. (2021), Mhatre et al. (2023), Rakhshan et al. (2020), AlJaber et al. (2023), Wuni (2022), Akinade et al. (2020), Charef and Emmitt (2021)
	Lack of Material Technology	Ding et al. (2023), Mhatre et al. (2023), Shooshtarian et al. (2023), Huang et al. (2018), Luciano et al. (2022), Liu et al. (2021), Domenech et al. (2019), Wuni (2022), Charef et al. (2022), Densley Tingley et al. (2017), Shooshtarian et al. (2020), Akinade et al. (2020), Campbell-Johnston et al. (2019), Charef and Emmitt (2021), Knoth et al. (2022)
	Lack of Material Classification	Munaro and Tavares (2023), Oluleye et al. (2023), Liu et al. (2021), AlJaber et al. (2023), Akinade et al. (2020)

3.7 Summary

The systematic review of business models and frameworks categorising the CE's DBPs identified 39 drivers, 46 practices, and 43 barriers. Some commonalities were identified between the DBPs. Some of the main commonalities were laws and legislation, taxes, case studies, IPD, LCA, BIM, circular tools, and procurement. This suggests that these areas are not yet developed within the construction industry, and their lack of, or improper development is causing a barrier to the overall development of the CE. For example, laws and legislation are a practice and a driver; however, a lack of laws and legislation is a barrier, suggesting that the current laws and legislation hinder the CE. This suggests that such commonalities between the DBPs are deficiencies in the development of the CE within the construction industry and therefore should be prioritised.

A key finding from the literature review was the lack of a consolidated taxonomy of the CE's DBPs. None of the reviewed journal articles contained a holistic account of either the drivers, practices, or barriers. Therefore, the literature review provided a comprehensive account of the CE's DBPs in the construction industry from the extant literature. The identified DBPs were developed into a holistic taxonomy (Figure 3.6) and categorised into the common themes previously identified within the literature (i.e. economic, institutional, socio-cultural, and technological).

Global Theme	No.	Practices	No.	Drivers	No.	Barriers
Economic	P1	Design for Closed Loops	D1	New Economic & Environmental Opportunities for Businesses	B1	Complexity of Construction
	P2	Design for Longevity	D2	Industrial Competition	B2	Profitable Linear Market
	P3	Design for Disassembly	D3	Secondary Material Production/Supply	B3	The Stigma Surrounding Secondary Materials
	P4	Closed-loop Material Specification	D4	Raw Material Volatility	B4	Lack of Short-term Benefits
	P5	Reduced Operational Impact	D5	Reduced Environmental Impact	B5	Risk of Innovating
	P6	Servitisation/PSS	D6	Servitisation/PSS	B6	Cost of Innovating
	P7	Take-Back Systems	D7	Take-back Schemes	B7	High Cost of Secondary Products
	P8	Recovery and Reuse Infrastructure	D8	Recovery and Reuse Infrastructure	B8	Lack of Infrastructure for Recovery and Reuse
	P9	Standardisation	D9	Standardisation	B9	Lack of Standardisation
	P10	Prefabrication	D10	Waste Reduction	B10	Lack of Time
	P11	Modularisation	D11	Cost and Time Efficiency	B11	Quality of Secondary Materials
	P12	Waste Management	D12	Improved Product Quality	B12	Lack of Segregation
	P13	Upcycling/Downcycling			B13	Low-value Recovered Materials
	P14	Urban Mining			B14	Immature Secondary Market
	P15	Financial Support			B15	Lack of Financial Support
Institutional	P16	Laws and Regulations	D13	Circular Laws and Legislation	B16	Lack of Supporting Laws and Legislation
	P17	Taxation	D14	Taxes (Relief and Penalties)	B17	Lack of Taxes (Relief and Penalties)
	P18	Goals and Targets	D15	Goals and Targets	B18	Lack of Goals and Targets
	P19	Supervision	D16	Supervision and Inspections	B19	Lack of Supervision
	P20	Incentives	D17	Financial Incentives	B20	Lack of Incentives and Penalties
	P21	Circular Procurement	D18	Procurement Strategies	B21	Lack of Procurement Strategy
	P22	Frameworks/Business Models	D19	Frameworks/Business Models	B22	Lack of Frameworks/Business Models
	P23	Top-down/Bottom-up Management	D20	Guidance and Best Practice	B23	Lack of Guidance and Best Practice
	P24	Material Standards/Classification	D21	Secondary Material Standards	B24	Lack of Government Support
	P25	The 3-12Rs of the Circular Economy			B25	Lack of Industry Adoption
	P26	The Lean Philosophy				
Social-Cultural	P27	Integrated Project Delivery (IPD)	D22	Integrated Project Delivery (IPD)	B26	Lack of Integrated Project Delivery (IPD)
	P28	Extended Responsibilities	D23	Responsibility and Recognition	B27	Lack of Responsibility and Recognition
	P29	Marketing and Awareness of the CE	D24	Marketing and Awareness Campaigns	B28	Lack of Marketing and Awareness of the CE
	P30	Knowledge Management and Education	D25	Education Programs	B29	Lack of Knowledge and Education
	P31	Establishing Communication and Information Sharing	D26	Data sharing	B30	Lack of Management
	P32	Understanding the Product, Process, and Consumer	D27	Society's Opinion of Unsustainable Practice	B31	Lack of Consumer Demand
	P33	Research and Development	D28	Research and Development	B32	Lack of Research and Development
			D29	New networks		
Technological	P34	Lack of Life Cycle Analysis (LCA) and Benchmarking	D30	Lack of Life Cycle Analysis (LCA) and Benchmarking	B33	Lack of Life Cycle Analysis (LCA) and Benchmarking
	P35	Data Collection and Communication	D31	Material Database	B34	Lack of Material Data
	P36	Case Studies	D32	Case Studies	B35	Lack of Case Studies
	P37	Building Information Modelling (BIM)	D33	Building Information Modelling (BIM)	B36	Lack of Information
	P38	Circularity Tools	D34	Circularity tools	B37	Lack of Circular Tools
	P39	Cost Modelling Tools	D35	Design tools	B38	Lack of Design Tools
	P40	Collaboration Tools	D36	Collaboration tools	B39	Lack of Collaboration Tools
	P41	Material Passports	D37	Material Tracking	B40	Lack of Material Tracking
	P42	Information Management and Transparency	D38	New Methods of Construction and Deconstruction	B41	Lack of Transparency
	P43	New Secondary Material Developments	D39	New Materials	B42	Lack of Material Technology
	P44	Digitalisation			B43	Lack of Material Classification
	P45	Internet of Things (IoT)				
	P46	Blockchain				

Figure 3.6: Theoretical framework taxonomy of the DBPs of the CE in the construction industry

Furthermore, the use of keywords such as ‘framework’ and ‘business model’ in the systematic literature review targeted frameworks and business models for review. However, within the sample, no theoretical, conceptual, or analytical business models or frameworks were identified. This highlights several barriers identified within the literature, such as a lack of circular tools, frameworks/business models, and guidance/best practices. This suggests the need for a full categorisation of the CE’s DBPs, as well as a tool for practitioners to use for guidance.

A second finding from the systematic literature review was the lack of empirical evidence of each driver, practice, and barrier within the construction industry and specifically the UK construction industry. Therefore, the taxonomy of DBPs should be explored and explained within the context of the UK construction industry. Additionally, some studies, such as Knoth et al. (2022), explored the difference between disciplines and found that the different roles within the construction industry have different barriers. This suggests that a comparison between disciplines’ experiences would provide data which would be beneficial to the overall understanding of the CE within the UK construction industry.

CHAPTER 4: FINDINGS AND DISCUSSION

This section looks at the qualitative and quantitative results from SC1 and SC2 on the DBPs of the CE, which were identified within the literature review. Firstly, the practices of the CE are qualitatively reviewed through the discourse between disciplines, the comparison between supply chains, and through a content analysis to gauge the level of development. Secondly, the quantitative responses of participants are analysed using the measure of central tendency to gain an overview through descriptive statistics for a discourse and comparative analysis between the disciplines and supply chains. Finally, the DBPs of the CE are compared to gain an overview of the presence and level of development.

This PhD study purposively selected two supply chains after the consideration of five separate entities. SC1 is a high-rise residential developer company that controls large amounts of the construction process in its group (Figure 4.1). The design, MEP (mechanical, electrical and plumbing), construction management, commercial management, sustainability, demolition and some suppliers are all controlled under one umbrella. SC2 is a residential housing developer firm that controls large amounts of its supply chain to improve the logistical performance and management of its developments (Figure 4.2). However, they subcontract several areas of both construction and management practices which they cannot facilitate. Their main group includes the construction management, commercial management, logistical management, sustainability, procurement, and design groups. Their external working groups are their suppliers and waste management providers.

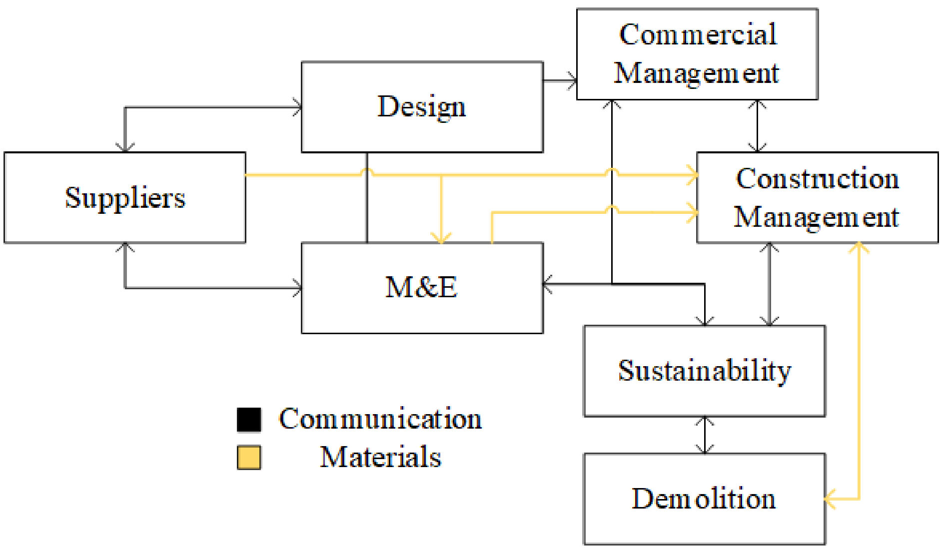

Figure 4.1: Structure of SC1

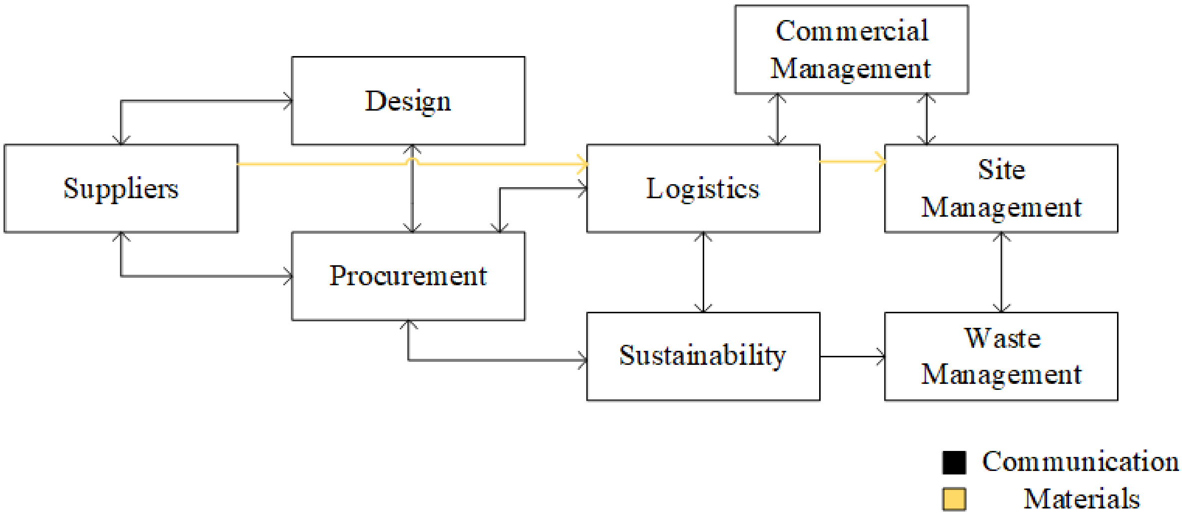

Figure 4.2: Structure of SC2

4.1 Exploration of Circular Economic Practices in Two Construction Supply Chains

This section looks at the qualitative data collected within SC1 and SC2 on the identified practices to view the awareness and development within the construction industry (Appendix A.1 and A.2). The analysis follows the order of the snowball sample that moved from site managers through to procurement. Overall, 48 practices were identified within the literature and discussed with the different working groups identified within SC1 and SC2. There are large gaps in data from both SC1 and SC2, where participants were unaware of the practices or had no information on their level of development within the supply chain. Each working group's identified practices are compared by their respective supply chain and evaluated based on the level of development. Looking at Figure 4.3, we can view the identified level of development versus the number of identified practices for each working group to fully understand the level of development within each supply chain. The number of practices known within a group was quantified based on their responses during the interview stage. Whereas the level of development was interpreted based on the level of knowledge and examples of operational practice provided by participants.

The construction and commercial teams in both supply chains identified a similar level of development within the supply chain, though the level of development differed. The design teams also had a similar level of knowledge towards the identified practices in both supply chains. The designers' knowledge of the circular practices was lower than the commercial and construction working groups, specifically, around the more practical applications of the CE. Both sustainability teams had the most holistic understanding of a broad range of practices in their supply chains, with varying levels of development between supply chains. The sustainability teams viewed the level of development as lower than other groups, compared to the number of practices identified. This was a similar finding to the construction management group, suggesting that individuals knowledgeable about CE practices and their practical implementation recognise that CE development is still in its infancy. The suppliers had a similar level of knowledge as the designers towards the identified practices. This suggests the design and supply of construction projects have little consideration for the practical applications, which may be a contributing factor to the waste produced during the construction stage.

The demolition working group in SC1 had a comprehensive understanding of the practical applications of the CE and examples of development. This could be due to the level of interaction with waste and its implications for the demolition group. This could also be the rationale behind their higher level of development, which stems from a need to manage and utilise waste to avoid the cost associated with processing it. The MEP working group within SC1 showed an understanding of modern methods of construction and LCA-type practices, but lacked information on the management of human resources for CE development. This could be due to the proximity of the group with other processes within the supply chain and the lack of inclusion within the wider strategy of the supply chain, which stems from the type of work and necessity of the group to be widely involved.

The waste management working group showed a good understanding and level of development within SC2 through their collection of data and education schemes, but had a limited amount of influence in order to implement changes within the supply chain. This is confirmed by the lack of identified practices and information within the supply chain. The logistics and procurement working groups for SC2 had little information on wider processes and provided the least information across the identified practices. However, the examples of practice identified by the participants were more detailed than other working groups, showing the level of development of select practices in the supply chain.

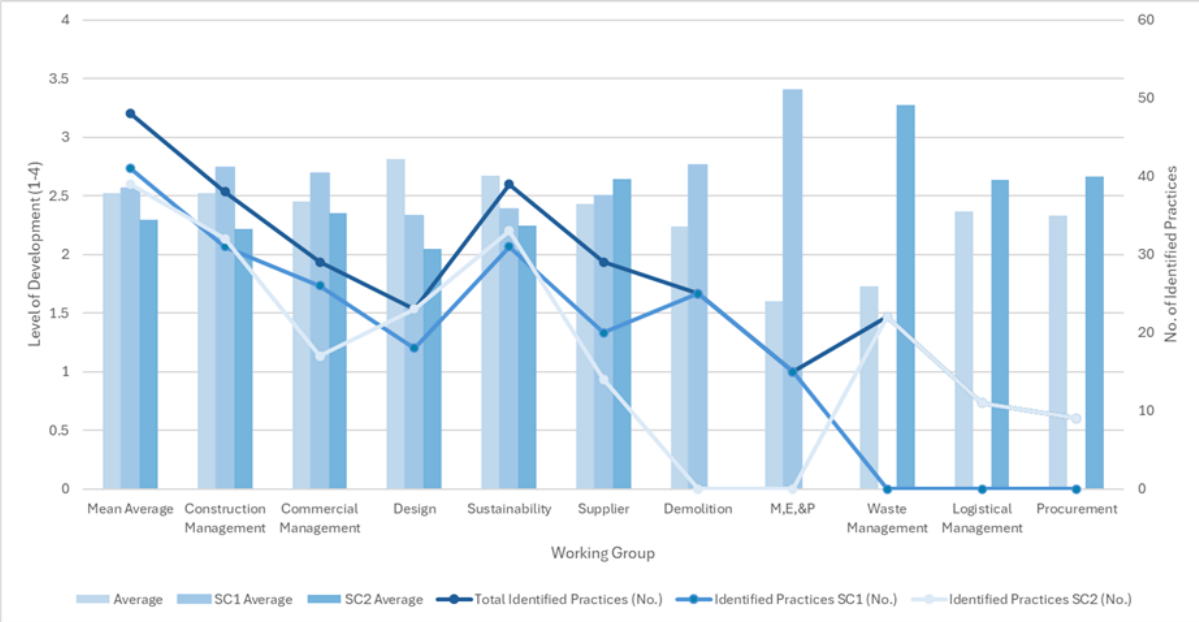

Figure 4.3: Identified average level of development for CE practices vs the number of identified practices by working group

4.1.1 Construction Management

For practices around the design for closed-loop, construction managers assumed that there is some level of consideration before the construction stage, without evidence. For example, "…we appoint competent designers on our behalf to do that design" or "… I think design people do that now, or do I believe they're all thinking about that". This shows a disconnect between the needs of the construction management teams and the design or planning for their processes, which could be causing excess waste. However, in terms of designing for longevity or disassembly, the two supply chains had differing answers based on the type of buildings that were being constructed. SC1 stated that there is a level of design for disassembly based on the lifespan of components, such as the facades, which limits the design for longevity. Whereas SC2 stated that houses are expected to have a longer lifespan, which limits the ability for disassembly, as the work is constructed in situ as one whole component.

Standardisation, modularisation, and prefabrication were all in practice within both supply chains, where feasible to the type of project. SC1 has large sections of repetitive components which can be standardised, modularised, and prefabricated. However, in SC2, the structures are largely in situ due to the nature of housebuilding, limiting the ability to apply modular thinking. This also limits the level of prefabrication and standardisation to smaller components that fit into the in-situ works. For example, SC1 stated that, "Our modular supplier, for example, they produce the pre-made elements of buildings such as pods, bathroom pods and premade utility cupboards." Whereas SC2 stated that, "All of our canopies are prefab, so we do not have to worry about timber." This shows that the level of application of modularisation and prefabrication to minimise waste differs based on specific building types and requirements. Whereas standardisation is applicable to components and elements on any scale or type of structure.

Both had a developing level of waste management, material classifications, upcycling/downcycling, and urban mining. Waste was recorded but not monitored or reviewed for improvements. For example, "…we have waste management plans. Are they used to reduce, monitor, or evaluate? I'm not quite sure." and "We definitely do not track it". However, material classifications and the recording of materials are conducted. For instance, "There are European codes that we're sort of initially use for the categorisation of various types of waste." Materials are upcycled or downcycled where possible. However, downcycling is more common, such as crushed materials. Overall, this shows that there are few proactive practices for the management of material consumption and waste on the construction site, which could be used to innovate wasteful practices.

Both supply chains noted that there are take-back systems in place, but stated that there are no circular clauses in the procured contracts. Contracts had generic clauses in both supply chains, such as "The procurement contract will generally say reduce waste as much as possible." and that "There's no forced implementation." However, the take-back systems are part of the contracted supply and fit works, suggesting there is a level of circular procurement in place. However, product as a service was a contentious point as both supply chains pointed out the difficulties with application, such as "…ownership is a massive problem", "Nobody wants to accept accountability…", and "…it would be a logistic nightmare, an administrative nightmare, also a customer service nightmare".

Due to the structure of both supply chains, being grouped companies, there is a natural level of SCM or integrated project delivery. However, the companies external to the groups have little information provided unless necessary. For example, "We definitely share it with the client…" and "I don't know about the subcontractors, but I'm guessing we do" This provides an insight into the lack of information between construction companies, highlighting the lack of requirement to share information unless requested.

Overall, the construction managers had a similar understanding of construction practices but lacked a wider perspective of other roles such as the design and rationale behind systems and their purposes. This implies that the driver behind these systems is unknown, causing a lower level of implementation or incorrect use of circular practices.

4.1.1.1 DIFFERENCES

SC1 construction managers identified some practices that were not identified by their counterparts in SC2. Modular construction is the foremost, with a high level of development within SC1 as noted above. Construction managers in SC1 suggested that closed-loop material specifications are conducted within the design stage but had no evidence to support their proposal. SC1 did have a higher level of adaptability for innovation, with practices focusing on R&D and secondary material innovations such as material reuse. Collaboration tools were also noted by the construction managers as a way to improve the accuracy of the works to be constructed and to communicate any revisions through BIM and digital platforms. The construction managers said that "a Revit typical master model and Federated model …of the designer's input into an all-encompassing model and from that the 2D design gets extracted for the various trades to install their design." Finally, the construction managers noted a level of LCA. Stating that "It's not something that we really focus on until the end". This could be beneficial to improve the understanding of waste production and highlight potential practices to mitigate waste and apply the CE.

The SC2 construction managers identified several practices not highlighted by their counterparts in SC1, including financial support, the establishment of clear goals and targets, top-down and bottom-up management strategies, implementation of best practice guidance, extended responsibilities, and the use of material passports. SC2 construction manages said that "We've got an operation manual that we all should follow" showing a level of best practice of guidance that has been developed. The construction managers stated that there was little top-down management and that the responsibility lies with the site managers to read the guidance and implement it as they see fit. However, there are targets per plot completion to incentivise the site managers. For example, "[10%] That's our target and we've got bonuses, and our bonuses are linked to those targets". The management strategy was also linked to the data on extended responsibilities. The site managers stated that the lack of management from the top meant that there is a varied level of responsibility among managers, making some construction sites more wasteful than others.

Material passports were also discussed; site managers said that they had never experienced their use. Furthermore, the financial support available to the sites made the managers feel like

“It’s cost-effective to throw it away. It's not cost-effective to recycle it”. Material passports could be used to increase awareness of sites to improve the understanding of the benefits of the circular economy.

4.1.1.2 SYNOPSIS: CONSTRUCTION MANAGEMENT

Ultimately, the construction managers of SC1 and SC2 are not vastly different (Table 4.1). The managers had a similar understanding of the processes available to them and the wastes produced. The main differences are the innovations applied to the different types of development. SC1 has a more innovative set of practices, such as modularisation, which enables the design for deconstruction, LCA, and lean management. SC2 has a higher focus on understanding their waste and providing incentives to their managers to reduce it and meet goals and targets set by the group leaders.

Table 4.1: Quantitative synopsis of the construction management’s Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)	SC2 (LoD)
Design for Closed Loops	2	2
Design for Longevity	1	3
Design for Disassembly	3	2
Closed-loop Material Specification	2	
Servitisation/PSS	3	1
Take-Back Systems	3	3
Recovery and Reuse Infrastructure	3	2
Standardisation	4	3
Prefabrication	4	3
Modularisation	4	
Waste Management	3	3
Upcycling/Downcycling	3	3
Urban Mining	3	3
Financial Support		1
Goals and Targets		4
Supervision	3	1

Incentives	2	4
Circular Procurement	2	2
Top-down/Bottom-up Management		1
Material Standards/Classification	3	4
The Lean Philosophy	3	3
Integrated Project Delivery (IPD)	3	3
Extended Responsibilities		2
Knowledge Management and Education	3	3
Establishing Communication and Information Sharing	3	1
Understanding the Product, Process, and Consumer	2	1
R&D	3	
Lack of Life Cycle Analysis (LCA) and Benchmarking	3	1
Data Collection and Communication	2	2
Case Studies		2
BIM(BIM)	3	1
Collaboration Tools	3	
Material Passports		1
Information Management and Transparency	2	2
New Secondary Material Developments	2	
Digitalisation	3	1

4.1.2 Commercial Management

Within the commercial management teams, SC1 had a higher level of development than their counterpart SC2. Common areas of practice identified by both groups were the operational performances of the construction stage and the mechanisms that could improve material consumption and waste. Design for closed loops was identified by both supply chains, but as a money-saving activity as opposed to a reuse or recycling practice. For instance, SC1 stated that "I guess it's something you should do because at the end of the day it does save money" and SC2 said that "We'll put it as like a value under the line as a kind of a cost saving exercise…". This shows the economic potential for the CE and the rationale behind the implementation of some of the practices. Both commercial working groups for SC1 and SC2 also implemented prefabrication for a similar rationale, with the added factors of time and quality.

The commercial teams identified product as a service as a practice within their supply chains. However, for housebuilding, only the services were seen to have a viable servitisation plan. Whereas SC1 viewed product as a service as their main business model for the high-rise apartment developments. For example, SC1 stipulated that "…the institutional managing agent will look after this building and keep it to the very highest standard to ensure it maintains its value as an asset and to ensure that the renters continue to pay what is a prime rents for prime experience." whereas SC2 said that "I don't think customers would want to bind to that, and they'd prefer to pay". This shows a difference in residential models for servitisation. Highlighting that consumers prefer to own and maintain their houses compared to renting or apartments, who like to have their properties maintained to preserve asset value.

Take-back systems were also identified within both commercial groups at different stages of development. SC1 stated that there was a push from the commercial team to apply take-back systems to their procurement and contracting model. Whereas SC2 stated that "Contractors who provide their own materials, such as dry liners, roof tyres, etc., will have to remove their materials from the site themselves.", highlighting a practical level of development. Similarly, with waste management, SC1 has limited space on site and therefore does little segregation of materials, whereas SC2 has a high level of segregation for practical waste management. Both commercial teams, however, have viewed the reuse of concrete and stone on-site as a financial benefit when downcycling it into an aggregate with practical examples of urban mining. Neither viewed upcycling as a common or feasible opportunity within their business.

In regard to the management and contracting of works. SC1's commercial team focused on a top-down strategy, where site management and subcontractors are issued with plans for the management of their works with little bottom-up communication or influence. SC2's commercial team couldn't describe the dynamic, suggesting a mutual or mixed model. Both commercial teams stated that there is a minimal requirement within the contracts to enforce practices towards materials and waste production, such as "There's no control we use in procurement." and "I can't imagine there's anything…". Both supply chains stated that the lack of clarification in the procurement and contracting strategies limits the amount of responsibility that can be placed on suppliers or subcontractors noting that "I don't think we place any responsibility on them" and "They're responsible for their waste.", however, they also stated that the costs and blame would be negotiated or that they "need to pass them on to someone". This shows that a culture within commercial teams is based on a lack of contractual responsibility and a reactionary set of negotiations to pass blame and expenses onto other entities. Both supply chains have a level of group cohesion; however, SC1 promotes a uniform management strategy for the CE, whereas SC2 doesn't have an "all-encompassing kind of strategy plan to put in place for designers, suppliers and contractors", showing a lack of integration in their delivery.

The digitalisation of SC1, identified by the commercial team, includes BIM and apps for monitoring purposes. However, SC2 only uses programs such as Microsoft Excel for data collection and management. This could be a contributing factor when analysing the costs associated with material consumption and waste. SC1 uses benchmarking software and cost analysis to monitor their production of waste and the quantity of waste within skips to maximise their capacity. SC2 monitors waste production and the quantity and costs of skips on a monthly basis. The different uses of technology could be influential on the effectiveness of the approach and whether the application is proactive or reactive.

4.1.2.1 DIFFERENCES

The commercial team identified a number of practices that their counterparts in SC2 did not. Initially, the design for longevity. The commercial team considers the lifespan and costs associated with different finishes. The commercial team also identified the specification of closed-loop materials for the projects to enable recycling and reuse. This could be due to the model of servitisation within SC1. Material classifications were also discussed as a method of identifying circular materials and managing them in the end-of-life stage. Standardisation and modularisation were identified by the commercial team as a useful practice to reduce waste and costs. The commercial team of SC1 stated that these practices were "not necessarily driven by a conscientious way of reducing waste… it's more about reducing the waste because waste costs me money". This shows the economic benefits of the CE and provides some level of explanation towards the development of practices within the construction industry. The SC1 commercial team noted that there are goals and targets for waste reduction and management, but these are normally set by the government or client. They found that enabling reuse and recycling within their site also assisted with the development of circular markets to reclaim lost value from their project or existing projects that were demolished or disassembled. SC1 also had numerous technologies as opposed to SC2's manual processes. The commercial team identified BIM, LCA, benchmarking, and data collection/transparency as key practices for the management of materials and waste. Some of the examples justifying these practices are "design clash detection", "I know what wastage we've run up the tree… it's high priority for me… because waste costs me money.”, and “We want visibility…”. This shows that the technologies applied to SC1 provide information and data to clearly understand their waste production, the associated cost, and where to implement practices to mitigate waste and expenditure.

SC2 has a unique partnership with their waste infrastructure devised by its commercial team to reduce the production of waste and the costs that stem from its creation. The commercial team does not focus on the waste levels themselves, so it has little information on the financial impact of waste. This is seen from their responses, “I've never really looked at one [waste management plan]” and “It's more so for the site managers”. This shows that the responsibility for the production of waste and its costs is given to the site teams to manage. The commercial team in SC2 does focus on the costs associated with the change in laws and legislation surrounding waste and is preparing for the new UK laws being put into place to mitigate the expenses associated with innovations. Value engineering and lean are also practised to a certain extent within the commercial team of SC2. Stating that it “is a way of saving materials”, but this is focused more on it being “…cheaper”.

4.1.2.2 SYNOPSIS: COMMERCIAL MANAGEMENT

Overall, both supply chains have a good understanding of the operational and contractual practices associated with the CE (Table 4.2). However, the view of the commercial teams focuses on the expenditure of waste and the costs of applying changes to the existing system, instead of the environmental performance to meet company targets. From the empirical data collected, the commercial team in SC1 seek new methods to resolve waste production and the associated costs with digital systems, for example. In contrast, SC2 sees expenditure on new innovations as a risk and unnecessary cost until laws and legislation force the change within its model. The dynamic in each supply chain rationalises the different levels of development between SC1 and SC2. As SC2 only innovate when necessary, they have a lower level of development compared to SC1, who seek innovations to reduce the wastefulness of their sites to mitigate any additional expenditure on materials.

Table 4.2: Quantitative synopsis of the commercial managers' Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)	SC2 (LoD)
Design for Closed Loops	2	2
Design for Longevity	3	
Closed-loop Material Specification	3	
Reduced Operational Impact	3	2
Servitisation/PSS	3	2
Take-Back Systems	2	3
Recovery and Reuse Infrastructure		2
Standardisation	4	
Prefabrication	4	3
Modularisation	4	
Waste Management	2	3
Upcycling/Downcycling	3	3
Urban Mining	3	3
Financial Support		
Laws and Regulations		3
Goals and Targets	3	
Circular Procurement	1	2
Top-down/Bottom-up Management	3	2
Material Standards/Classification	3	
The Lean Philosophy		3
Integrated Project Delivery (IPD)	2	2
Extended Responsibilities	1	2
Marketing and Awareness of the CE	2	
Establishing Communication and Information Sharing	2	
Lack of Life Cycle Analysis (LCA) and Benchmarking	3	1
Data Collection and Communication	3	
BIM(BIM)	3	
Information Management and Transparency	3	

Digitalisation	3	1

4.1.3 Design Management

In relation to the design for the CE, SC1 and SC2 had similar applications and limitations in designing for closed loops. Both supply chains were limited by their control over the design. SC1 joins projects after the key parameters of the project are set, and SC2 have standardised drawings set by group directors. Both utilise materials from pre-existing buildings on their sites as crushed aggregates, but fail to utilise other materials from the site. Neither identified the purposeful selection of methods or materials for reclamation through closed loops. In terms of longevity, SC1 considers the lifespan of materials and components but does not select them based on their lifespan. Whereas SC2 have longer warranties on their houses and the designers "like to think our houses are going to be there forever". This shows that the business model of housebuilders is to design long-lasting structures for their clients as a prerequisite. Both supply chains identified a lack of consideration for closed-loop material specification. SC1 designers stated that product declarations are sometimes considered, but have scarcely any influence on the choice of material for their buildings. SC2 designers stated that they are "…pretty much led by what's available". Overall, the designers showed little consideration for the CE and noted that they are led by the availability and price of materials.

Focusing on standardisation, prefabrication, and modularisation, SC1 and SC2 had different levels of developed practice based on the nature of their structures. Standardisation for both supply chains was a key practice stating that "…the more the repeat nature of the work, the bigger benefit it brings us in terms of the program…" and "…we've got standard products, our standard house types, because we know them, they're all costed, we know how economical they are, um, and then sales will have their favourites, ones that they know how they sell". This highlights the benefits of standardised designs to increase the understanding of products and processes, to simplify and refine the construction industry for the application of other strategies, such as the CE. SC1 identified a higher level of development when prefabricating components compared to SC2. SC1 prefabricates "…precast floors, precast columns, bathroom pods that all come in a sequence of deliveries that are to suit the build.", whereas SC2 didn't provide examples but stated that more elements are being prefabricated because "It keeps the waste produced on site down". Similarly, with modular practices, SC1 had examples of practice such as bathroom pods and utility cupboards, whereas SC2 stated that they are "…looking at new sorts of modular forms of construction". This could be due to the nature of construction as noted in the design section, that SC1 have more repetitive works with a lower perceived lifespan, whereas SC2 focus on durable in-situ works.

In terms of systems, SC1 noted that servitisation is sometimes requested by the client or passed on to a third party. In comparison, SC2 noted that they have "…a 10-year warranty. And I think there's 2 years that we'll go back and fix things" which acts as a service of the structure. However, for the full application of the servitisation strategy in SC" "…there's a there's a cultural issue. I think we want to own our homes.", and "…think about the logistics of it… you'd have about 2000-3000 houses potentially". They also noted that they "can see the applicability to apartments". This shows that the designers for SC2 have identified barriers to the servitisation of houses compared to their applicability to high-rise residential developments, which were confirmed by SC1. For take-back systems, designers for SC1 stated that they are a section of the procurement process for some subcontractors, whereas SC2 required site management teams to establish take-back systems on an ad hoc basis. Designers for both supply chains noted that the waste information from the construction stage has no significant impact on their designs and that the information is not fully communicated with them. This could be a significant enabler of waste production for both supply chains as wasteful designs or practices could be increasing the levels of consumption and waste without the potential for mitigation. Both design teams also noted that the procurement of materials and works did not contain any clauses for waste levels or CE recovery or reuse, which could be a contributing factor to waste generation. Both supply chains also practice some levels of Lean construction through value engineering to reduce time and cost, which has a certain level of impact on the levels of materials consumed and the waste produced. However, the reduction of waste was not a key factor in value engineering exercises, for example, "…more towards reducing costs rather than waste, but that might have a result of reducing waste as well".

For data collection, interpretation, and digitalisation, both sets of designers identified practices. SC1 established more lines of communication with the suppliers compared to SC2, which established communication with subcontractors. This could be due to the methods of construction of both supply chains, with SC1 relying on the production of prefabricated modular sections and SC2 relying on in-situ works. Both sets of designers showed little consideration for the material consumption or waste during the processes of the production stage and higher levels of consideration for the consumers' desires. For LCA, both working groups for design stated that LCA isn't conducted. SC1 uses BIM for each project but does not apply any form of LCA to the model. Whereas SC2 doesn't use BIM and stated that "…we've never quite got to the point where it's the answer to our problems." then elaborating on the current process "Before CAD house type design was really easy because you drew a plan, then you put a bit of tracing paper over it… and then that never changed". This shows that the designers in SC1 have adopted more innovative technologies for their design to integrate higher levels of consideration for the building. Whereas SC2 are performing a manual process for their design, which could be a crucial reason for their lack of design considerations for the construction stage and CE. When discussing benchmarking, SC1 noted that benchmarks and waste data are not reviewed until project completion, compared to SC2, which does not perform any benchmarks for its designs. SC1 also noted that they are looking at secondary material innovations and can see the benefits from early investigations, whereas SC2 have not considered the use of secondary materials by design.

4.1.3.1 DIFFERENCES

SC2 identified some additional practices in contrast to SC1. The design for disassembly was noted as a practice that is incompatible with their business model and consumer demands. This is because they "…think our houses are going to be there forever. So, we're not thinking about taking them down…". This either suggests an incompatibility between designing for disassembly and house construction, or a lack of information on the practical applications within the design team for their house designs. In regard to incentives, the designers for SC2 couldn't identify incentives for their team, but did note the competition between sites to be the least wasteful region. This could provide some insight into the lack for CE applications within the design stage. Furthermore, the integration between the design team of SC2 and the rest of the supply chain is lacking. One participant stated that "… an architect designs something and then hands it over and the builder builds it, a commercial person buys. It means that there's a disconnect between what you're designing and what you're building". Another participant stated that "We have very little contact with the contractors and the suppliers". Both of these statements show that the disconnect between the designers and the rest of the supply chain could be having an impact on the supply and construction of their structures, which is causing more waste than required. In terms of data collection on their designs, the designers in SC2 stated that "It's not something I often get involved in unless there's a focus on a particular trade or material". This suggests that there is little refinement of the designs following their trial when initially developed. As the design team have stated that the house types are used over a number of years with slight adaptations for updates in legislation, this could be a primary source of waste production with little data collection or understanding of the impact.

4.1.3.2 SYNOPSIS: DESIGN MANAGEMENT

The design teams highlighted a lower level of knowledge surrounding the application and development of the CE (Table 4.3). This was especially true in regard to the operational practices during the supply and construction of their respective structures. The designers in SC1 highlighted a higher level of knowledge and application for modern methods of construction and digital processes. This has provided benefits for the design team, suppliers, and the construction team by developing standardised prefabricated modular components and communicating information through digitalised BIM models. SC2, on the other hand, are still following a traditional format for their design and construction, whereby the designers produce drawings based on the needs of the consumer with little to no regard for the construction teams or materials, causing more variations and waste on their sites.

Table 4.3: Quantitative synopsis of the design manager's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)	SC2 (LoD)
Design for Closed Loops	2	2
Design for Longevity	2	3
Design for Disassembly		1
Closed-loop Material Specification	2	1
Servitisation/PSS	3	2
Take-Back Systems	3	3
Standardisation	3	3
Prefabrication	3	4
Modularisation	4	2
Waste Management	2	2
Incentives		3
Circular Procurement	1	1
Material Standards/Classification	2	2
The Lean Philosophy	3	3
Integrated Project Delivery (IPD)		2
Establishing Communication and Information Sharing	3	1
Understanding the Product, Process, and Consumer	2	2

Lack of Life Cycle Analysis (LCA) and Benchmarking	1	2
Data Collection and Communication		2
BIM(BIM)	3	1
Information Management and Transparency		3
New Secondary Material Developments	2	1

4.1.4 Sustainability Management

Within the sustainability working groups for SC1 and SC2, participants identified the largest number of practices in comparison to the other groupings. Both sustainability groups had a similar level of knowledge towards the practices, but had different focuses for their development of the CE. When discussing design and planning, SC1's sustainability team noted that they have limited control over the design for closed loops as they are specified before they start working with clients, however, they did note that they are attempting to get "…more involved in sort of stage three and earlier design aspects." because they "…know we need to consider it". In contrast, SC2 noted that closed loops aren't considered during the design stage, and their establishment is the responsibility of the site management team. This could be an enabler of material loss from the system, as the unstructured reactionary process of establishing closed loops causes more materials to be sent to landfill compared to planned closed loops for materials to be recovered. Both supply chains stated that the design is a large barrier to applying the CE. This can be seen by responses from SC1 and SC2, such as "…concept architects' design. So, they're not actually helping the circular economy…" and "…there are lots of priorities in the house design process and reducing waste is probably fairly low down…". The main difference between the two supply chains is the level of control over the design. SC2 has full control over their house types, whereas SC1 has a limited amount of control. This would suggest that CE applications for SC2 could be easily applied in comparison.

Looking at standardisation and prefabrication, both supply chains noted a push towards standardised and prefabricated elements of their structures. SC1 stated that there has been some application "…of facade systems and things", but the lack of design control means that it is difficult to always apply said practices. SC1 also noted the influence of clients when establishing standardised elements, stating that "…if they're not putting in more standardised items and then you see it with clients asking for bespoke finishes…". Moreover, SC1's sustainability team said that they "…are big on prefabrication…" but they "…wouldn't say that reducing waste is necessarily the main reason behind it…" and that it is more of a time and quality-based practice. On the other hand, SC2's sustainability team said that "…there's a big been a big drive recently for standardisation and I think standardisation will reduce waste". They also noted that more standardisation means more data on the commercial and operational performances of their product to improve their business's profitability. In terms of prefabrication, SC2's sustainability team noted that there are some cases of prefabricated elements, but not many. They commented by saying "It could make sense commercially, makes sense from a waste point of view, from a carbon point of view… I mean, it really is a very, very good idea. We absolutely should be doing". This shows that it is something that is potentially in development and could have a significant impact on their practice to reduce waste and increase financial profitability.

For operational practices such as servitisation, take-back systems, waste management, and infrastructure, both sustainability teams had a similar perspective. In terms of servitisation, SC1 said that "…it's definitely feasible in terms of doing it, it's just people trying to get away from that traditional sort of blame culture", which contradicts previous working groups for SC1 who say it is already at an early stage of development. SC2 stated that the concept of servitisation for a house contradicts the standard business model of the sector, which is "…buy the land, get planning permission, build the homes, sell the homes…". However, one participant did comment on the benefits that servitisation could bring, such as supply chain collaboration, increased quality, longevity, and long-term revenue. Both supply chains provided little information on take-back systems, considering that the other working groups discussed their application with subcontractors and suppliers. For waste management, SC1 said that their waste management plans are useful for BREEAM certification, but they "…don't know necessarily how well that is to reduce the amount of waste that we produce…" and that the monitoring is only conducted every six months or after project completion. SC2 discussed the use of waste management plans on each site to record the waste produced by the different classifications and view the waste produced as a group. However, the sustainability team also noted that they "… do not have any involvement at all really in producing or monitoring them". They also said, "I don't know a lot about waste management plans. It's not something we look at in the sustainability team". Improving this could have a large impact on the reduction of waste within SC2, as the sustainability team does not investigate or monitor the waste produced or its environmental impact. Therefore, the analysis and monitoring of the waste management records could identify numerous areas for CE applications to improve the environmental and commercial performance of the supply chain. Both supply chains also plan the infrastructure for waste and collect data on the types of waste and quantity of skips and their capacity.

For management and cultural practices, SC1 and SC2's sustainability teams had similar levels of knowledge with different levels of development. The sustainability team for SC1 said that the business follows a top-down model for their development and that there's a "… lack of people wanting to pursue this from our like board level directors". Compared to SC2's sustainability team, who described it as a mixture of top-down and bottom-up, where "…the business units do innovate occasionally… the innovation tends to stay within that business unit until someone at a group level hears about it or comes across it". Both sustainability teams stated that the current laws and legislation are driving changes to a CE with different steps for planning permission. For business models or frameworks, SC1 said that they use the BREEAM framework to monitor their performance. They did however suggest "a business model to keep the industry thriving to keep construction actually viable, it has to be done in the business has to adapt to do it." and that "…it is not a sole driving factor for what the board level will except they want to see the cost benefit". SC2 on the other hand said that "What the business units needed above all was to be told. These are the things that you need to do". They noted that some of the monitoring framework was "… lots of very granular data." that is too difficult for sites to understand, and that they need to be told "… here are the three things you can do". They said that a business model or framework would "… show us how to change." by identifying "… three or four things that they should be doing every single time very consistently, and that that kind of messaging can cut through in a way that the data I think…". This shows that there is a demand for clarity regarding the CE through a list of instructive practices to apply to the construction industry, instead of interpreting the data themselves to identify and innovate practices. For circular procurement, which could outline some practices for clear application of the CE, both supply chains noted that there is little within the contracts used to specify waste management or the CE to guide and enforce practice. When looking at incentives or penalties, SC1 discussed an ongoing investigation into the expenditure of waste and using it as an incentive to increase the management and reduction of waste. SC2 said that there are bonuses for hitting waste and carbon targets for their site management teams. However, there were no clear penalties for either supply chain that were discussed. This highlights the lack of consideration of the expenditure and environmental impact of waste, which would cause penalties for the supply chains. In terms of the Lean philosophy, SC1 identified just-in-time delivery, whereas SC2 discussed an early level of value engineering. They both showed a limited knowledge of the topic.

For data and digitalisation, both supply chains commented on a number of practices. For establishing communication, SC1 discussed the need for consistency in the companies working on projects to understand the flow of information and the overall strategy. They discussed a level of data sharing with clients on the waste produced, but stated that there isn't a standard level of communication between projects and companies. SC2 only discussed communication with suppliers and the collection of EPDs for their products, which is in its early stages. For knowledge and education, SC2 stated that there are frequent inductions to inform contractors of the waste management strategy on site. In contrast, SC1 is seeking to implement a similar process to educate practitioners on its site and to improve the level of waste management on their projects. In regard to LCA, SC2 stated that there are no EPDs for their houses due to the variation of different sites; however, an LCA is performed on new house designs to ensure that they comply with regulations. SC1, on the other hand, track their material waste in the form of LCA to ensure that they meet BREEAM requirements for their buildings. SC1 noted that BIM is used to determine material quantities for their projects and collect data. Compared to SC2, where the sustainability team could only assume that it is used. For data collection, SC1 noted that it isn't frequently shared with other companies. Compared to SC2, who collect data and shares it within their group and with suppliers to improve the quality of their products. However, they did discuss the quality of their data, which varies based on the project due to the responsibility of monitoring waste that is placed on the site management team. SC2 also discussed their waste contractor, who provides consistent data on their waste production and suggests possible improvements to the sites. SC1 discussed how their data is used to increase the transparency of waste production on their sites. SC2 said that the amount of data is decreasing their transparency on their waste management as they are "…drowning in data and they have a very hard time interpreting that data". Both sustainability teams said that the main digital technology they use is Microsoft Excel. SC1 said that benchmarking the data is difficult due to the unique nature of their projects, but they do benchmark individually against the BREEAM framework. SC2 stated that no benchmarking is conducted, which could be impactful based on the repetitive nature of their projects. For material passports, SC1 said "I think we're a long way from truly having a material passport", and SC2 said that the "… audience would not be appropriate, and you'd get very limited use of the information…". This suggests that the use of material passports for sites is not as applicable as logistical practitioners. For cost modelling tools, SC1 said that "…when you show a cost benefit, there's much quicker buying than just a sustainability benefit". SC2 agreed by saying that "…providing cost data can help a great deal with bringing to light just how expensive waste management is". This highlights the constraints that are placed on the sustainability team and how they are required to find a commercial case for the application of sustainable practices, such as the CE.

4.1.4.1 DIFFERENCES

The differences between SC1 and SC2 were minimal. The SC1 sustainability team mentioned a level of design for disassembly; however, this was not for their new buildings but for existing buildings which were marked for demolition. SC1 identified a level of downcycling and urban mining from their demolition company in regard to concrete reuse. SC1 also said that their main set of best practices or guidance for the CE comes from the BREEAM accreditation framework. Finally, they discussed collaboration tools and SCM, saying the "Communication line needs to be improved…" and that "…you're truly going to be able to work around the circular economy is if you have one project team that delivers the project from start to finish rather than switching consultants, designers and everything like that. Because otherwise that's where things get lost in translation…". This suggests that communication and collaboration tools are a vital part of delivering the CE in practice and enabling practitioners to increase the transparency of data for accurate applications.

In SC2, they discussed modular applications within the housing sector as a difficult method to apply to "…economies of scale…" due to planning permission. The sustainability team suggested reforms in planning permission to increase its viability to reduce the waste generated from construction activities. This also led to financial support to increase the feasibility of producing modular homes on a large scale. Furthermore, the sustainability team in SC2 noted that the goals set by the government are difficult to meet without the ability to apply strategies. These goals have also been used to incentivise their site managers with monetary bonuses. to achieve and monitor these goals, SC2 use sustainability champions as a supervisory practice compared to SC1. They also identified a level of the 3Rs within their business and design, but noted that it is "…not as big a priority…". As part of this, they are aiming to understand the product, process, and consumer by contacting suppliers for EPDs and reviewing their 'favoured' products for their consumers. Finally, SC2 have investigated the use of blockchain, and they stated that they "…think its greatest potential is probably in providing real transparency through our supply chain". This provides an insight into the needs of the construction industry to understand their supply chain for the generation of material data for CE or other applications.

4.1.4.2 SYNOPSIS: SUSTAINABILITY MANAGEMENT

The sustainability teams of SC1 and SC2 both had a good insight into the variety of practices that were identified within the literature (Table 4.4). SC1's sustainability team showed a higher level of application of the practices; however, SC2 showed a more diverse range of practices. Both sustainability teams stated that the level of development within the supply chains was at an equal or lower level than the other working groups. Overall, they identified a more comprehensive list of practices and their development than the other working groups. The main disadvantage facing the sustainability team is the commercial and operational working groups who require more clarity on the financial benefits/implications and the operational requirements and responsibilities for CE applications.

Table 4.4: Quantitative synopsis of sustainability manager's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)	SC2 (LoD)
Design for Closed Loops	3	2
Design for Disassembly	2	
Closed-loop Material Specification	2	2
Servitisation/PSS	1	2
Take-Back Systems	3	3
Recovery and Reuse Infrastructure	3	4
Standardisation	1	3
Prefabrication	3	3
Modularisation		1
Waste Management	3	3
Upcycling/Downcycling	3	
Urban Mining	3	
Financial Support		1
Laws and Regulations	2	3

Goals and Targets		3
Supervision		3
Incentives	2	3
Circular Procurement	3	2
Frameworks/Business Models	3	2
Top-down/Bottom-up Management	3	3
Material Standards/Classification	4	4
The 3-12Rs of the Circular Economy		2
The Lean Philosophy	2	1
Integrated Project Delivery (IPD)	2	
Knowledge Management and Education	2	3
Establishing Communication and Information Sharing	2	3
Understanding the Product, Process, and Consumer		3
Lack of Life Cycle Analysis (LCA) and Benchmarking	3	1
Data Collection and Communication	2	3
Case Studies		2
BIM(BIM)	3	1
Cost Modelling Tools	2	2
Collaboration Tools	1	
Material Passports	2	1
Information Management and Transparency	3	2
Digitalisation	1	1
Blockchain		1

4.1.5 Suppliers

The suppliers for SC1 and SC2 identified a limited number of similar practices. For the design of closed loops, SC1 said that "It gives you the resilience in the activities to follow, design to reduce wastage and if… possible, like increase percentage of recycled was down cycled or up cycled material." but that it is "…, not a satisfactory extent…". SC2 said that they "… are actively now looking at about grinding that waste, grinding up clay, and brick to use it back in our products". This suggests that the design for closed loops in the suppliers of SC2 is not yet a developed practice, but is developing. Both suppliers said that take-back systems were not a feasible solution due to operational and financial aspects. However, SC1's supplier did note that they refurbish damaged goods if they are repairable. SC1's suppliers said that the recovery and reuse infrastructure is limited for their products compared to other manufacturers. In contrast, SC2's suppliers stated that they have "… not got the capability. So, we need to we need to invest…". This shows that the recovery and reuse of materials is being considered, but the infrastructure available is the main concern for companies, and that investment is required to support them. In regard to data collection, SC1's suppliers identified acceptable levels of waste to be monitored, collected big data on the process, and used BIM and digital twin software for their products. In contrast, SC2's suppliers stated that they mainly collect data on Microsoft Excel for purely reporting purposes.

4.1.5.1 DIFFERENCES

SC1's suppliers identified multiple practices that weren't discussed by their counterparts in SC2. Design for disassembly was discussed as a practice to recover materials from their components and to repair and replace damaged materials in their products. Moreover, the specification of closed-loop materials was identified as a practice within the suppliers for SC2 as a mechanism to increase the reuse and recyclability of their products, stating that "It gives you the resilience…". On a similar point, the suppliers said that "… repetition and standardisation is a route for efficiency and with it comes reducing waste". This shows that standardisation is a fully developed practice within the suppliers of SC1 who have identified the benefits when applying the CE. For servitisation, the suppliers said that "Serviceability is a way to increase the revenue", this shows a focus on increasing the commercial benefits of applying circular models to traditional products. Upcycling and downcycling were identified by the suppliers as a concept but not yet as a practice. When discussing financial support, the suppliers said that "It's a reason that supports, like sustainable goals, because when it is driven by cost saving or by things like this, it aligns more with other objectives…" because "… some sustainability goals are perceived to be against profit or cost saving". This highlights the dual purpose of the CE as a financial and environmental strategy for businesses and that the suppliers in SC1 understand the benefits of the CE. When discussing circular procurement, the suppliers said that "…early on, procurement is where you look for opportunities or improvement or leverage the effort done in design. If this is not considered, you've just wasted like we've just wasted a big effort that was done by in one phase that was wasted by the following one". This highlights the deficiencies identified by other working groups that have struggled to apply practices due to a lack of contractual reinforcement and clarification. Focusing on the 3Rs, one of the participants said that "… some people explicitly recognise the process… where others would implicitly do it because they don't explicitly see the sustainable benefit". This supports some of the responses from the construction management group, who could identify the practices but lacked the understanding of the rationale surrounding their use. The suppliers at SC1 also identified Lean as a practice and discussed the differences in manufacturing for the automotive industry and the construction industry. A participant said that "Unlike the automotive industry or such industries that will champion lean production, we don't have a standard product with the same dimensions", and that "… is why construction will never be as efficient as the automotive industry…". This shows that Lean can be applied to the construction industry, but not as consistently as a more standardised manufacturing process in the automotive manufacturing industry. For communication, the suppliers stated that their message changes based on the audience. If the audience has a more commercial mindset, they focus on the cost of the practices; if it is more environmental, they focus on the sustainable benefits. This stresses the importance of understanding your client to promote the CE in a palatable way for higher levels of adoption. The suppliers at SC1 also use more data-driven digital technologies, such as BIM, to benchmark their performances. They justified the use of these practices are it "… is what the industry is looking for, but the thing is like with any database you need to build the information, like you need to have what's required". They also said that the lack of data is the biggest gap to developing circularity tools and that cost modelling tools can be developed from databases to drive the CE.

SC2 discussed the operational impact of their supplies by incorporating recovered materials into their products, saying that they "… can make some more sustainable products and hopefully that will benefit everyone in the business…" and that this will reduce their carbon footprint, and the amount of gas and electricity required to make their product. This also connects to the incentives identified by the suppliers, as it provides a commercial and environmental incentive to innovate. This also provides an insight into their drive for R&D to improve the circularity of their products compared to SC1.

4.1.5.2 SYNOPSIS: SUPPLIERS

The comparison between SC1 and SC2 is stark (Table 4.5). SC1 identified more practices at a higher level of development, whereas SC2 had more R&D ongoing to innovate their practice. Both suppliers had little consideration for the construction stage and focused on their own systems compared to the use or logistics of their product.

Table 4.5: Quantitative synopsis of the suppliers' Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)	SC2 (LoD)
Design for Closed Loops	3	3
Design for Disassembly	3	
Closed-loop Material Specification	3	
Reduced Operational Impact		3
Servitisation/PSS	3	
Take-Back Systems	1	2
Recovery and Reuse Infrastructure	3	2
Standardisation	4	
Waste Management	3	
Upcycling/Downcycling	3	
Financial Support	3	
Incentives		3
Circular Procurement	3	
Material Standards/Classification		2
The 3-12Rs of the Circular Economy	2	
The Lean Philosophy	2	
Marketing and Awareness of the CE		3
Knowledge Management and Education		3
Establishing Communication and Information Sharing	2	
Understanding the Product, Process, and Consumer		3
R&D		3
Lack of Life Cycle Analysis (LCA) and Benchmarking	2	2

Data Collection and Communication	3	3
BIM(BIM)	2	
Circularity Tools	1	
Cost Modelling Tools	1	
New Secondary Material Developments		3
Digitalisation	2	1

4.1.6 Demolition Management

The demolition working group for SC1 identified a variety of practices from the taxonomy. For closed-loop design, the demolition group stated that they are participating in early discussions to include recovered materials in new structures, such as steel members. They did, however, comment on the difficulty of the process in terms of the logistics and storage of materials/components, the inclusion in the design process to include materials/components, and information on the material requirements for the new project. As part of the demolition stage, they commented on the lack of design for longevity, which hampers their ability to disassemble, recover, and reuse materials. Regarding the disassembly, the demolition group said that "…designers need to be looking at how these things are dealt with at the end of life. So, it's about designing something that can be removed, and when that material is removed, it can be segregated, isolated, and that might be that you're just lifting out the whole pod". This highlights the barrier faced by demolition companies trying to implement the CE. The demolition group concluded with "And if they can't be encouraged, they have to be told. And therefore, legislation has to come in", which shows the deep desire of the demolition contractor to implement the CE and their frustration with the current design and legal system. The demolition also said that standardisation is a key practice to assist the disassembly and recovery of materials at the end-of-life stage, as it produces standard methods for recovery. Similarly to modularisation, it was found that it assists the recovery of materials and components during the disassembly stage. For instance, "You're taking it away in a lorry, you know, and you can strip it somewhere else in another facility…". This shows that the design of the structure is a massive influence on the recovery of materials and components in the end-of-life disassembly of structures.

In terms of management systems, the group said that servitisation is a key practice to increasing the lifespan and quality of materials in the end-of-life stage. Specifically, the participants said, “I think that's brilliant because a lot of the time things can't be reused because they're not being maintained.” and that “Preventative maintenance is way better than reactive and everybody knows that”. This shows that servitisation could be a key enabler of the CE in the operational and end-of-life recovery or reuse. For waste management, the participants provided examples of records and monitoring for their projects and stated that it is a key practice for quantifying, segregating, and recycling their waste materials. Regarding the infrastructure, participants discussed the use of recycling facilities; however, they also stated that there are developments occurring in their business to increase their infrastructure for the storage of materials and components to be reused within their projects. Urban mining was also connected to this plan as the company stated their push for the disassembly of structures provides revenue for them and their clients.

For top-down and bottom-up management, the participants stated that there is always a mix within every business of “…leaders in the business that have vision… And you have people that… see them as an annoyance”. This confirms the views of other responses collected from participants that have stated that the effectiveness of the CE is dependent on the manager or site. For laws and legislation, the participants found that the government’s plans are not backed with sufficient knowledge for its application and that the “… industry is really taking up the baton and moving forward with it…”. This suggests that more stringent laws and legislation could direct practitioners towards the CE and provide enforcement to instil a CE within the construction industry. Similarly, with taxation, the group said that it was a driver for companies to change because “…you end up with fines, varying degrees. And again, it's really quite expensive”, which provides a financial driver for companies. For circular procurement, a participant said “… ultimately because we're all out to make money unless the procurement process acknowledges the value of green initiatives, whether it be steel or reuse or circular economy or whatever. If it isn't, we will keep getting undercut by the cheapest companies that just want to go in and bash something down and shoot everything in a skip and send it away”. This suggests that standardised contracts need to be reformed to include more waste and material management for an enforcement technique and to avoid more wasteful companies from undercutting less wasteful companies on projects and mitigating the more circular practices from achieving work. Procurement, therefore, could be a driving practice for circular companies to gain more work and further support circular development. Furthermore, the financial incentive described in the discussion on procurement was also a factor in the demolition group’s incentives and penalties response by saying “… there is a monetary driver as well that is obviously helping us both from a compliance point of view and from a monetary progress planning programming point of view". This shows that the financial element of the CE is a key driver of the CE as it incentivises businesses to adopt the strategy.

For the Lean philosophy, value engineering was the main practice discussed; however, this is related to Lean but is not specifically part of the Lean philosophy. The demolition ground had an alternative point of view compared to the other working groups by stating that "Now the initiatives and the value engineering is generally focused around, can you give us a greener option?" and that it is "… something we've got to do in in selling our services of the Green still provider…". This shows the shift from value engineering as a cost-saving exercise to an environmental practice for reducing waste and reusing materials and components. It also demonstrates a new form of marketing of the value that stems from the application of the CE. The integration of the demolition contractor within the design stage was also a core topic in the discussion. The demolition contractor discussed a disconnect with the rest of the supply chain and said that "Integration of our [demolition] work. Way earlier on into the design stage. Measuring up, identifying, and looking at what can be reused within the same site, which is the perfect scenario…". This shows that the demolition contractor has the knowledge of applying the CE, but is limited based on their incorporation within the supply chain to apply practices which could benefit multiple working groups within the construction industry. For education, the demolition group linked it to SCM and early integration within the process by saying "…getting involved early, being allowed the time to influence what's needed. That is the number one thing. And when you do that, you're able to educate, influence, allow time, develop the relationship…". This shows that the education process is enabled by collaboration and integrated delivery, as it creates relationships to communicate knowledge.

For digital technologies, the demolition group implements BIM and scanning technologies to create accurate digital models of the structures for selective disassembly and for the identification of components and materials to be recovered and reused within new projects. For this, they discussed the creation of an IoT to create a "… library of terminology that's come out of nowhere with regards to the usable lengths that all sorts". This categorisation of usable elements has assisted their business when utilising those materials in new projects by producing a catalogue of materials for designers to view. This IoT has also enabled an early development of material passports for the components, which are connected to their database and BIM model for more accurate tracking and delivery.

4.1.6.1 SYNOPSIS: DEMOLITION MANAGEMENT

The demolition group had a high level of knowledge of the practices associated with the CE and provided numerous examples of their development or application (Table 4.6). This suggests that demolition companies face the highest impacts from waste generation and are actively seeking to innovate with circular practices to reduce or utilise their waste through recovery, reuse and recycling. However, there seems to be an impediment with other professionals in the supply chain, such as designers, clients, and construction managers, to achieve their ultimate goals of turning the waste into value.

Table 4.6: Quantitative synopsis of the demolition management's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)
Design for Closed Loops	3
Design for Longevity	2
Design for Disassembly	2
Servitisation/PSS	2
Take-Back Systems	2
Recovery and Reuse Infrastructure	3
Standardisation	3
Modularisation	3
Waste Management	4
Upcycling/Downcycling	4
Laws and Regulations	2
Taxation	4
Incentives	3
Circular Procurement	2
Top-down/Bottom-up Management	2
The Lean Philosophy	3
Integrated Project Delivery (IPD)	2
Marketing and Awareness of the CE	3
Knowledge Management and Education	2

Understanding the Product, Process, and Consumer	4
Case Studies	2
BIM(BIM)	3
Material Passports	3
Digitalisation	3
IoT	3

4.1.7 Mechanical, Electrical, and Plumbing (MEP)

The MEP working group in SC1 identified a limited number of practices. For the design of closed loops, they focused on packaging. As their components are largely prefabricated or specialist, the waste produced is primarily cardboard and plastic, which would justify this focus. In terms of standardisation, modularisation and prefabrication, the group discussed their bathroom and utility room designs, which are prefabricated, standardised and produced as modular sections which showing a high level of development for these practices. In terms of servitisation, the group discussed the MEP products as a statutory requirement to be serviced against the current standards. This contrasts with other elements of the building, which other participants viewed as problematic. This could be due to the legislation in place for MEP products, their value or cost, and or their specialist requirements.

In terms of waste management, the group did not have any plans in place for the management of waste as they are completed by the construction managers. The MEP group simply track the purchase orders for their materials and components. This was similar to the consideration for the recovery and reuse infrastructure. The group had a knowledge of the Lean philosophy, but did not feel there was any application of the strategy in their group. However, SCM and IPD did contain some Lean practices that benefitted their clients. Furthermore, the participants stated that their group model increased integration and collaboration and if the group didn’t exist, “It becomes adversarial contracting rather than collaborative contracting.”, which creates waste.

For digital technologies, the team identified the use of BIM as a core practice to identify clashes in their design and increase collaboration with the design teams. They also stated that they use BIM and sensors “… to evaluate the post-occupancy and usage of the building and evaluate the operational efficiency of the building versus design”, which shows a level of LCA. This data is then communicated as the services “… would all be tracked. Water metres, gas metres, and we can feed that into energy management systems as well, which will track against target energy use. ", which provides an example of data communication based on the LCA. This data also provides a benchmark to improve the performance of the building during its operational use and for the MEP group to improve future designs.

4.1.7.1 SYNOPSIS: MECHANICAL, ELECTRICAL, AND PLUMBING

The MEP group provided good examples of their understanding of the CE (Table 4.7), however, their interaction with the wider application is limited, which lowered their knowledge and application of practice, which could impact other groups such as the construction managers or commercial teams. The application of digital tools within the group was higher than their counterparts and contributes to a data-led decision-making process.

Table 4.7: Quantitative synopsis of MEP's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC1 (LoD)
Design for Closed Loops	3
Servitisation/PSS	4
Recovery and Reuse Infrastructure	1
Standardisation	4
Prefabrication	4
Modularisation	4
Waste Management	3
The Lean Philosophy	3
Integrated Project Delivery (IPD)	3
Lack of Life Cycle Analysis (LCA) and Benchmarking	4
Data Collection and Communication	4
BIM(BIM)	4
Information Management and Transparency	3
Digitalisation	4

4.1.8 Waste Management

The waste management group for SC2 provided a good overview of developed and proposed practices for the CE within their respective supply chain. For waste management, the group said "… we provide a site waste management plan for almost every site… We rely on the site to notify us that they want a site risk management plan and to give us some information to be able to plan out how much waste we expect the site to generate and put in kind of the waste predictions that are available on our portal". This shows that SC2 collects useful data on the quantities and types of waste being produced on its construction sites. This data is also used by the working group to provide suggestions on closed-loop materials such as packaging. This is also linked to the development of takeback schemes, which the waste management group promotes to be "… written into the contracts…", which shows the early development of circular procurement mechanisms. The infrastructure behind the waste management groups is designed to obtain planning permission, and the group provides instructions for how the waste generated can be managed.

For the governance of SC2, the waste management group said that there is a level of top-down from the umbrella company and a level of bottom-up based on the competition developed around the performance trackers of each region of sites. The working group provided some information on laws and legislation around the CE, but this mainly focused on obtaining planning permission with waste management plans, suggesting a limited level of laws and legislation surrounding the CE. The waste management contractor did note the impact of taxation on the management and culture of waste generation and segregation on site, stating that "Everyone got a lot more serious about putting their hazardous waste in the right drum and put polishing up their hazardous waste practice when the cost of getting rid of expanding foam quadrupled". This shows that taxation is a big motivating factor for companies to correctly manage their waste to improve the potential for reuse or recycling. For best practice and guidance, the group discussed BREEAM as a guide for implementation, which is similar to other participants in SC1. This was also the main focus of the discussion around frameworks and business models, as a participant said that "… there aren't that many very successful circular business models in place". This suggests a need for more frameworks that can be used within practice to assist and guide practitioner to enable tailored solutions based on their product type. There was also some discussion focusing on the supervision of waste management practices. The supervision provided by the waste management group supports the enforcement of correct procedures by "photographing the waste; they will provide feedback to the site manager on the visit about their waste performance. They'll identify any particular issues of contamination trades that aren't segregating well and the reasons for that". This highlights the guidance and information needed to successfully inform and educate professionals on the correct procedure for applying the CE. This education is also provided in the form of inductions for subcontractors, and the information is passed to "… the buying and production team…" but the responsibility for communication is "… down to them then if they want to field it on to other agencies". This is also increasing the awareness of construction professionals towards the application of the CE. The group stated that "I'm definitely seeing in the house builder industry that there is an awareness of the big picture that there wasn't before". This shows that the CE is making its way into practice and that the 'bigger picture' is becoming more prevalent in the industry.

For digital technologies and data, the group said that the waste information is collected through Microsoft Excel and transferred to an online portal to show a company-wide view of waste performance. This collection of data could be used as a guide for improved practice; however, the waste management group said that "… some regions of the company… retrospectively look at the plans…". This shows that although the data is available to assist practice, it isn't referred to frequently or by standard to reduce waste management practices. The group did state that they "… pull out the data at the end of the plan to see how their site compared against our waste predictions…". This is a good example of reflection to improve the application of the CE using data to benchmark performances, but the level of impact is uncertain without the integration of practitioners into the process.

4.1.8.1 SYNOPSIS: WASTE MANAGEMENT

The waste management group showed a good understanding and level of development towards the practices of the CE (Table 4.8). However, the practices that they implement or seek to develop are hampered by their external position to the core group of companies within the supply chain, limiting their ability to influence the development and implementation of best practices for the CE. Ultimately, the data that the waste management contractors collect is a core enabler of implementing tailored practices for the supply chain that is justified through benchmarking practices.

Table 4.8: Quantitative synopsis of the waste manager's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC2 (LoD)
Closed-loop Material Specification	3
Take-Back Systems	4
Recovery and Reuse Infrastructure	4
Waste Management	4
Laws and Regulations	3
Taxation	3
Supervision	4
Incentives	3
Circular Procurement	3
Frameworks/Business Models	2
Top-down/Bottom-up Management	3
Material Standards/Classification	4
Integrated Project Delivery (IPD)	3
Marketing and Awareness of the CE	3
Knowledge Management and Education	4
Establishing Communication and Information Sharing	3
Lack of Life Cycle Analysis (LCA) and Benchmarking	3
Data Collection and Communication	4
Information Management and Transparency	3
Digitalisation	3

4.1.9 Logistical Management

For the logistical management in SC2, the majority of practices identified were process and technologically based. For the design of closed loops, the group focused on logistical materials and components, for instance, "... they will repatriate pallets back to us, so they go to their facilities, they're refurbished, and then they come back to us". They also have customer returns for components which can be reused or repaired. This shows a practical level of development for reuse within the logistical group and the development of recovery infrastructure that is planned before application. Moreover, this is a prime example of take-back systems and how they enable the CE. For waste management, the logistical group largely uses mixed waste for their materials, with the occasional use of specialised recycling for high levels of steel, for example. The group also discussed the benefits of supervision on site, stating that "… there's less damage, less waste, skips are used. So, there's an absolute correlation with materials controller on site". This shows that supervision on site has a benefit for the management of materials and the reduction of waste. In terms of Lean, the logistics group seek to implement time-saving strategies and standardised processes. They also utilise the just-in-time strategy for deliveries and material flows to the construction sites. The logistics group have also implemented new digital systems for the tracking of materials and wait times to collect data, create information, and have a transparent process for the products and the consumers on site. This also enabled their ability to benchmark consumption, waste, processes, and reuse or repairs of components and materials.

4.1.9.1 SYNOPSIS: LOGISTICAL MANAGEMENT

The logistics team of SC2 has applied some digital technologies to enable the CE within their group (Table 4.9). Furthermore, they have increased the application of the CE in the construction stage by developing processes such as take-back schemes and material tracking to understand where waste is produced and to mitigate the wasting of components that can be repaired, such as lintels or pallets.

Table 4.9: Quantitative synopsis of the logistical manager's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	**SC2 (LoD)**
Design for Closed Loops	3
Take-Back Systems	4
Recovery and Reuse Infrastructure	2
Waste Management	2
Supervision	2
Top-down/Bottom-up Management	2
The Lean Philosophy	3
Understanding the Product, Process, and Consumer	3
Lack of Life Cycle Analysis (LCA) and Benchmarking	1

Information Management and Transparency	3
Digitalisation	3

4.1.10 Procurement

The procurement team for SC2 identified the fewest practices of the working groups. This could suggest a rationale behind the lack of implementation further down the supply chain. For the design for closed loops, the groups stated that they have "… done a recent thing on waste management around reduced size plasterboard." to reduce the amount of waste from plasterboard that is not designed for the dimensions of their buildings. This could potentially develop into a common practice with all suppliers and increase the communication between parties. This is also linked to their identification of standardisation among the materials and components used within their buildings to "… have a smaller range", and to simplify the management of materials for the logistical and construction processes. They did note the benefits of supervision on site for the materials and management of supplies, saying that "… they're worth their weight in gold, they save money, don't cost money". This shows the requirement of material managers and supervision on-site to reduce the production of waste. For the Lean philosophy, the procurement group discussed the lack of trust with some of the practices, such as just-in-time but noted that the storage of materials on site increases the opportunity for waste to occur. With communication and data collection, the procurement group stated that "… there is some exchange of information around waste with one or two suppliers" but overall, there is little data sharing or communication between the procurement team and suppliers or construction sites. The final practice discussed was the digitalisation of the process, to which the group stated that it was primarily emails or Microsoft Excel.

4.1.10.1 SYNOPSIS: PROCUREMENT

Overall, the procurement team showed a lack of connection with the other stages and their requirements to establish less wasteful practices or the CE (Table 4.10). This lack of engagement could be a reason for the lack of circular procurement within contracts with suppliers or subcontractors. Furthermore, the lack of knowledge on the practices could have limited their development or the performance of initiatives.

Table 4.10: Quantitative synopsis of the procurement manager's Level of Development (LoD): 1 = far below standard, 4 = far above standard

Practice	SC2 (LoD)
Design for Closed Loops	3
Take-Back Systems	3
Waste Management	4
Supervision	2
The Lean Philosophy	2
Integrated Project Delivery (IPD)	3
Establishing Communication and Information Sharing	3
Data Collection and Communication	3
Digitalisation	1

4.1.11 Overview of practices by supply chain

This section seeks to discuss the level of development of the CE within the sampled supply chains, the comparison of working groups within each supply chain, and the potential practices that could be developed within each supply chain and their respective working groups (Figure 4.4).

4.1.11.1 DEVELOPED PRACTICES

The level of CE development within the supply chains was promising for those that had been applied in practice (Table 4.11). Practices such as prefabrication, standardisation, and modularisation were in the stage of practical application. This confirms findings in the literature, such as Guerra and Leite (2021), who stated that standardisation is applicable to multiple building types and that prefabrication is a common practice to reduce waste in construction. Moreover, this fits with Torgautov et al.'s (2022) discussion on the use of modular design as an effective way of reducing waste on construction sites. The level of development of these practices recorded in the empirical data collection fits Kręt-Grześkowiak and Baborska-Narożny's (2023) view of the practices as immature within practices and still within the developmental stage. However, there was some variance between the supply chains based on the nature of the two buildings, with SC2 focusing on in-situ work instead of modular or prefabricated components.

Another practice that was identified by practitioners as developing is upcycling and downcycling. Many examples provided by participants discussed crushing materials for aggregates, which is a form of downcycling, whereas no examples were provided for upcycling. This is consistent with the findings of De Silva et al. (2023), who suggested that downcycling was the primary focus of the construction industry, and there is a need to move towards upcycling to increase the value of recovery, as discussed by Hossain et al. (2020). Taxation was also seen as a developed practice to develop the CE within construction. Participants noted the costs of removing waste through a linear process and how the expenditure due to tax is creating a commercial driver for companies to use practices from the CE. However, SC1 was more concerned about the level of expenditure related to tax on waste and developed their practices to mitigate this impact, which can be seen in their development of modular and prefabricated practices. This aligns with the findings of Shooshtarian et al. (2022), who discussed the impact of taxes on waste in the Australian construction sector.

The mean level of development for national or local goals and targets was also in the developing category. Both supply chains had different levels of goals within their organisation, but had a similar opinion on their benefits of driving and guiding the development of practice within their organisations. Some participants stated that the national goals offer a lower level of guidance for their practice, but they encouraged company-focused goals, which drove competition to become less wasteful which led to the development of the CE. This aligns with Gembali et al. (2024), who suggested that national goals are lacking in detail but could inspire targets within organisations and Torgautov et al. (2022), who stated that clear goals would increase the performance of the CE within organisations.

Practices that were under development stem from the developed practices. For instance, urban mining and the design for closed loops are both developing from the taxation of waste, which pushed companies to upcycle or downcycle their waste to evade additional costs from waste tax. The practice of downcycling waste within the supply chains has developed from the commercial impact of the linear waste process and has developed a level of urban mining. Once the materials have been downcycled, the supply chains have sought to use the downcycled materials within their designs to optimise the monetary value from the waste materials. This aligns with the study conducted by Köhler et al. (2022), who discussed the benefits of designing for materials recovery in the demolition stage. However, the literature largely states a conscious design for closed loops, whereas the examples identified are reactionary to the resulting waste of demolished pre-existing structures. Outside of the main construction stage, the suppliers discussed a lack of materials from demolition companies to develop sustainable processes for the production of secondary goods. This was also discussed as a barrier when mining the construction industry by Giorgi et al. (2022) and could contribute to downcycling on-site instead of upcycling within factories. Another practice that is developing is waste management within the construction industry. All of the participants discussed the use of waste management plans to monitor waste. These waste management plans were implemented as law by the UK government, which has since been retracted. This could be a reason for the practices being at a lower level of development, as the practice is no longer mandated by law and is devolving within the industry. This links to the level of development of laws and legislation within the construction industry, which participants viewed as underdeveloped for the CE, but on a path towards developing guidance and policies.

This aligns with the previous discussion on national goals and targets, which were viewed as developed, but participants stated that there is no guidance or structure to reach targets, leaving development to private companies. This could provide a rationale for the lack of development within the supply chains, as the government has not implemented a plan or laws to develop practices. This could provide context to the data collected from SC2, which highlighted a higher level of goals within their organisation and a higher level of concern regarding government laws. This is reinforced by other studies, such as Cheng et al. (2023), who studied the positive impact of CE laws in China, which increased CE development within private construction companies. Another point of development within the supply chains was R&D. This has developed due to the aforementioned lack of laws and guidance from the government, which has forced companies to innovate privately.

Finally, there was an identified level of development for the IoT. Participants stated that the digital collection of materials within a database assists with monitoring and tracking, as well as standardisation practices. This shows that organisations are looking for practices that would simplify the development of the CE within practice and enable further development. This is consistent with Guerra and Leite (2021) and Çetin et al. (2021), who proposed developing an IoT for traceability and monitoring to enable the core CE practices.

Table 4.11: Practices with the highest level of development

No.	Practices	Avg. (SC1)	No.	Practices	Avg. (SC2)
P19	Taxation	1.00	P18	Laws and Regulations	1.33
P8	Modularisation	1.20	P16	National/Local Goals and Targets	1.50
P7	Prefabrication	1.40	P7	Prefabrication	1.75
P6	Standardisation	1.71	P32	Knowledge Management and Education	1.75
P13	Upcycling/Downcycling	1.80	P21	Material Standards/Classification	1.80
P5	Reduced Operational Impact	2.00	P26	Incentives	1.80
P14	Urban Mining	2.00	P10	Take-Back Systems	1.88
P15	Financial Support	2.00	P19	Taxation	2.00
P16	National/Local Goals and Targets	2.00	P6	Standardisation	2.00
P20	Best Practice Standards/Guidance	2.00	P13	Upcycling/Downcycling	2.00

4.1.11.2 UNDERDEVELOPED PRACTICES

Practices that were below developing or developed were vast (Table 4.12). Both supply chains have developed similar practices and have little to no information on the others. This shows that there are more considerations for developing broader operational and economic practices, such as standardisation or prefabrication, than the core environmental or enabling CE practices. This was highlighted by multiple participants from both supply chains who frequently discussed the implementation of practices as a commercial benefit as opposed to associating them with the CE. Key practices that were identified at a low level of development such as the design for the CE.

Closed-loop material specifications were underdeveloped in both supply chains, whereas the design for longevity and disassembly had some conceptual level of development. The design for longevity was higher in SC2, who favour durable in-situ works, compared to SC1, which had a higher level of design for disassembly with their modular approach. SC1's level of development for design follows the findings of Ababio and Lu (2023), who identified the use of digital systems for design and tracking to enable the design for disassembly, which were also at a higher level than SC2, which would suggest that these practices enable other CE applications.

The lack of design for closed loops within both supply chains could be linked to Ababio and Lu's (2023) and Ababio et al.'s (2023) studies, which found a lack of data and information surrounding the construction industry to plan for closed loops. The lack of design for the CE identified within the empirical data collection could provide an understanding of the lack of application in the later stages, as suggested by Christensen et al. (2022) and Eray et al. (2019). This could also be a consideration for the lack of development of take-back systems within the supply chains due to the lack of design or consideration in regard to material waste.

SC2 provided evidence of several take-back systems in operation that have been retroactively applied on an ad hoc basis. Whereas SC1 hasn't managed to develop take-back systems in full and only has a minimal level of rudimentary take-back systems within its own business. This is also linked to the findings for recovery and reuse infrastructure, which both supply chains agreed are underdeveloped, highlighting that there are limited opportunities to recover or reuse materials that are wasted. Financial support was also listed as a practice with a low level of development. SC1 considered the support available as developing through financial benefits and R&D, whereas SC2 viewed it as non-existent. This difference could be for multiple reasons, such as a lack of awareness towards the financial aspects of the CE suggested by Wong et al. (2024), a lack of funding from governments proposed by Maher et al. (2023) and Tokazhanov et al. (2022), or a lack of understanding of financial drivers such as tax, which was identified by Shooshtarian et al. (2022), Iyer-Raniga et al. (2023), and Litleskare and Wuyts (2023). This difference could also be due to the applied practices in each supply chain, with SC1 applying financial practices such as product as a service to maintain capital from their investments. The level of adoption is largely linked to financial incentives, as previously discussed. These incentives were scarcely identified by participants within this study and were only adopted by SC2 as a motivation strategy for construction managers to implement waste management practices. This shows that the incentives, such as loans, tax levies, reduced operational expenditure, and industrial competition, identified by Adams et al. (2017), Maher et al. (2023), and Iyer-Raniga et al. (2023), are not being promoted effectively within the sampled supply chains.

Other undeveloped practices identified within the sampled supply chains were the 3-12Rs of the CE and the Lean philosophy. The 3-12Rs were scarcely discussed within the conducted interviews, whereas Lean was known by several participants but not applied. De Silva et al. (2023) discussed the importance of the 3-12Rs to establish a culture of the CE within the business, which could suggest that the lack of awareness and application of the CE in SC1and2 is due to a lack of structure or understanding of the CE model. Lean, on the other hand, was more known within the suppliers working group, showing that the operational side of the construction industry has more benefits from the use of Lean, as stated by Marzouk et al. (2019).

This also links to another practice with a limited level of development, SCM/IPD. Both supply chains had some level of SCM/IPD, but did not identify it as a practice to be implemented; instead, they described it more as a natural collaboration based on necessity or proximity. This could provide a rationale for the lack of consideration and transparency between the different working groups of each supply chain, which was noted by Giorgi et al. (2022) and Tosi et al. (2024). With companies external to the main developer in the supply chains, the level of collaboration on the desired strategy for materials was scarcely communicated.

The lack of development towards communication and information sharing shows a further hindrance to the implementation of CE practices within the construction projects and supply chains, as identified in studies by Ababio et al. (2023) and Köhler et al. (2022). The main form of information stemmed from the procurement contracts on site, although participants stated the materials and waste sections were limited to broad clauses with little to no enforceable control measures. Select subcontractors had take-back systems stated in their contracts to manage the production of waste by those external to the main developer. This use of procurement did have an impact on the development of the CE within both supply chains, as it enabled other practices such as the take-back schemes, but in practice, the elements of the procurement route regarding materials and waste are absent, suggesting that circular procurement hasn't been fully realised or developed within the supply chains. The ambiguity within the contractual elements of the procurement also created waste through a lack of clear responsibilities for the management of materials and waste.

Both supply chains viewed the lack of clear responsibility as one of the least developed practices within their respective supply chains. SC2 did have a higher result based on their occasional appointment of material controllers on their projects, which had a "…significant impact…" on the amount of waste generated due to the reduction of material damages during the delivery and storage of materials. This shows that the supervision of materials and waste can improve the retention of materials and reduce waste generation on site, which could be a reason for the developing stage of supervision within both supply chains. Compared with the literature that primarily focused on government responsibility, supervision, and manufacturers' responsibility (Huang et al., 2018; Fernandes and Ferrão, 2023; Fonseca et al., 2023; Shooshtarian et al., 2022), the results of this study found that the responsibility of different disciplines and developer-led supervision of different projects needs to be developed to improve the CE.

Practices linked to digitalisation, data collection, and circular tools were also seen as underdeveloped. Digitalisation, on average, was underdeveloped; however, SC1 had a developing level of digitalisation. This highlights the severe lack of development within SC2 towards digitalising their process to improve the design, operation, and construction of their supply chain. This difference between supply chains can also be seen when looking at the development of BIM, which was developing within SC1 and not present within SC2. This could be due to the nature of the projects with SC1 developing high-rise structures and SC2 developing houses, as suggested by Jahan et al. (2022). The benefits of BIM and digitalisation within SC1 could substantiate the increased level of development within SC1 towards operational practices such as standardisation, prefabrication, and modularisation of their projects.

Other developed practices in SC1 could have also been improved by the development of digital systems within SC1, such as the design for disassembly as suggested by Marzouk et al. (2019). The level of digitalisation also had an impact on the collection and analysis of data on the performance of waste and material management. Both supply chains ranked it as underdeveloped due to the use of manual software such as Microsoft Excel, which also limits the transparency of the data for wider use within each supply chain. Bao et al. (2019) and Ababio and Lu (2023) found that a lack of data sharing and data transparency limits the ability for other stakeholders to make data-led decisions to apply the CE. This lack of data could also substantiate the lack of LCA conducted on the structures to understand the product and process for the construction stage in order to identify wasteful practices. Moreover, the inability to use circular and cost modelling tools to understand the impacts of their practices. An alternative rationale for the lack of circular and cost modelling tools could be the immaturity of tools or the lack of awareness among practitioners as to their use, benefits, or availability.

Other mechanisms, such as blockchain and material passports, were not seen as developed in either supply chain. Neither supply chain had considered blockchain as a practice to collect data on their supply chains and increase data transparency to enable data-led decisions for the CE. However, SC1 had looked at but not developed material passports through the development of EPDs for their products. This could be due to the increased level of data collection and digitisation within SC1 that enables them to classify and analyse materials and components. Finally, frameworks and business models were seen as undeveloped. SC2 stated that there were several available, but they were theoretical and provided little to no guidance on the practical applications of the CE to assist its development. Whereas SC1 follow the BREEAM framework on several of their project, which gives them measurable performances to achieve to improve their circularity. Wong et al. (2024) suggested that the use of digitalisation could assist practitioners in conducting and meeting BREEAM standards, which could substantiate their increased adoption of the framework compared to SC2. Besides the BREEAM framework, SC1 also stated that there are no practical frameworks focused purely on the CE to guide practitioners in developing circular practices within their company.

Table 4.12: Practice with the lowest level of development

No.	Practices	Avg. (SC1)	No.	Practices	Avg. (SC2)
P18	Laws and Regulations	3.00	P39	Digitalisation	3.43
P23	Circular Procurement	3.00	P8	Modularisation	3.50
P27	Case Studies	3.00	P3	Design for Disassembly	3.50
P28	The 3-12Rs of the Circular Economy	3.00	P15	Financial Support	4.00
P46	Collaboration Tools	3.00	P36	BIM(BIM)	4.00
P48	Secondary Material Innovations	3.00	P41	IoT	4.00
P45	Cost Modelling Tools	3.50	P43	Material Passports	4.00
P24	Extended Responsibilities	4.00	P46	Collaboration Tools	4.00
P42	Blockchain	4.00	P42	Blockchain	4.00
P44	Circularity Tools	4.00	P44	Circularity Tools	4.00

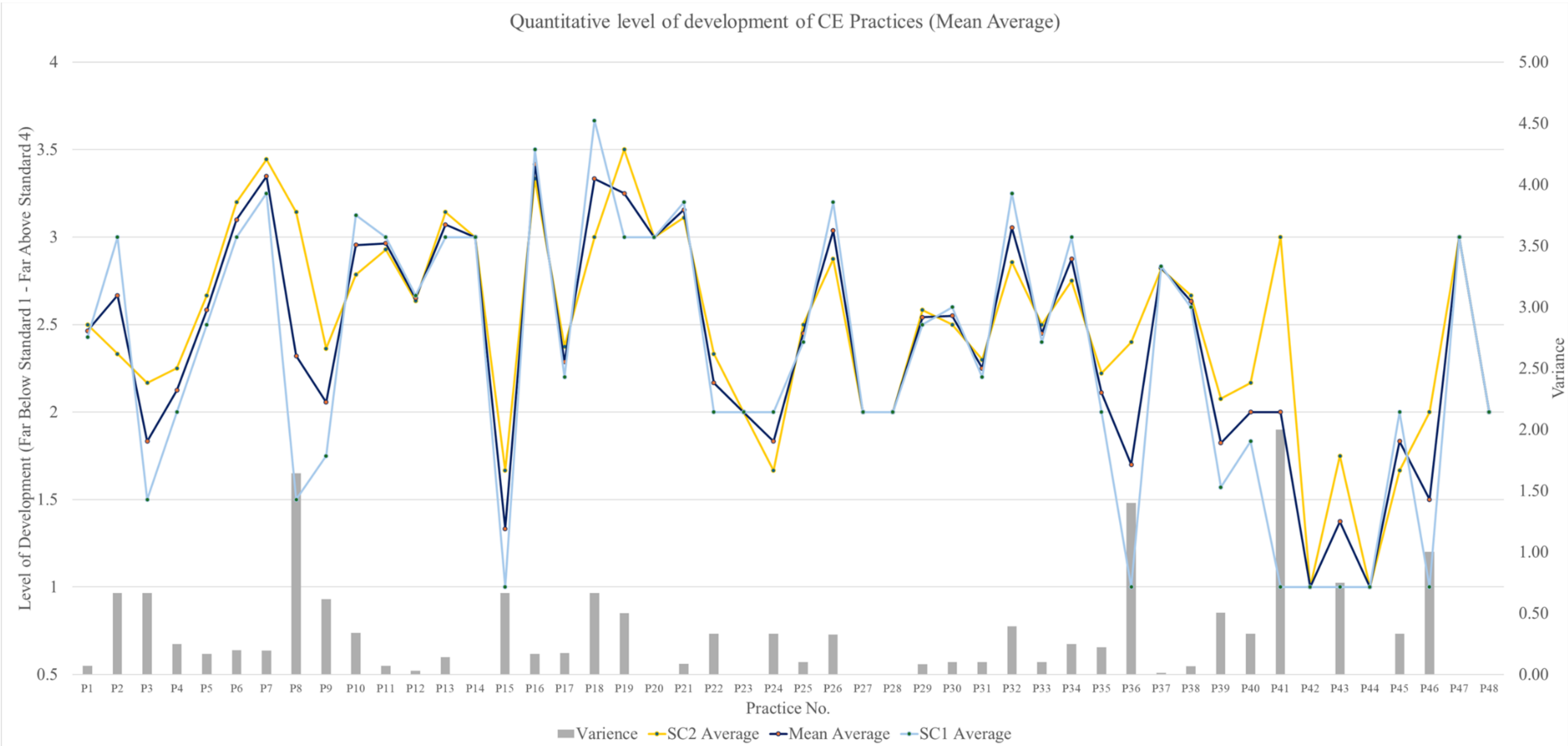

Figure 4.4: Quantitative overview of the qualitative responses of participants in SC1 and SC2 on the practices of the CE

4.2 Drivers and Barriers

This section looks at the empirical data collected on the drivers and barriers of the CE that have been identified within the literature (Appendix A.3 and B.4). Overall, 39 drivers and 45 barriers were identified within the literature within 4 themes. Firstly, working groups are analysed to contrast the differences between disciplines in each supply chain. Then the drivers are analysed in an overview to compare supply chains.

4.2.1 Construction management

Both supply chains had similar results for the drivers and barriers of the CE within their organisation, with some small levels of variance. The main drivers (Figure 4.5) for SC1's construction managers were the reduction of waste, procurement strategies, new methods of construction/deconstruction, material tracking, BIM, and circularity tools. This shows that the push towards the CE within their business is backed by innovation through procedure and technology, which links to the developing practices of SC1, which were also in this area. The least important drivers for SC1's construction management group were product as a service, secondary material standards, and best practice guidance. The findings for product as a service could be due to the implications and responsibility linked to the construction managers, resulting in a lower driver for their role. For best practice guidance and secondary material standards, the low score could be due to the level of innovation within SC1, which has developed best practices within the organisation, reducing the overall need for external direction. SC2, on the other hand, listed their top drivers as new opportunities, procurement strategies, reduced operational impact, financial support, R&D, and case studies. Both SC1 and SC2's construction managers ranked procurement as a leading driver for the CE. This could be due to the requirement on-site to assign roles and responsibilities with contractual reinforcement to assist with the management of materials and waste.

SC2's focus on new opportunities, reduced operational impacts, and case studies shows that they are motivated to change and adapt to market requirements, but lack the guidance that case studies would provide. This links with the qualitative finding where participants from SC2 described a reluctance to change until the process was a legal requirement or proven. This reinforces the desire from the construction managers for R&D to improve the level of knowledge and detail of processes on site to reduce the wastage of rework. Finally, the construction managers listed financial support as a top driver, which could link to the bonuses they receive for reducing waste below specified levels. Some of the drivers that were ranked lowest in SC2's construction manager group were goals and targets, supervision, product as a service, SCM/IPD, data sharing, and collaboration tools. Several of these drivers are practices that would influence the construction manager's role and increase their responsibility for performance, which could be a reason for their low rank within the drivers. Goals and targets are already in place within SC2 for the construction managers, which would suggest that they are ineffective at driving the CE among construction managers. Supervision, SCM/IPD, data sharing, and collaborative tools would increase the level of transparency and communication with construction managers, which they could have seen as control measures for their role. Product as a service was ranked lowly by both supply chains, suggesting that it is not a driver for construction managers. This could be due to the increased workload and scrutiny on construction managers to implement it.

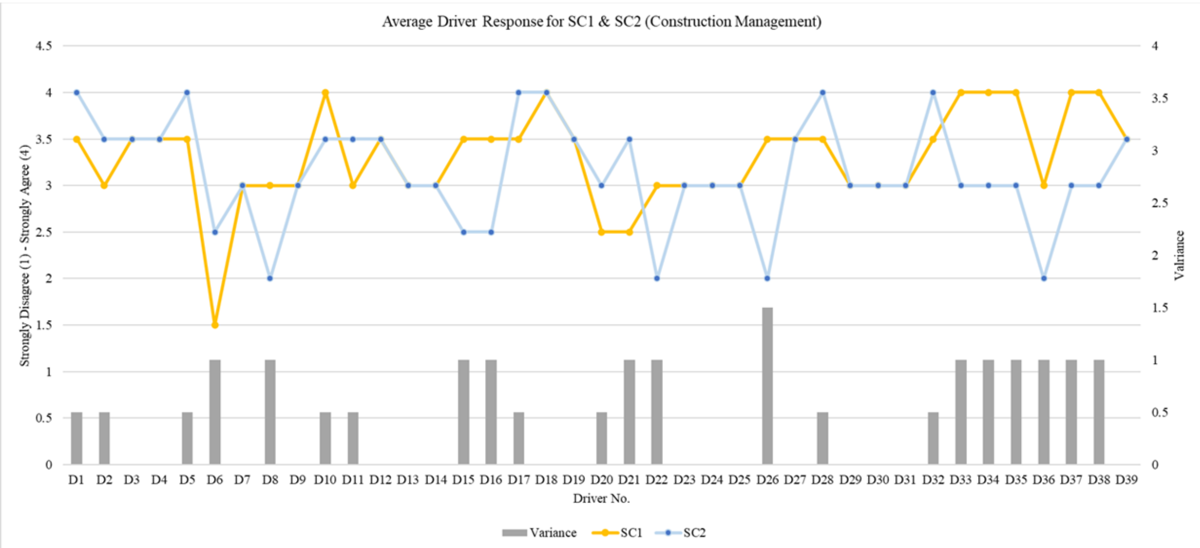

Figure 4.5: Average driver response for SC1 and SC2 (construction management)

The barriers experienced by the construction managers were more sporadic, with several instances of variation between supply chains (Figure 4.6). SC1's top barriers were around the commercial, institutional, and technological themes of the CE. In terms of SC1's commercial barriers, the construction managers found that the secondary market was immature, and the materials recovered from their projects were a low value with little to no opportunity for financial benefit. Johnston et al. (2019) stated that these barriers are significant and persistent, but could also be due to the lack of material contribution from companies suggested by Adams et al. (2017). These findings show that SC1's construction managers do not see the financial benefit of recovering waste, which Adams et al. (2017) proposed would continue to compromise the development of infrastructure, which could enable the financial benefits from recovering waste. The financial benefits for SC1 could also contribute to supporting the development of CE, which was also highlighted as a barrier for SC1. Other institutional barriers for SC1 were the current government support, laws, and goals. This shows that SC1 either does not have guidance or direction for developing the CE (Mahpour, 2018; Wuni, 2022) or is hampered by the current system (Mignacca and Locatelli, 2021). Some of the impacts of these barriers could be mitigated by developing internal goals and policies to drive the CE, however, the national laws and legislation will still persist until circular laws are developed. Other barriers for SC1's construction managers were technological and stemmed from a lack of material data, classification, and tools. Wuni (2022) suggested that the lack of information on materials and processes also limits the ability for companies to identify opportunities for improvement. This could contextualise the lack of financial benefits seen by SC1's construction managers. A lack of case studies was also seen as a barrier for SC1's construction managers. The lack of awareness towards cases of the CE could limit the practical application as companies may not believe the benefits (Ababio and Lu, 2023). Similarly, SC1 found that a significant barrier was the lack of frameworks or business models for the CE in construction. Charef et al. (2021) stated that frameworks are key to simplify the CE for its application in construction whereas Knoth et al. (2022) discussed the how frameworks increased the level of knowledge transfer in Nordic practice. This suggests that a simple and practical framework could alleviate other barriers within SC1 and the wider construction industry.

SC2's construction management identified similar barriers to SC1 such as the low value of materials, infancy of the secondary market, lack of case studies, and a lack of frameworks and business models. This shows that the lack of understanding of the CE in practice, perceived value of applying recovery practices, and structures for practice have had an impact on the development of both supply chains. Other barriers that were seen as prevalent in SC2's construction management group were the quality of secondary goods, a lack of consumer demand, and the demand for raw materials. SC2's construction management group shows a focus towards the consumer and the materials used in their buildings, compared to SC1's construction managers' focus on finances and data-led decision making. Both, however, seek guidance for the identification of opportunities and application of practice through laws and frameworks.

Some barriers have large amounts of variance between the two construction management teams. Whereas SC2 viewed the quality of secondary goods as a barrier, SC1's construction managers did not view this as a significant barrier. The type of building of each supply chain could explain this as Campbell-Johnston et al. (2019) found in their study. Campbell-Johnston et al. (2019) suggested that the inconsistency of secondary material supplies can impact projects from using said materials as standard. SC2, as a house developer, would require a steady supply of materials for repetitive work, whereas SC1 construction tailors projects. This suggests that the infancy of secondary material production and supply poses a larger barrier to organisations with repetitive work compared to tailored projects. This could also be the case for the consumers' stigma, which was ranked higher in SC2. As SC1 has more collaboration with their clients, they can discuss the use and quality of secondary materials compared to SC2, who have to assume the consumers' desires. In addition, the next barrier with variance is linked to the project types and time for consideration. SC1's construction managers found that they have little to no time to consider the CE on their projects, which could be due to the one-off nature of their projects. Linear laws, government support, and goals and targets were seen as higher barriers in SC1 than in SC2. This could be due to the level of development in SC1, which is trying to implement CE with little to no guidance from the government, compared with SC2, which does not develop without government or legal direction. Moreover, SC1 viewed circular infrastructure as a higher barrier than SC2. This could be due to the tailored nature of SC1's projects and materials or due to the incorporation of a waste management contractor in SC2, which has alleviated the barrier through guidance, planning, and practice implementation. SC2 also has an integrated supply chain, which would contextualise their results for IPD, whereas SC1 identified it as a barrier to their practice. This could also be the rationale behind the variation for information management and material data/classification as SC2 collects data from their logistical management group and their waste management contractors to improve practice. This shows that an integrated approach to the supply chain develops practices that enable the CE through data-led decision-making as suggested by Wuni (2022), Mahpour (2018), and Adabre et al. (2023).

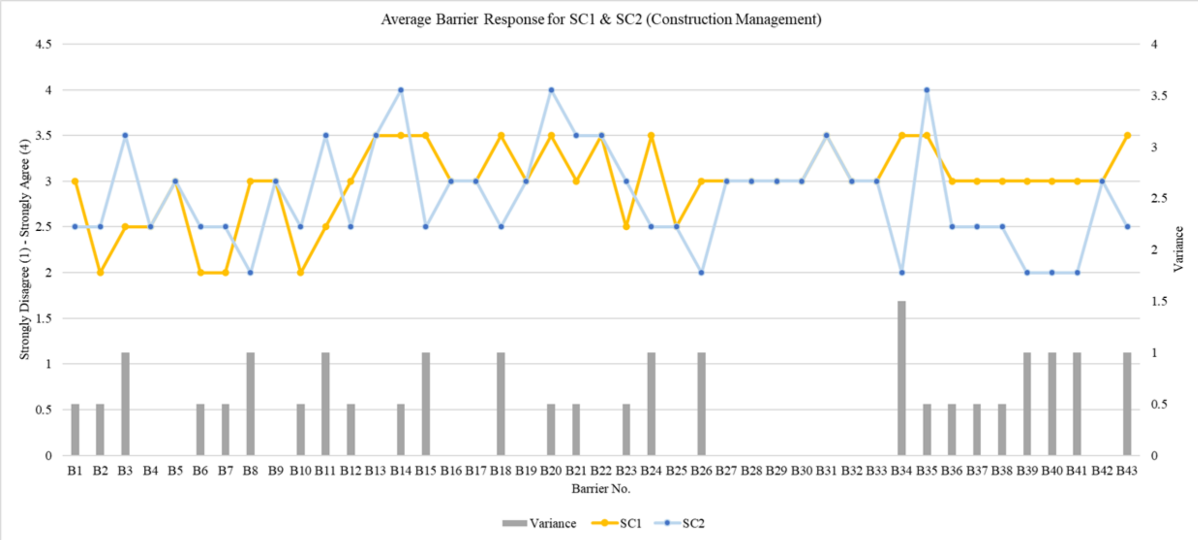

Figure 4.6: Average barrier response for SC1 and SC2 (construction management)

4.2.2 Commercial Management

The commercial managers in both supply chains had similar results, barring four drivers within the technology theme (Figure 4.7). New methods of construction, material tracking, BIM, and circularity tools were all lower in SC2 than SC1 and are the only drivers not viewed by the commercial management team in SC2. This could be due to the lack of innovation within SC2 based on the traditional nature of their projects. SC1 had some drivers that were perceived as lesser, such as goals and supervision. The main variance between supply chains was in the technological theme. New methods of construction were higher in SC1 based on their development and innovation compared to SC2's traditional buildings. The commercial management team in SC1 viewed material tracking as a larger driver than SC2. Compared to the development of practices, this is an interesting result as SC2 has a higher level of development in regard to material tracking. This suggests that it could be seen as a lower driver in SC2 due to the higher level of development already driving practice. BIM was also ranked higher in SC1 than SC2's commercial management group. Based on earlier findings, the commercial managers use BIM to calculate materials and finances from their BIM designs, which enables their use for the CE. This was also suggested by Charef et al. (2022), Chen et al. (2022), and AlJaber et al. (2023). Similarly, SC1 viewed circular tools as a driver which aligns with their use of technology to collect data and apply changes for improved practice. SC2's commercial managers didn't view circular tools as a driver, which suggests a lack of information on the benefits of circular applications. All other drivers were agreed upon by both supply chains, highlighting multiple avenues to drive the commercial management teams.

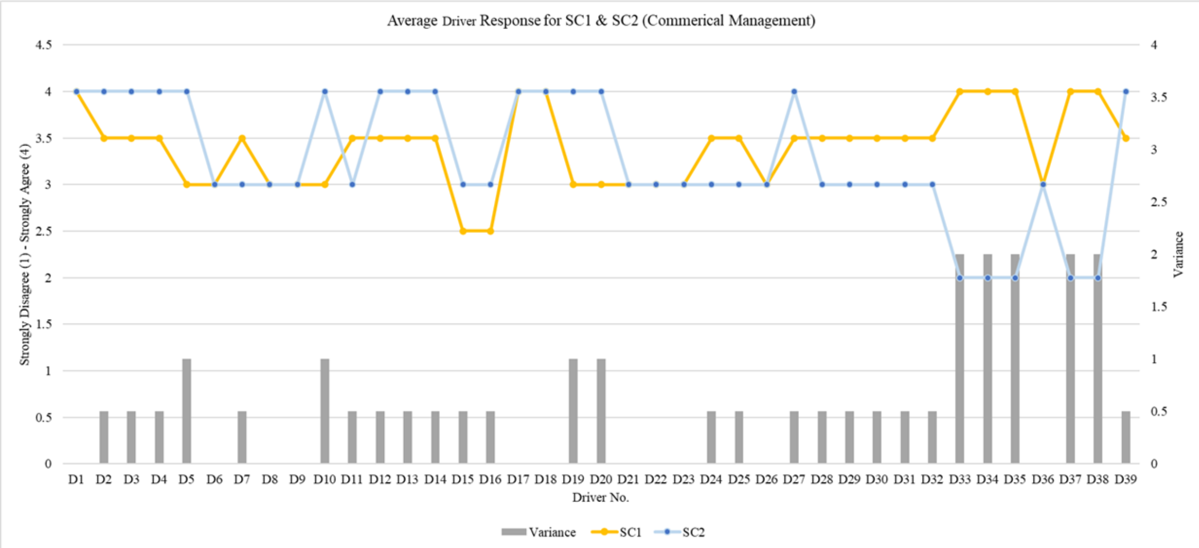

Figure 4.7: Average driver response for SC1 and SC2 (commercial management)

In the former half of the barriers for both supply chains, there is a large amount of fluctuation between SC1 and SC2 (Figure 4.8). SC1 viewed barriers such as the profitable linear market, high cost of secondary materials, cost of innovating, lack of time, and lack of industry adoption as less prevalent than SC2. This suggests that SC1 is less concerned about the time and cost of innovating towards the CE than SC2's commercial management group. This aligns with their development of practices that incorporate new technologies and methods of construction compared to SC2. SC2 didn't view the lack of short-term benefits, the complexity of construction, and the lack of waste management as barriers compared to SC1's commercial management group. This could be due to the appointment of a waste management contractor to organise their waste and reduce the associated costs. The low ranking for the complexity of construction could be due to the repetitiveness of their projects, which use the same materials and methods of construction. Both commercial management teams viewed the remaining barriers as present, which suggests there are many obstacles to overcome to develop a full CE.

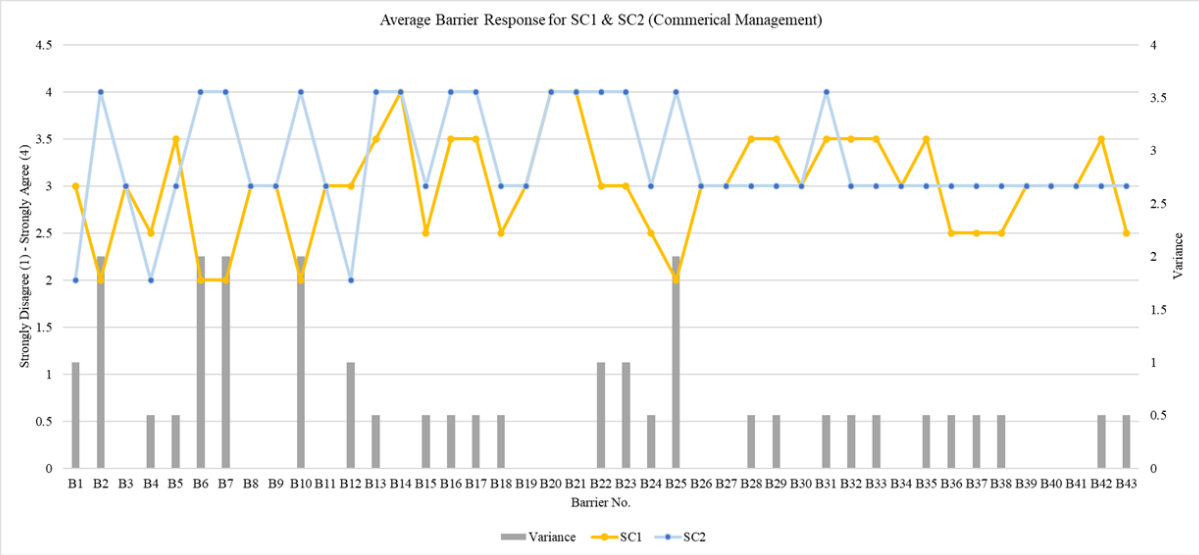

Figure 4.8: Average barrier response for SC1 and SC2 (commercial management)

4.2.3 Design

The designers in SC1 favoured drivers for new methods, finances, governance, and technology (Figure 4.9). Based on the practices developing in SC1, it would justify the drive for new methods of construction and deconstruction, as well as new opportunities for income. This has been identified as a focus in SC1 to innovate, and the designers are also seeking innovations to improve their systems. This reinforces Domenech et al. (2019), who reviewed case studies in Europe to identify drivers of the CE. Domenech et al. (2019) found that the CE provides new economic and environmental opportunities to increase the output of projects. SC1 could be utilising the CE for similar purposes to drive the economic and environmental performance of their business. This is also linked to the time and cost drivers identified by the designers in SC1. Cost and time efficiency were seen as the top drivers, suggesting that the improvement of the design using new methods would improve these elements on their project. For this, financial incentives and support were also a driver, which was also found when discussing practices. SC1 supports innovations to improve the performance of their projects, which would contextualise the increased level of practical development. This is reinforced in the literature by Domenech et al. (2019) who investigated cases within Europe, Ababio and Lu (2023) and Adams et al. (2017) who found that the CE improves the financial performances of businesses through multiple avenues, and Charef et al. (2022) who found that the time and cost efficiency of the CE was a driver that could be improved with the use of BIM. Charef et al. (2022) study also reinforces drivers identified by SC1's designers, which focused on BIM, material tracking, and CE tools. From the analysis of SC1's practices, SC1 has developed BIM and material tracking within their practices, but lacks tools for the CE. This suggests that the use of CE tools could be a catalyst for wider development within companies with digital platforms and material tracking. Finally, laws, taxes, goals, and standardisation were seen as strong drivers of SC1's design team. This suggests that the designers of SC1 are looking for structure and guidance for the application of the CE. The development of CE laws and legislation could provide justification for the use of circular designs and encourage their acceptance in practice. This is similar to taxes and goals, which would provide a target for practitioners to aspire to.

SC2's designers had fewer and weaker drivers overall in comparison to SC1. Some of the top drivers for SC2's designers were around material markets and governance. SC2's designers had a focus on secondary materials and raw materials. They ranked the supply of secondary materials and the volatility of raw material markets as a driver for changing to a CE. Linked with the designers' use of secondary materials in practice, this shows that the supply chain is looking for alternative materials for their current traditional materials. This justifies their rank for new secondary material innovations, which was one of their top drivers, as it can provide a new alternative to raw materials, which are increasing in price. The designers also ranked laws, legislation, and taxes as a large driver for changing their practice. This could be for a similar reason as SC1, to guide and justify the application of the CE.

There were significant levels of variance between SC1 and SC2's designers. SC2 didn't view some of the technological drivers as present, such as BIM and material data, whereas SC1 utilise these to conduct innovations in the practice. SC1, on the other hand, didn't view operational impacts, business models, and IPD as drivers for their practices. This could be due to the operation impact assessments being conducted by the MEP group, the development of their own models for business, and the current level of integration with their supply chain. Overall, SC1 viewed the drivers as more proficient than SC2, which shows that SC1's designers could be incentivised through different avenues, whereas SC2's designers are more rigid.

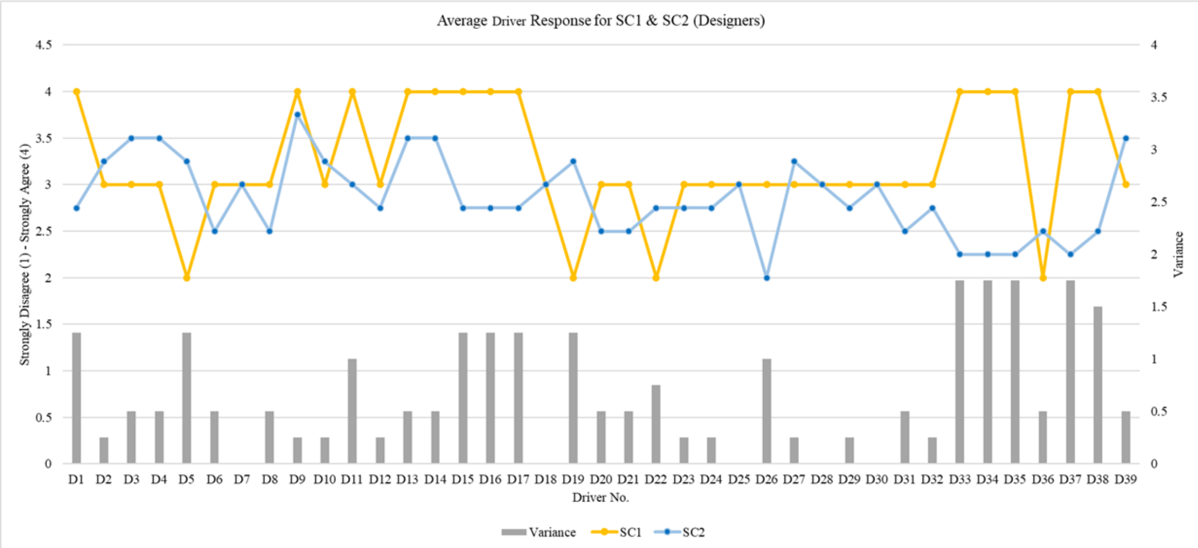

Figure 4.9: Average driver response for SC1 and SC2 (design)

For the barriers of SC1 and SC2's designers, a similar pattern to the drivers was seen (Figure 4.10). SC2's designers recorded a median level for their barriers, barring stigma of secondary materials' quality and a lack of waste management, which were ranked as disagree. This could be due to their use of secondary materials in practice and their appointment of a waste contractor. SC2's largest barriers were linear laws and legislation, taxes, government support, and a lack of consumer demand. Based on the supply chain's drivers, the lack of government laws and support would suggest that SC2 will not change without government and legal guidance and if their consumers do not desire circular innovations. SC1, on the other hand, had more barriers within the former half of the barriers and fewer in the latter half. This suggests that their development of research has alleviated barriers to technological applications. However, SC1's design team did rank some economic and institutional barriers as present. Firstly, the conditions of the primary and secondary markets could suggest difficulties with design specification. Adams et al. (2017), Akinade et al. (2020), and Campbell-Johnston et al. (2019) identified the lack of secondary materials as a barrier for designers as they do not like risks, and the secondary market is immature and unstable, which produces inherent risks for supply chains. This is also linked to their ranking for the high cost of secondary materials, showing that the secondary market has many uncertainties that are posing a barrier to SC1's designers. The costs of the CE and risks were some of the other top barriers for SC1's design team, reinforcing previously inferred statements. Other barriers viewed as a priority for SC1's design team were the current linear laws, taxes, and a lack of support from the government.

This could be similar to the drivers recorded for SC1's designers, which suggested a desire for guidance from the government to innovate and develop a CE.

Similar to the drivers for both design groups, there were consistent levels of variance between the recorded barriers. SC1's designers viewed barriers as more impactful than SC2's. The main variance was present within the economic and institutional themes. The most notable levels of variance were the stigma surrounding secondary materials, which SC2 didn't agree with, and the lack of goals and government support, which was higher in SC1, and the lack of material classification, which was higher in SC1 and could be due to the increased level of technology in SC1 compared to SC2.

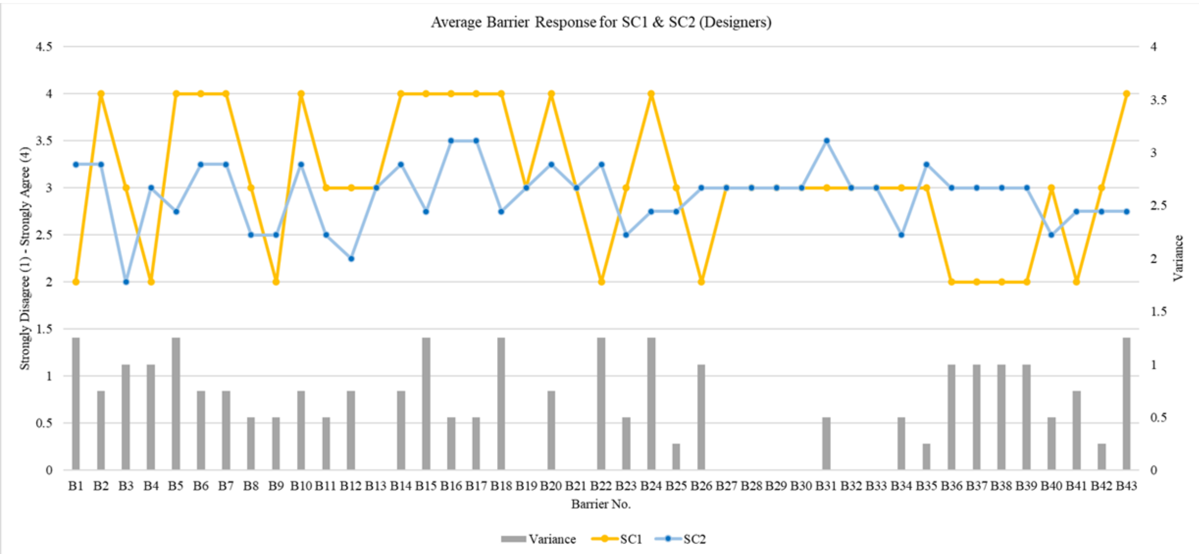

Figure 4.10: Average barrier response for SC1 and SC2 (design)

4.2.4 Sustainability

Both sustainability teams ranked the drivers as agree, showing they could be used, except for frameworks and business models in SC2 (Figure 4.11). This could be due to SC2's sustainability team's views on current models that were shared during the qualitative data collection, stating that they were theoretical and possess little impact in practice. Both supply chains shared common drivers such as procurement strategies, laws, taxes, guidance/best practices, material standards, goals/targets, and supervision. These similarities show that sustainability teams in the construction industry might have similar ideas for the CE and how to adopt it. This could be due to education, holistic knowledge of their supply chains, or based on their career origin, which, in the case of this study, stemmed from environmental sciences as opposed to construction. The was little variance between supply chains; however, the economic theme has some variation. The time and cost of the CE and secondary materials were seen as more proficient in SC1 than SC2's sustainability team. This could be due to the higher level of material and cost data in SC1, which would increase their knowledge of current practice to inspire circular innovations. Improving quality through the CE was seen as a lower driver for SC1; this could be due to the stigma of secondary materials and their quality, or a belief that the CE does not impact the quality of buildings or construction. New materials from the CE were viewed as a lesser driver in SC2 than in SC1. This contradicts the opinions of the design team in SC2, who ranked it as a higher driver for their practice. This suggests that there is a difference in approach of opinion as to the development of the CE between disciplines in SC2. Overall, both sustainability teams had similar results on the drivers of the CE and what would incentivise adoption of the strategy and its practices.

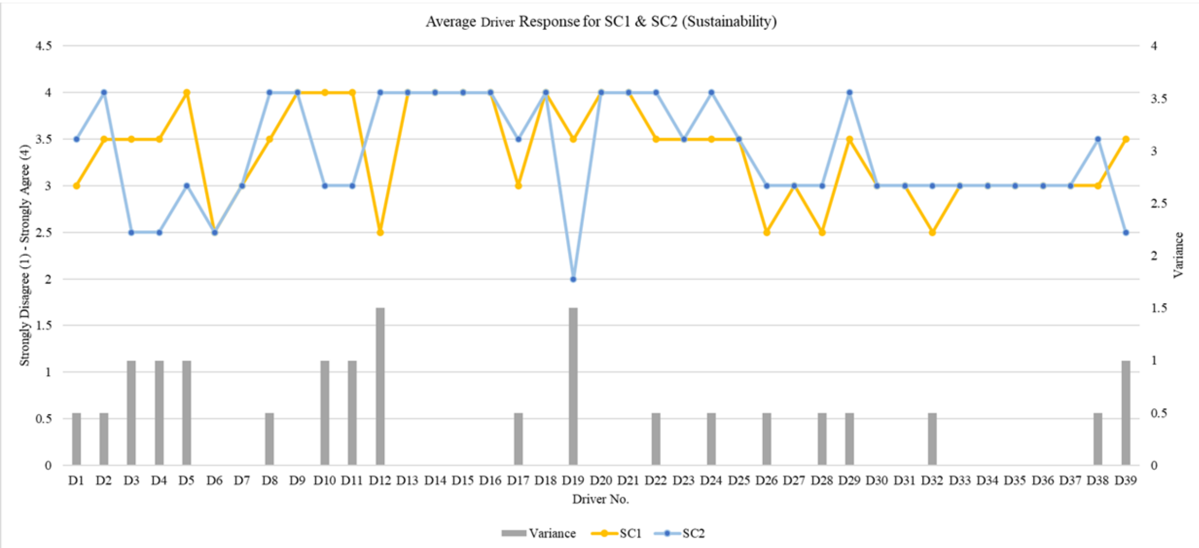

Figure 4.11: Average driver response for SC1 and SC2 (sustainability)

The barriers for both supply chains followed a similar trend, with different levels recorded (Figure 4.12). SC1 didn't disagree with any of the identified barriers, whereas SC2 disagreed with several across the different themes. SC2's sustainability team did not view the immature secondary market and low value of recovered materials as a barrier. This could be due to their frequent use of secondary materials and their insight into the commercial performances of waste recovery. This could also be the reason behind their low ranking for the stigma of secondary materials and the lack of short-term benefits. Other barriers that SC2's sustainability team disagreed with are the lack of waste infrastructure and management. This could be due to their appointment of a waste management contractor to reduce and recover waste on their projects. Finally, SC2's sustainability group disagreed with the lack of material tracking. SC2 has adopted material tracking within its logistical and waste management groups, which could be the reason for this result. The highest barriers for SC2's sustainability team were a lack of R&D, knowledge and education, material data, LCA, and benchmarking. This suggests that the lack of digitalisation within SC2, as highlighted in the data collected on the development of practices, could be posing a barrier to the sustainability team's decision-making and implementation of the CE in their supply chain. SC1's sustainability team's top-ranked barriers were the government's laws, taxes, and support, as well as a lack of case studies. This suggests that the biggest barrier to SC1 is the lack of guidance and support to innovate. This can also be seen when comparing both supply chains; SC1 has pushed innovation and research to develop, whereas SC2 follows government guidance and laws and is therefore underdeveloped compared to SC1. This highlights the need for governments to support and guide the construction industry to ensure all companies are developing equally to develop a CE. There was some variance between barriers, such as the value of recovered materials, the stigma of secondary materials, and the lack of short-term benefits, which were more prevalent in SC2's sustainability team, and case studies, which were more of a barrier to SC1's sustainability team. Overall, both sustainability teams had similar views on the barriers to their implementation of the CE.

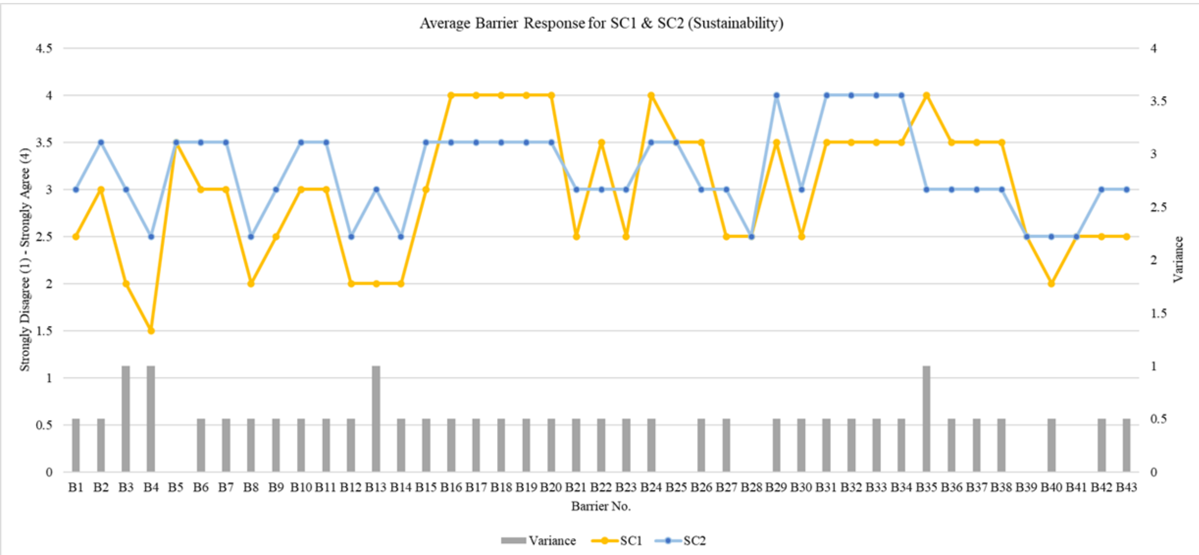

Figure 4.12: Average barrier response for SC1 and SC2 (sustainability)

4.2.5 Suppliers

The suppliers had a higher level of variance than most groups (Figure 4.13). This could provide context on the difficulties the construction industry has experienced when trying to unify its structures towards a common goal or strategy, such as the CE. The highest level of variance was the improved quality of CE products, guidance/best practices, material standards, targets, and supervision, which SC2 viewed as higher than SC1. The top drivers for SC1 are commercial and operational. The main drivers for SC1's suppliers are material markets, both linear and secondary, cost, time, and waste reduction, and financial incentives or support. This shows that SC1's suppliers are commercially focused and seek to innovate based on the financial incentives, but require support to initiate the transition. Additionally, SC1's suppliers ranked LCA as a core driver, which could be an enabler to their other top drivers. Finally, SC1's suppliers listed standardisation as a driver, which suggests that repetitive work is an enabler for data collection and optimisation. SC2, on the other hand, contained some similar drivers such as standardisation, financial incentives and support. SC2's suppliers also ranked improved quality, responsibility/recognition, and government laws, taxes, supervision, targets, standards, and guidance as key drivers. This shows that SC2's suppliers seek government change to enable their transition to a CE through multiple factors. It also suggests that they seek to maximise their product quality and wish to be recognised for their practice. Overall, it highlights SC2's aspirations to improve and their lack of support in implementing the CE.

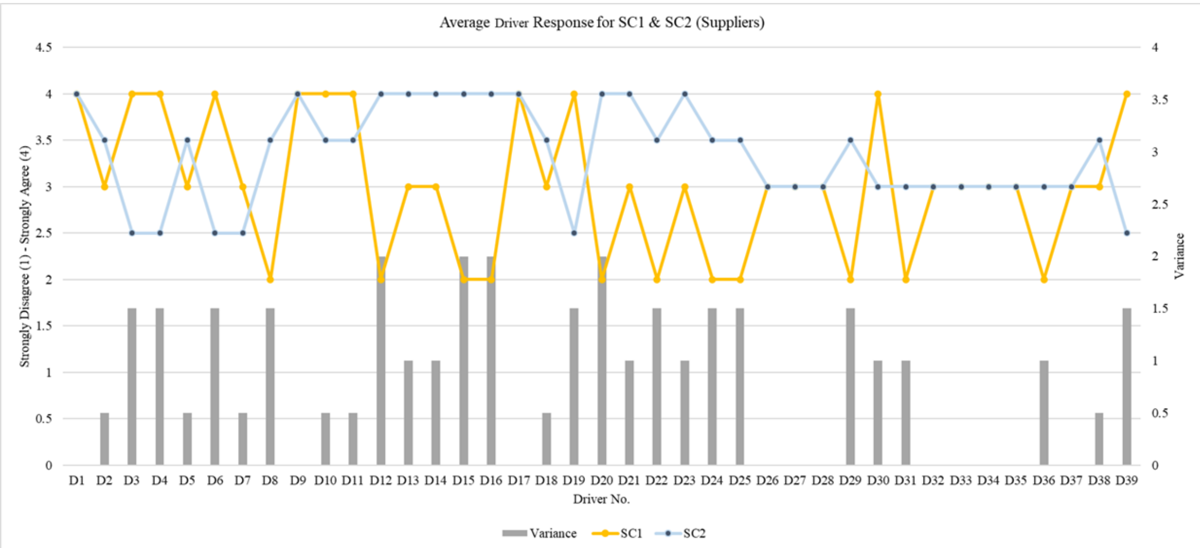

Figure 4.13: Average driver response for SC1 and SC2 (suppliers)

The barriers for SC1 were lower overall than SC2 for the supplier group (Figure 4.14). SC2's suppliers agreed that all the barriers were present, barring a lack of short-term benefits. Whereas SC1 had multiple barriers that were not seen as present. Some of the barriers that were not experienced by SC1's suppliers were a lack of financial support, government laws, goals, support, and infrastructure. This suggests that SC1's suppliers do not need the same support and guidance from the government that the construction groups do. Knowledge, education, R&D, best practice, and material technologies were also ranked as disagree. This suggests that

SC1's suppliers have the facilities and infrastructure in place to innovate and manage their development independently. SC1's suppliers also believed that LCA, benchmarking, collaboration tools, transparency, material tracking, material classification, can IPD were not barriers to their development. This shows that SC1's suppliers have developed technology to apply the CE, alleviating the barriers. SC1's top barriers were low value recovered materials, immature secondary markets, the complexity of construction, a lack of incentives/penalties, and a lack of business models or frameworks. This suggests that SC1's processes are already prepared to transition to a CE and that they need markets, incentives and models to progress with their transition. SC2's suppliers, on the other hand, ranked profitable linear markets, the high cost of secondary materials, the quality of secondary materials, the cost of transitioning, the lack of financial support, and a lack of time to design and implement the CE. This suggests that SC2's suppliers require a business model or tool to provide financial plans to communicate and develop secondary markets and products to transition to a CE. The main variance between suppliers was the institutional, social-cultural, and technological barriers that weren't identified in SC1.

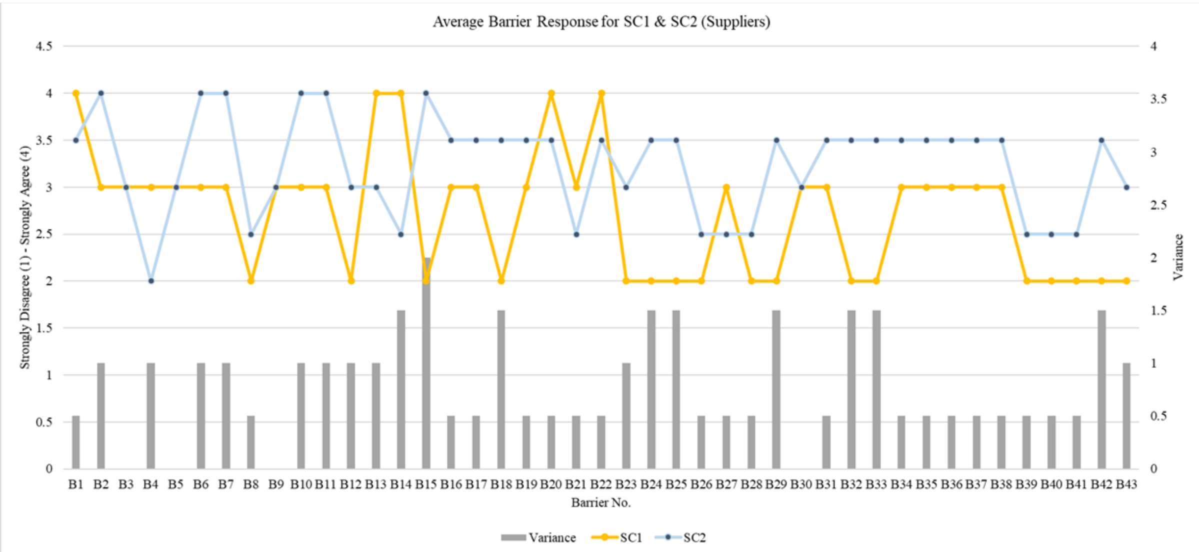

Figure 4.14: Average barrier response for SC1 and SC2 (suppliers)

4.2.6 Demolition

The demolition working group in SC1 viewed all the drivers a present with the potential to improve the adoption of the CE (Figure 4.15). The lowest drivers were guidance and best practice. Based on the analysis of the demolition group's practice, we can see that they are beyond the current best practice, which would reinforce their response for the driver. Take-back schemes were also ranked as one of their lower drivers. This could be due to the nature of the group's work, which doesn't require take-back schemes with suppliers or subcontractors. Every other driver for the demolition group was ranked highly and can be used to increase the development of the CE.

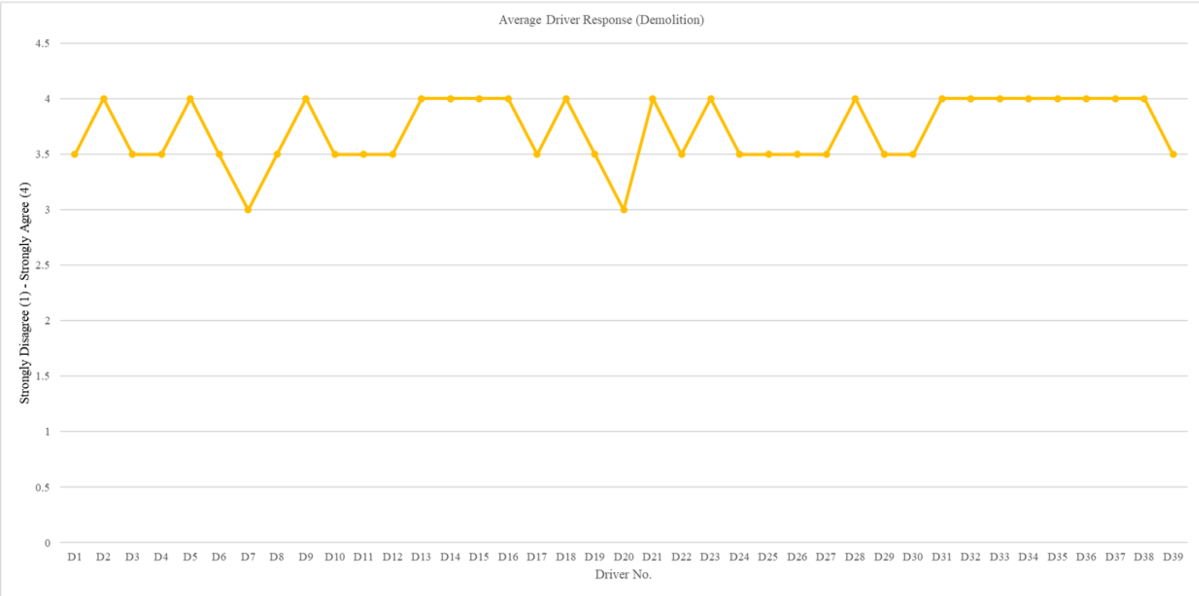

Figure 4.15: Average driver response for the demolition working group (SC1)

The barriers for SC1's demolition group were more sporadic (Figure 4.16). The group didn't view a lack of waste management as a barrier. Based on their contribution within the practices section, this is due to the use of waste management plans and segregation within the construction industry. Some of their highest-ranked barriers are the high cost of secondary materials, the stigma surrounding secondary materials, the government's laws, support, and targets, as well as a lack of incentives/penalties, responsibility/recognition, material classification, standardisation, and case studies. These barriers are divided into three categories: economic, institutional, and technological. The economic barriers identified by the group are market-related and are out of their control. Similarly, with government laws, support, targets, and incentives/penalties. Technology, on the other hand, is advancing and will improve over time. From the analysis of CE practices, material classification and standardisation were discussed as developing practices, which will provide case studies for future projects. Overall, the main barriers for the demolition group in SC1 were either external or developing and can be alleviated over time.

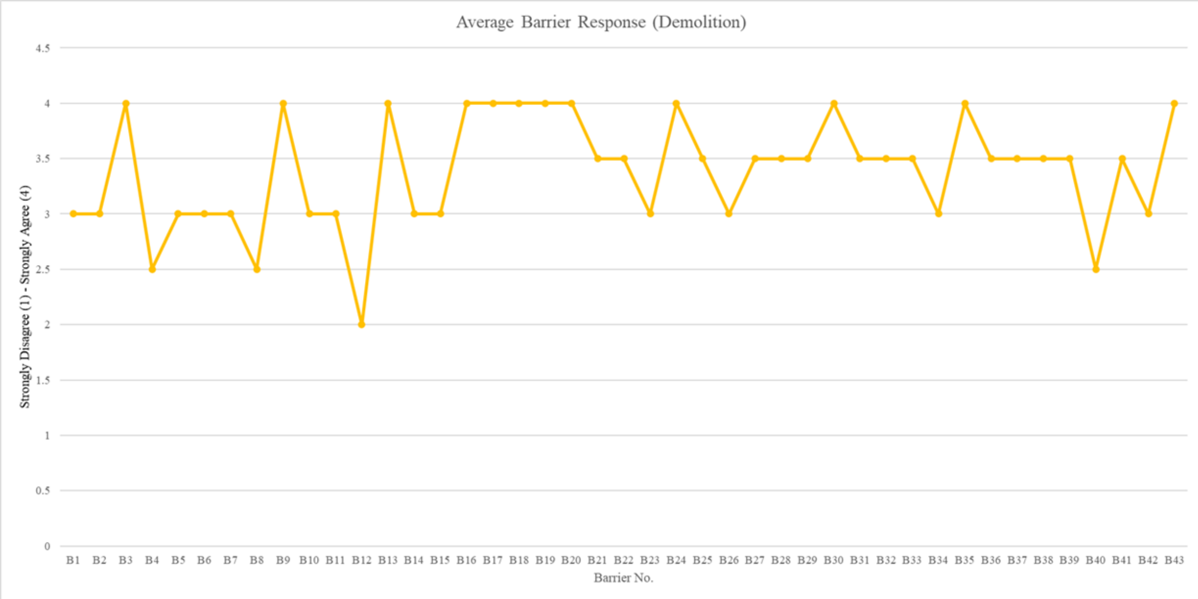

Figure 4.16: Average barrier response for the demolition working group (SC1)

4.2.7 Mechanical, Electrical, and Plumbing

The MEP group in SC1 had fluctuations between drivers, clearly presenting the highest and lowest (Figure 4.17). Some of the highest-ranked drivers were the improved quality of products, laws, taxes, servitisation, and LCA. These drivers clearly link to the type of work conducted in the MEP group. From the analysis of their practices, LCA and servitisation are key developed practices to understand and improve the quality of their product. Laws are currently providing targets for the performance of buildings, which guide MEP practice and increase the demand from clients for less impactful, higher-quality services. Taxes could also have a significant impact on the demands from consumers who may wish to analyse their buildings' performance through LCA to reduce their operational impact. Drivers that the MEP group disagreed with fall into economic, social-cultural, and technological. Economically, the MEP group didn't believe in new opportunities from the CE. This could be due to their limited scope and current level of development. Cost and time efficiency were also of low priority, which could be due to the current level of development or the belief that the CE does not facilitate these factors. This is similar to the financial support, incentives, and penalties for transitioning, which the MEP ground didn't view as a driver. The market for secondary materials and the volatility of the raw materials market were also ranked as disagree, suggesting a lack of requirement to engage in material innovation. The MEP group also disagreed with several institutional drivers, such as supervision, inspection, responsibility, and recognition. This could be due to their solitary role within the supply chain and a desire not to be checked or responsible for anything beyond their role. This could also be a factor in the ranking for IPD, which was also ranked as disagree. Finally, data sharing and collaboration tools were ranked lowly, further reinforcing the earlier point that the MEP group pursues an isolationist model.

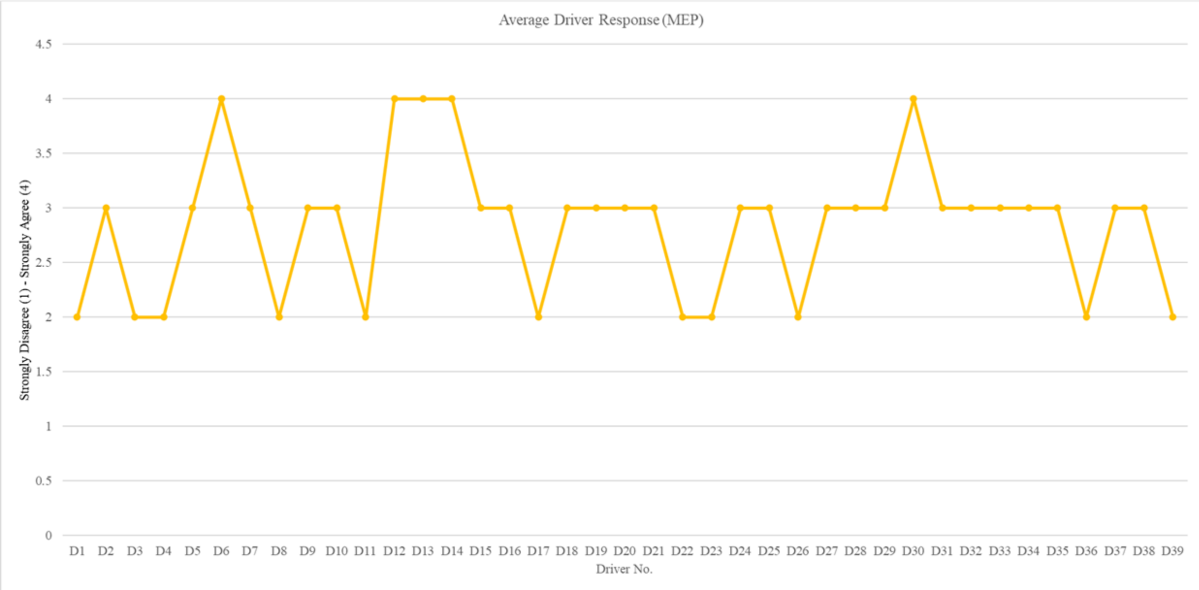

Figure 4.17: Average driver response for the MEP working group (SC1)

The barriers for the MEP group in SC1 largely fall into the economic and institutional themes, whereas the barriers that were not present were spread evenly across each theme (Figure 4.18). The highest-ranked barriers were the secondary market, cost, time, risk, linear laws, industry adoption, and the complexity of construction. These barriers show a focus on the commercial factors of the CE within the business and the wider secondary materials market. As well as the difficulties and trends of the wider industry, and the governmental barriers that control practice. Overall, these can be attributed to the immaturity of the CE and its regulation and are not necessarily internal barriers for the group. The barriers that were not believed to be present were vast. Firstly, the value of recovered materials. This could be different to other groups because of the technical nature of MEP components. Procurement, supervision, inspection, incentives, penalties, IPD, transparency, responsibility, recognition, and collaboration tools were not seen as barriers which link to the MEP group's weakest drivers, suggesting that these aspects are developed and therefore do not drive or block the development of the CE. Overall, the MEP group had the fewest drivers and barriers, suggesting that they are either more developed or protected from the implications of transitioning to a CE.

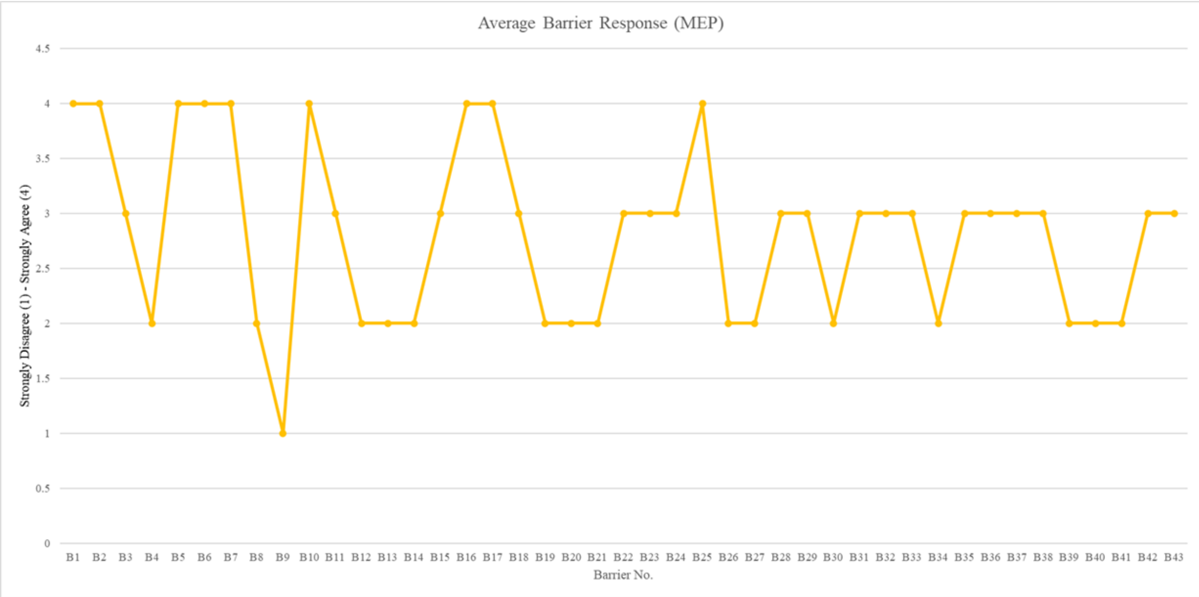

Figure 4.18: Average barrier response for the MEP working group (SC1)

4.2.7 Waste Management

The waste management group in SC2 viewed all bar one driver as present (Figure 4.19). Secondary material standards were not viewed as a driver within the group. This could be due to their knowledge of current standards for materials mitigating the potency of the driver. The highest drivers for the group were waste reduction, operational impact reduction, take-back systems, standardisation, servitisation, and LCA. This shows a focus on assessing and reducing wastes through multiple practices. This is consistent with the data provided for the practices of the CE. Other barriers which were ranked as strongly agree were laws, taxes, society's opinion, responsibility, recognition, best practices, and frameworks/business models. This shows that the driver for the waste management group also focuses on the structure and implementation of the CE through governmental and organisational directives. Overall, all of the drivers could be used to incentivise the transition to a CE in the waste management group.

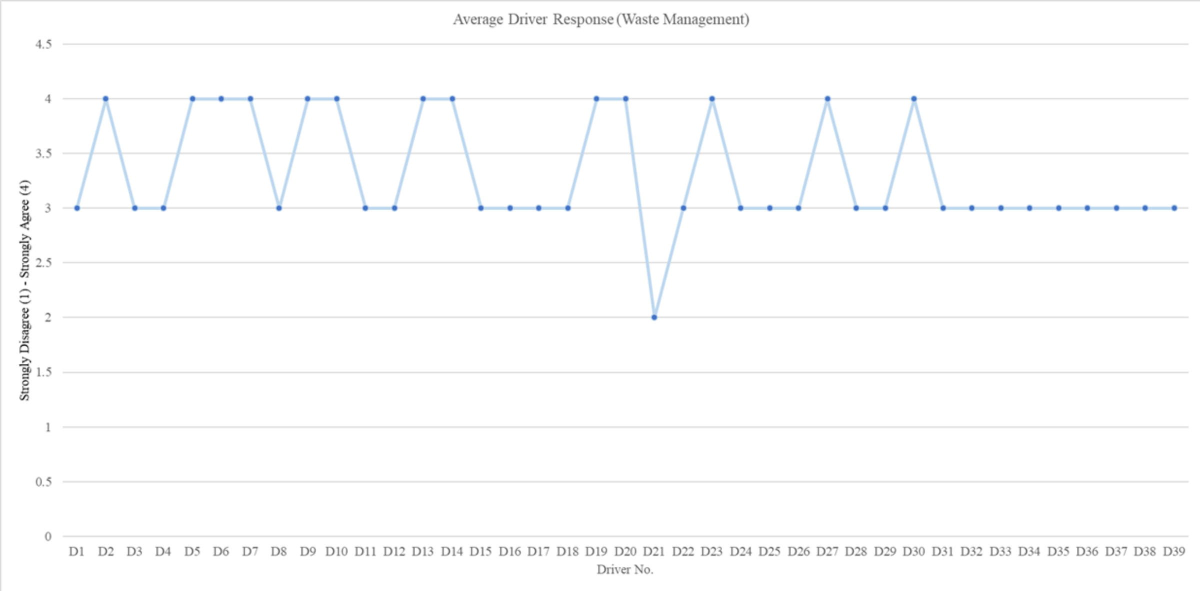

Figure 4.19: Average driver response for the waste management working group (SC2)

The waste management group for SC2 identified multiple barriers that are impeding their practice, and some that were not prevalent within their group (Figure 4.18). The main barriers for the waste management group were industrial adoption, the complexity of construction, consumer demand, and best practices. This suggests that there is not enough adoption in the construction industry as a whole to develop practice on an individual basis due to the complexity of construction and the lack of consumer demand. Moreover, the group listed a lack of supporting laws and taxes as a barrier, which could be the industry-wide incentive to overcome the previously stated barriers. The waste management group also ranked the lack of management, responsibility, recognition, and supervision as key barriers, suggesting that the organisational and contractual structure is lacking clarity or alignment with the application of strategies such as the CE. Finally, some technological barriers faced by the group were standardisation, BIM, circularity tools, and business models/frameworks. This suggests that there is too much variance within the supply chain and that digitalisation, circular tools, and frameworks are required to assist, track, and guide the transition to a CE.

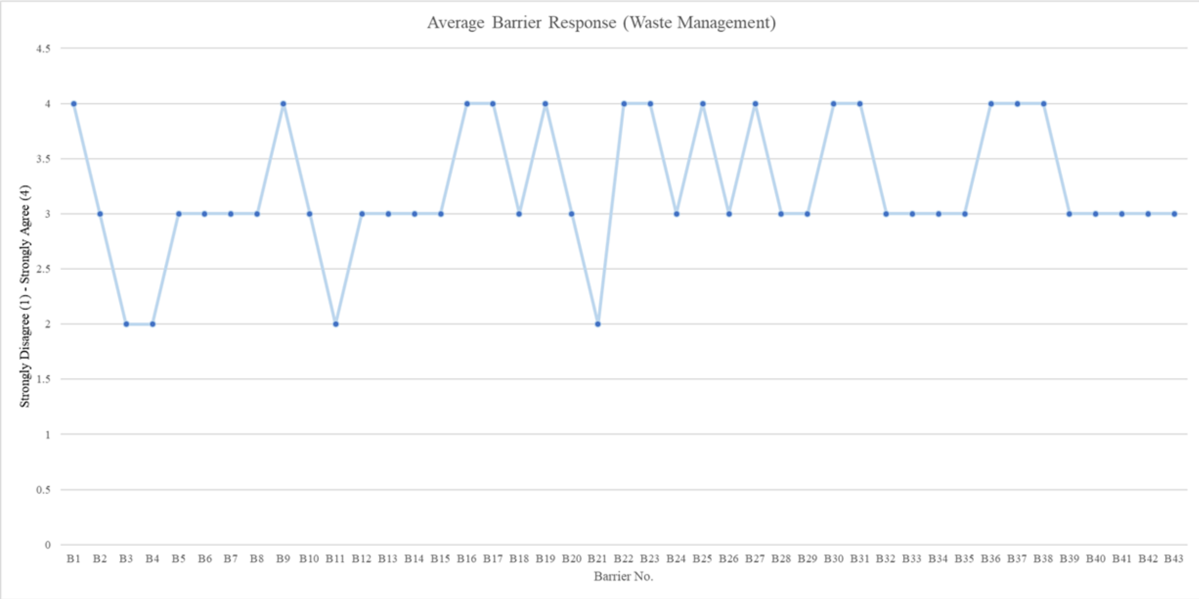

Figure 4.20: Average barrier response for the waste management working group (SC2)

4.2.8 Logistical Management

For the logistical management group in SC2, all of the drivers were ranked highly, showing that there are multiple avenues to encourage the transition to a CE (Figure 4.21). The highest drivers are within the institutional, social-cultural, and technological themes. This is consistent with their development of practice and the general culture of SC2, which focuses on the government's targets and the company ethos. One difference within the logistical management group compared to others is the drivers for technology, which were higher. This is similar to the findings for the practices of the CE, where the logistical team had the highest level of technological development compared to the other working groups of SC2.

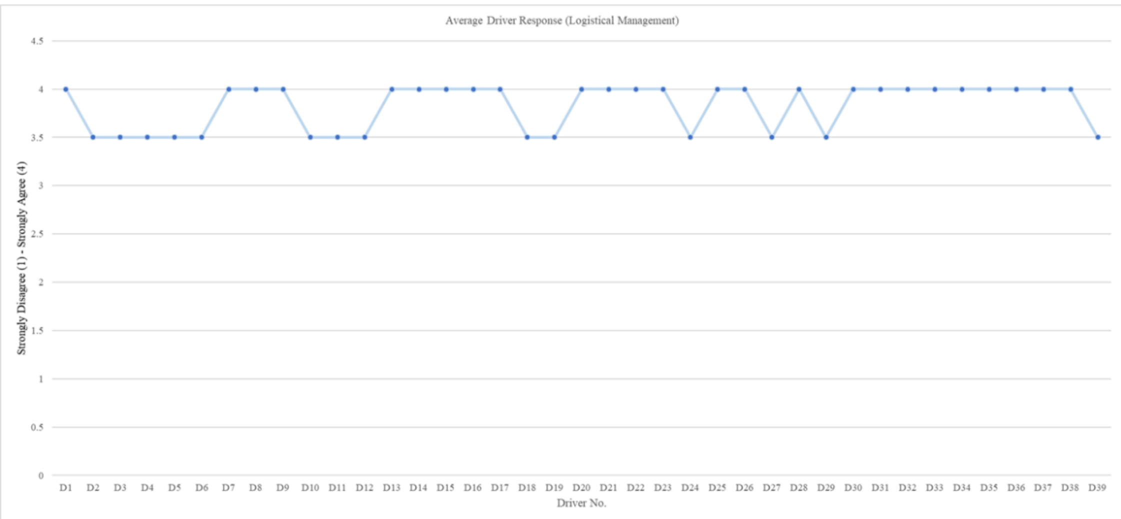

Figure 4.21: Average driver response for the logistical management working group (SC2)

The logistical management group of SC2 also found that all the barriers were present (Figure 4.22). This is interesting based on their development of practices and their responses to the drivers. The highest barriers within the group were the complexity of construction, lack of short-term benefits, industry adoption, material data, business model/framework, circular tools, and BIM. The complexity of construction and lack of short-term benefits are inherent in their role due to their contribution to the supply chain, which enables the collection and delivery of products to be used on projects. However, the lack of tools, BIM, material data, and frameworks suggests a lack of information and guidance for data-led decision making. The lowest-ranked barriers were the value of recovered materials, the stigma of secondary materials, and a lack of case studies. This suggests uncertainty within the group towards the quality and use of secondary materials, which could be overcome with case studies and material standards.

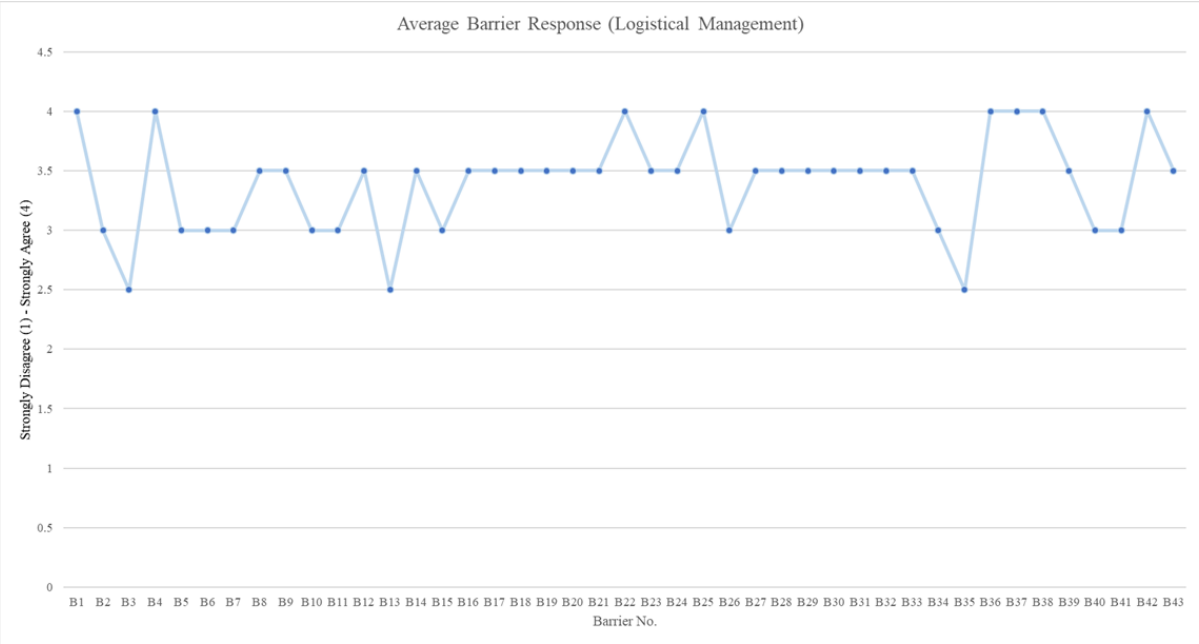

Figure 4.22: Average barrier response for the logistical management working group (SC2)

4.2.9 Procurement

The procurement group of SC2 view each driver as present (Figure 4.23). The higher-ranking drivers were procurement strategies, government laws, support, taxes, and targets, as well as recovery infrastructure, servitisation, take-back schemes, business models/frameworks, society's opinion, responsibility, recognition, and standardisation. This shows a focus on mechanisms and guidance to implement practices to meet government and consumer demands. The application of DBPs has all been consistent with this focus on meeting government and consumer demands.

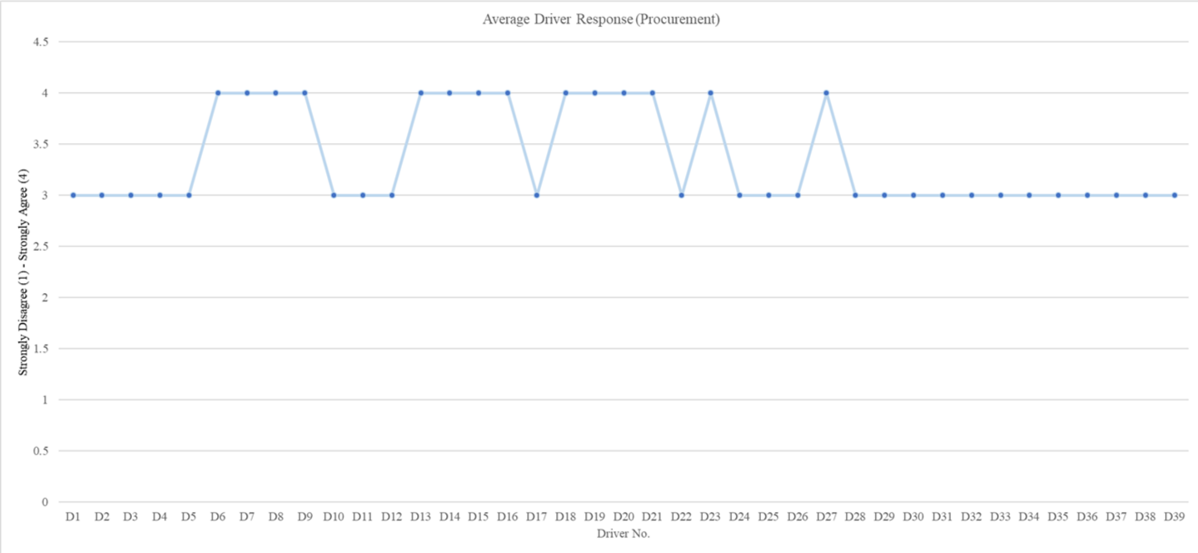

Figure 4.23: Average driver response for the procurement working group (SC2)

The barriers for the procurement group were also prevalent (Figure 4.24). The group had a higher focus on economic, institutional, and socio-cultural barriers, which is consistent with the procurement role. One barrier fell into the disagree category: a lack of waste management. This can be contextualised by the role of the waste management contractor, which has implemented waste management practices for the supply chain. The highest barriers were the lack of a secondary market, the lack of government support, laws, taxes, and the lack of best practices and industry-wide adoption. Overall, this highlights the many barriers that the procurement group are facing to establish suppliers while meeting the needs of the designers, construction managers, commercial managers, and consumers.

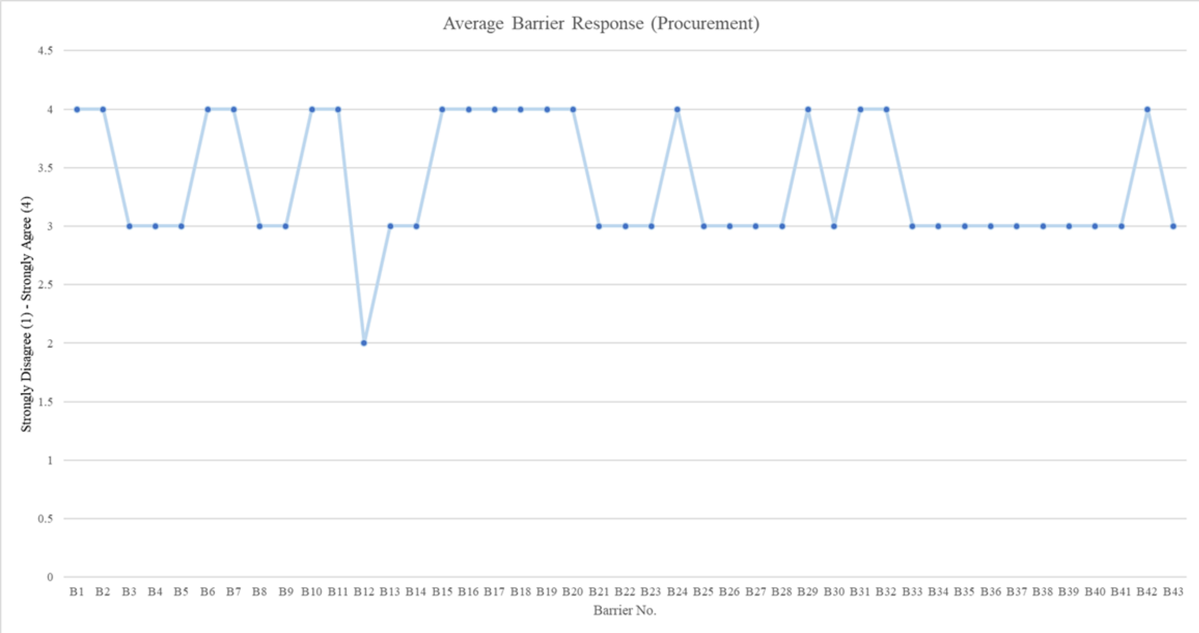

Figure 4.24: Average barrier response for the procurement working group (SC2)

4.2.10 Overview of Drivers by Supply Chain

Comparing the mean average of both supply chains (Figure 4.25), it can be seen that the drivers are present throughout both supply chains. The weakest drivers are secondary material standards, infrastructure, servitisation, data sharing, and collaboration tools. The rationale behind the low rank of secondary material standards could be due to the common standards in place for all construction materials, primary or secondary. For data sharing and collaboration tools, this could be due to intellectual property and risk avoidance, which are common in industries other than construction. For recovery infrastructure, it was commonly accepted that the current infrastructure is sufficient, which could justify its low priority. Finally, servitisation was contested in SC2 as a practice that was incompatible with their business model, which would have lowered the average. This also suggests that servitisation is not applicable to all business models or project types. The largest drivers on average are circular procurement strategies, laws, taxes, and standardisation. Procurement was commonly linked with barriers within the interviews, such as a lack of responsibility. Due to the legal nature of procurement, it was seen by participants as a practice that could enforce strategies and standards between members of the supply chain. Governmental practices were frequently ranked highly in each working group as drivers. However, there was a similar trend within the barriers, suggesting that the government holds the strongest driving power in the UK and is contributing the least to the development of a CE across the industry. Finally, standardisation was commonly ranked highest in the DBPs for both supply chains. This shows that the practice has been identified by each group as a way to simplify their products and organise the wastes produced to enable the CE in practice.

There was some variation between supply chains. Guidance/best practice, new methods of construction/deconstruction, material tracking, BIM, and circularity tools had the highest level of variance. SC2 desired more guidance and best practices to assist them in developing, whereas SC1 had begun to innovate on their own, which can be seen from the development of their practice. SC1 ranked new methods of construction/deconstruction as a key driver compared to SC2, which can be seen based on their development of modular and prefabricated elements. SC1 also ranked technological drivers such as BIM and material tracking higher than SC2, which can be seen in the level of development for said practices. This also contextualises their ranking for circularity tools, which their higher development of digital technologies would allow them to utilise compared to SC2.

Table 4.13: Top and bottom drivers of SC1 and SC2 (Mean average)

No.	Drivers (Top 10)	Avg. (SC1)	No.	Drivers (Top 10)	Avg. (SC2)
D18	Procurement strategies	3.75	D13	Laws and legislation	3.73
D13	Laws and legislation	3.67	D14	Taxes (relief and penalties)	3.73
D14	Taxes (relief and penalties)	3.67	D9	Standardisation	3.67
D38	New methods of construction and deconstruction	3.58	D2	Competitive markets	3.53
D9	Standardisation	3.58	D5	Reduced operational impact	3.53
D37	Material tracking	3.58	D27	Society's opinion of unsustainable practice	3.53
D33	BIM(BIM)	3.58	D1	New opportunities	3.47
D34	Circularity tools	3.58	D10	Waste reduction	3.47
D11	Cost efficiency	3.50	D18	Procurement strategies	3.47
D10	Waste Reduction	3.50	D20	Guidance and best practice	3.47
No.	**Drivers (Bottom 10)**	**Avg. (SC1)**	**No.**	**Drivers (Bottom 10)**	**Avg. (SC2)**
D31	Material database	3.25	D22	Integrated Project Delivery (IPD)	3.13
D32	Case studies	3.25	D38	New methods of construction and deconstruction	3.13
D21	Secondary material standards	3.17	D8	Recovery and reuse infrastructure	3.07
D7	Take-back schemes	3.17	D31	Material database	3.00
D8	Recovery and reuse infrastructure	3.00	D37	Material tracking	2.87
D22	Integrated Project Delivery (IPD)	3.00	D33	BIM(BIM)	2.87
D36	Collaboration tools	3.00	D34	Circularity tools	2.87
D20	Guidance and best practice	2.92	D36	Collaboration tools	2.87
D26	Data sharing	2.92	D6	Servitisation and maintenance	2.80
D6	Servitisation and maintenance	2.83	D26	Data sharing	2.73

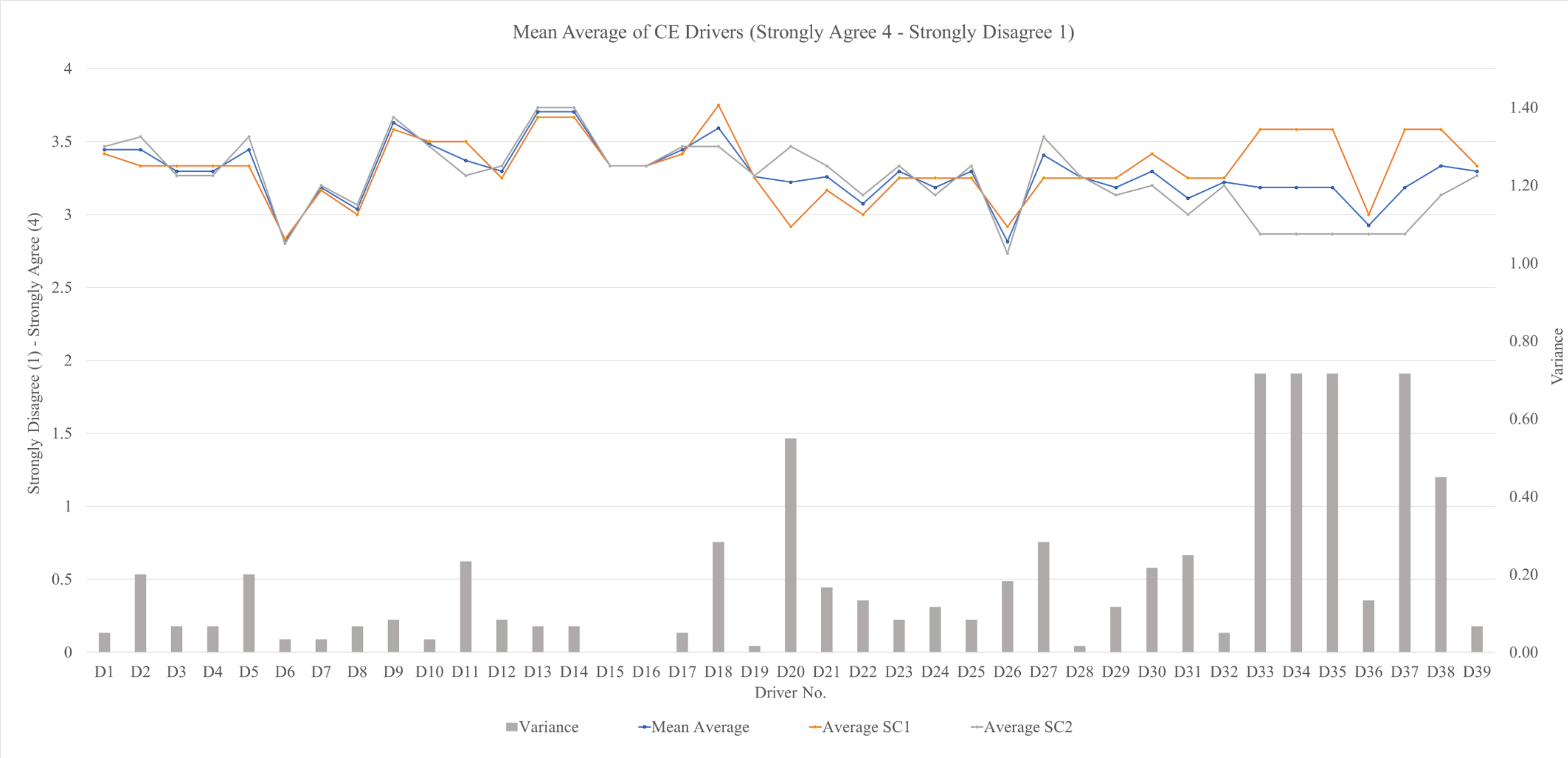

Figure 4.25: Mean average of CE drivers (Strongly agree 4 – Strongly disagree 1)

4.2.11 Overview of Barriers by Supply Chain

Comparing the mean average of both supply chains (Figure 4.26), it can be seen that there is some fluctuation between the barriers and variation between supply chains. The top barriers for both supply chains were supporting laws, taxes, the demand of the consumer, incentives/penalties, and a lack of business model or framework (Table 4.14). These barriers suggest two things: a lack of support/guidance, and a lack of commercial justification for the CE. Firstly, a lack of guidance from a legal perspective and a commercial perspective due to government directions, such as new laws and tax reliefs/penalties. Secondly, a lack of guidance from research and the creation of frameworks or business models to structure and apply the CE within their businesses. The bottom barriers were waste management, recovery infrastructure, material tracking, transparency, and a lack of short-term benefits. These barriers are interconnected and likely the bottom for a similar reason. The waste management and recovery infrastructure was identified as developed or developing within both supply chains, suggesting a good level of practice in place for the CE. In this effort, material tracking and transparency are utilised either digitally or manually to understand the levels of materials and waste being consumed and produced. Finally, the record of waste recovery and management is being financially quantified, highlighting the short-term commercial benefits to each supply chain. This link provides some rationale for the barriers being ranked lowest.

Compared with the driver's comparison, the barriers had more variance between the supply chains. Profitable linear markets, the high cost of secondary materials, the quality of secondary materials, the cost of innovation, the time required to innovate, the associated risks, lack of short-term benefits, industry adoption, best practices, consumer demand, and case studies all had high levels of variance. The majority of these barriers were higher in SC2, with the exception of the risk of innovating and a lack of case studies. Based on the nature of the barriers, it could be suggested that SC2 have more uncertainty of the commercial aspects of the CE and secondary market and are therefore more aware of what other members of the construction industry are doing to ensure that they are competitive and meet the demands of consumers. SC1, on the other hand, are more focused on the risks of their developing practices and innovations and seek case studies to alleviate said risks. Overall, the barriers that varied between the supply chains are based on the business models and targets of each supply chain.

Table 4.14: Top and bottom barriers of SC1 and SC2 (Mean average)

No.	Barriers (Top 10)	Avg. (SC1)	No.	Barriers (Top 10)	Avg. (SC2)
B16	Lack of supporting laws and legislation	3.67	B31	Lack of consumer demand	3.67
B17	Lack of taxes (relief and penalties)	3.67	B16	Lack of supporting laws and legislation	3.53
B20	Lack of incentives and penalties	3.67	B17	Lack of taxes (relief and penalties)	3.53
B35	Lack of case studies	3.50	B20	Lack of incentives and penalties	3.53
B5	Risk of innovation	3.42	B22	Lack of business models and frameworks	3.47
B18	Lack of goals and targets	3.33	B2	Profitable linear market	3.33
B24	Lack of government support	3.33	B7	High cost of secondary materials	3.33
B19	Lack of supervision	3.33	B6	Cost of innovation	3.33
B31	Lack of consumer demand	3.33	B10	Lack of time	3.33
B32	Lack of R&D	3.25	B19	Lack of supervision	3.33
No.	**Barriers (Bottom 10)**	**Avg. (SC1)**	**No.**	**Barriers (Bottom 10)**	**Avg. (SC2)**
B9	Lack of standardisation	2.83	B28	Lack of marketing and awareness	2.93
B39	Lack of collaborative tools	2.83	B34	Lack of material data	2.93
B2	Profitable linear market	2.75	B43	Lack of material classification	2.93
B7	High cost of secondary materials	2.75	B43	Lack of short-term benefits	2.80
B6	Cost of innovation	2.75	B26	Lack of Integrated Project Delivery (IPD)	2.80
B10	Lack of time	2.75	B39	Lack of collaboration tools	2.80
B23	Lack of best practice	2.67	B8	Lack of infrastructure for recovery and reuse	2.73
B8	Lack of infrastructure for recovery and reuse	2.58	B3	The stigma surrounding secondary materials	2.67
B40	Lack of material tracking	2.58	B36	Lack of information	2.67
B11	Lack of short-term benefits	2.17	B40	Lack of material tracking	2.67

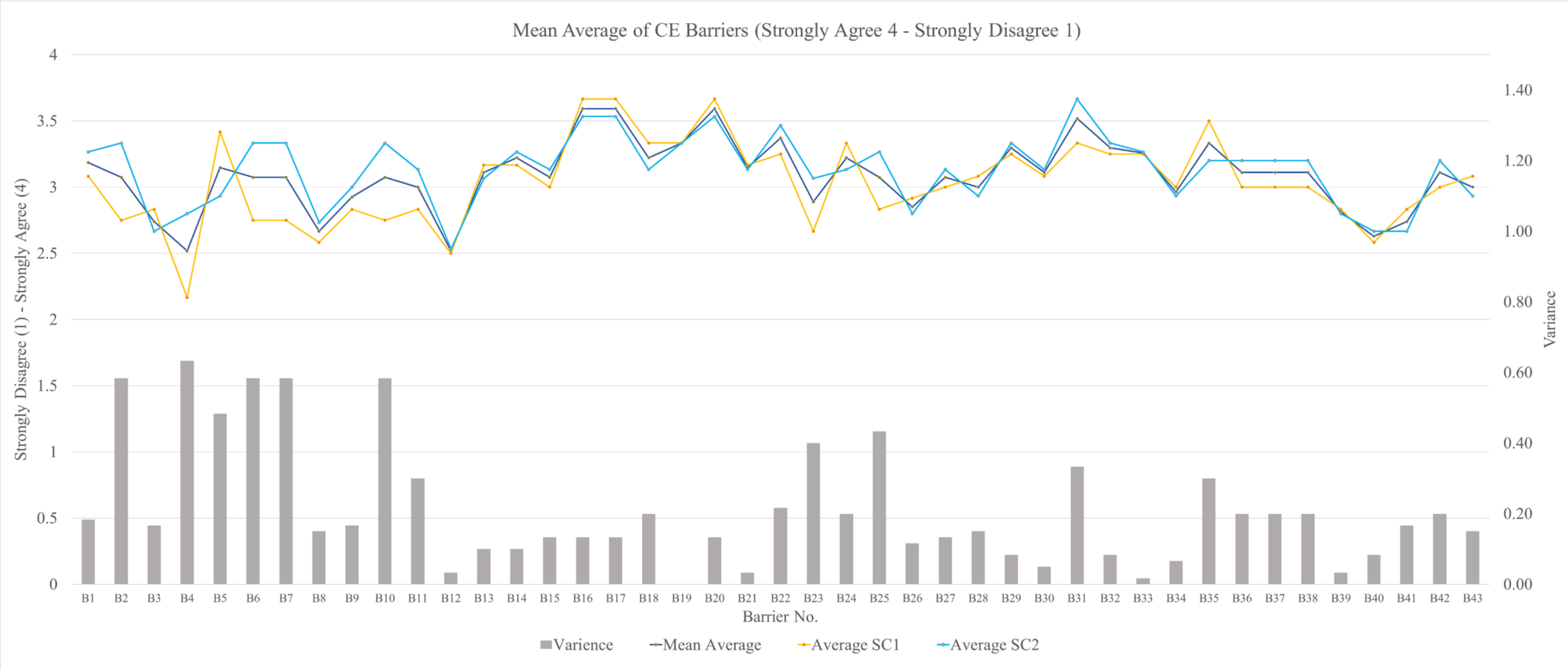

Figure 4.26: Mean average of CE barriers (Strongly agree 4 – Strongly disagree 1)

4.3 Cross-Analysis of the DBPs of the Circular Economy

When looking at the DBPs of the taxonomy in unison (Figure 4.27), there are clear correlations between like-for-like domains. Within the economic theme, recovery and reuse infrastructure, practice was seen as underdeveloped/developing, the driver as agree, and the barrier was between agree and disagree. This shows that the development of recovery and reuse infrastructure would benefit the CE in practice, but a lack of it isn't seen as a barrier due to the presence of linear options. Another available comparison is standardisation, which was categorised as developed, seen as a driver, and the lack of standardisation was viewed as a barrier. This shows that standardisation is a key practice for the CE and generally within the construction industry to simplify processes, materials, and designs to enact more complicated practices. Servitisation also had an interesting dynamic whereby the practice was underdeveloped, the driver was between agree and disagree, and the barrier was ranked as agree. This suggests that there is a driver for implementing a PSS; however, there are barriers to implementing it at the moment, which explains the underdeveloped nature of the practice. Some of the more straightforward comparisons were financial support and incentives/penalties. Financial support was seen as underdeveloped, and a lack of financial support was identified as a strong barrier. Similarly, incentives/penalties were seen as underdeveloped, a key driver, and there is a lack of incentives/penalties. Both suggest that a lack of developed practice is inflating the driver and barrier domains and that developing financial support, incentives, and penalties would improve the transition to a CE.

For the institutional theme, laws and regulations, taxes, goals and targets, supervision, procurement, frameworks/business models, and best practices were comparable. Laws and regulations were seen as developing; however, they were also ranked as a significant driver and barrier of the CE, suggesting that they need to improve to assist the transition. Taxes were seen as a developed, large driver and a large barrier to a CE. This suggests that the tax system for linear goods and waste is working to incentivise and penalise supply chains to circular options; however, the high ranking of the barrier suggests that the taxes of circular goods are too high, and levies should be put in place to further incentivise the transition to a CE. Furthermore, supervision and inspections were listed as underdeveloped, a driver, and the lack of them was seen as a barrier. This shows that supervision would be a key practice for improving the circularity of practice within the supply chains. Additionally, goals and targets and guidance and best practice could be beneficial to enable supervision by providing criteria for inspections. Goals and targets were seen as developing, a driver, and the lack of them were seen as a barrier. Similarly, best practice and guidance were seen as lacking, which poses a barrier and is a key driver of the CE. These suggest that the development of goals and targets and guidance and best practice would improve the development of the CE and its application. Procurement was also a comparable domain; the practice was seen as underdeveloped, it was seen as a powerful driver, and the lack of circular procurement was seen as a barrier to a CE. This suggests that the development of circular procurement criteria would clarify the CE in practice and enforce its implementation. Finally, frameworks and business models were seen as underdeveloped within construction, a driver for practice, and the lack of them was seen as a barrier. This suggests that the development of frameworks and business models for construction would assist with guiding and evaluating the CE's development in practice.

For the social-cultural theme, IPD, responsibility and recognition, marketing and awareness, knowledge and education, and consumer-focused domains were comparable. The IPD domain results were neutral as a practice or barrier; this shows that IPD is not developing, and the lack of IPD does not currently pose a barrier. IPD was found as a driver within both supply chains, showing that it could benefit the CE. IPD could also be beneficial when developing responsibility and recognition within the supply chains to which the participants said were underdeveloped, could drive the CE, and the lack of responsibility poses a barrier to a CE. Knowledge and education were also comparable domains; as a practice, it was seen as neither developed nor underdeveloped, it was seen as a driver, and the lack of knowledge and education was seen as a barrier. This suggests that the generation of knowledge and education for the CE needs to be improved to advance the CE. Similarly, the understanding of the CE amongst consumers was lacking in practice, present as a motivational driver, and posed a barrier. This suggests that consumers need to be better understood and marketed to increase the support of the CE. Additionally, marketing and awareness were seen as underdeveloped, a driver for the CE, and the lack of marketing and awareness was seen as a barrier. The similarities between education, consumers, and awareness show that there is a lack of social practices being conducted to inform and indoctrinate consumers and practitioners into a CE systems thinking.

Within the technological theme, LCA, material data, case studies, BIM, material tracking, transparency, circular design, and collaboration tools were comparable. LCA and BIM were seen as underdeveloped, a driver, and the lack of LCA/BIM was seen as a barrier to CE development. This suggests that there is a lack of data collection within the construction industry to understand the performance of the CE. Additionally, a lack of case studies was identified; however, it was seen as a driver, and the lack of studies was seen as a barrier to understanding the implementation of the CE. Material databases, material tracking, and information transparency were also seen as underdeveloped in practice, a driver to a CE's development, and a barrier when missing. Finally, circular, design, and collaboration tools were seen as severely underdeveloped, and big drivers/barriers to the development of the CE within practice.

Global Theme	No.	Practices	Mean Average	No.	Drivers	Mean Average	No.	Barriers	Mean Average
Economic	P1	Design for Closed Loops	2.50	D1	New Economic & Environmental Opportunities for Businesses	3.44	B1	Complexity of Construction	3.19
	P2	Design for Longevity	2.33	D2	Industrial Competition	3.44	B2	Profitable Linear Market	3.07
	P3	Design for Disassembly	2.17	D3	Secondary Material Production/Supply	3.30	B3	The Stigma Surrounding Secondary Materials	2.74
	P4	Closed-loop Material Specification	2.25	D4	Raw Material Volatility	3.30	B4	Lack of Short-term Benefits	2.52
	P5	Reduced Operational Impact	2.67	D5	Reduced Environmental Impact	3.44	B5	Risk of Innovating	3.15
	P6	Servitisation/PSS	2.36	D6	Servitisation/PSS	2.81	B6	Cost of Innovating	3.07
	P7	Take-Back Systems	2.79	D7	Take-back Schemes	3.19	B7	High Cost of Secondary Products	3.07
	P8	Recovery and Reuse Infrastructure	2.64	D8	Recovery and Reuse Infrastructure	3.04	B8	Lack of Infrastructure for Recovery and Reuse	2.67
	P9	Standardisation	3.20	D9	Standardisation	3.63	B9	Lack of Standardisation	2.93
	P10	Prefabrication	3.44	D10	Waste Reduction	3.48	B10	Lack of Time	3.07
	P11	Modularisation	3.14	D11	Cost and Time Efficiency	3.37	B11	Quality of Secondary Materials	3.00
	P12	Waste Management	2.93	D12	Improved Product Quality	3.30	B12	Lack of Segregation	2.52
	P13	Upcycling/Downcycling	3.14				B13	Low-value Recovered Materials	3.11
	P14	Urban Mining	3.00				B14	Immature Secondary Market	3.22
	P15	Financial Support	1.67				B15	Lack of Financial Support	3.07
Institutional	P16	Laws and Regulations	3.00	D13	Circular Laws and Legislation	3.70	B16	Lack of Supporting Laws and Legislation	3.59
	P17	Taxation	3.50	D14	Taxes (Relief and Penalties)	3.70	B17	Lack of Taxes (Relief and Penalties)	3.59
	P18	Goals and Targets	3.33	D15	Goals and Targets	3.33	B18	Lack of Goals and Targets	3.22
	P19	Supervision	2.50	D16	Supervision and Inspections	3.33	B19	Lack of Supervision	3.33
	P20	Incentives	2.88	D17	Financial Incentives	3.44	B20	Lack of Incentives and Penalties	3.59
	P21	Circular Procurement	2.00	D18	Procurement Strategies	3.59	B21	Lack of Procurement Strategy	3.15
	P22	Frameworks/Business Models	2.33	D19	Frameworks/Business Models	3.26	B22	Lack of Frameworks/Business Models	3.37
	P23	Top-down/Bottom-up Management	2.38	D20	Guidance and Best Practice	3.22	B23	Lack of Guidance and Best Practice	2.89
	P24	Material Standards/Classification	3.11	D21	Secondary Material Standards	3.26	B24	Lack of Government Support	3.22
	P25	The 3-12Rs of the Circular Economy	2.00				B25	Lack of Industry Adoption	3.07
	P26	The Lean Philosophy	2.58						
Social-Cultural	P27	Integrated Project Delivery (IPD)	2.50	D22	Integrated Project Delivery (IPD)	3.07	B26	Lack of Integrated Project Delivery (IPD)	2.85
	P28	Extended Responsibilities	1.67	D23	Responsibility and Recognition	3.30	B27	Lack of Responsibility and Recognition	3.07
	P29	Marketing and Awareness of the CE	2.75	D24	Marketing and Awareness Campaigns	3.19	B28	Lack of Marketing and Awareness of the CE	3.00
	P30	Knowledge Management and Education	2.86	D25	Education Programs	3.30	B29	Lack of Knowledge and Education	3.30
	P31	Establishing Communication and Information Sharing	2.30	D26	Data sharing	2.81	B30	Lack of Management	3.11
	P32	Understanding the Product, Process, and Consumer	2.50	D27	Society's Opinion of Unsustainable Practice	3.41	B31	Lack of Consumer Demand	3.52
	P33	Research and Development	3.00	D28	Research and Development	3.26	B32	Lack of Research and Development	3.30
				D29	New networks	3.19			
Technological	P34	Lack of Life Cycle Analysis (LCA) and Benchmarking	2.22	D30	Lack of Life Cycle Analysis (LCA) and Benchmarking	3.30	B33	Lack of Life Cycle Analysis (LCA) and Benchmarking	3.26
	P35	Data Collection and Communication	2.82	D31	Material Database	3.11	B34	Lack of Material Data	2.96
	P36	Case Studies	2.00	D32	Case Studies	3.22	B35	Lack of Case Studies	3.33
	P37	Building Information Modelling (BIM)	2.40	D33	Building Information Modelling (BIM)	3.19	B36	Lack of Information	3.11
	P38	Circularity Tools	1.00	D34	Circularity tools	3.19	B37	Lack of Circular Tools	3.11
	P39	Cost Modelling Tools	1.67	D35	Design tools	3.19	B38	Lack of Design Tools	3.11
	P40	Collaboration Tools	2.00	D36	Collaboration tools	2.93	B39	Lack of Collaboration Tools	2.81
	P41	Material Passports	1.75	D37	Material Tracking	3.19	B40	Lack of Material Tracking	2.63
	P42	Information Management and Transparency	2.67	D38	New Methods of Construction and Deconstruction	3.33	B41	Lack of Transparency	2.74
	P43	New Secondary Material Developments	2.00	D39	New Materials	3.30	B42	Lack of Material Technology	3.11
	P44	Digitalisation	2.08				B43	Lack of Material Classification	3.00
	P45	Internet of Things (IoT)	3.00						
	P46	Blockchain	1.00						

Figure 4.27: Taxonomy with quantitative data for empirical data collection

4.4 Summary

Both supply chains had different levels of development and faced different drivers and barriers. When comparing the two supply chains, SC1 had a focus on modern methods of construction and technology, whereas SC2 had a focus on commercial and socio-cultural practices. Both had similar results for the institutional practices with varying levels. When comparing working groups, the construction management, commercial management, and sustainability teams had similar responses to the supply chains' development. The design and supplier groups had different opinions to the rest of their supply chains. This comparison was similar when looking at the drivers and barriers in each supply chain. However, the comparison between supply chains showed contrasting results compared to the practices section, where there were some similarities between supply chains.

4.4.1 Drivers

For the identified drivers of the CE, all of them were viewed as present when taking the mean average across each supply chain. A level of variance was seen for guidance/best practice, BIM, circular, cost, and collaboration tools, material tracking, and new methods of construction/deconstruction between the supply chains. The small level of variance highlights different approaches between each supply chain. SC1, for example, seeks new innovations and digital tools to improve the performance of its practice. Compared to SC2, who seek best practice and guidance to inform their transition to a CE. This highlights the divide between innovative and traditional conservative organisations within the construction industry. Overall, the results of the CE's drivers were positive, showing that there is a range of drivers that could motivate the construction industry to transition to a CCE.

4.4.2 Practices

The practices had a higher level of variance compared to the drivers and barriers of the CE. Different disciplines had different levels of knowledge of the practices in theory and operation. However, the average responses between supply chains showed a level of similarity across most practices. The practices with a higher level of variance were primarily in the economic and technological themes. SC1 had a higher level of development for economic practices such as standardisation, prefabrication, and modularisation. SC1 also possessed a higher level of digital technologies, such as BIM and LCA, which allowed them to understand the generation and impact of waste materials and enact practices for their reduction. SC2 on the other hand, had a higher level of waste management practice and infrastructure, which allowed the categorisation and recovery of waste. The higher level of development within SC2 for the management of waste also provided data on the types of waste to develop targets to minimise waste generation on their projects. Although both supply chains had a good level of development amongst the CE's practices, a significant number were either underdeveloped or not present within the supply chains. This suggests that as the CE develops, more practices will emerge within the industry and mitigate the barriers opposing the current CE transition.

4.4.3 Barriers

The identified barriers of the CE were also present at a concerning level. The only barrier below the 2.5 level of presence was the lack of short-term benefits in SC1. This suggests that as an overall mean average, all of the barriers were present and need addressing to increase the adoption and transition of the CE's practices within the construction industry. However, the barriers have the potential to be mitigated through the adoption of practices and use of drivers, for example, technological practices for data collection and interpretation. Some barriers varied between supply chains based on project type and level of innovation towards the CE. Due to the higher level of development within SC1 towards practices in the economic and technological themes, SC1's barriers for the associated themes were reduced compared to SC2. This shows that the implementation of practices that stem from drivers can assist with the mitigation of barriers for the transition towards the CE.

4.4.4 Lessons Learned from Empirical Studies to Inform Circular Economic Development

Common DBPs that were present throughout each group and supply chain were laws and regulations, guidance/best practices, frameworks, and business models. These commonalities suggest that, above all, the supply chains require guidance through a model that can assess their circular needs and prescribe practices that can assist them to develop in a tailored fashion to achieve their organisational targets. Based on the analysis of both supply chains, it would also require the ability to compare disciplines and working groups to tailor the strategy to their needs, whilst meeting the overall goals of the supply chain. Characteristics suggested by participants during the empirical data collection are a framework that is simple, measurable, prescriptive, holistic, scalable, and adaptable to mitigate barriers from a lack of government and institutional guidance, whilst developing examples of best practice and case studies.

CHAPTER 5: DEVELOPMENT OF THE ANALYTICAL CIRCULAR CONSTRUCTION ECONOMY (ACCE) FRAMEWORK

This section presents the development and use of the Analytical Circular Construction Economy (ACCE) framework. The framework was developed from the literature review, as well as the qualitative and quantitative data from the analysis and results of the semi-structured interviews (Figure 5.1). The systematic literature review (1) provided the theories for the identification of the CE's DBPs (2) within four themes (3). The DBPs were developed into a theoretical framework (4) and investigated within the empirical data collection (5). Both the theoretical framework and findings from the empirical data collection were then used to develop the analytical framework (6). The framework is then used by identifying DBPs within the literature review (1) or theoretical framework (4), and inputted into the analytical framework (6). The results presented within the framework can then be reviewed against the theoretical framework and literature review before repeating the process. This chapter is presented in two stages: initially, the development of the framework, followed by the characteristics and use of the framework.

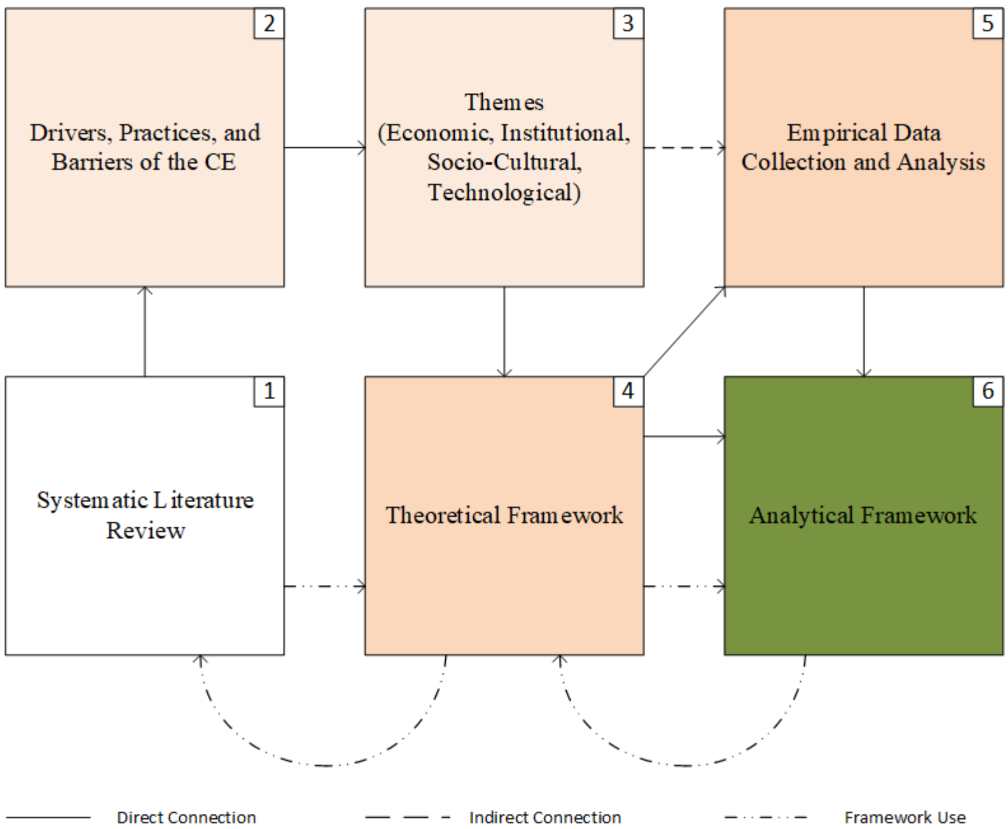

Figure 5.1: Development and use of the frameworks

5.1 Framework development and revision

Based on the findings from the qualitative and quantitative analyses, it was determined that a framework of the CE to guide practical application is a core requirement to advance the CE. Compared to existing frameworks, the results from the empirical data collection found that a practical framework is desired within the analysed supply chains. Some of the key characteristics identified are as follows: simple, measurable, prescriptive, scalable, adaptable, and holistic. This suggests that the existing theoretical framework is not sufficient to meet the needs of practitioners in their transition towards a CCE and that a new framework of an analytical design is required to include the characteristics identified within the empirical studies.

Multiple revisions were developed to meet the criteria identified within the empirical data collection (Figure 5.2). Initially, a taxonomy was developed from the literature to create a theoretical framework for the structure of the CE (1). The theoretical framework was then used as a basis for the metrics on the DBPs of the CE. The DBPs were then investigated within the empirical data collection to understand the development of the CE in practices, and factors driving and posing barriers to development. This highlighted the need for an analytical framework for measuring the DBPs within supply chains, working groups, companies, and as an industry to guide the CE within construction.

The early frameworks sought to attach the DBPs to the construction lifecycle at different scales of practice (2 and 3). Frameworks 2 and 3 provided some structure to the practices within the lifecycle and operations dynamics; however, the size of the framework meant that all of the DBPs could not be easily incorporated within the figure. To account for this, a new framework was developed (4) to include more DBPs with less emphasis on their dynamic within the construction lifecycle. Drivers were noted on the left, barriers were noted on the right, and practices were placed in the centre with correlating titles to state their scale within the lifecycle (i.e., concept, process, or system). This increased the functionality of the framework by making it more compact; however, it was still overly complicated and did not convey all of the information captured within the theoretical framework (1). Furthermore, the framework was static and did not provide any measurable characteristics or analytical abilities to guide practitioners. Furthermore, framework 4 was then combined with the Royal Institute of British Architects' plan of works to add familiarity and practicality for practitioners (5). This allowed the framework to meet the holistic, prescriptive, and scalable characteristics, but did not meet the adaptable, measurable, and simple requirements. This forced a change in the design to ensure that the framework was simple, adaptable, and measurable while retaining the holistic, prescriptive, and scalable characteristics.

The circular model was then developed (6-9) as a framework that measures and analyses the DBPs quantitatively through a Likert scale. The final circular framework completely redesigned the former frameworks with a focus on the measurability of the DBPs and the requirements of practitioners to be simple, measurable, prescriptive, scalable, adaptable, and holistic. This framework could be used at different scales of the business and repeated to view changes or developments. The measurement of the metrics provided guidance to prescribe practices based on necessity, and identified drivers, as well as the identification of barriers to development to be mitigated. The framework was designed to be simple to understand, adaptable to different scales and focuses, and to contain a holistic set of metrics that could be selected based on the users' preferences. To increase the understanding and simplicity of the framework, a methodological model was also developed to instruct the user on the designed approach to applying the framework.

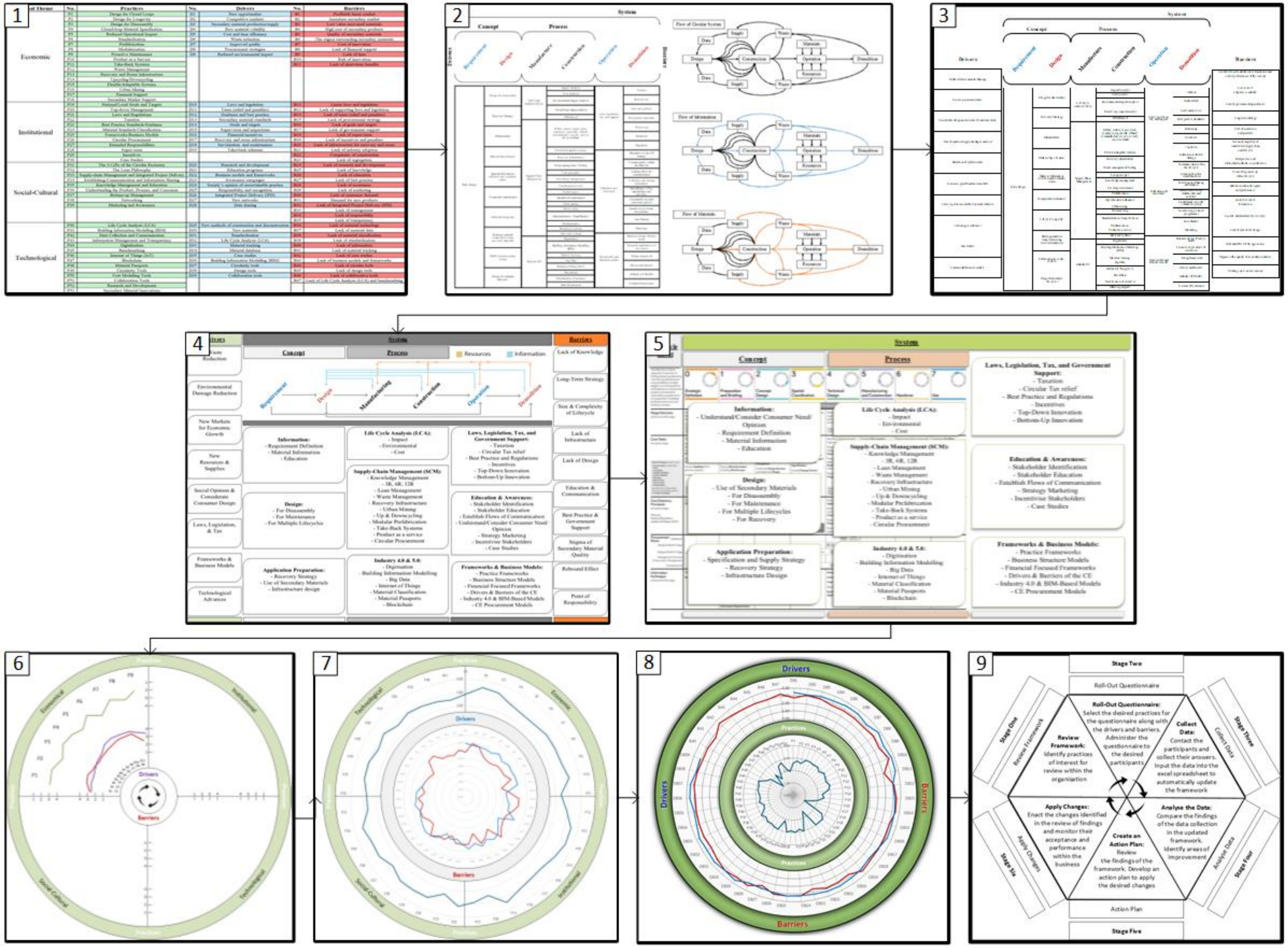

Figure 5.2: Development of ACCE framework

5.2 The circular measurement framework

Figure 5.3 shows the taxonomy developed from the literature of the CE's DBPs. The DBPs are assigned to themes which state their focus (i.e. economic, institutional, social-cultural, and technological). This categorisation assists organisations in selecting practices based on their focus for development. Each driver, barrier, and practice have a code attached to it to assist its identification within the analytical framework (Figure 5.4). The taxonomy has therefore developed into a legend for selecting domains and interpreting the analytical framework. For further information, the taxonomy provides direction to the systematic literature review, which provides context and examples of practice for practitioners to view for guidance. The taxonomy is a core development of the CE for the holistic understanding of the range of DBPs within the CCE.

Global Theme	No.	Practices	No.	Drivers	No.	Barriers
Economic	P1	Design for Closed Loops	D1	New Economic & Environmental Opportunities for Businesses	B1	Complexity of Construction
	P2	Design for Longevity	D2	Industrial Competition	B2	Profitable Linear Market
	P3	Design for Disassembly	D3	Secondary Material Production/Supply	B3	The Stigma Surrounding Secondary Materials
	P4	Closed-loop Material Specification	D4	Raw Material Volatility	B4	Lack of Short-term Benefits
	P5	Reduced Operational Impact	D5	Reduced Environmental Impact	B5	Risk of Innovating
	P6	Servitisation/PSS	D6	Servitisation/PSS	B6	Cost of Innovating
	P7	Take-Back Systems	D7	Take-back Schemes	B7	High Cost of Secondary Products
	P8	Recovery and Reuse Infrastructure	D8	Recovery and Reuse Infrastructure	B8	Lack of Infrastructure for Recovery and Reuse
	P9	Standardisation	D9	Standardisation	B9	Lack of Standardisation
	P10	Prefabrication	D10	Waste Reduction	B10	Lack of Time
	P11	Modularisation	D11	Cost and Time Efficiency	B11	Quality of Secondary Materials
	P12	Waste Management	D12	Improved Product Quality	B12	Lack of Segregation
	P13	Upcycling/Downcycling			B13	Low-value Recovered Materials
	P14	Urban Mining			B14	Immature Secondary Market
	P15	Financial Support			B15	Lack of Financial Support
Institutional	P16	Laws and Regulations	D13	Circular Laws and Legislation	B16	Lack of Supporting Laws and Legislation
	P17	Taxation	D14	Taxes (Relief and Penalties)	B17	Lack of Taxes (Relief and Penalties)
	P18	Goals and Targets	D15	Goals and Targets	B18	Lack of Goals and Targets
	P19	Supervision	D16	Supervision and Inspections	B19	Lack of Supervision
	P20	Incentives	D17	Financial Incentives	B20	Lack of Incentives and Penalties
	P21	Circular Procurement	D18	Procurement Strategies	B21	Lack of Procurement Strategy
	P22	Frameworks/Business Models	D19	Frameworks/Business Models	B22	Lack of Frameworks/Business Models
	P23	Top-down/Bottom-up Management	D20	Guidance and Best Practice	B23	Lack of Guidance and Best Practice
	P24	Material Standards/Classification	D21	Secondary Material Standards	B24	Lack of Government Support
	P25	The 3-12Rs of the Circular Economy			B25	Lack of Industry Adoption
	P26	The Lean Philosophy				
Social-Cultural	P27	Integrated Project Delivery (IPD)	D22	Integrated Project Delivery (IPD)	B26	Lack of Integrated Project Delivery (IPD)
	P28	Extended Responsibilities	D23	Responsibility and Recognition	B27	Lack of Responsibility and Recognition
	P29	Marketing and Awareness of the CE	D24	Marketing and Awareness Campaigns	B28	Lack of Marketing and Awareness of the CE
	P30	Knowledge Management and Education	D25	Education Programs	B29	Lack of Knowledge and Education
	P31	Establishing Communication and Information Sharing	D26	Data sharing	B30	Lack of Management
	P32	Understanding the Product, Process, and Consumer	D27	Society's Opinion of Unsustainable Practice	B31	Lack of Consumer Demand
	P33	Research and Development	D28	Research and Development	B32	Lack of Research and Development
			D29	New networks		
Technological	P34	Lack of Life Cycle Analysis (LCA) and Benchmarking	D30	Lack of Life Cycle Analysis (LCA) and Benchmarking	B33	Lack of Life Cycle Analysis (LCA) and Benchmarking
	P35	Data Collection and Communication	D31	Material Database	B34	Lack of Material Data
	P36	Case Studies	D32	Case Studies	B35	Lack of Case Studies
	P37	Building Information Modelling (BIM)	D33	Building Information Modelling (BIM)	B36	Lack of Information
	P38	Circularity Tools	D34	Circularity tools	B37	Lack of Circular Tools
	P39	Cost Modelling Tools	D35	Design tools	B38	Lack of Design Tools
	P40	Collaboration Tools	D36	Collaboration tools	B39	Lack of Collaboration Tools
	P41	Material Passports	D37	Material Tracking	B40	Lack of Material Tracking
	P42	Information Management and Transparency	D38	New Methods of Construction and Deconstruction	B41	Lack of Transparency
	P43	New Secondary Material Developments	D39	New Materials	B42	Lack of Material Technology
	P44	Digitalisation			B43	Lack of Material Classification
	P45	Internet of Things (IoT)				
	P46	Blockchain				

Figure 5.3: Theoretical framework

Each driver and barrier can be measured by participants on a scale of one to four. This scale can be adapted by the user to increase or decrease the level of detail of the data collected. For this study, the drivers and barriers are on a scale of 1 to 4 (Strongly Disagree to Strongly Agree). Practices are on a scale of 1 to 4 (far below standard to far above standard). The measurement of the DBPs is based on the midpoint between the positive and negative, which would be 2.5.

If the drivers are above 2.5, then they are present and can be used to drive the CE. If the barriers are above 2.5, they are a potential problem for developing the circular economy. If the practices are below 4, they can be improved. If they are below 2.5, they are not developed within the organisation.

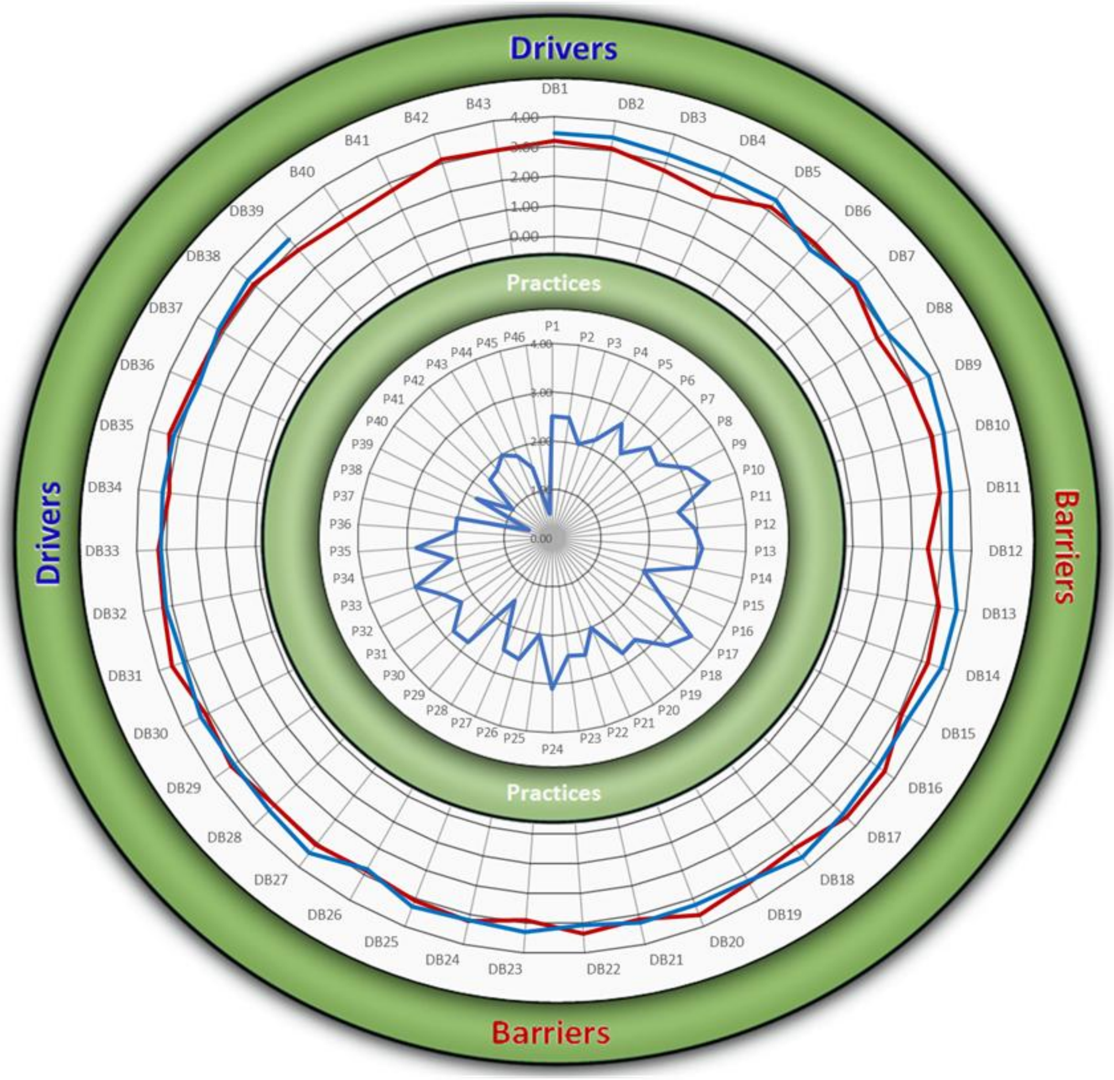

Figure 5.4: Analytical framework

The analytical framework was developed using Excel to provide a known platform for the use of practitioners. Once the data is collected, it can be copied and pasted within the designated columns, which will automatically update the analytical framework. The practices can be selected based on the organisation's interests to understand the drivers and barriers for the specified practices. This can also be conducted separately with different groups, disciplines, companies, and scales (micro, meso, macro). When grouped, the results can be combined to gain an overview of the CE's DBPs. On the analytical framework, the drivers are measured along the blue line, the barriers are measured along the red line, and the practices are within the centre of the circle. The instruction model guides the user on the use of the analytical framework (Figure 5.5). The instruction model has six stages that can be repeated to gain continuous evaluation of development towards a CE. The stages are as follows:

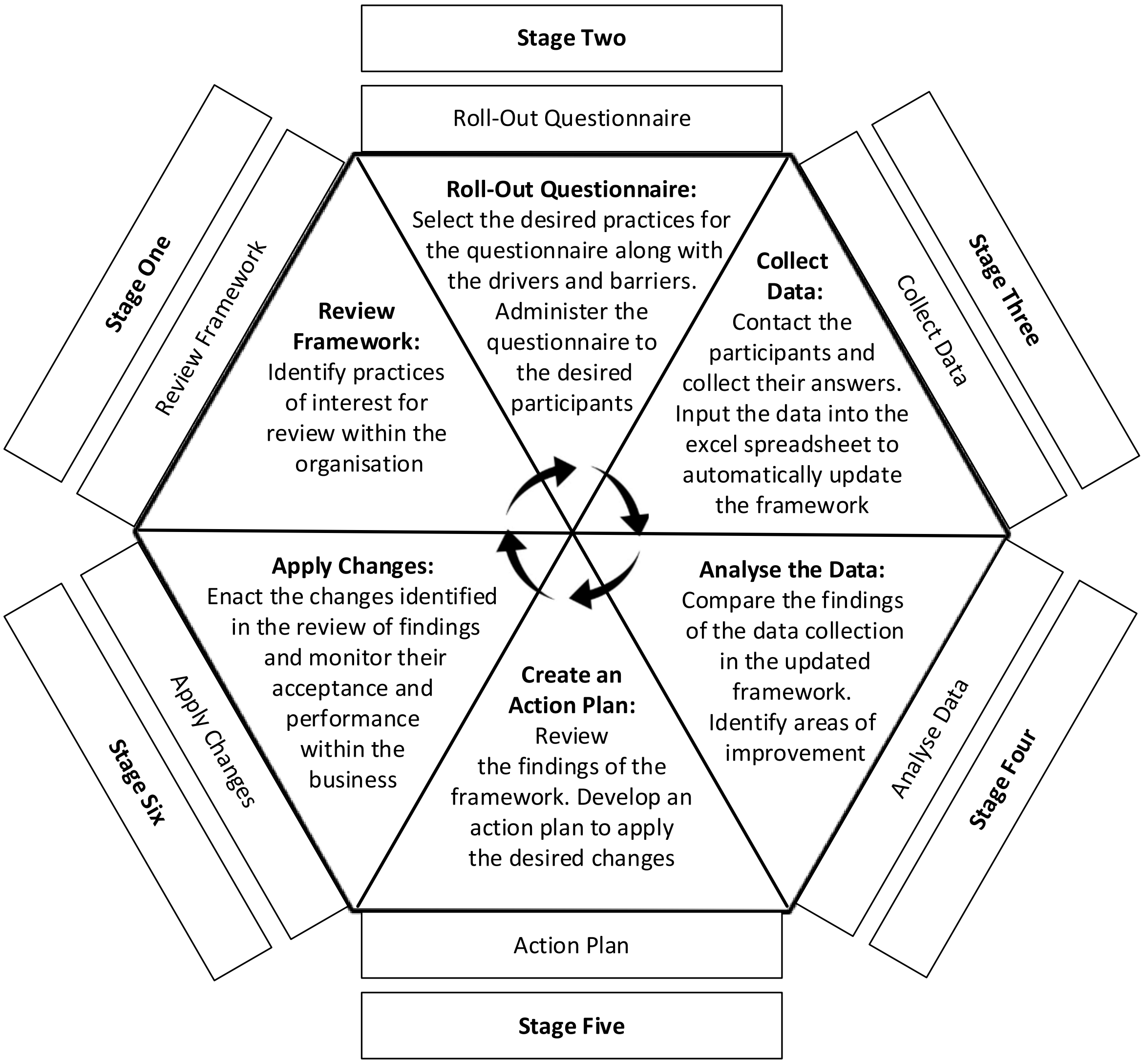

Figure 5.5: Instructions for use

Stage 1: Review Framework – Initially, the user needs to review the framework to select the practices, drivers, and barriers that they wish to focus on (Figure 5.6). For an initial investigation, all of the DBPs might be selected to get a broad view of the potential for circular development. Once the DBPs are reviewed and selected, the questionnaire can be issued to the desired sample.

Global Theme	No.	Practices	No.	Drivers	No.	Barriers
Economic	P1	Design for Closed Loops	D1	New opportunities	B1	Profitable linear market
	P2	Design for Longevity	D2	Competitive markets	B2	Immature secondary market
	P3	Design for Disassembly	D3	Secondary material production/supply	B3	Low value recovered materials
	P4	Closed-loop Material Specification	D4	Raw material volatility	B4	High cost of secondary products
	P5	Reduced Operational Impact	D5	Cost and time efficiency	B5	Quality of secondary materials
	P6	Standardisation	D6	Waste reduction	B6	The stigma surrounding secondary materials
	P7	Prefabrication	D7	Improved quality	B7	Cost of innovation
	P8	Modularisation	D8	Procurement strategies	B8	Lack of financial support
	P9	Proactive Maintenance	D9	Reduced environmental impact	B9	Lack of time
	P10	Product as a Service			B10	Risk of innovation
	P11	Take-Back Systems			B11	Lack of short-term benefits
	P12	Waste Management				
	P13	Recovery and Reuse Infrastructure				
	P14	Upcycling/Downcycling				
	P15	Flexible/Adaptable Systems				
	P16	Urban Mining				
	P17	Financial Support				
	P18	Secondary Market Support				

Figure 5.6: Sample of the theoretical framework

Stage 2: Roll-Out Questionnaire – Stage two is the deployment of the data collection mechanism. This questionnaire (Figure 5.7) can be ranked using the pre-selected Likert scale (1-4) or with a higher level of detail (e.g. 1-7). The questionnaire can be issued through several types of software (e.g. Microsoft Forms) to the desired sample. The sample could be specific disciplines, divisions, projects, companies, or whole supply chains.

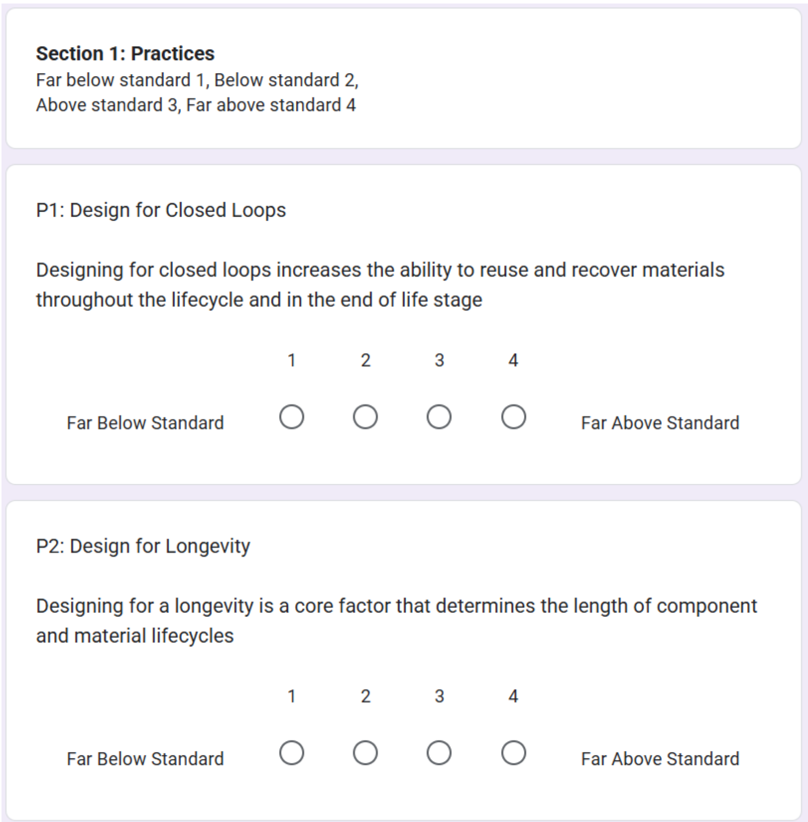

Figure 5.7: Example of questionnaire for data collection

Stage 3: Collect Data – Stage three is the collection of data from the participants in the sample. The data is inputted into the tool in Excel (Figure 5.8). The data is automatically input into the analytical framework for users to view and analyse.

Barrier	Barrier Average	Barriers	Participant #1	Participant #5	Participant #12
B1	2.67	Profitable linear market	2	2	4
B2	3.00	Immature secondary market	3	4	2
B3	3.00	Low-value recovered materials	3	4	2
B4	2.67	High cost of secondary materials	2	2	4
B5	2.67	Quality of secondary materials	3	2	3
B6	2.67	The stigma surrounding secondary material	3	2	3
B7	2.67	Cost of innovation	2	2	4
B8	3.33	Lack of financial support	3	4	3
B9	2.67	Lack of time for consideration	2	2	4
B10	3.33	Risk of innovation	3	3	4
B11	2.33	Lack of short-term benefits	2	3	2
B12	3.33	Linear laws and legislation	3	4	3
B13	3.33	Lack of supporting laws and legislation	3	3	4
B14	3.33	Lack of taxes (relief and penalties)	3	3	4
B15	2.67	Lack of procurement strategy	3	3	2
B16	3.33	Lack of goals and targets	3	4	3
B17	3.33	Lack of government support	3	4	3
B18	2.67	Lack of supervision	3	3	2
B19	3.00	Lack of incentives and penalties	3	4	2
B20	2.67	ack of infrastructure for recovery and reu	3	3	2
B21	3.00	Lack of industry adoption	2	3	4
B22	3.33	Complexity of construction	3	3	4
B23	2.67	Lack of segregation	3	3	2
B24	3.00	Lack of research and development	4	2	3
B25	3.00	Lack of knowledge	4	2	3
B26	3.00	Lack of education	4	2	3
B27	2.67	Lack of best practice	3	2	3
B28	3.00	Lack of awareness	4	2	3
B29	3.00	Lack of marketing	4	2	3
B30	3.33	Lack of consumer demand	3	4	3
B31	2.67	Demand for new products	3	2	3
B32	2.67	Lack of Integrated Project Delivery (IPD)	3	3	2
B33	2.67	Lack of management	3	3	2
B34	2.67	Lack of responsibility	3	3	2
B35	2.67	Lack of transparency	3	3	2
B36	3.00	Lack of material technology	4	2	3
B37	3.00	Lack of material data	3	4	2
B38	3.33	Lack of material classification	3	4	3
B39	2.33	Lack of standardisation	3	3	1
B40	3.00	Lack of information	3	4	2
B41	2.67	Lack of material tracking	3	3	2
B42	3.33	Lack of case studies	4	3	3
B43	3.33	Lack of business models and frameworks	3	4	3
B44	3.00	Lack of circular tools	2	4	3
B45	3.00	Lack of design tools	2	4	3
B46	2.67	Lack of collaborative tools	3	3	2
B47	3.00	of Life Cycle Analysis (LCA) and benchma	4	2	3

Driver	Driver Average	Drivers	Participant #1	Participant #5	Participant #12
D1	3.00	New opportunities	3	4	2
D2	3.00	Competitive markets	4	2	3
D3	3.00	Secondary material production/supply	3	4	2
D4	3.00	Raw material volatility	3	4	2
D5	2.67	Cost and time efficiency	3	3	2
D6	3.67	Waste reduction	4	4	3
D7	3.67	Improved quality	3	4	4
D8	3.67	Procurement strategies	4	4	3
D9	3.33	Reduced environmental impact	3	4	3
D10	3.33	Laws and legislation	3	3	4
D11	3.33	Taxes (relief and penalties)	3	3	4
D12	2.67	Guidance and best practice	3	2	3
D13	2.67	Secondary material standards	3	2	3
D14	3.33	Goals and targets	3	4	3
D15	3.33	Supervision and inspections	3	4	3
D16	3.00	Financial incentives	3	4	2
D17	2.67	Recovery and reuse infrastructure	3	3	2
D18	2.33	Servitisation and maintenance	1	2	4
D19	3.00	Take-back schemes	3	3	3
D20	3.33	Research and development	4	3	3
D21	3.00	Education programs	4	2	3
D22	3.33	Business models and frameworks	3	4	3
D23	3.00	Awareness campaigns	4	2	3
D24	3.33	ociety's opinion of unsustainable practi	3	4	3
D25	2.67	Responsibility and recognition	3	3	2
D26	2.67	Integrated Project Delivery (IPD)	3	3	2
D27	3.00	New networks	2	3	4
D28	3.00	Data sharing	3	4	2
D29	3.67	methods of construction and deconstru	4	4	3
D30	3.00	New materials	3	4	2
D31	3.00	Standardisation	3	3	3
D32	3.33	Life Cycle Analysis (LCA)	3	3	4
D33	3.67	Material tracking	4	4	3
D34	3.00	Material database	4	2	3
D35	3.33	Case studies	4	3	3
D36	3.67	Building Information Modelling (BIM)	4	4	3
D37	3.67	Circularity tools	4	4	3
D38	3.00	Design tools	2	4	3
D39	2.67	Collaboration tools	3	3	2

Practice	Practice Average	Practices	Participant #1	Participant #5	Participant #12
P1	2.67	Design for Closed Loops	2	3	3
P2	3.00	Design for Longevity	3	3	3
P3	2.67	Design for Disassembly	2	3	3
P4	3.00	Closed-loop Material Specification	3	3	3
P5	3.00	Reduced Operational Impact	3	3	3
P6	3.33	Standardisation	4	3	3
P7	3.00	Prefabrication	3	3	3
P8	3.33	Modularisation	4	3	3
P9	3.33	Proactive Maintenance	3	3	4
P10	3.33	Product as a Service	3	3	4
P11	3.33	Take-Back Systems	3	3	4
P12	3.33	Waste Management	3	3	4
P13	2.67	Recovery and Reuse Infrastructure	3	2	3
P14	1.67	Upcycling/Downcycling	2	2	1
P15	2.67	Flexible/Adaptable Systems	2	3	3
P16	1.33	Urban Mining	1	2	1
P17	1.67	Financial Support	2	1	2
P18	1.00	Secondary Market Support	1	1	1
P19	2.67	National/Local Goals and Targets	2	2	4
P20	3.33	Top-down Management	4	3	3
P21	3.00	Laws and Regulations	3	3	3
P22	3.00	Taxation	3	3	3
P23	2.00	Best Practice Standards/Guidance	1	2	3
P24	2.00	Material Standards/Classification	2	2	2
P25	3.00	Frameworks/Business Models	3	3	3
P26	2.67	Circular Procurement	2	3	3
P27	3.00	Extended Responsibilities	3	2	4
P28	3.00	Supervision	2	3	4
P29	3.00	Incentives	3	3	3
P30	2.33	Case Studies	2	2	3
P31	3.00	The 3-12Rs of the Circular Economy	3	3	3
P32	3.00	The Lean Philosophy	3	3	3
P33	3.33	ain Management and Integrated Proje	3	3	4
P34	3.00	hing Communication and Information	3	3	3
P35	2.67	Knowledge Management and Educatio	2	3	3
P36	3.00	standing the Product, Process, and Con	3	3	3
P37	2.00	Bottom-up Management	2	2	2
P38	2.33	Networking	3	2	2
P39	2.67	Marketing and Awareness	3	2	3
P40	2.67	Life Cycle Analysis (LCA)	2	2	4
P41	3.33	Building Information Modelling (BIM)	3	3	4
P42	3.00	Data Collection and Communication	3	3	3
P43	3.00	ormation Management and Transparen	3	3	3
P44	3.33	Digitalisation	3	3	4
P45	2.67	Benchmarking	2	2	4
P46	2.33	Internet of Things (IoT)	3	1	3
P47	1.00	Blockchain	1	1	1
P48	2.33	Material Passports	3	1	3
P49	2.00	Circularity Tools	2	1	3
P50	2.67	Cost Modelling Tools	2	3	3
P51	3.00	Collaboration Tools	3	3	3
P52	2.33	Research and Development	2	2	3
P53	1.33	Secondary Material Innovations	2	1	1

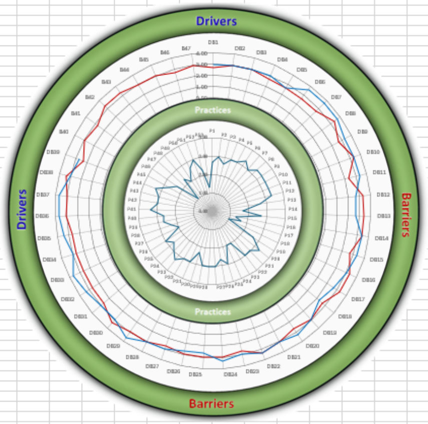

Figure 5.8: Excel tool for data collection and input into the analytical framework

Stage 4: Analyse Data – Once the analytical framework has been updated with the data from the desired sample, the data can be assessed to view the DBPs of the given sample. Multiple analytical frameworks can be developed to compare samples from disciplines, divisions, projects, companies, or whole supply chains (Figure 5.9). This analysis should provide the user with guidance towards the level of development of circular practices, drivers that can be utilised to increase circular development, and potential barriers to developing circular practices within the sample.

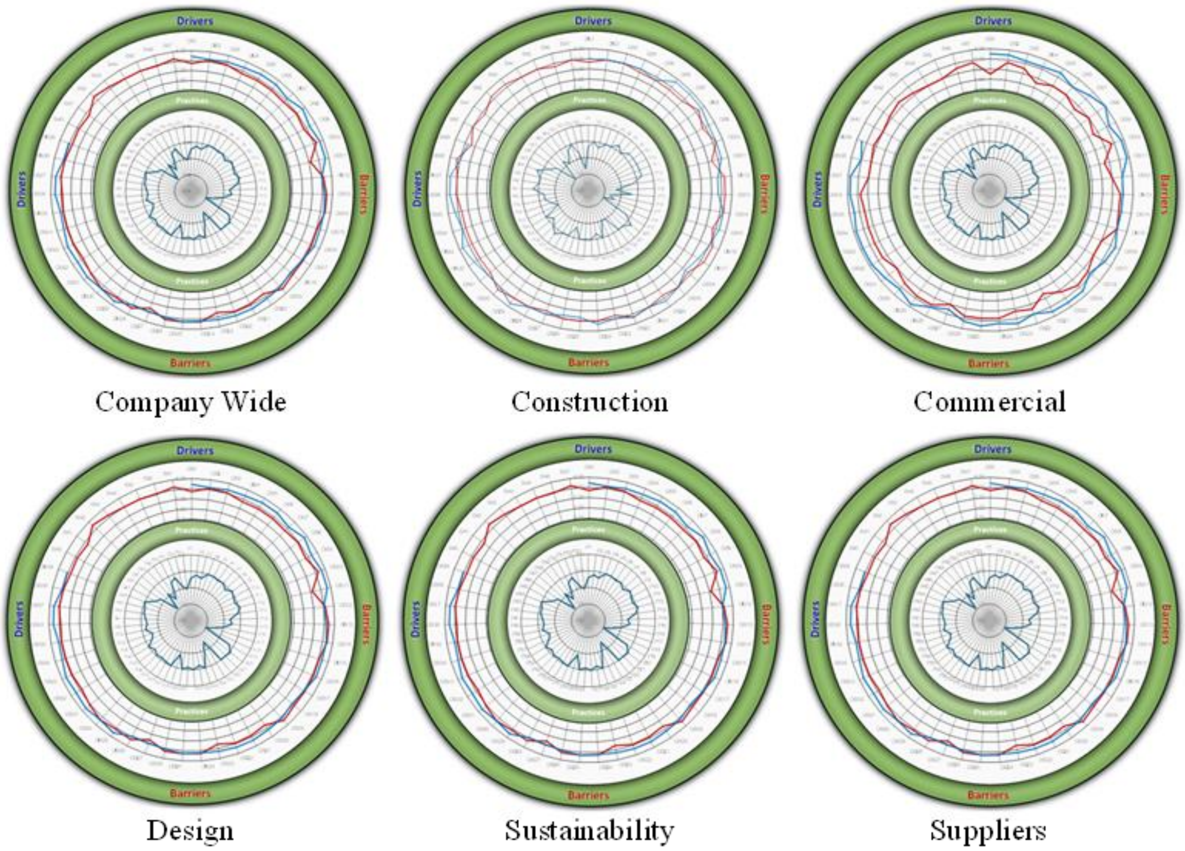

Figure 5.9: Framework comparison of disciplines

Stage 5: Create an Action Plan – From stage four, a plan of action can be developed to improve the development of circular practices. The user can view the progress of practices to see if there are improvements or shortcomings that need to be adjusted, drivers can be prioritised to improve the adoption of circular practices, and plans can be developed to overcome or mitigate barriers to the desired development of practices.

Stage 6: Apply Changes – When the action plan has been developed based on the progress, needs, and barriers identified by the analytical framework, changes to the sample can be actioned to improve circularity. Once changes have been applied and an appropriate amount of time for impact has passed, the stages can be repeated to reassess the desired sample (e.g. companies, supply chains, disciplines, etc) and analyse changes to the system.

5.3 Summary

The development of the theoretical framework provided a basis for data collection and the creation of an analytical framework. The combination of the theoretical framework and analytical framework provides a method of analysing the CE within different samples and guiding users to the available literature on the practice, driver, or barrier. Overall, the proposed analytical framework could provide guidance that is simple, holistic, prescriptive, measurable, adaptable, and can be scaled to different sample sizes. Based on the requirements identified by practitioners within the empirical data collection, the developed theoretical and analytical frameworks should meet the functions required by practitioners within the construction industry. The framework in practice should be practical, efficient, flexible, applicable, effective, and acceptable to the construction industry.

CHAPTER 6: FRAMEWORK EVALUATION AND VALIDATION

In this chapter, the designed theoretical framework (taxonomy), analytical framework (ACCE), and empirical findings will be evaluated and validated. Two focus groups and two independent specialist interviews were conducted to gain internal and external evaluation and validation. Firstly, the structure of the focus groups and specialist interviews is discussed, followed by the internal focus groups and the external independent specialist interviews. Finally, the results of the evaluation and validation are reviewed and discussed to identify possible amendments and future research.

6.1 Evaluations and validation structure

The validation stage of this study relies on the interpretations of industry peers to assess the usefulness of the final product, as suggested by Cameron and Price (2009). Due to the reliance on industrial acceptance of the research, focus groups and specialist interviews were selected for the validation stage to determine the opinion of industry practitioners and gain feedback. For this purpose, two focus groups and two specialist interviews were used to evaluate the developed framework and assess the validity of the results of the study.

Two focus groups were conducted within the participating supply chains to assess the study's internal validity. Two specialist interviews with two independent CE specialists were then held to explore the external validity of the study. All participants were asked the same set of questions in a confirmatory focus group structure to demonstrate the utility of the analytical framework within their business. Each supply chain received a report containing only its own results. The external specialists, by contrast, were given a single report in which the results from both supply chains were merged, so that they could review a representative output of the framework without seeing proprietary data, as suggested by Tremblay et al. (2010).

Validation was split into two tasks: (1) testing the framework's practicality, efficiency, and flexibility (Table 6.1), and (2) asking industry experts whether the results for each supply chain were applicable, effective, and acceptable in practice (Table 6.2). The attributes of the questions are derived from a framework developed by Tzortzopoulos (2004) with adapted questions to suit the needs of the topics (e.g. Talebi et al. (2016)).

Table 6.1: Validation Questions (Task 1)

Attributes	Corresponding questions
Practicality	In terms of clarity and practicality, is the framework easy to use and interpret?
Efficiency	Do the resources required (e.g. time) to use the framework outweigh the potential benefits of understanding the path towards a circular economy in your organisation?
Flexibility	Is the framework adaptable and generalisable for different scales (macro, meso, micro), project sizes, types of businesses or projects, and working teams (e.g. national/local, companies, business units, and disciplines).

Table 6.2: Validation Questions (Task 2)

Attributes	Corresponding questions
Applicability	Do the results of the framework reflect the current state of circular transition within your team, business unit, supply chain, or organisation?
Efficacy	Does the framework help you to understand the maturity of the circular economy within your team, business unit, supply chain, or organisation?
	Does the framework help to guide you to implement the circular economy within your team, business unit, supply chain, or organisation?
Acceptability	Does the proposed framework have the potential to be accepted by practitioners and be used in the industry?

6.1 Results

The validation events (two focus groups and two specialist interviews) were run as a confirmatory process to assess the framework's practicality in real-world settings. For each question, participants chose one of three responses, namely approve, amend, or a suggestion for future research, and their comments were reviewed to identify the advantages and improvements of the framework.

6.1.1 Focus Group One – SC1

Focus group one consisted of four participants from a range of disciplines within SC1 (Table 6.3). The participants endorsed all evaluation categories but recommended several amendments to the second category, Efficiency (Table 6.4).

Table 6.3: Focus group participant demographics

Question	Role	Experience (Years)
Participant #1	Construction Manager	26
Participant #2	Designer	13
Participant #3	Director of Commercial Management	25
Participant #4	MEP Director	35

Table 6.4: Focus group responses for SC1

Question	Participant #1	Participant #2	Participant #3	Participant #4
Practicality	Approve	Approve	Approve	Approve
Efficiency	Approve	Amend	Amend	Future Research
Flexibility	Approve	Approve	Approve	Approve
Applicability	Approve	Approve	Approve	Approve
Efficacy	Approve	Approve	Approve	Approve
Efficacy	Approve	Approve	Approve	Approve
Acceptability	Approve	Approve	Approve	Approve

6.1.1.1 PRACTICALITY

For the practicality of the framework, all four participants of SC1 approved the framework. The construction manager noted that “It's clear, concise, and it says the message and visual as well, it’s not loads and loads and loads of data that we can just get lost in”. The commercial management participant stated that “…it's practical. It seems easy to understand…” and the MEP participant said that they “…certainly like the visual. The graphic that you can use to quickly see what the results are. That's very user-friendly and like you say, I think we all believe we're Excel gurus in the industry anyway, so filling it in Excel is fine”. This shows that the framework met all of the practical aspects of the supply chain for multiple disciplines and created a simple tool for collecting and visualising data of the CE to guide development.

6.1.1.2 EFFICIENCY

The participants' responses to the efficiency of the framework in SC1 were mixed. The construction manager and MEP director approved the framework stating that "I think the time to actually use what we've just done is no problem at all, it's a simple process. Simple to do timewise" and "So just to summarise them for efficiency in terms of the questionnaire and the tool, it's all quick, easy to use". The construction manager also notes that "… some examples for each question… would help you... The design manager focused on the time and resources to implement the development of CE practices and the initial use of the framework saying that "… initially you're going to have to invest some time and resources in order to implement something like this, and then obviously that cost and time will come down as time goes on and it becomes more of a standard day-to-day practice". The commercial manager also discussed the need for examples and case studies as future research to develop the CE stating that "It needs a kind of lead by demonstrating an example and a kind of case study, almost to make it feasible". This shows that the framework can be efficient in its use, but needs examples and case studies to back up the framework with guidance on application. This was also a leading barrier identified in the empirical data collection, showing that the amendments and future research for the efficiency of the framework are external to the use of the framework and more focused on the current state of research and application of the CE in general.

6.1.1.3 FLEXIBILITY

In terms of flexibility, all participants of the SC1 focus group approved of the framework. The construction manager provided "… a general observation that it's going to apply for all…", the design manager said that "Approve. I would say it is adaptable and flexible", and that it would be suited to a framework agreement. The commercial manager said that "I suppose global or kind of all-reaching in terms of all disciplines, but the bigger point touched on is the fact that you know everyone can use it. Everyone sees the efficiency of it. Everyone can see that can be flexible for use by all different parties". And the MEP director said that "… if you were to split it into divisions of how we operate… the scoring and the use of the document would probably be quite different because we all have different perspectives whether we're a designer or an installer, operations or a commercial person. But you cover all bases with that", and that it could help different roles understand each other's needs. This shows that the flexibility criteria of the framework were met with the analytical model and its adaptability to different scales and structures.

6.1.1.4 APPLICABILITY

For the applicability of the results from the framework, all participants approved of the data collected in their supply chain. The design manager stated that "… the top drivers and some barriers for the commercial perspective, don't surprise me one bit" and the MEP director said that they had "… no problem with the proof of that data". This shows that the type of data collected for the framework can provide an accurate account of the development, drivers, and barriers of the CE within different roles and holistic supply chains.

6.1.1.5 EFFICACY OF UNDERSTANDING

For the efficacy of understanding the development of the CE using the framework, all participants in the SC1 focus group approved. The construction manager said that "… it shows how much we consider the circular economy and how far it is developed amongst our designers and mass suppliers, not just within our business", the design manger said "Yes, I think it helps… it shows where we are on the journey", the MEP director said that "The league tables are quite clear. In terms of where you would look to apply your focus", and the commercial manager said that "… it is all about data providing confidence for decision makers" This shows that the framework does assist practitioners' understanding of the CE, their development, and the development of other members of the supply chain.

6.1.1.6 EFFICACY OF GUIDANCE

The efficacy of CE guidance from the framework was also listed as approve by all participants in SC1's focus group. The design manager discussed the benefits of the framework in guiding companies and disciplines to navigate each other's development. The design manager said, "I think what's been good as you spoke to not just the construction company, but the suppliers, the wider economy. And what was surprising some of the results she showed were how many different drivers people have. So, whereas we might try and implement something to achieve our drivers, the supplier isn't bothered by our drivers. They've got their own drivers. So, I think it will help you implement that". The construction manager furthered this by saying, "Unfortunately, it's very difficult because everyone's got an opinion and a different view of interpreting it, and that's a challenge. But if everyone can be on that same journey, it's much more viable. So, the framework helps". This shows that the flexibility and adaptability of the framework help with the guidance of practitioners towards one another as well as for their own practice.

6.1.1.7 ACCEPTABILITY

For the acceptability of the framework within the construction industry, participants approved of the framework as long as there was engagement with the process. The construction manager said, “I would approve, but as long as it's deeply rooted [in all parties]”, and the design manager said, “I’ll approve it and say as long as it's done with the clients…”. This suggests that the participants like the collaborative aspect of the framework and would find it most effective when used in tandem with other stakeholders. It also suggests that for the framework to be utilised in companies and on projects, it would need to be initiated by the client or within a framework agreement, as previously suggested by the participants. The commercial manager and MEP director simply approved of the framework being accepted by practitioners as an effective and adaptable tool, suggesting that it could be used independently by companies and teams.

6.1.2 Focus Group Two – SC2

Focus group two consisted of four participants from a range of disciplines within the supply chain (Table 6.5). The focus group approved of each category with some amendments and future research for questions one, four, and five (Table 6.6).

Table 6.5: Focus group participant demographics

Question	Role	Experience (Years)
Participant #1	Logistical Manager	20
Participant #2	Designer	35
Participant #3	Construction Manager	30
Participant #4	Commercial Manager	6

Table 6.6: Focus group responses for SC2

Question	Participant #1	Participant #2	Participant #3	Participant #4
Practicality	Approve	Amend	Amend	Approve
Efficiency	Approve	Approve	Approve	Approve
Flexibility	Approve	Approve	Approve	Approve
Applicability	Future Research	Approve	Approve	Future Research
Efficacy	Amend	Amend	Approve	Approve
Efficacy	Approve	Approve	Approve	Approve
Acceptability	Approve	Approve	Approve	Approve

6.1.2.1 PRACTICALITY

In terms of the practicality of the framework and its use, participants approved of the framework and offered some slight adjustments to the descriptions of the questionnaire. The logistics manager said that they "… like how it is easy to use, and you know within one click all the information is displayed". The commercial manager said that "… the forms easy to fill out, you obviously click in one of the four options going through the different sections in terms of how it's going to be used and perceived" And the project manager said "As long as the people you are presenting it to understand the scoring system … I think it's a great tool because it's very pictorially easy to understand. I think practically, yes, it is easy to do". This shows that the form and analytical framework are easy to use and interpret; however, there are some amendments required to the description of each driver, barrier, and practice to ensure a full understanding is conveyed to the participant. This leads onto the caveat discussed by the commercial manager who said "… perhaps having an introduction to what it is with you're asking these people and then what it is we hope to achieve from the questions that we're posing to them", which further suggests the need for the questionnaire descriptions to be clarified. Finally, an amendment suggested by the designer was the time required for the questionnaire to be conducted, saying that they "… don't think it'll be that easy to use or have time to do it". This relates to the barrier identified within the empirical data collection of both supply chains, which suggested a lack of time to consider the CE. Overall, the questionnaire was deemed practical; however, more descriptions are required to improve the understanding of the respondent when completing the questionnaire.

6.1.2.2 EFFICIENCY

In terms of efficiency, the SC2 focus group approved of the time and resources required to use the framework. The project manager said that "Yes, in terms of time, in terms of filling the form out, if the questions are easy to understand and read, it's a 5–10-minute ask, isn't it? So … it's fairly quick to do". The commercial manager said that "Copying and pasting the form results into the framework took you a minute or so.". The designer said that "… it's quite an easy-to-operate and create system, isn't it? So, it's just effectively one person's time to create the form and then correlate all the information". The only concern identified was the perceived importance of the framework amongst participants, which was identified by the logistical manager who said, "I suppose it's just getting the importance across to people that you know it is an important thing to". This shows that the framework is efficient in terms of time and resources and can be conducted within SC2 with only a marginal cost.

6.1.2.3 FLEXIBILITY

When assessing the flexibility of the framework, participants of the SC2 focus group approved of its flexibility to different scales and participant roles. The logistical manager, designer, and project manager all agreed that the framework is flexible. The commercial manager elaborated by saying "…from a flexibility point of view to prove that. As you can change the question, obviously, it's flexible in that respect, and also, you can drill down into various departments or whatever you want to drill down into to see the splits. So, you can see whether or not people concur with the same questions from different backgrounds. So, I think from a flexibility point of view that's fine". This shows that the framework can be adapted to meet the needs of individual companies, participants, job roles, whole supply chains, or for the entire construction industry to be analysed.

6.1.2.4 APPLICABILITY

For the applicability of the results, the designer and project manager both approved of the data collected. The logistical manager and commercial manager both selected future research. The logistical manager said that "I would say no, it doesn't. Certainly, in what I see on site. I would think that future research is really needed on this. There's work still to be done on certain areas of the circular economy". Whereas the commercial manager said, "If you wanted accurate results from this, you'd have to be talking hundreds of people so that everyone's thoughts were taken into consideration for various departments. So, I would say future research there, so the results were accurate of the kind of current state of the market at the moment in terms of the results that you've provided”. This suggests that the results for the sample may be applicable; however, to gain a full picture of the CE within SC2, the framework would have to be used to analyse a larger sample of the supply chain to gain a more holistic understanding of the CE and its development.

6.1.2.5 EFFICACY OF UNDERSTANDING

For the efficacy of understanding the framework, all of the participants in SC2’s focus group approved. The project manager said that “It's just understanding where it applies and getting that across really and making sure we touch all the areas that we need to” Suggesting that there is difficulty understanding the application of the CE, which relates back to their desire for case studies. The commercial manager said, “I wouldn't say I could tell from the research how mature it is within my team” and “…it highlights the areas that we think need improvement or we're looking at, we're looking strong…”. The logistical manager added on, saying “…I would say probably not, because I think there's a lack of knowledge to do with the circular economy…”. This suggests that although the framework is easy to understand, the lack of knowledge within the construction industry towards the CE and its application creates a lack of understanding for the full use of the framework.

6.1.2.6 EFFICACY OF GUIDANCE

For the efficacy of guidance, participants approved of the direction that the framework provided, but noted a desire for case studies to reinforce implementation of practices identified by the framework. The logistical manager said, “… it does help me, but where I would struggle would be with the implementation”, the designer stated that they “… think it does help”. The project manager reiterated that “… as long as the case studies were there that you can refer back to them, then it would be very useful…”. Following a similar path as the project manager, the commercial manager said, “I think you can use it as a useful tool to aid where we can improve and stuff. Like you said, the case studies intertwined with that. We can go look at the exact ways of improving each area”. This shows that the framework provides good guidance for development and areas for development, and combined with a literature review of case studies, it could provide a complete guide to applying the CE in practice.

6.1.2.7 ACCEPTABILITY

When discussing the acceptability of the framework by practitioners, all of the participants approved of the framework. The logistical manager said “in-house would be feasible. The wider construction industry, I don't know. I think if it's an industry standard, and I think if it's anonymised", the designer said "I think it does have potential… it could be useful for the company", the project manager said "I'd say it's definitely useful tools to have", and the commercial manager said "I definitely think they're useful tools to have" This shows that the framework can be accepted by a wide range of roles within the construction industry. It also shows that practitioners can perceive value in the use of the framework to gauge the development and prescribe practices.

6.1.3 Specialist interviews

Two structured interviews were conducted, which consisted of two independent CE specialists (Table 6.7). Both specialists approved of each category with no amendments or future research (Table 6.8).

Table 6.7: Specialist interview participant demographics

Question	Role
Participant #1	CE Consultant
Participant #2	CE Consultant

Table 6.8: Specialist Interview Responses

Question	Participant #1	Participant #2
Practicality	Approve	Approve
Efficiency	Approve	Approve
Flexibility	Approve	Approve
Applicability	Approve	Approve
Efficacy	Approve	Approve
Efficacy	Approve	Approve
Acceptability	Approve	Approve

6.1.3.1 PRACTICALITY

For practicality, both specialists approved of the framework. Participant one said, “The form itself is straightforward. The one to four is straightforward. The submit at the bottom is straightforward, so the structure is easy enough”. Participant two concurred by saying “It's easy to use and easy to capture the data. Very clear. So, I'll say it's easy and very practical to use. Maybe the only suggestion I hope you're going to put it as an app” This suggests that the framework is practical and meets its purpose with a suggestion to innovate the conceptual model into an app for easier application.

6.1.3.2 EFFICIENCY

For efficiency, both participants approved. Participant one said, “You're taking my 10 minutes and multiplying it by how many people are in the company. That's the question. I don't see how you get much shorter. This suggests that the use of the framework is efficient, but there could be a quicker method of collecting the data required for the framework. Participant two also approved and suggested the use of “… an app which is easy to use, track and trace materials. So that it becomes live, and then it constantly updates, rather than people's perspectives. It's also capturing live data, but this is for future research purposes”. To conclude, participant two said, “It's efficient to use, it's the right data that is not being captured at the moment. A framework that helps them capture that is great. Every organisation would want to know how much they're wasting so they can save. So, I'll say yes”.

6.1.3.3 FLEXIBILITY

Both participants approved of the framework’s flexibility to different scale and projects with participant two saying “Yes. I'll say that the scales are adaptable, you can adapt them to suit any industry. That's what I'd say even as I was responding to some of your questions I could see. It can work in oil and gas”. This shows that not only would the framework be flexible within the construction industry, but it could also be adapted easily for other industries or the economy in general.

6.1.3.4 APPLICABILITY

Both participants of the interviews approved of the applicability of the results gathered during the empirical data collection, with no contradiction to their belief in the current state of the CE. Participant two provided one comment, which was “Yes, 100%”. This shows that the data collected from SC1 and SC2 were in line with their specialist experience consulting on developing the CE in industries.

6.1.3.5 EFFICACY OF UNDERSTANDING

In regard to the efficacy of understanding the framework, participant one said, "I'd be cautious with that one, but the rest of it sounds about right". This suggests that the level of knowledge within the industry towards the CE is not comprehensive and therefore would limit the level of understanding when interpreting the framework. Participant two on the other hand, said, "Yes, I'd say it outlines quite clearly. Where the design team is sitting, it's very clear. Like the commercial team is worried about both. And it's something that, I, coming from a commercial team, would also be looking at the sustainability and the operational side of things in this in the commercial. And it captures the maturity of that environment. If all teams start to mature as a commercial team or is other teams and understand the interdisciplinary links between the teams, it can help that maturity. So, I agree" This shows that the interpretation of the framework would need to have a good level of understanding of the CE to interpret and prescribe practices as well as differentiating the needs of different samples (e.g. roles, divisions, companies).

6.1.3.6 EFFICACY OF GUIDANCE

Both participants approved of the framework's effectiveness to provide guidance to practitioners by saying, "It could do … could guide could inform" and "Yes, definitely, definitely. On the behaviour side, it helps to outline and helps you, so you know which areas you're targeting. So, it outlines what people prioritising or disciplines are prioritising, it helps to formulate the solution, so I agree". This shows that the framework can function as a guide for companies to understand the DBPs of developing a CE. This also suggests that it can be used as a guide for understanding different disciplines, divisions, and companies to formulate a tailored solution for applying the CE.

6.1.3.7 ACCEPTABILITY

For the acceptability of the framework, both participants approved; however, participant one proposed one criterion for acceptance: "If it meets an industry need to align across the organisation, then yes". This suggests that companies may not see a need for company alignment and may prefer applying the CE in individual cases, which could be remedied through case studies and education. Participant two, on the other hand, said "Yes, the visuals of it definitely are very impactful because it's easier to look at and have that rapid categorisation of issues. So, you can be clear on what's happening”. This suggests that the simple design and ease of use would increase the acceptance of the framework by practitioners.

6.2 Summary

As summarised in Table 6.9, it can be seen that the most common response was approve for every evaluation category across all participant groups. These attributes, flexibility, efficacy of guidance, and acceptability by practitioners, were unanimously approved. The main amendments requested were: (1) adding case studies to illustrate how organisations should act on the framework’s findings, and (2) reducing the time and resources needed to gather data from large samples, possibly through a dedicated app. The first amendment concerns what users do with the results, not the framework itself; it can be addressed by adding case-study examples drawn from the literature.

The SC2 focus group also called for a larger sample and clearer questionnaire wording to make the results more representative and easier to interpret. Both points can be addressed in future iterations: expand the sample to obtain a more representative picture of an entire supply chain and refine item descriptions to improve respondent comprehension.

Overall, the framework was approved by multiple disciplines in SC1 and SC2 for each category. Both specialists also approved of each category, which suggests that the framework is practical, efficient, flexible, applicable, effective, and acceptable to practitioners.

Table 6.9: Summary of participant responses in focus groups (FG1 and FG2) and interviews (I1 and I2)

	FG1				FG2				I1	I2
Question	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**
Practicality	Ap.	Ap.	Ap.	Ap.	Ap.	Am.	Am.	Ap.	Ap.	Ap.
Efficiency	Ap.	Am.	Am.	FR	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.
Flexibility	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.
Applicability	Ap.	Ap.	Ap.	Ap.	FR	Ap.	Ap.	FR	Ap.	Ap.
Efficacy	Ap.	Ap.	Ap.	Ap.	Am.	Am.	Ap.	Ap.	Ap.	Ap.
Efficacy	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.
Acceptability	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.	Ap.

CHAPTER 7: CONCLUSION

This chapter concludes the overall thesis by summarising and reviewing the study. Initially, the aim and objectives will be reviewed to determine the success of the study regarding the approach to filling the existing gap in knowledge. The research contributions will then be discussed to determine the impacts of the study on academia and practitioners. The limitations and future research of the study will also be discussed for the advancement and improvement of future investigations.

7.1 Achievement of research objectives

In this section, the objectives of the study will be reviewed against the study's approach and findings to determine the successes of the study in regard to achieving the outlined objectives.

O1: To identify the DBPs of the CE in the construction industry from the literature for the development of a comprehensive taxonomy.

Objective one was met through the systematic literature review in Chapter 3. Objective one sought to identify the DBPs of the CE in construction. This was required because an initial sample of CE literature was collected using broad keyword strings. This provided a sample of over ten thousand journal articles on the CE. The sample was analysed with bibliometrics to view the publication frequency and geographical location to understand the body of knowledge in more detail. The sample was then processed through a scientometric analysis to view the common keywords within the sample, their frequency, connections, and infancy. The bibliometric and scientometric analysis provided direction for the study by identifying the novel areas of the literature on the CE in construction, and this was used to refine the selection of keywords for the search strings associated with the DBPs of the CE. The resulting sample size provided 34 sources for the drivers and barriers, and 58 sources for the practices of the CE. The samples were analysed for the existing DBPs as well as the themes that were used for categorisation in Chapter 3. The identified DBPs were then developed into a theoretical framework of the CE for a comprehensive taxonomy for a holistically categorised guide. The final taxonomy contains 39 drivers, 43 barriers, and 46 practices categorised into 4 themes: economic, institutional, social-cultural, and technological. The findings of the literature review and development of the comprehensive taxonomy provided a holistic compendium that provides a structure for the DBPs of the CE in the construction industry. By identifying the DBPs of the CE within construction and developing the comprehensive taxonomy, objective one was achieved.

O2: To explore the presence and level of development of DBPs of CE in the UK construction industry.

Objective two focuses on the exploration of the DBPs within the construction industry and can be seen in Chapter 4. Objective two was met within the collection and analysis of empirical data. The methods of empirical data collection were designed based on the identified DBPs of the CE outlined in the comprehensive taxonomy developed from the existing literature. Semi-structured interviews were selected as the optimal method for the collection of data on the DBPs, as they allow for the exploration of a defined set of criteria. Open-ended qualitative questions were used to explore and describe the practices of the CE. This allowed for the exploration and explanation of key features of the CE's practices, either theoretically or empirically in practice. The drivers and barriers of the CE were measured using closed-ended questions to determine the presence and severity of their influence on the practitioners. The use of closed-ended questions was the most advantageous option for the drivers and barriers, as it provided a scale in which to measure the impact of their presence.

Two supply chains within the UK construction industry were purposefully selected for the empirical data collection based on their building type (residential) and their supply chain connectivity. Initial participants were purposefully selected based on their experience and influence within their given supply chain. Once interviewed, the participant referred the study to other participants and disciplines to initiate a snowball sample to infiltrate other companies, divisions, and disciplines within the supply chain. The snowball sample reached 10 different disciplines: construction management, commercial management, design management, sustainability management, demolition management, MEP management, logistical management, procurement management, and waste management. The sample consisted of 32 participants, 14 from supply chain one, and 18 from supply chain two.

The empirical data were analysed using multiple methods to assess the participants' responses. A content, comparative, and discourse analysis were conducted on the qualitative data collected on the practices of the CE. The content analysis provided an overview of the level of development of CE practices within the sample by identifying the explanation of practices in a theoretical or practical context. A comparative analysis was also conducted to identify the differences between supply chains one and two. This allowed for the analysis of each company's development of the CE in practice to identify different approaches.

Finally, a discourse analysis was conducted on each working group of disciplines within their respective supply chains to identify differences between disciplines within the same supply chain and any discourse between participants within the same discipline. The qualitative data were then quantified based on the level of explanation provided by participants on any given practice to provide quantitative data for the analysis of the overall development of the practices. The practices were quantified on a scale of 1-4 (far below standard – far above standard). Far above standard would include examples of practice, and far below standard would be selected when a participant had no knowledge of the practice. The measures of central tendency were then analysed to gain the mean average level of development of each working group, supply chain, and for the overall sample of participants. The results showed whether the practice was above or below standard within the working group, supply chain, or overall, if it scored on average higher than 2.5 (above standard). The development of practices varied significantly between working groups and supply chains based on the needs of the supply chain or discipline. Overall, SC1 focused more on innovative practices such as prefabrication, modularisation, and BIM, whereas SC2 focused on operational practices such as standardisation and waste management.

The empirical data on the drivers and barriers of the CE were measured on a Likert scale to gain a quantitative dataset. The range for the Likert scale was 1-4 (strongly disagree – strongly agree). The measures of central tendency were analysed within the dataset to identify the mean average of each working group, supply chain, and for the overall sample of participants. The results showed whether the driver or barrier was present within the working group, supply chain, or overall, and if it scored on average higher than 2.5 (agree). A comparative analysis was conducted to investigate differences between supply chains and identify any fluctuations in the presence and severity of the drivers and barriers. Additionally, a discourse analysis was conducted to identify any differences between working groups within a given supply chain or a select working group. The empirical data for the drivers and barriers showed that all of the 39 drivers and 43 barriers were present within each supply chain. The study also highlighted the difference between working groups, and which drivers or barriers were more impactful in each given discipline. This provided insights into the experiences and opinions of each discipline to identify DBPs that were more present or important to individual disciplines. This could further be used to tailor CE development strategies to enable disciplines to evolve the CE across the construction industry.

O3: To develop a framework based on the findings from the literature review and empirical studies to facilitate the incorporation of CE practices within the construction industry.

The systematic literature review identified the DBPs for the development of a theoretical framework in the form of a taxonomy consisting of 39 drivers, 43 barriers, and 46 practices categorised into 4 themes: economic, institutional, social-cultural, and technological (Chapter 3). The DBPs were empirically investigated within two supply chains to identify the presence and development of each category. From the empirical investigation, guidance, laws, frameworks and business models were identified as lacking, suggesting the need for direction when applying the CE. Some characteristics of a CE framework suggested by the participants in the empirical studies were simple, measurable, prescriptive, scalable, adaptable, and holistic. From these characteristics, an Analytical Circular Construction Economy (ACCE) framework was developed.

The ACCE framework employs the categorisation of the initial taxonomy to structure the measured variables in a holistic format. The framework was designed to measure the DBPs of the CE, collect data, and visually represent the findings in a simple format. The results of the ACCE framework can also be adapted to different scales (e.g. discipline, division, company, supply chain, or industry) and to select desirable DBPs based on the user's focus. The findings of the ACCE framework also provide a measure of the presence or level of development to guide users when prescribing practices to their operation. Objective three was reached by developing the ACCE framework using the taxonomy and empirical studies to formulate a framework based on the needs of practitioners aimed at facilitating the incorporation of CE practices. The incorporation of practices is achieved by measuring the current state of practices, the presence of drivers and barriers, and the application of practices while taking advantage of drivers and mitigating barriers.

O4: To validate the framework and evaluate the applicability and appropriateness of the proposed framework through UK-based case studies in assessing their transition to a CCE.

The ACCE framework was subjected to two rounds of validation: internal and external. Both rounds of validation consisted of the same structured questions to measure the practicality, efficiency, flexibility, applicability, efficacy, and acceptability of the framework. The participants interacted with the framework to experience the data collection, analysis, and review of the framework to determine the practicality, efficiency, and flexibility. The second stage reviewed the results of the given supply chain to determine the applicability, efficacy, and acceptability of the results and guidance of the framework.

The first round of validation was internal within the initial samples of SC1 and SC2. The first round consisted of two focus groups with a diverse sample of disciplines from each supply chain. Responses were gauged with approve, amend, or future research. SC1 approved of the framework in each category with some suggestions for the efficiency of the framework (i.e. the descriptions within the survey). SC2 was largely approved with some amendments (ie., an introduction to the survey (practicality) and additional information for application (efficacy)) and future research (i.e. a larger sample size). This showed that the framework met the criteria for approval and proof of concept, as well as validating the results of the empirical data collection.

The second round of validation conducted was external interviews with specialists in the field of the CE. The interviews followed the same process as the first round of validation, with one exception: the second stage consisted of the combined results of both supply chains to ensure anonymity and confidentiality. Both specialists approved of each category, showing that the framework meets each criterion identified within the empirical data collection.

Aim: This research aims to encapsulate the CE's DBPs into a framework to facilitate the UK construction industry's transition to a Circular Construction Economy (CCE).

To fill the gap in knowledge and meet the aim of the PhD study, four key objectives needed to be met (as outlined above). The initial step of meeting the aim of this research was to encapsulate the DBPs of the CE. The creation of a comprehensive and holistic taxonomy created a structure to encapsulate the CE and provide a foundation for empirical studies. Following the empirical studies, the development of the ACCE framework was possible. The framework was then validated by construction experts and CE specialists as a framework that can facilitate the development of the CE in practice. By completing each objective to create and validate the theoretical and analytical frameworks, the aim of the study was fulfilled.

7.2 Research Contributions

In this section, the contributions to knowledge and practice will be discussed to highlight the impacts of the study in both fields.

7.2.1 Contributions to Theory

7.2.1.1 BIBLIOMETRIC AND SCIENTOMETRIC ANALYSIS

The bibliometric and scientometric analyses of the extant literature in Chapter 3 provide a cross-sectional view of the current body of knowledge surrounding the CE within the construction industry. Over 5,000 journal articles were used within the sample for the bibliometric and scientometric analyses. The bibliometric analysis provides a view of the publication frequency and geographical location for 2024. The bibliometric analysis provides a foundation for future comparison to determine the trajectory of CE knowledge and theory. Furthermore, the scientometric analysis provides an overview of the CE's keywords and their infancy. This provides an in-depth picture of the age of keywords and topics within the existing body of knowledge and their connections. The review of the scientometric analysis can provide direction for the creation of new studies, such as the direction it provided in this study. Keywords that are scarcely connected and new to the scientometric analysis can be viewed as new topics for the advancement of CE research that will further contribute to the development of theory.

7.2.1.2 COMPREHENSIVE TAXONOMY

The systematic literature review in Chapter 3 provided a sample of journal articles that had identified or categorised either the drivers, barriers, or practices of the CE. A key finding from the review of literature was a lack of comprehensive frameworks or business models that contained DBPs. Existing frameworks would contain either the drivers, barriers, or practices, or the drivers and barriers (e.g. Ababio and Lu, 2023; Charef, 2022; Abadi et al., 2021; Çimen, 2021). The review of literature also identified inconsistencies between the different studies, which identified some drivers, barriers, or practices, but not a complete list, even if they had been identified in earlier studies (Adams et al., 2017; Benachio et al., 2020; Guerra et al., 2021). This suggested that there was a lack of rigour in previous literature reviews, which developed inconsistencies and repeated findings within the body of knowledge. Due to this, a comprehensive taxonomy was developed to coalesce the identified DBPs into one unified theoretical framework. This contribution to theory can establish a baseline for future research and empirical studies into the DBPs of the CE.

7.2.1.3 EXISTING LITERATURE LACKS EMPIRICAL DATA

The review of literature in Chapter 3 identified the DBPs of the CE within the construction industry. However, the existing studies lacked empirical data for validation of their findings (e.g. Benachio et al., 2020, Çimen, 2021, Ababio and Lu, 2023, Charef, 2022). Some studies conducted empirical data collection to validate the drivers or barriers within their study (e.g. Adams et al., 2017; Shooshtarian et al., 2023; Campbell-Johnston et al., 2019). However, the studies largely focus on individual stages of the construction lifecycle or specific disciplines. The existing literature also lacks combined empirical studies of the DBPs to investigate correlations between each domain (e.g. Wuni, 2022; Wuni, 2023; Wuni and Shen, 2022). This study provides empirical data on a comprehensive set of DBPs with a holistic approach to stages in the construction lifecycle and the different stakeholders and disciplines it includes. Although the data is not generalisable to the wider construction industry, the empirical case study data provides validation and insights for the studies without empirical evidence and can guide future studies into the DBPs of the CE.

7.2.1.4 ANALYTICAL FRAMEWORK

The development of the ACCE framework in Chapter 5 is unique among existing frameworks. The most common framework developed by MacArthur (2013) lacks granular detail on the application of practices, the framework is not designed for the construction industry, and does not contain additional factors, such as the drivers and barriers of the CE. Other frameworks within the extant literature are primarily theoretical or conceptual and provide little direction for the development of the CE (e.g. Bherwani et al., 2022; Çetin et al., 2021; Fernandes and Ferrão, 2023; Maher et al., 2023). The ACCE framework provides a comprehensive list of DBPs, which can be contrasted to analyse the development of the CE in a comprehensive format. The framework is also scalable to different sample sizes (e.g. disciplines, divisions, companies, supply chains, or industries) and, due to its simplicity and analytical design, it can provide guidance for the advancement of theory.

7.2.2 Contributions to Practice

7.2.2.1 COMPREHENSIVE REVIEW/GUIDE

The comprehensive systematic review of literature in Chapter 3 provided a holistic taxonomy of the DBPs of the CE in the construction industry. The taxonomy provides a list of the DBPs for practitioners to review and investigate further if desired. The systematic literature review provides further context and examples of the DBPs for practitioners to investigate for guidance to apply or further research the topic. This differs from existing guidance as it provides a comprehensive and holistic guide to a CE's DBPs, whereas existing guidance is fragmented and lacking. The comprehensiveness of the literature review provides holistic guidance on the whole construction lifecycle and external factors for each stakeholder or discipline within the construction industry, whereas other studies and guides focus on specific stages or disciplines (Çetin et al., 2021; Fernandes and Ferrão, 2023; Daly, 2023; Köhler et al., 2022).

7.2.2.2 ANALYTICAL FRAMEWORK

The existing frameworks for the CE are lacking a cohesive and comprehensive set of DBPs (Wuni, 2022; Wuni, 2023; Wuni and Shen, 2022; Benachio et al., 2020). The existing frameworks' focus on either the drivers, barriers, or practices limits the ability for correlations between factors to be analysed. Additionally, the drivers, barriers, and or practices of the existing frameworks are not complete and are fractured, resulting in missing information for practical applications (Adams et al., 2017; Benachio et al., 2020; Guerra et al., 2021). Furthermore, existing frameworks in the literature are largely theoretical or conceptual, offering limited practical guidance for the development of the Circular Economy (CE) (Bherwani et al., 2022; Çetin et al., 2021; Fernandes and Ferrão, 2023; Maher et al., 2023).

In contrast, the ACCE framework in Chapter 5 presents a detailed and structured list of DBPs that can be systematically compared to support a comprehensive analysis of CE development. Its simplicity and analytical structure make it scalable across various sample sizes—such as disciplines, organisational divisions, companies, supply chains, or entire industries—allowing it to effectively inform both practice and the advancement of CE theory. The ACCE framework has been developed in a format that is familiar and commonly used within the UK's construction industry (Microsoft Excel) to enable the use and analysis of data. The framework was also developed based on the needs of practitioners and validated by practitioners and specialists in the CE field to ensure that it would be acceptable and practical within the construction industry.

7.2.2.3 BENCHMARK DATA

The empirical data studies from two construction supply chains in Chapter 4 and the results from the ACCE framework in Chapters 5and6 provide a benchmark of the CE within SC1 and SC2. The findings of the ACCE framework's application developed a foundational benchmark for the advancement of the CE within its respective supply chain. Combined, the findings provide a benchmark to guide the development of the construction industry and further research. Although the findings are non-parametric case studies and are therefore not generalisable, the findings provide a case study for the development and guidance of the CE within other projects, academic or practical. Additionally, the proof of concept of the ACCE framework allows for benchmarks to be developed in practice for the comparison of projects or the collection of interval data within the same project.

7.3 Limitations

In this section, the identified limitations of the studies will be addressed.

7.3.1 Network availability

The available network at the start of the study was minimal. This hampered the ability of the researcher to commence data collection with the knowledge of and access to the sample. Due to the lack of an available network of participants, organisations and supply chains were identified and contacted for participation. The process of identifying and enrolling supply chains into the study was time-consuming and limited the progress of the research. Once a company that met the research requirements were enrolled, a snowball sample was selected to identify participants for data collection. This method limited the speed of data collection and increased the potential for bias within the study, as participants would recommend other participants based on experience and opinion.

7.3.2 Subjectivity and Bias

Subjectivity and bias are common limitations in research. This PhD study relies on the experiences and opinions of participants, which entails a level of subjectivity. To reduce the level of subjectivity within the study, participants' responses were compared, and the measures of central tendency were used to find a common truth between subjects. However, there will always be a level of subjectivity within the results when using human participants to collect data. This subjectivity is also subject to bias on behalf of the participant and researcher. Participants within organisations could suffer from the Hawthorne effect, where their behaviour changes when observed (Sedgwick and Greenwood, 2015). This bias could be in effect due to concerns on behalf of the participant as to their company's external view and the innate desire to maintain a good company persona. This could also be due to the participant's desire to answer the questions 'correctly'. There could also be an aspect of researcher bias within the study, such as interviewer bias. While conducting the interviews and focus groups, questions could have been asked differently, the rapport with the participant could have varied, or the interviewer could have reacted differently to answers. Both the subjectivity and potential bias of the study will have created some limitations with the study's rigour and validity.

7.3.3 Methodological Design

Due to the exploratory and explanatory nature of the study, mixed methods were used to collect data in the most impactful way to analyse the DBPs. However, this limited the ability of the research to run statistical analyses on the DBPs in unison to determine correlations. On reflection, the use of purely quantitative data could have increased the quality of the data analysis for the review of causal relationships between DBPs and allowed for the analysis of correlations between the datasets.

7.3.4 Replicability/Generalisability

One of the core limitations of the study is the use of case studies and non-parametric data. The study is not replicable due to the relation of the data to specific cases that were being used as context. Furthermore, the purposive and snowball sampling methods limited the ability to perform parametric sampling as the sample size was too small and contained rich data that was valuable for the understanding of the CE. This has limited the generalisability and replicability of the study's findings. However, the ACCE framework can be replicated to develop generalisable datasets.

7.3.5 Validation

The validation of this PhD study relied on internal and external validation. Based on the availability of participants within each supply chain, members who participated in the main empirical studies were invited to participate in focus groups, which could have introduced a level of bias within the validation stage, as they have personal and professional investment in the study. However, this bias was mitigated through the use of external validatory interviews. Additionally, the use of focus groups as a method of data collection could have instituted various social impacts within the collective, for example, group acceptance, the suppression of minority opinions, and the provision of cultural as opposed to individual opinions. Finally, the availability of CE specialists within the UK limited the number of validation and evaluation interviews, which reduced the external validation of the study to two participants.

7.4 Future Research

In this section, areas for further studies and research will be discussed.

7.4.1 Application of the ACCE framework

This PhD study provided proof of concept for the ACCE framework; however, the full use of the framework to identify, apply, review, and repeat the process is still required. Application of CE practice and performance measurement using the ACCE framework would provide further data on its use in practice. This could also be expanded to other sectors of the construction industry, such as infrastructure and civil engineering projects.

7.4.2 ACCE framework app development

The validation of the ACCE framework identified the need to develop an application for handheld devices to ease the use of the framework within the construction industry. Developing the ACCE framework into an application could reduce the time taken to use the framework for the completion of surveys or the review of data and guidance. The application could also be used for tracking interval data within various samples of a supply chain or holistically.

7.4.3 Generalisable results

This PhD study relied on case studies and non-parametric data to investigate the CE's DBPs for the development of the ACCE framework. For further study, the ACCE framework could be used within a larger sample of the UK construction industry to develop parametric datasets to create generalisable results for wider development of the CE. The study could also employ a wider Likert scale to gain more granular data.

7.4.4 Application of individual practices or groupings

Based on the results of the empirical data collection, a number of practices of the CE are novel and scarcely applied within the UK construction industry. A point of further study could be the selection and application of individual practices or groupings to measure the impact of CE practice on the levels of waste production on different types of construction projects. For instance, material tracking, material passports, and blockchain were ranked as underdeveloped within the empirical studies. Said practices could improve the management of information and transparency within a supply chain, mitigating the associated barriers.

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APPENDIX A: RAW DATA FROM THE EMPIRICAL STUDIES OF THE PHD

Practice No.	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24
Practices	Design for Closed Loops	Design for Longevity	Design for Disassembly	Closed-loop Material Specification	Reduced Operational Impact	Product as a Service	Take-Back Systems	Recovery and Reuse Infrastructure	Standardisation	Prefabrication	Modularisation	Waste Management	Upcycling/Downcycling	Urban Mining	Financial Support	Laws and Regulations	Taxation	National/Local Goals and Targets	Supervision	Incentives & Penalties	Circular Procurement	Frameworks/Business Models	Top-down/Bottom-up Management	Material Standards/Classification
Participant #1																								
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Participant #3																								
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P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39	P40	P41	P42	P43	P44	P45	P46
Material Standards/Classification	The 3-12Rs of the Circular Economy	The Lean Philosophy	Supply-chain Management and Integrated Project Delivery	Extended Responsibilities	Marketing and Awareness	Knowledge and Education	Establishing Communication and Information Sharing	Understanding the Product, Process, and Consumer	Research and Development	Life Cycle Analysis (LCA)	Data Collection and Communication	Case Studies	Building Information Modelling (BIM)	Circularity Tools	Cost Modelling Tools	Collaboration Tools	Material Passports	Information Management and Transparency	Secondary Material Innovations	Digitalisation	Internet of Things (IoT)	Blockchain

Appendix A.1: Participant responses for the practices of the CE

	Supply Chain No.	SC1	SC2	Mean	SC1	SC2	Mean	SC1	SC2	Mean	SC1	SC2	Mean	SC1	SC2	Mean	SC1	SC1	SC2	SC2	SC2			
Practice	Practices	Construction Management			Commercial Management			Design			Sustainability			Supplier			Demolition	M,E,&P	Waste Management	Logistical Management	Procurement	Mean Average	Mean Average (SC1)	Mean Average (SC2)
P1	Design for Closed Loops	2	2	2	2	2	2	2	2	2	3	2	2.5	3	3	3	3	3		3	3	2.50	2.57	2.43
P2	Design for Longevity	1	3	2	3		3	2	3	2.5			0			0	2					2.50	2.00	3.00
P3	Design for Disassembly	3	2	2.5			0		1	1	2		2	3		3	2					2.00	2.50	1.50
P4	Closed-loop Material Specification	2		2	3		3	2	1	1.5	2	2	2	3		3			3			2.20	2.40	2.00
P5	Reduced Operational Impact			0	3	2	2.5			0			0		3	3						2.75	3.00	2.50
P6	Servitisation/PSS	3	1	2	3	2	2.5	3	2	2.5	1	2	1.5	3		3	2	4				2.23	2.71	1.75
P7	Take-Back Systems	3	3	3	2	3	2.5	3	3	3	3	3	3	1	2	1.5	2		4	4	3	2.73	2.33	3.13
P8	Recovery and Reuse Infrastructure	3	2	2.5		2	2			0	3	4	3.5	3	2	2.5	3	1	4	2		2.63	2.60	2.67
P9	Standardisation	4	3	3.5	4		4	3	3	3	1	3	2	4		4	3	4				3.14	3.29	3.00
P10	Prefabrication	4	3	3.5	4	3	3.5	3	4	3.5	3	3	3			0		4				3.43	3.60	3.25
P11	Modularisation	4		4	4		4	4	2	3		1	1			0	3	4				2.65	3.80	1.50
P12	Waste Management	3	3	3	2	3	2.5	2	2	2	3	3	3	3		3	4	3	4	2	4	2.93	2.86	3.00
P13	Upcycling/Downcycling	3	3	3	3	3	3			0	3		3	3		3	4					3.10	3.20	3.00
P14	Urban Mining	3	3	3	3	3	3			0	3		3			0						3.00	3.00	3.00
P15	Financial Support		1	1			0			0		1	1	3		3						2.00	3.00	1.00
P16	Laws and Regulations			0		3	3			0	2	3	2.5			0	2		3			2.50	2.00	3.00
P17	Taxation			0			0			0			0			0	4		3			3.50	4.00	3.00
P18	Goals and Targets		4	4	3		3			0		3	3			0						3.25	3.00	3.50
P19	Supervision	3	1	2			0			0		3	3			0			4	2	2	2.70	3.00	2.40
P20	Incentives	2	4	3			0		3	3	2	3	2.5		3	3	3		3			2.77	2.33	3.20
P21	Circular Procurement	2	2	2	1	2	1.5	1	1	1	3	2	2.5	3		3	2		3			2.00	2.00	2.00
P22	Frameworks/Business Models			0			0			0	3	2	2.5			0			2			2.50	3.00	2.00
P23	Top-down/Bottom-up Management		1	1	3	2	2.5			0	3	3	3			0	2		3	2		2.43	2.67	2.20
P24	Material Standards/Classification	3	4	3.5	3		3	2	2	2	4	4	4		2	2			4			3.10	3.00	3.20
P25	The 3-12Rs of the Circular Economy			0			0			0		2	2	2		2						2.00	2.00	2.00
P26	The Lean Philosophy	3	3	3		3	3	3	3	3	2	1	1.5	2		2	3	3		3	2	2.58	2.67	2.50
P27	Integrated Project Delivery (IPD)	3	3	3	2	2	2		2	2	2		2			0	2	3	3		3	2.50	2.40	2.60
P28	Extended Responsibilities		2	2	1	2	1.5			0			0			0						1.50	1.00	2.00
P29	Marketing and Awareness of the CE			0	2		2			0			0		3	3	3		3			2.75	2.50	3.00
P30	Knowledge Management and Education	3	3	3			0			0	2	3	2.5		3	3	2		4			2.79	2.33	3.25
P31	Establishing Communication and Information Sharing	3	1	2	2		2	3	1	2	2	3	2.5	2		2			3		3	2.30	2.40	2.20
P32	Understanding the Product, Process, and Consumer	2	1	1.5			0	2	2	2		3	3		3	3	4			3		2.53	2.67	2.40
P33	Research and Development	3		3			0			0			0		3	3						3.00	3.00	3.00
P34	Lack of Life Cycle Analysis (LCA) and Benchmarking	3	1	2	3	1	2	1	2	1.5	3	1	2	2	2	2		4	3	1		2.12	2.67	1.57
P35	Data Collection and Communication	2	2	2	3		3		2	2	2	3	2.5	3	3	3		4	4		3	2.82	2.80	2.83
P36	Case Studies		2	2			0			0		2	2			0	2					2.00	2.00	2.00
P37	Building Information Modelling (BIM)	3	1	2	3		3	3	1	2	3	1	2	2		2	3	4				2.00	3.00	1.00
P38	Circularity Tools			0			0			0			0	1		1						0.50	1.00	0.00
P39	Cost Modelling Tools			0			0			0	2	2	2	1		1						1.75	1.50	2.00
P40	Collaboration Tools	3		3			0			0	1		1			0						1.00	2.00	0.00
P41	Material Passports		1	1			0			0	2	1	1.5			0	3					1.75	2.50	1.00
P42	Information Management and Transparency	2	2	2	3		3		3	3	3	2	2.5			0		3	3	3		1.80	1.00	2.60
P43	New Secondary Material Developments	2		2			0	2	1	1.5			0		3	3						2.00	2.00	2.00
P44	Digitalisation	3	1	2	3	1	2			0	1	1	1	2	1	1.5	3	4	3	3	1	1.83	2.67	1.00
P45	Internet of Things (IoT)			0			0			0			0			0	3					1.50	3.00	0.00
P46	Blockchain			0			0			0		1	1			0						0.50	0.00	1.00
	Mean Average	2.77	2.19	10.00	2.72	2.29	18.00	2.41	2.09	24.00	2.38	2.28	9.00	2.45	2.57	18.00	2.76	3.43	3.30	2.55	2.67	2.25	2.40	2.11
	Mean Average (Working group)	2.48			2.51			2.25			2.33			2.51										
	Number of Practices Identifeid	30	31		25	17		17	22		29	32		20	14		25	14	20	11	9			

Appendix A.2: Content analysis of qualitative responses to the CE's practices by working group and supply chain

Driver	Drivers	P#1	P#2	P#3	P#4	P#5	P#6	P#7	P#8	P#9	P#10	P#11	P#12	P#13	P#14	P#15	P#16	P#17	P#18	P#19	P#20	P#21	P#22	P#23	P#24	P#25	P#26	P#27	Mean Average	Average SC1	Average SC2
D1	New Economic & Environmental Opportunities for Businesses	3	3	4	2	4	3	4	4	3	4	2	4	4	4	4	4	3	4	3	4	3	4	4	3	3	4	2	3.4	3.4	3.5
D2	Industrial Competition	4	3	3	3	2	4	3	4	4	3	3	4	3	4	3	4	4	3	4	4	3	4	3	4	3	4	3	3.4	3.3	3.5
D3	Secondary Material Production/Supply	3	3	3	3	4	3	3	4	3	4	2	3	4	4	4	4	4	3	3	3	3	2	4	3	3	3	4	3.3	3.3	3.3
D4	Raw Material Volatility	3	3	3	3	4	3	3	4	3	4	2	3	4	4	4	4	4	3	3	3	3	2	4	3	3	3	4	3.3	3.3	3.3
D5	Reduced Environmental Impact	3	3	4	4	4	4	2	4	3	3	3	3	3	4	3	4	4	4	4	4	4	3	4	3	3	3	3	3.4	3.3	3.5
D6	Servitisation/PSS	1	2	2	2	2	4	3	3	2	3	4	3	3	3	4	4	2	2	3	2	3	3	3	2	4	4	3	2.8	2.8	2.8
D7	Take-back Schemes	3	4	3	3	3	4	3	3	3	3	3	3	4	3	3	3	3	2	3	3	3	3	4	3	4	4	3	3.2	3.2	3.2
D8	Recovery and Reuse Infrastructure	3	3	1	2	3	3	3	3	2	2	2	3	3	3	2	3	3	3	4	3	4	4	4	4	4	4	4	3.0	3.0	3.1
D9	Standardisation	3	4	3	3	3	4	4	3	4	4	3	3	3	3	4	4	4	4	4	3	4	4	4	4	4	4	4	3.6	3.6	3.7
D10	Waste Reduction	4	3	3	4	4	4	3	4	3	3	3	3	3	4	4	4	4	4	3	4	4	3	4	3	3	3	3	3.5	3.5	3.5
D11	Cost and Time Efficiency	3	4	3	2	3	3	4	4	4	3	2	4	3	3	4	4	4	4	3	4	4	3	4	3	3	3	3	3.4	3.5	3.3
D12	Improved Product Quality	3	4	3	3	4	3	3	4	3	2	4	3	4	4	2	4	2	4	3	3	3	4	4	4	3	3	3	3.3	3.3	3.3
D13	Circular Laws and Legislation	3	4	2	3	3	4	4	4	4	3	4	4	3	4	3	4	4	4	4	4	4	4	4	4	4	4	4	3.7	3.7	3.7
D14	Taxes (Relief and Penalties)	3	4	2	3	3	4	4	4	4	3	4	4	3	4	3	4	4	4	4	4	4	4	4	4	4	4	4	3.7	3.7	3.7
D15	Goals and Targets	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	4	4	4	4	4	4	4	4	4	4	4	3.3	3.3	3.3
D16	Supervision and Inspections	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	4	4	4	4	4	4	4	4	4	4	4	3.3	3.3	3.3
D17	Financial Incentives	3	3	4	2	4	3	4	4	3	4	2	4	4	4	4	4	3	4	3	4	3	4	4	3	3	4	2	3.4	3.4	3.5
D18	Procurement Strategies	4	4	4	3	4	3	3	4	3	2	3	4	4	4	3	4	4	3	4	3	4	4	4	4	4	3	4	3.6	3.8	3.5
D19	Frameworks/Business Models	3	3	3	4	4	4	2	4	3	3	3	3	3	4	4	4	3	3	3	3	4	2	3	2	4	4	3	3.3	3.3	3.3
D20	Guidance and Best Practice	3	2	3	1	2	4	3	3	2	3	3	3	3	4	2	2	4	4	4	4	4	4	4	4	4	4	4	3.2	2.9	3.5
D21	Secondary Material Standards	3	2	4	2	2	2	3	3	2	2	3	4	2	3	3	4	4	4	4	4	4	4	4	4	4	4	4	3.3	3.2	3.3
D22	Integrated Project Delivery (IPD)	3	4	2	2	3	3	2	2	3	3	2	3	3	3	2	4	4	3	3	4	3	4	4	4	3	4	3	3.1	3.0	3.1
D23	Responsibility and Recognition	3	4	3	2	3	4	3	3	3	3	2	3	3	3	3	4	4	4	4	3	3	4	4	3	4	4	3	3.3	3.3	3.3
D24	Marketing and Awareness Campaigns	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	3	3	3	3	4	4	4	4	3	3	3	3.2	3.3	3.1
D25	Education Programs	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	4	4	3	4	3	3	4	4	3	4	4	3.3	3.3	3.3
D26	Data sharing	3	2	2	2	4	3	3	2	2	2	2	3	3	3	3	3	3	3	4	3	2	3	4	3	3	4	2	2.8	2.9	2.7
D27	Society's Opinion of Unsustainable Practice	3	3	4	3	4	4	3	3	3	4	3	3	4	4	3	4	4	4	3	4	2	2	4	4	4	3	3	3.4	3.3	3.5
D28	Research and Development	4	3	4	3	3	3	3	4	3	3	3	4	3	3	3	4	3	3	4	3	2	3	4	3	3	4	3	3.3	3.3	3.3
D29	New networks	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	3	3	3	3	4	4	4	4	3	3	3	3.2	3.3	3.1
D30	Lack of Life Cycle Analysis (LCA) and Benchmarking	3	4	3	3	3	4	3	3	3	4	4	3	4	3	4	3	3	3	4	3	3	3	4	3	3	4	2	3.3	3.4	3.2
D31	Material Database	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	3	3	4	3	3	3	4	3	3	4	2	3.1	3.3	3.0
D32	Case Studies	4	3	4	3	3	3	3	4	3	3	3	4	3	3	3	4	3	3	4	3	2	3	4	3	3	4	2	3.2	3.3	3.2
D33	Building Information Modelling (BIM)	4	3	3	3	4	3	4	3	2	2	3	4	4	2	3	4	3	3	4	3	3	3	4	3	3	4	2	3.2	3.6	2.9
D34	Circularity tools	4	3	3	3	4	3	4	3	2	2	3	4	4	2	3	4	3	3	4	3	3	3	4	3	3	4	2	3.2	3.6	2.9
D35	Design tools	4	3	3	3	4	3	4	3	2	2	3	4	4	2	3	4	3	3	4	3	3	3	4	3	3	4	2	3.2	3.6	2.9
D36	Collaboration tools	3	4	2	2	3	3	2	2	3	3	2	3	3	3	2	4	3	3	4	3	3	3	4	3	3	4	2	2.9	3.0	2.9
D37	Material Tracking	4	3	3	3	4	3	4	3	2	2	3	4	4	2	3	4	3	3	4	3	3	3	4	3	3	4	2	3.2	3.6	2.9
D38	New Methods of Construction and Deconstruction	4	3	3	3	4	3	4	3	2	2	3	4	4	2	3	4	3	4	4	4	3	3	4	4	3	4	3	3.3	3.6	3.1
D39	New Materials	3	3	3	3	4	3	3	4	3	4	2	3	4	4	4	4	4	3	3	3	3	2	4	3	3	3	4	3.3	3.3	3.3

Appendix A.3: Participant responses to the drivers of the CE

Barrier No.	Barriers	P#1	P#2	P#3	P#4	P#5	P#6	P#7	P#8	P#9	P#10	P#11	P#12	P#13	P#14	P#15	P#16	P#17	P#18	P#19	P#20	P#21	P#22	P#23	P#24	P#25	P#26	P#27	Mean Average	Average SC1	Average SC2
B1	Complexity of Construction	3	4	2	3	3	4	2	3	4	3	4	2	4	2	4	4	3	4	2	3	2	3	4	3	4	4	3	3.19	3.08	3.27
B2	Profitable Linear Market	2	2	2	3	2	3	4	3	3	3	4	1	3	4	3	4	4	4	2	4	2	4	4	3	4	2	4	3.07	2.75	3.33
B3	The Stigma Surrounding Secondary Materials	3	2	4	2	2	2	3	3	2	2	3	4	2	3	3	4	3	4	4	2	1	2	2	4	3	3	2	2.74	2.83	2.67
B4	Lack of Short-term Benefits	2	1	2	2	3	2	2	3	3	4	2	2	3	2	3	3	2	2	2	3	1	2	4	3	3	4	3	2.52	2.17	2.80
B5	Risk of Innovating	3	4	3	3	3	3	4	3	3	2	4	4	3	3	3	3	4	2	3	3	3	4	4	3	3	2	3	3.15	3.42	2.93
B6	Cost of Innovating	2	2	2	3	2	3	4	3	3	3	4	1	3	4	3	4	4	4	2	4	2	4	4	3	4	2	4	3.07	2.75	3.33
B7	High Cost of Secondary Products	2	2	2	3	2	3	4	3	3	3	4	1	3	4	3	4	4	4	2	4	2	4	4	3	4	2	4	3.07	2.75	3.33
B8	Lack of Infrastructure for Recovery and Reuse	3	3	1	2	3	3	3	3	2	2	2	3	3	3	2	3	2	3	2	3	2	2	4	3	3	3	4	2.67	2.58	2.73
B9	Lack of Standardization	3	3	3	2	3	4	2	3	2	2	1	3	3	3	3	4	3	3	4	3	2	3	4	3	3	3	4	2.93	2.83	3.00
B10	Lack of Time	2	2	2	3	2	3	4	3	3	3	4	1	3	4	3	4	4	4	2	4	2	4	4	3	4	2	4	3.07	2.75	3.33
B11	Quality of Secondary Materials	3	2	4	2	2	2	3	3	2	2	3	4	2	3	3	4	4	4	2	4	2	4	4	3	4	2	4	3.00	2.83	3.13
B12	Lack of Segregation	3	3	2	2	3	3	3	3	2	2	2	3	3	2	2	1	2	3	3	2	2	3	4	2	2	3	3	2.52	2.50	2.53
B13	Low-value Recovered Materials	3	3	3	3	4	3	3	4	3	4	2	3	4	4	4	4	3	4	4	2	1	2	2	4	3	3	2	3.11	3.17	3.07
B14	Immature Secondary Market	3	3	4	2	4	3	4	4	3	4	2	4	4	4	4	4	2	3	2	3	2	2	4	3	3	3	4	3.22	3.17	3.27
B15	Lack of Financial Support	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	4	4	2	4	2	4	4	3	4	2	4	3.07	3.00	3.13
B16	Lack of Supporting Laws and Legislation	3	4	2	3	3	4	4	4	4	3	4	4	3	4	3	4	4	3	4	4	4	4	4	3	4	3	4	3.59	3.67	3.53
B17	Lack of Taxes (Relief and Penalties)	3	4	2	3	3	4	4	4	4	3	4	4	3	4	3	4	4	3	4	4	4	4	4	3	4	3	4	3.59	3.67	3.53
B18	Lack of Goals and Targets	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	4	3	4	4	4	4	4	3	4	3	4	3.22	3.33	3.13
B19	Lack of Supervision	3	4	3	2	3	4	3	3	3	3	2	3	3	3	3	4	4	3	4	4	4	4	4	3	4	3	4	3.33	3.33	3.33
B20	Lack of Incentives and Penalties	3	3	4	2	4	3	4	4	3	4	2	4	4	4	4	4	4	3	4	4	4	4	4	3	4	3	4	3.59	3.67	3.53
B21	Lack of Procurement Strategy	3	4	3	3	3	2	3	4	3	3	2	4	4	4	3	4	3	3	3	3	2	2	4	4	3	3	3	3.15	3.17	3.13
B22	Lack of Frameworks/Business Models	3	3	3	4	4	4	2	4	3	3	3	3	3	4	4	4	4	4	3	3	3	3	4	3	3	4	3	3.37	3.25	3.47
B23	Lack of Guidance and Best Practice	3	2	3	1	2	4	3	3	2	3	3	3	3	4	2	2	3	3	4	3	2	3	4	3	3	3	4	2.89	2.67	3.07
B24	Lack of Government Support	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	4	3	4	4	4	4	4	3	4	3	4	3.22	3.33	3.13
B25	Lack of Industry Adoption	2	2	2	2	3	4	3	3	3	3	4	2	2	4	2	4	4	3	3	4	3	4	4	3	3	4	3	3.07	2.83	3.27
B26	Lack of Integrated Project Delivery (IPD)	3	4	2	2	3	3	2	2	3	3	2	3	3	3	2	4	3	2	2	3	4	3	2	3	3	4	4	2.85	2.92	2.80
B27	Lack of Responsibility and Recognition	3	4	3	2	3	4	3	3	3	3	2	3	3	3	3	4	3	3	3	3	2	2	4	4	3	3	4	3.07	3.00	3.13
B28	Lack of Marketing and Awareness of the CE	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	2	2	3	3	3	3	4	2	3	3	4	3.00	3.08	2.93
B29	Lack of Knowledge and Education	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	4	3	3	4	3	4	4	4	4	3	4	3.30	3.25	3.33
B30	Lack of Management	3	4	3	2	3	4	3	3	3	3	2	3	3	3	3	4	3	3	4	3	2	3	4	3	3	3	4	3.11	3.08	3.13
B31	Lack of Consumer Demand	3	3	4	3	4	4	3	3	3	4	3	3	4	4	3	4	4	3	3	4	3	4	4	4	4	3	4	3.52	3.33	3.67
B32	Lack of Research and Development	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	4	3	3	4	3	4	4	4	4	3	4	3.30	3.25	3.33
B33	Lack of Life Cycle Analysis (LCA) and Benchmarking	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	4	3	3	4	3	4	4	4	3	3	4	3.26	3.25	3.27
B34	Lack of Material Data	3	2	2	2	4	3	3	2	2	2	2	3	3	3	3	3	4	3	3	4	3	4	4	4	3	2	4	2.96	3.00	2.93
B35	Lack of Case Studies	4	3	4	3	3	3	3	4	3	3	3	4	3	3	3	4	4	4	4	3	4	3	3	3	3	2	4	3.33	3.50	3.20
B36	Lack of Information	2	3	2	2	4	4	2	3	3	3	3	3	2	3	3	4	4	4	3	3	3	3	4	3	3	4	4	3.11	3.00	3.20
B37	Lack of Circular Tools	2	3	2	2	4	4	2	3	3	3	3	3	2	3	3	4	4	4	3	3	3	3	4	3	3	4	4	3.11	3.00	3.20
B38	Lack of Design Tools	2	3	2	2	4	4	2	3	3	3	3	3	2	3	3	4	4	4	3	3	3	3	4	3	3	4	4	3.11	3.00	3.20
B39	Lack of Collaboration Tools	3	4	2	2	3	3	2	2	3	3	2	3	3	3	2	4	2	2	3	3	3	3	4	2	3	3	4	2.81	2.83	2.80
B40	Lack of Material Tracking	3	3	1	2	3	3	3	3	2	2	2	3	3	3	2	3	2	3	2	3	2	2	4	3	3	2	4	2.63	2.58	2.67
B41	Lack of Transparency	3	4	2	2	3	3	2	2	3	3	2	3	3	3	2	4	2	2	3	3	3	3	4	2	3	2	3	2.74	2.83	2.67
B42	Lack of Material Technology	4	4	3	2	2	3	3	3	3	3	3	3	4	3	2	4	3	4	2	3	2	3	4	3	4	4	3	3.11	3.00	3.20
B43	Lack of Material Classification	3	3	2	2	4	3	4	3	3	2	3	2	3	3	2	4	3	3	4	3	2	3	4	3	3	3	4	3.00	3.08	2.93

Appendix A.4: Participant responses to the barriers of the CE

APPENDIX B: CONSENT FORMS

Appendix B.1: Consent form template (34 completed participant consent forms available on request)

Template Consent Form

School of Engineering and the Built Environment

This research is being undertaken by Nathan Johns for a PhD project on the Development of a Circular Economic Framework for the Built Environment and is being supervised by Dr. Saeed Talebi, Saeed.Talebi@bcu.ac.uk during the period 06.09.21 to 06.09.24. This research aims to This research aims to develop a novel framework that encapsulates the CE to proactively mitigate waste whilst prioritising value and resource retention by focusing on the influence of the main contractor, and a copy of the final report will be made available to all participants when the work is submitted and graded in Approx. August 2024.

Please note that you are able to withdraw form this study at any time up until two weeks after participation without giving reason or explanation. All responses will be treated in the strictest of confidentiality and will not be share willingly or otherwise with any third party. Data and information analysed will be anonymised to preserve your identity and all information collected will be securely destroyed upon successful completion of the award.

SECTION ONE

Title of study: Development of a Circular Economic Framework for the Built Environment

Researchers' contact email: Nathan.Johns@bcu.ac.uk

SECTION TWO - INFORMATION

Please can you answer the following questions by placing a tick (√) in the appropriate boxes below. Thank you for completing this consent form.

Question	**Response**	
	Yes	**No**
Have you read and fully understood the letter/information sheet that accompanies this invitation to participate in this research?		
Do you agree to participate in this proposed dissertation research conducted by the School of Engineering and the built Environment?		
Have you been given opportunity to ask additional questions about the research study?		
Do you understand that you are free to withdraw from this study, at any time and without giving reasons?		
Do you give permission for the research team members (Nathan Johns and Dr. Saeed Talebi) to have access to your anonymised responses and/or data/information?		
Do you understand that all information and data collated will be anonymised, securely stored during the research period and securely destroyed at the end of this study?		
Any other additional comments:		

NB: Please sign below to confirm that you have voluntarily decided to participate in this dissertation study (as detailed above) and that you have read and fully understood the accompanying letter/information sheet. Your signature will also certify that you have had every opportunity to pose questions about the research and that your questions have been satisfactorily answered.

SIGNATORIES TO THIS CONSENT

Signature of participant: **Date:**

Name (block letters):

Signature of Researcher: **Date:**

Name (block letters):

Signature of Supervisor: **Date:**

Name (block letters):

Please produce three copies of this signed consent form and cover letter – one for the participant, researcher and researcher's supervisor.

Appendix B.2: Participant Information Sheet

TEMPLATE INFORMATION SHEET

School of Engineering and the Built Environment

This research is being undertaken by **Nathan Johns** for a final year project on **the Development of a Circular Economic Framework for the Built Environment** and is being supervised by **Dr. Saeed Tablebi, Saeed.Talebi@bcu.ac.uk** during the period **06.09.21 to 06.09.24** This research aims to **develop a novel framework that encapsulates the CE to proactively mitigate waste whilst prioritising value and resource retention by focusing on the influence of the main contractor,** and a copy of the final report will be made available to all participants when the work is submitted and graded in **Approx. August 2024**.

QUESTIONS AND ANSWERS – ABOUT THIS RESEARCH

Please note that this information sheet is here to provide basic information about this research project and why you have been invited to participate – specifically common questions arising are listed and answers to these provided. Any further queries will be answered prior to agreeing to your consent to participate. Thank you.

No	Question	Answer
1	Title of your project?	Development of a Circular Economic Framework for the Built Environment
2	What research being conducted?	This research project is investigating the circular economy within the construction industry and specifically seeks to **develop a novel framework that encapsulates the CE to proactively mitigate waste whilst prioritising value and resource retention by focusing on the influence of the main contractor.** The objectives are to To explore the impact of anthropic economic consumption and waste as a problem domain on the natural climate as well as the proposed solutions of the CE in which to mitigate the problem To investigate the principles of the CE within the context of the construction industry for the development of a conceptual mitigation framework To develop a CE mitigation framework for the use of main contractors in advising and incorporating a close-loop CE lifecycle within the construction industry based upon the findings from the literature review and empirical studies

		To evaluate the developed mitigation framework within the construction industry's main contractors and their spheres of influence within the lifecycle
3	Why have I been invited to participate?	You have been invited to participate as a professionally competent and knowledgeable practitioner who has accrued many years of experience working in the industry – your views and opinions will be invaluable to the research.
4	What input do you require from me?	The research will require information and data from you, colleagues within your organisation or about your organisation directly. This data and information will include: secondary data such as past reports and/or perceptions and opinions.
5	'Where will data collection or surveys take place?	Data collection will take place online via 'Online Surveys' or MS Team.
6	How often will I need to participate in this research and for how long?	You will be required to partake in an interview that will only take approximately one hour.
7	At what stage in the process will I have the opportunity to discuss my participation?	You will be able to comment on your participation at the end of a process if commenced, before the process has commenced, or after data analysis/publication.
8	Who is responsible for the information and data collected when this study is complete?	Responsibility for information and data collected is the responsibility of the lead researcher and their supervisor – who must abide by Birmingham City University research ethics rules and regulations.
9	Who will have access to the information and data?	Only the lead researcher and staff at Birmingham City University.
10	What will happen to the information data supplied when this research is complete?	At the end of the study, all information and data will be securely disposed of (including raw data) and only anonymised data will be used for publishing the findings as part of this dissertation study. At no time will any data be passed to a third party (willingly or otherwise).
11	How will the information and data be used?	The information and data will be used to create a research paper that will not contain any personal details of participants or organisations supporting this work.
12	How long is the research project duration?	The research term commences in September each year and the final paper is handed in during May. Marks and graded are awarded in June. Contact with participants will only be at short, intermittent periods so as not to disrupt your working arrangements.
13	Is my data and information secure?	All information is stored electronically on the University's secure 'One Drive' and/or locked away in a secure cupboard.
14	Can I have access to the research results?	Yes. The study's results will be made freely available to all survey participants.
15	What if I do not wish to participate in this research project?	Participation is completely voluntary and you do not have to participate.

16	What about if I change my mind during the research project?	You can withdraw from the research at any stage of the process.
17	Who do I contact if I experience any concerns or if the study generates any adverse effects?	In the first instance, you need to contact my supervisor (Saeed.talebi@bcu.ac.uk) who should refer the matter to the Faculty Academic Ethics Committee. If participants have concerns about the use of their data, guidance is available as an attachment here: https://icity.bcu.ac.uk/cebe/Research/CEBE-Faculty-Academic-EthicsCommittee/Guidelines-and-Resources. Also, please contact BCU_ethics@bcu.ac.uk for complaints about the research.