Circular Supply Chain Management for Sustainability: Evidence from a Developing Country

By

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Declaration

I hereby declare that all parts of the thesis or any section are the results of my empirical research work. Any parts or sections that are used from any sources or persons are all properly acknowledged and cited. No parts of the thesis are submitted to any other program.

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Dedication

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Abstract

What if a product lasts for a long time without waste? This fundamental question lies at the heart of the circular product design (CPD), which rethinks the product design and manufacturing in the era of mounting waste, climate change, and resource depletion. However, product design cannot work alone to address all such challenges, as it is only the starting point for applying circular thinking across supply chain functions. Considering this, product design requirements must align with technology and supply chain practices to meet all circularity principles (R's strategies). This study aims to investigate how manufacturing firms utilise their design capabilities and technologies (such as additive manufacturing) for CPD to operationalise circular supply chain management (CSCM) through top management commitment, thereby enhancing sustainability performance.

In pursuit of the research aim, this study investigates how circular product design, supported by additive manufacturing and design capabilities, facilitates the operationalisation of circular supply chain management through top management commitment to enhance sustainability performance. A mixed-methods approach is used to address the research question within the manufacturing firms in Bangladesh. Building on the principles of using dynamic capability theory and institutional theory, this study confirms that AM plays a significant role in CPD. This relationship further demonstrates that integrating design capabilities such as design for assembly and disassembly and design for recyclability, along with material selection capabilities, leads to CPD that improves the performance of new products. The findings further demonstrate that CSCM practices drive economic, social, and environmental performance when they are accepted and managed under three types of pressures (coercive, normative, and mimetic) alongside top management commitment.

By combining dynamic capabilities with institutional drives for CPD, this study advances these theoretical perspectives in the context of CSCM. The study also provides valuable insights for manufacturers and policymakers seeking to integrate circularity principles into their product design and supply chain practices to advance sustainable development goals (SDGs). Finally, the study highlights the limitations of how design capability, technological adoption, and institutional environment shape the transformation towards a circular supply chain. These limitations will help open the avenues for future research.

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List of Abbreviations

3DP	3D Printing
AM	Additive Manufacturing
ASTM	American Society for Testing and Materials
AVE	Average Variance Extracted
BGMEA	Bangladesh Garments Manufacturer Exporter Association
BIDA	Bangladesh Investment Development Authority
BKMEA	Bangladesh Knitwear Manufacturers and Exporters Association
BOI	Board of Investment
BSRM	Bangladesh Steel Re-rolling Mills
CE	Circular Economy
CLSC	Close Loop Supply Chain
CP	Coercive Pressures
CPD	Circular Product Design
CSC	Circular Supply Chain
CSCM	Circular Supply Chain Management
CUMBA	Chittagong University MBA Association
DCs	Dynamic Capabilities
DCT	Dynamic Capabilities Theory
DfAD	Design for Assembly and Disassembly
DfM	Design for Modularity
DfR	Design for Recyclability
DT	Digital Technologies
EBS	Everything but Arms
EcoP	Economic Performance
EOL	End of Life
EnvP	Environmental Performance
EU	European Union
ESPR	Eco-design for Sustainable Products Regulation
FMCG	Fast Moving Consumer Goods
GSP	Generalised System of Preferences
GPRS	General Packet Radio Service

ICMEB	The Institute of Cost and Management Accountants of Bangladesh
IPs	Institutional Pressures
IS	Industrial Symbiosis
ISO	International Standard Organisation
IT	Institutional Theory
LEED	Leadership in Energy and Environmental Design
LCA	Life Cycle Assessment
MP	Mimetic Pressures
NGO	Non-Governmental Organisation
NP	Normative Pressures
NPD	New Product Development
NPP	New Product Performance
PD	Product Design
PLE	Product Life Extension
RMG	Ready Made Garments
RE	Reverse engineering
ROI	Return on Investment
ScoP	Social Performance
SDG 11	Sustainable Cities and Communities
SDG 12	Responsible Consumption and Production
SDG 13	Climate Action
SEM	Structural Equation Modelling
SLR	Systematic Literature Review
SME	Small-Medium Enterprise
SPSS	Statistical Package for the Social Sciences
TBL	Triple Bottom Line
TMC	Top Management Commitment
UN	United Nations
VRIN	Valuable, Rare, Inimitable, and Non-substitutable

Chapter 1: Introduction

1.1 Research Background

Global waste increases in a wave-like fashion due to rapid industrialisation and technological development. The World Bank estimates global waste could reach 3.4 billion tons annually by 2050, which would be 73% more than in 2016 (World Bank, 2018). This leads to environmental degradation through landfill pollution, ocean plastic pollution, and contaminated substances, which threaten climate change and biodiversity (United Nations Environment Programme, 2021). Similarly, the extraction of natural resources increased significantly from 22 billion to 70 billion tonnes in 2010, placing significant pressure on their availability (Kalaitzi et al., 2019; Schandl et al., 2018). All these unforeseen threats are not addressed by the traditional product and production system, which needs to follow the progression of the newly shaped circular economy (CE) based production system (Ellen MacArthur Foundation, 2013).

Consequently, persistent obstacles and challenges in the production system demand the transformation of the existing product and production system. The switch from a linear economy to a CE calls for fundamental rethinking of product design to achieve sustainable value creation (Burke et al., 2023). Linear production models are predominantly structured around a ‘take, make, and dispose’ system that drives resource depletion and excessive waste, causing significant environmental degradation (Ajibade et al., 2025). By contrast, the CE seeks to value recovery or value retention through reuse, remanufacturing, recycling, and material recovery (Ellen MacArthur Foundation, 2016). Implementing such circularity principles is a priority at the design stage, as prior literature indicates that more than 80% of a product’s environmental impact is determined before manufacturing begins (Diaz et al., 2021; Schoormann et al., 2025). Although most products are still not designed for repair, disassembly, or recycling, this can lead to the emission of material and premature disposal

(Saidani et al., 2019). To resolve these issues, organisations need to cultivate and utilise design and manufacturing technologies for circular product design and establish circular supply chain management (CSCM) practices to improve sustainable performance.

Specific capabilities such as systems thinking in design, organisational learning, stakeholder coordination, material selection, and resource reconfiguration help firms redesign products for reuse and recovery by enabling them to identify lifecycle problems, integrate new knowledge, collaborate across boundaries, and change existing design routines (Bocken et al., 2016; Teece et al., 1997). These capabilities qualify as dynamic capabilities (DCs) because they are higher-level capacities that allow firms to deliberately adapt and reconfigure product design practices in response to changing environmental and market conditions (Teece, 2007). DCs serve as a starting point for understanding how firms shift from traditional linear production to circular models by operationalising CPD for CSCM. DCs refer to the organisational capabilities that firms apply to sense new opportunities, seize them through investment and coordination, and reconfigure organisational practices and supply relationships accordingly (Teece, 2007). Within the domain of CPD, these capabilities determine whether firms can rethink product design and material selection to enable repair, modularity, remanufacture, and material recirculation. Hence, it calls for adaptive and flexible organisational capabilities. Without such adaptive capability-utilisation, most circular initiatives remain incremental or symbolic rather than transformative (Bocken et al., 2016; Scarpellini et al., 2020). Thus, the capitalisation of a group of DCs is not an optional enhancement; it is the foundational mechanism that makes CPD technically and operationally feasible.

Additive manufacturing (AM) provides a technological avenue for design and manufacturing through which dynamic capabilities can directly shape CPD. AM enables component redesign for disassembly and repair, localised production of spare parts, reduced material

input, and extension of product life through on-demand part replacement (Kunovjanek et al., 2022; Rejeski et al., 2018). However, AM only contributes to circularity when guided by purposeful design rules and organisational learning processes. Manufacturing firms must be able to experiment with new geometries, validate material properties, coordinate digital build files across suppliers, and define new reverse logistics and quality verification routines (Strong et al., 2020). In other words, it is technology that directs and governs the application of AM, leading to new product outcomes rather than merely new forms of production flexibility.

Once these CPD routines stabilise, the focus shifts to operationalisation. Operationalisation refers to the process by which new concepts, ideas, or variables are translated into concrete, measurable, and observable terms, and embedded as "how things are done" within the organisation and its supply network (Scott, 2010). The adoption of circular product design supported by AM is influenced by regulatory expectations (coercive pressures), professional and industry norms (normative pressures), and imitation of perceived leaders (mimetic pressures) (DiMaggio & Powell, 1983). Yet prior research shows that institutional pressures by themselves are insufficient for deep operationalisation; they require organisational capabilities to translate external pressures into internalised routines, shared standards, and supply chain collaboration (Glover et al., 2014; Siems et al., 2023). Therefore, dynamic capabilities precede and enable the operationalisation of circular supply chain practices, ensuring that they are not only adopted but also required for sustainable performance.

Beyond institutional pressures, top management commitment (TMC) constitutes a crucial factor impacting the potential success of CSCM. In practice, top managers act as catalysts to conform to institutional expectations. Moreover, top management needs to design a new product for CE as a strategic priority or a compliance formality (Burke et al., 2023; Swink, 2000). These factors jointly contribute to adequate resource allocation, active participation

across all departments, and the involvement of selected suppliers and control mechanisms to ensure new product performance (Aslam et al., 2020). In an operational context, transitions to CE embrace unknown risk, new cost structures, and uneven collaboration requirements across the supply network. Without proactive and effective TMC, employees and supply chain partners tend to follow traditional linear routines. Therefore, TMC and institutional pressures do not act as substitutes, but as dual mechanisms that translate external pressures into operationalised practices for the circular supply chain (Farooque et al., 2019).

The alignment of dynamic capabilities and AM both support circular product design, which, in turn, has direct implications for CSCM through the connection between institutional pressures and TMC. When CPD is put into practice, supply chains are better able to support closed-loop material flows, coordinated repair and refurbishment, extended product lifecycles, and reduced waste (Pellegrino et al., 2025). This integrated configuration contributes to the triple bottom line (TBL) of sustainability: reducing environmental impact through waste and emissions avoidance, enhancing social value through responsible resource stewardship, and improving long-term economic performance by lowering total lifecycle costs and stabilising material supply risks (Bocken et al., 2016; Elkington, 1998). TBL supports all sustainability dimensions, ranging from environmental integrity to social equity and economic viability, and has become a dominant lens for evaluating this shift (Elkington, 1998). In this sense, CSCM is not a standalone initiative but the downstream outcome of capability development, technology-driven circular design, and institutional anchoring within supply chain and product design.

1.2 Research Gap and Questions

Manufacturing firms are under intense pressure to design products based on circular strategies that reduce waste and errors, increase design flexibility, and improve speed and efficiency (Castro-Lopez et al., 2023; Collins & Browning, 2019). Product design based on

CE strategies transforms the traditional manufacturing system, aiming to address resource waste and emissions challenges by extracting the value from waste and achieving a sustainable outcome (Sharma et al., 2022). Under these circumstances, manufacturing firms urge to adopt circular design within a product that decouples growth from resource depletion and waste (Bocken & Ritala, 2022; Geissdoerfer et al., 2017). While CPD is understood as applying CE principles to the product design process (Bakker et al., 2014; Sumter et al., 2020), CSCM practices require implementing them through closed-loop systems and resource management (Centobelli et al., 2020; Govindan & Hasanagic, 2018b). Nevertheless, despite their significance, existing literature does not view the two approaches as complementary practices (Alghababsheh, 2024; Geissdoerfer et al., 2018).

Moreover, AM is considered an enabling technology for achieving circularity at the product level through design flexibility, reparability, and localised manufacturing (Ford & Despeisse, 2016; Garmulewicz et al., 2018). However, how AM contributes to loop closure and circular material flow within the supply chain is less examined (Das et al., 2025; Kellens et al., 2017; Pieroni et al., 2019). Consequently, although implementing CPD and AM both positively influence innovation and product performance (Hofmann & Jaeger-Erben, 2020), limited research has examined how circular design translates into performance measures.

Prior literature increasingly indicates that successful CSCM adoption depends on both external institutional pressures (coercive, normative, and mimetic) and internal commitment from top management (DiMaggio & Powell, 1983; Nair et al., 2025). Nevertheless, prior research indicates that CSCM intentions do not necessarily translate into action without TMC and integration processes (Burke et al., 2023; Hazen et al., 2021). Dynamic capabilities of an organisation, such as sensing, seizing, and transforming (Chari et al., 2022; Teece, 2007), play a key role in the integration of AM and CPD processes, yet empirical research gives preference to the perspective of the firm over that of supply chains and does not discuss the

process of spreading these capabilities through the circular supply chain framework (Ajibade et al., 2025; Faisal, 2023).

Based on the study domain, the study highlights two critical gaps in existing research on this subject. First, the empirical understanding of the synergy between AM and dynamic capabilities in the creation of tangible new products and supply chains through the implementation of circular design is inadequate (Eyers et al., 2022; Garmulewicz et al., 2018; Hofmann & Jaeger-Erben, 2020). The second gap is the lack of integration of CSCM processes and their role in achieving tangible TBL through TMC and institutional pressures (Centobelli et al., 2020; Geissdoerfer et al., 2023; Nair et al., 2025). To address these gaps, this study poses the following research questions:

- **RQ1:** How can CPD be effectively operationalised within the CE, and what role does AM play in enabling these strategies?
- **RQ2:** How do organisational and dynamic design capabilities support the effective use of AM to operationalise CPD and improve new product performance?
- **RQ3:** How do external pressures and TMC affect the implementation and adoption of CSCM? How does the process result in sustainability benefits?

Based on these research questions, this study aims to systematically examine the role of AM and material selection in CPD, considering institutional pressures and TMC for CSCM practices to achieve TBL in sustainable performance.

1.3 Research Objectives

Based on the research gap, the study plans to achieve the following objectives:

1. To systematically review the literature to identify and synthesise how CPD is conceptualised and operationalised within the CE, with particular emphasis on AM's role in enabling and enhancing CPD strategies.

2. To empirically investigate how organisational capabilities, particularly material selection and dynamic design capabilities, including design for assembly and disassembly, modularity, and recyclability, enable the effective use of AM to operationalise CPD, and to evaluate their impact on new product performance (NPP).

3. To empirically examine how institutional pressures, specifically coercive, normative, and mimetic pressures, and TMC influence the adoption and operationalisation of CSCM practices, and to evaluate how these practices contribute to TBL in sustainability performance.

1.4 Relevant Theories

Two theories are applied in this study, namely dynamic capability theory and institutional theory, to explain the roles of organisational and design capabilities in the operationalisation of CSCM by considering the role of AM and TMC. Dynamic capabilities theory has been used as a theoretical lens for Paper 2 (Chapter 3), and institutional theory has been adopted for Paper 3 (Chapter 4).

1.4.1 Dynamic Capabilities Theory

First, dynamic capabilities theory (DCT) explains how companies manage to adapt, integrate, and reconfigure organisational resources and capabilities in response to changes in technology, markets, and the environment (Teece et al., 1997). Moreover, DCT applies to product development and technology adoption, as the use of AM depends not only on technological resources but also on capabilities to align AM with CPD concepts and sustainability requirements (Aguiar et al., 2022; Jugend et al., 2024). Dynamic capabilities comprise three interdependent dimensions: sensing, seizing, and transforming (Teece, 2007). Specifically, sensing involves identifying opportunities arising from the need to comply with CE demands, advances in AM technology, customer needs, and sustainable material use. Furthermore, the seizing process implies resource mobilisation and the use of relevant

technology and design capabilities, such as design for assembly and disassembly, modularity, and recyclability, to ensure repair, reuse, remanufacture, and recycling of materials (Aguiar et al., 2022; Govindan & Hasanagic, 2018b; Sauerwein et al., 2017). Subsequently, transformation involves reallocating resources to integrate a circular approach into product development (De Arroyabe et al., 2021; Teece, 2018). In addition, material selection supports this process by incorporating sustainable, recyclable materials (Mestre & Cooper, 2017). Nevertheless, this study treats material selection as an organisational capability. This is because material selection is a routine decision for manufacturers, driven primarily by production constraints and customer requirements rather than by strategic adaptation (Mesa, 2023). As such, it represents a standard operational practice, not a component of dynamic capability, which instead involves the ability to reconfigure resources in response to change. Moreover, AM provides the technology to transform these capabilities into CPD through accuracy, personalisation, design freedom, and reduced material waste (Priyadarshini et al., 2025). Consequently, DCT reflects organisations' ability to detect circularity opportunities, exploit them through AM and appropriate design capabilities, and adapt product development processes for CPD. As a result, the process might improve NPP in terms of cost-effectiveness, efficiency, quality, and customer satisfaction (Pinheiro et al., 2019), thereby contributing to a deeper transformation of the organisation toward circularity and sustainability (Zils et al., 2025).

1.4.2 Institutional Theory

Another theoretical approach to understanding CSCM implementation is institutional theory (IT). Specifically, IT argues that organisations adopt certain practices not only to improve efficiency, but also because institutions pressure them to legitimise and conform (DiMaggio & Powell, 1983; Scott, 2010). These pressures are typically categorised as coercive, which originate from governments, laws, and other influential actors; normative, which arise from

professional norms, industry bodies, and social expectations; and mimetic, whereby firms imitate successful organisations (DiMaggio & Powell, 1983). Consequently, in the context of CSCM, such pressures may prompt companies to implement practices such as reducing, reusing, recycling, remanufacturing, reverse logistics, and closed-loop supply chains (Farooque et al., 2019; Tapia et al., 2021). Nevertheless, prior studies on IT recognise that organisations are not merely subjected to institutional pressure; rather, they can interpret, negotiate, resist, or enable institutional transformation based on their resources and circumstances (Tina Dacin et al., 2002). Furthermore, the notion of institutional logics suggests that firms may, at times, experience competing institutional pressures from government, markets, and customers (Greenwood et al., 2011). Moreover, recent CE literature indicates that different institutional pressures may have varying degrees of impact, and that organisational and supply chain circumstances can amplify or hinder these effects (Calzolari et al., 2023; Calzolari et al., 2025). Consequently, IT helps to explain why organisations face external pressure to implement circular practices, while top management commitment clarifies how that pressure translates into action within organisations (Zhou et al., 2024).

Both DCT and IT offer useful theoretical lenses for investigating CSCM and sustainability. According to DCT, organisational internal capabilities explain how companies can adjust themselves and use such technologies as AM to implement CPD, whereas IT helps understand the impact of external pressures on implementing circular practices. Chapter 2 connects these two theoretical perspectives through the strategic management framework that guides for Chapter 3, 4 and 5.

1.5 Research Context: Bangladesh

Bangladesh is a developing country in South Asia, where most of the population was employed in agriculture in the past. The agro-based economy has now gradually shifted to a

manufacturing-based economy (30-34% of GDP), primarily dominated by the ready-made garment (RMG) industry, which is known as Bangladesh's economic engine (Nath, 2021). Approximately 84.4% of export earnings are generated from the RMG sector, which employs nearly 4.2 million workers, most of whom are women (Sarkar et al., 2025). Although women are well represented in Bangladesh's manufacturing workforce, particularly in the ready-made garments industry, they remain significantly underrepresented in management and supervisory roles (Macchiavello et al., 2020; Samara, 2026). RMG sector expansion mostly relies on the availability of labour with low costs, trade preferences such as EU duty-free access under the Everything but Arms (EBS), Generalised System of Preferences (GSP) from the USA, and strong backward linkages in spinning, knitting, and dyeing that reduce import dependence (Razzaque & Rahman, 2019). However, the industry has faced global scrutiny, particularly after the 2013 Rana Plaza disaster, prompting buyers, regulators, and local firms to adopt stricter compliance and workplace safety standards (Alam, 2025). While these reforms improved building safety and labour oversight, challenges remain in low wages, environmental impacts, and reliance on a single export sector. For instance, the manufacturing industry generates an estimated 577,000 metric tons of textile waste annually, has limited in-house recycling capacity, and faces new heat stress risks in factories due to excessive CO2 emissions (Abtew et al., 2025).

Apart from garments, other companies are beginning to contribute to the manufacturing sector. The plastics industry, for example, generated USD 3-7 billion and is being recognised as one of the fastest-growing, with over 6,000 mostly SME-based units employing up to 1.5 million people (BIDA, 2025). Plastic exports reached USD 200 million in 2022–23, while other industries also followed, namely packaging, textiles, pharmaceuticals, Fast Moving Consumer Goods (FMCG), and electronics (Islam & Hossen, 2025). Additionally, the steel industry in Chittagong is led by firms such as BSRM and GPH ISPHAT, which supply

deformed bars, structural steel, and other steel products essential for infrastructure development, shipbuilding, and real estate (Absar et al., 2022). Moreover, the textile sub-sector of RMG has strengthened through backward integration. At present, local textiles meet 90 percent of knitwear fabric demand and three-quarters of yarn demand, reducing reliance on imports (Razzaque & Rahman, 2019). Additionally, the sewing thread industry operates at a specialised level, replacing the fully import-dependent sector, creating a market of approximately USD 3.66 billion in 2024 and anticipated to reach around USD 4.28 billion by 2033. More importantly, the denim sector has also emerged as a niche strength, positioning Bangladesh as one of the world's largest suppliers to global retailers (Elma, 2025).

All these sectoral developments indicate that Bangladesh is no longer a garment-dependent economy but also an effective multi-sectoral hub. RMG remains the pioneer yet has given rise to several industries, including textile, plastics, steel, sewing thread, and denim, all of which show clear signs of industrial deepening. Several policy and national strategy initiatives, such as the Plastic Industry Development Policy 2020, along with initiatives like export processing and special economic zones, and the government's Vision 2041, enable the government to diversify exports and build a resilient, higher-value industrial base (Khan & Kamal, 2018). However, all these policies and strategies are still at a nascent stage due to lagging export diversification, limited financial support, and sustainability constraints.

Considering all policies and initiatives, including the 8th Five-Year Plan, CE adoption is a priority for Bangladeshi manufacturing firms, particularly in the textile and garment industries. Most adoption occurs due to regulatory compliance and market pressure. The Rana Plaza disaster led to substantial reforms and a renewed emphasis on sustainability in compliance policy. Moreover, complying with regulation is indispensable for obtaining recognition from the relevant authority. In line with these compliance regulations, Bangladesh has emerged as a global leader in sustainable manufacturing, with over 250 green

factories certified under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) standards, including 71 with platinum ratings (Financial Express, 2025).

The RMG industry is increasingly embracing circular practices, including recycling, reusing, reducing, and remanufacturing. Regulatory agencies, such as the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), have initiated the "Circular Fashion Partnership." These initiatives aim to develop the textile recycling industry by capturing post-production fashion waste and redirecting it into new products (BGMEA, 2025).

Despite these adoptions, CE practices within manufacturing industries remain uneven. The probable reason might be that there are still a variety of technical, operational, and regulatory challenges (Rahman et al., 2025). Many industries are still facing challenges like limited recycling infrastructure, informal waste management practices, and the absence of standardised regulations. These challenges hinder the real practices of circular initiatives (Alam, 2025). Although RMG is an early adopter of circular initiatives, full-fledged circular practices are still at an early stage and require sustained policy support and investment to achieve widespread implementation (Mustafa, 2025; Rahman et al., 2025).

Bangladesh is accelerating its CE practices beyond RMG. Manufacturers nowadays are increasingly introducing circular practices aiming to enhance sustainability performance and resource efficiency (Nath et al., 2025). In the furniture sector, firms like Hatil, for example, are recycling wood dust into briquettes for fuel and repurposing fabric offcuts into rebounded mattresses, and simultaneously utilising rooftop solar energy to power operations (Razzaque et al., 2020). Similarly, several other industries, such as ceramics, steel, and cement, are adopting sustainable production techniques, including energy-efficient kilns and waste heat recovery systems, to reduce emissions and resource use (Solgi et al., 2021). Social initiatives, such as 'Waste Concern' have pioneered decentralised composting and organic waste

recycling, transforming waste into usable resources and promoting community-based environmental consciousness (Kadir et al., 2024). Additionally, some industries are using biodegradable plastics and standardised components to enlarge product diversification and reduce environmental impact (Moshood et al., 2021).

Additionally, the manufacturing industry in Bangladesh, which is adopting AM alongside CE, is growing to increase production and operational efficiency, thereby ensuring economic growth, productivity, and competitiveness across the textile, garment, automotive, and plastics industries (Suva & Rahman, 2025). Moreover, AM is a manufacturing tool that reduces lead time and enhances operational efficiency through its inherent design flexibility, which aligns with the goals of Bangladesh's manufacturing industries.

1.6 Methodology

For this study, a mixed-methods research design with a parallel approach was used, in which quantitative and qualitative data provided alternative perspectives on the research objectives. The study developed a single overall dataset, using distinct instruments and constructs for the quantitative survey and qualitative interview components. The quantitative part analysed the relationship between AM, CPD, dynamic design capabilities, institutional pressures, top management commitment, CSCM, and sustainability performance. On the contrary, the qualitative part of the research provided contextual information on these relationships and ensured triangulation. Combining both methodologies was expected to enhance interpretation by integrating empirical measurements with participants' real life experiences (Teddlie & Tashakkori, 2008).

For the quantitative study, the data were collected through a well-formulated questionnaire using five-point Likert-scale questions. The questionnaire was based on existing literature and further validated through a pilot study conducted with academic and industry experts. Data were collected using a non-probability sampling method supplemented by snowball

sampling. After screening and removing invalid responses, the researcher collected 313 valid responses for quantitative analysis. The researcher then analysed the data using SPSS and AMOS, including descriptive analysis, non-response and common method bias, measurement model evaluation, validity checks, correlation analysis, and structural equation modelling.

The qualitative study included semi-structured interviews with 25 senior managers and male professionals in medium-to-large manufacturing firms in Bangladesh. Respondents were selected purposefully based on their expertise in manufacturing processes, CE, and CSCM. The interviews were conducted in person or in zoom and recorded with respondents' permission, then transcribed and analysed using content analysis. The qualitative results served as an interpretative basis for the quantitative outcomes. Chapters 3 and 4 discuss the detailed methodology of the quantitative and qualitative research design, sample, data-gathering methods, measuring instruments, data analysis, and validation.

1.7 Theoretical, Practical, and Policy Implications

1.7.1 Theoretical Contributions

The paper contributes to the literature on AM, CPD, CSCM, and sustainability in four main ways. First, this paper develops an integrated strategic management framework that connects design capabilities supported by AM and CPD strategy to CE principles, addressing the fragmentation in the existing literature, particularly in case studies and cost-based models (Mishra et al., 2018). Paper-1 (Chapter 2) provides a comprehensive overview of AM by examining its circular benefits, including waste reduction and resource recovery, as well as its limitations, including high energy consumption, material constraints, and difficulties with process scaling (Ford & Despeisse, 2016). Moreover, the empirical findings validates the main AM capabilities, such as mass customisation, complex geometry, localised production, customer engagement, and product quality, and the relevance of these capabilities to CPD strategy (Sauerwein et al., 2019). Additionally, identifying boundary conditions in

Paper 1 for AM-enabled CPD expands knowledge of digital technology use in the context of CE.

Second, the study identifies organisational and dynamic design capabilities as critical facilitators of AM-enabled CPD. Unlike prior studies that emphasise identifying the most significant barriers to AM integration, it empirically demonstrates how materials selection and designs (assembly and disassembly and recyclability), enable the incorporation of AM in CPD (Jugend et al., 2024; Wang et al., 2022). The study further confirms that AM is not only a design technique but also a manufacturing technology that could facilitate circularity and improve new product performance (Despeisse et al., 2017). By examining the dynamics among dynamic capabilities, AM, and CPD, the study contributes to the body of knowledge by highlighting the organisational capabilities needed to adjust product design while ensuring product performance (Chari et al., 2024).

Third, this study advances the CSCM literature by proposing an integrative theoretical framework to understand the interrelations among external institutional pressures, top management commitment, and CSCM adoption, which together drive better sustainability performance. Instead of considering these factors separately, this study reveals their interconnectedness and shows that CSCM adoption serves as a mechanism for their effects on sustainability performance (Agyabeng-Mensah et al., 2022). Empirical findings also reveal the contextual nature of institutional pressures both domestic and international, where regulatory effectiveness depends on economic motivations and the availability of market opportunities. The incorporation of TMC in transforming institutional pressures into circular practices adds value to the institutional and strategic management approaches and the organisational transition to CSCM (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019).

Fourthly, this research extends the existing empirical knowledge base on AM, CPD, and CSCM in developing contexts such as the Bangladeshi manufacturing environment. Even

though earlier research in Bangladesh has mainly concentrated on applications such as recycling, including the use of waste plastics in AM (Salman et al., 2025), this study expands the circular perspective by using multiple R strategies, especially reduce, reuse, and recycle, along with AM-enabled CPD and CSCM. It also goes beyond current research on AM readiness in Bangladesh (Suva & Rahman, 2025) by showing how AM can support CPD and other CSCM practices.

1.7.2 Practical Implications

Beyond theory, this research also contributes to practice in several ways. First, by synthesising fragmented literature on AM and CPD, the research offers a structured framework for using AM to implement CPD. These strategies will help firms to design their products in accordance with circular economy goals. Understanding the limitations of AM technologies (scalability, materials used, energy consumption) will also help anticipate potential implementation problems.

Second, the research findings will provide practical guidelines for developing organisational capabilities for AM-enabled CPD to improve NPP. The findings show that AM-enabled CPD can improve cost efficiency, product quality, and customer satisfaction by developing the necessary organisational capabilities. Therefore, along with investment (internal and external) in AM, firms should invest in sustainable material selection, design for assembly and disassembly, modularity, and recyclability.

Third, this study offers valuable perspectives on operationalising CSCM. Empirical results suggest that although pressures from institutions such as government, businesses, and customers can support CSCM implementation, TMC is also needed to translate these pressures into action. Practitioners should therefore consider combining management' commitment to CSCM with institutional pressures and integrating circularity into strategic decisions.

1.7.3 Policy Implications

The study also offers insightful guidelines for policymakers seeking to facilitate CSCM adoption and move toward a circular economy model. The research stresses the importance of combining regulatory pressures with contextual incentives, such as tax incentives and other financial and market-based measures like training and enriching the educational base, to motivate companies to adopt AM technology and follow circular practices. This approach aligns with Bangladesh's 8th Five-Year Plan, Plastic Industry Development Policy 2020, and Vision 2041, as it supports reducing waste production and adopting higher-level circular approaches such as reuse and remanufacturing. Moreover, policymakers could promote the process by developing standards, policies, and incentives for attracting foreign direct investment to apply CPD principles of durability, reparability, modularity, and recyclability in the manufacturing practices and thereby enhance CSCM practices (Ahmed et al., 2022).

1.8 Linkages among Three Papers

The first paper establishes the conceptual foundation of the thesis through a systematic literature review of AM in the context of the CE, with a specific focus on CPD, to answer the research questions. This study synthesises existing literature to identify the core design functions that underpin CPD, such as material selection, design for assembly and disassembly, modularity, and recyclability, while also clarifying the potential role of AM in enabling these functions. By mapping out the state of knowledge, Paper 1 defines the theoretical building blocks on which the subsequent empirical investigations rest to provide an answer to the RQ1: *How can CPD be effectively operationalised within the CE, and what role does AM play in enabling these strategies?*

Building on this foundation, the second paper moves from a conceptual exploration grounded in empirical testing to examine RQ2: *How do organisational and dynamic design capabilities support the effective use of AM to operationalise CPD and improve NPP?* It examines how

firms deploy organisational and dynamic design capabilities related to CPD, including sustainable material selection, modularity, recyclability, and ease of assembly and disassembly, in conjunction with additive manufacturing. The study investigates whether these capabilities, when enabled by AM, facilitate not only circular product design but also the performance of new products. In doing so, the paper operationalises the design functions identified in the first study and provides evidence of their practical value in firm-level innovation and circular design strategies.

The third paper then extends the analysis from the level of product design and firm capabilities to the broader supply chain. It addresses the institutional and management commitments that enable a circular supply chain to address RQ3: *How do external pressures and TMC affect the implementation and adoption of CSCM? How does the process result in TBL benefits?* Specifically, it investigates how institutional pressures and TMC act as critical enablers for embedding circularity at the supply chain level, thereby advancing the triple bottom line of sustainability, e.g., economic, environmental, and social outcomes. Together, the three papers form a coherent progression: from identifying key design functions (paper one), to testing their enactment as organisational and dynamic capabilities within firms (paper two), and finally to exploring the systemic conditions necessary to achieve sustainable circular supply chains (paper three). Figure 1.1 illustrates the relationship among the three papers discussed in the next three chapters.

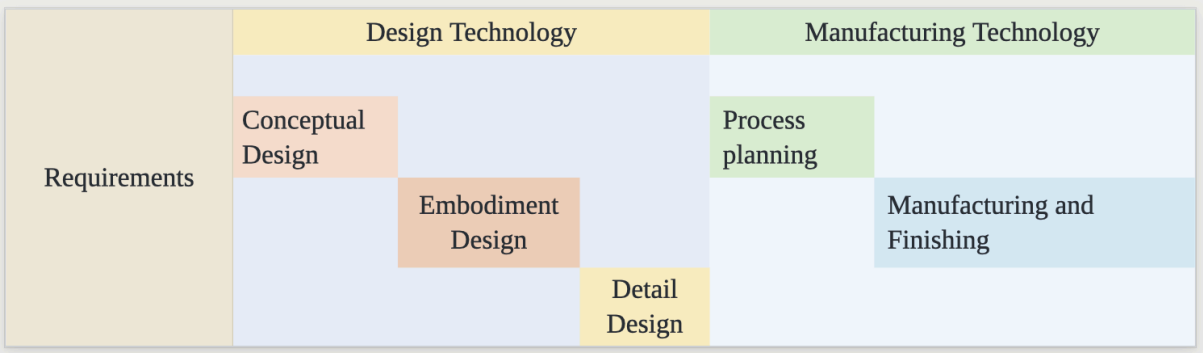


Figure 1.1: Linkages among Three Papers.

1.9 Structure of the Thesis

The thesis is structured across five chapters. The first chapter presents the background and rationale of the study, outlines the research aim, and formulates the research questions and objectives. It also introduces the overall research methodology and highlights the thesis's theoretical and practical contributions. The second chapter (Paper-1) is based on a systematic literature review that seeks to minimise contradictions in the existing literature to identify the role of AM in CPD. The chapter then conceptualises and operationalises CPD strategies within the CE, with a particular focus on the role of AM in enabling and strengthening these strategies. This part also identified the core capabilities for CPD based on the reviewed articles, based on a strategic management framework, such as material selection, modularity, recyclability, and design for assembly and disassembly. The third chapter (Paper-2) explores how organisational capabilities, specifically material selection and design capabilities, work in combination with AM to support CPD and evaluates how these AM-enabled capabilities enhance new product performance in terms of cost, efficiency, quality, and customer satisfaction. The fourth chapter (Paper-3) extends the analysis to the supply chain level by examining how institutional pressures (coercive, normative, and mimetic) and TMC influence the adoption of circular supply chain practices, and assesses how these practices, when supported by AM and CPD, contribute to environmental, social, and economic outcomes. The thesis's overall conclusions are presented in Chapter Five. This chapter summarises the

findings for each research objective and integrates them into a coherent set of contributions. It also outlines the theoretical, practical, and policy implications of the research and identifies limitations that provide avenues for future investigation.

The following chapter, the concept of additive manufacturing (AM) is systematically reviewed in relation to its significance for the design of circular products. It synthesises the contributions of AM technology to resource efficiency, including extending product lifetimes, repairing products, remanufacturing products, and advancing material circularity. Based on results, this following chapter identifies various enabling factors, challenges, and knowledge gaps in the domains of AM and CPD and proposes a strategic management framework.

Chapter 2: Role of Additive Manufacturing in Circular Product Design: A Systematic Review and Guidance for Future Research

2.1 Abstract

Product design constitutes a critical mechanism for advancing the circular economy (CE) by facilitating resource recovery, fostering eco-innovation, and supporting sustainable business practices. However, the role of additive manufacturing (AM) in product design and CE is scattered and contradictory in the existing literature. The study examines the potential role of

AM technology in facilitating circular product design (CPD). Moreover, the study also explores the broader implications of AM adoption across other business domains, including design innovation, operational efficiency, strategic dimensions, and sustainability. A systematic literature review is conducted to resolve the contradictions in the current literature, integrate insights on AM's role in CE and CPD, and provide directions for future studies. A content analysis of 149 scholarly articles indicates that AM enhances CPD by enabling flexible design, supporting product customisation, and extending product lifespans, thereby promoting business sustainability. The study further indicates that key CE strategies, such as modular design, reverse engineering, closed-loop supply chains, and life-cycle assessments, can be enabled by AM technology. Additionally, it underscores the legal, socio-cultural, technical, and organisational barriers and offers an integrated framework encompassing environmental, operational, and strategic domains to support managerial adoption of AM for CPD. This study contributes to the existing literature on AM and CPD by offering practical insights and developing propositions to guide future research endeavours.

Keywords: Product Design, Circular Economy, Systematic Literature Review, Additive Manufacturing, Adoption Challenges.

2.2 Introduction

The transition towards a circular economy (CE) necessitates a fundamental transformation in product design and manufacturing processes. Circular product design (CPD) is fundamental to this transition (Jugend et al., 2024; Wang et al., 2022). In contrast to the conventional linear model (make, take, and dispose), which depends on virgin raw materials and shortened product lifespans, CPD prioritises strategies such as design for disassembly, material recovery, and product longevity (Bocken et al., 2016; Geissdoerfer et al., 2017). These strategies maintain resources in closed-loop systems. Consequently, CPD addresses problems such as resource depletion, climate change, and biodiversity loss by reducing waste and

environmental pollution, and by promoting recycling and reuse (Ripple et al., 2017; Schöggl et al., 2020). CPD also opens new economic opportunities through recycling and remanufacturing (Lieder & Rashid, 2016). Many industries now recognise CPD's value for sustainable production (Dzhengiz et al., 2023; Howard-Grenville et al., 2019). Moreover, in the widespread applications of digital technologies, one of the most obvious changes in manufacturers is that they are gradually more interested in integrating additive manufacturing (hereafter referred to as "AM") into CE and CPD (Despeisse et al., 2017; Friesike et al., 2019; Khorram Niaki & Nonino, 2017).

Although AM provides promise for theory and practice, it can lead to increased energy use and material waste, difficulty in building complex geometries that obstruct repair and material recovery, and high rejection rates that exacerbate waste (Gebler et al., 2014; Huang & Schmid, 2018). These challenges are reinforced by traditional linear business models, weak institutional frameworks, and limited material recyclability. As a result, the widespread adoption of AM for circular practices is constrained (Despeisse et al., 2017). Overcoming these two-fold outcomes requires thorough research to align design and manufacturing technologies with the principles of the CE and CPD (Tukker, 2015; Wang et al., 2022). Nevertheless, the strategic integration between AM and CPD remains insufficiently explored and warrants a comprehensive review. Three main gaps are identified within the existing studies that drive this review.

First, to date, many studies have failed to provide a comprehensive review and summary of the changes that AM brings to CPD. AM enables CE by enhancing resource efficiency, minimising waste, and facilitating product customisation (Ford & Despeisse, 2016; Soriano-Pinar et al., 2023). However, existing studies barely link AM directly to CPD strategies. Most existing studies focus on operational benefits (Sonar et al., 2022), economic analysis (Mellor et al., 2014), or simple two-fold models of AM-based circularity (Tavares et al., 2025), rather

than adopting a full design approach. Empirical work has examined AM's technical features (Kellens et al., 2017) and its potential for closed-loop systems (Lu et al., 2023), but has not explained how AM's unique strengths can be matched with CPD principles. Moreover, the research is fragmented. Despite research highlighting benefits such as reducing costs, design flexibility, and localised production (Despeisse et al., 2017; Rejeski et al., 2018), localised production is less eco-efficient (Tavares et al., 2025). Most of these findings come from separate case studies or technology-specific analyses. As a result, prior studies often overlook the broader picture of how these benefits unfold within CE systems (de Mattos Nascimento et al., 2022; Kohtala et al., 2021). As a result, existing literature offers limited strategic guidance on deliberately aligning AM with circular product design principles to deliver consistent sustainability outcomes.

Second, while AM has strong potential to support CE principles (Garmulewicz et al., 2018; Kellens et al., 2017), its environmental and operational downsides are still debated. Previous studies have pointed to problems such as high energy use, limited material options (Arian et al., 2021; Gebler et al., 2014), and poor compatibility with standard recycling systems, especially for polymer-based products (Garmulewicz et al., 2018; Sanchez et al., 2020). Moreover, difficulty in rebound effects, where easier production can lead to more consumption (Kohtala et al., 2021), and major challenges in unlocking CE in practice. These challenges include regulatory barriers, technical limits (Goddin et al., 2019), and economic risks (Kumke et al., 2018). On the positive note, a few studies show that AM can improve supply chains through just-in-time production, which reduces waste (Khorram Niaki & Nonino, 2017), and through resource recovery through recycling and remanufacturing (Despeisse et al., 2017). However, despite these benefits in product design and supply chain efficiency, large-scale adoption of AM still faces environmental and operational barriers. As

a result, further research is needed to address these gaps and enhance the effectiveness of AM within CE frameworks.

Third, while additive manufacturing enables mass customisation, complex geometries, and greater customer involvement in production (Tofail et al., 2018), existing research primarily frames these capabilities in terms of product quality and user engagement (Gibson et al., 2021; Kleer & Piller, 2019). However, how these technical features can be systematically aligned with CE and CPD principles to deliver measurable sustainability outcomes remains unclear, revealing a critical gap in the literature. AM often struggles to significantly influence CE, due to high energy use (Mellor et al., 2014), and poor material recyclability (Sanchez et al., 2020). These issues raise doubts about its role in CE, although it can reduce waste and shorten lead times (Despeisse et al., 2017). Customer engagement can improve product customisation, but it also creates challenges in quality control and workflow (Zawadzki et al., 2018). AM's layer-by-layer process allows for customisation (Guo & Leu, 2013), but often requires post-processing time to fix defects (Levy, 2010). These shortcomings reveal a significant technical challenge. AM's strengths do not automatically guarantee CE compatibility, as trade-offs in scale, material reuse, and process efficiency limit its sustainable performance.

Against this backdrop, a strategic management framework has been used to grasp the full technological potential of AM for supporting organisational sustainability outcomes by showing how firms drive CPD in practice (Bocken et al., 2016; Burke et al., 2023). Moreover, a sustainability-driven strategic management framework provides a consistent analytical structure for comparing studies in a systematic literature review (SLR), making it easier to identify patterns, antecedents, and implementation challenges (Tranfield et al., 2003). A total of 149 published articles from 1 January 2013 to 31 December 2025 were reviewed to validate the role of AM in CE and product design. This integrative framework

helps manufacturers increase the effectiveness and efficiency of their circular product development initiatives (Janssen & Dankbaar, 2008). Therefore, this SLR aims to identify AM's actual role in supporting various product design components within CE principles, ultimately determining how AM contributes to product design and manufacturing within the context. Therefore, this study attempts to answer the following research questions:

RQ1: How can the AM be systematically integrated into CE and CPD for strategic frameworks to guide circular initiatives?

RQ2: What environmental and operational trade-offs affect the adoption of AM in CE systems, and how can these be managed to align their benefits with product design?

RQ3: To what extent do AM's technical properties support CE and CPD objectives, and what improvements to mitigate challenges are required to enhance sustainability performance?

This study made several noteworthy contributions to the literature on AM in the CE and CPD. First, it advances an integrated strategic framework that systematically links AM's technological capabilities with CE-driven product design strategies. A strategic integrative framework is used to address the current fragmentation of research, dominated by isolated case studies and operational or cost-centric models, and to enable the systematic alignment of AM with CPD and sustainability performance. Second, it reconciles conflicting evidence on AM's role in CE and CPD by documenting the benefits it generates, such as waste reduction, resource recovery, and supply chain efficiency, alongside its technical and operational limitations, including high energy intensity, material constraints, and scalability barriers. Third, this review addresses the lack of empirical evidence on key technical claims of AM, including mass customisation, complex geometry, localised production, customer involvement, and product quality. By synthesising existing studies, it demonstrates that these

capabilities are indeed supported by AM and can be effectively integrated into product design (Aboutaleb et al., 2017; Ford & Despeisse, 2016; Gibson et al., 2021). Fourth, this study clearly identifies the challenges that AM poses for product design in CE, which further complicate the challenges of employing digital technologies for CE (Trevisan et al., 2023). Finally, this study provides actionable propositions for implementing AM in CPD, offering both theoretical underpinnings for researchers and practical strategies for sustainable supply chain practitioners.

The remainder of the chapter is structured as follows: Section 2.3 discusses the theoretical underpinnings of additive manufacturing (AM), the circular economy (CE), and circular product design (CPD). This is followed by a method employed for this review in section 2.4. A detailed analysis of the study is then discussed in section 2.5. This is followed by a research proposition encompassing the dimensions and components of AM, CPD, and CE in section 2.6. Finally, offer a conclusion with practical limitations and future directions of the research in section 2.7.

2.3 Theoretical Underpinnings

This subsequent section examines phase by phase evolution of AM by reviewing its historical development and its development integration with CE and CPD. Subsequently, the study review AM as a design and manufacturing technology, focusing on its unique advantages. The study further reviewed the integration between AM and CE, emphasising how AM supports closed-loop systems, resource efficiency, and remanufacturing. Finally, the study explored the CE and CPD literature, assessing how AM-driven design strategies enhance strategic management framework.

2.3.1 Evolution of Additive Manufacturing

The shift from mass production to mass customisation is expedited by the adoption of digital technologies (Gebhardt et al., 2022; Hedenstierna et al., 2019). In 1913, Henry Ford, a

pioneer of the assembly line, fundamentally transformed mass production. In contrast to mass production, the late 1980s witnessed the advent of mass customisation, which facilitated the build-to-order concept (Fogliatto et al., 2012). The progression of manufacturing practices, as depicted in Table 2.1, illustrates the transition to additive manufacturing (AM) technology that has supplanted '3D printing' to denote its industrial sophistication. AM refers to a new form of design and manufacturing technology, in contrast to conventional subtractive manufacturing, which designs objects layer by layer from digital models, adding material only where required, which explains the term additive (ASTM, 2012; Gibson et al., 2021). This production enables the build of complex geometries and ensures efficiency with material, positioning AM as a relevant approach for CE strategies (Despeisse et al., 2017; Gebler et al., 2014). Moreover, AM signifies the most recent paradigm shift, enabling digital, on-demand production with unparalleled design flexibility, minimal material waste, and seamless integration with Industry 4.0 (Gibson et al., 2021). Unlike the nascent stages of 3D printing, contemporary AM achieves enhanced precision, material adaptability, and large-scale production through advanced measurement and standardised processes (ISO/ASTM 52900:2021), rendering it essential for high-performance applications in aerospace and biomedical engineering, where mechanical properties and repeatability are of paramount importance (Georgantzinos et al., 2025).

Table 2.1: Evolution of Additive Manufacturing

Modes of Manufacturing	Concept and Evolution Time	Explanation	References
Conventional Manufacturing	Make-to-order. (Mass Production) (1913)	Manufacturing systems are designed for a specific type of product with large quantities	(Eyers et al., 2018)
Modern Manufacturing	Build-to-order. (Mass Customisation) (Late 1980s)	A type of manufacturing mode using general-purpose technology to design the product for control of manufacturing, assembly, and logistics.	(Da Silveira & Slack, 2001; Hedenstierna & Disney, 2018)
	Rapid prototyping (RP) (1980)	RP is used to produce models and prototype parts.	(Gardan, 2017)
	3D printing (3DP) (Late 1980s)	3DP) is a rapid prototyping technology employed to produce tools, customized components, intricate final parts, and spare parts	(Chowdhury et al., 2019; Garrett, 2014)

Additive Manufacturing (AM) (2011)	AM is "a process of joining materials to make objects from 3D model data, usually layer upon layer, instead of subtractive manufacturing methodologies."	(ASTM, 2012)

2.3.2 Additive Manufacturing as a Design and Manufacturing Technology

The role of AM is a subject of ongoing debate, with historical usage in both design and manufacturing settings (Chaney et al., 2022). In general, AM was used for prototyping new designs and then evolved into direct digital manufacturing for functional parts. Nowadays, AM is increasingly accessible to end consumers, supporting them throughout the product development process (Wang, Lin, et al., 2019).

In recent years, AM has been widely adopted across design-intensive industries and large-scale manufacturing firms (Alexander et al., 2021; Dong et al., 2022; Gibson et al., 2021; Salem et al., 2020). AM enables advanced customisation and structural efficiency, driving its integration into industrial-scale production processes. For example, 60-70% of industries primarily use AM for prototyping and design validation, only 15-25% have fully integrated it into end-use part production, with leading adoption in the medical/dental (30%) and aerospace (25%) companies owing to the benefits of customisation and structural efficiency (Fidan et al., 2023). The AM market, valued at $18-20 billion in 2023 and growing worldwide, is projected to grow at 23.9% annually, reaching $46.76 billion by 2029 (Technavio, 2024). This growth is driven by advancements in metal 3D printing, hybrid manufacturing, and AI-driven automation, alongside an increasing emphasis on sustainable production, with 40% of manufacturers exploring AM to reduce waste (Kantaros et al., 2025). This trend underscores AM's expanding role from prototyping to full-scale industrial manufacturing.

Pradel and their associates reviewed 81 articles on design for AM and found that AM serves both as a design technology (conceptual, embodiment, and detail design) and manufacturing

technology (process planning and manufacturing & finishing) (Pradel et al., 2018). Figure 2.1 illustrates AM's dual role in design and manufacturing technology.

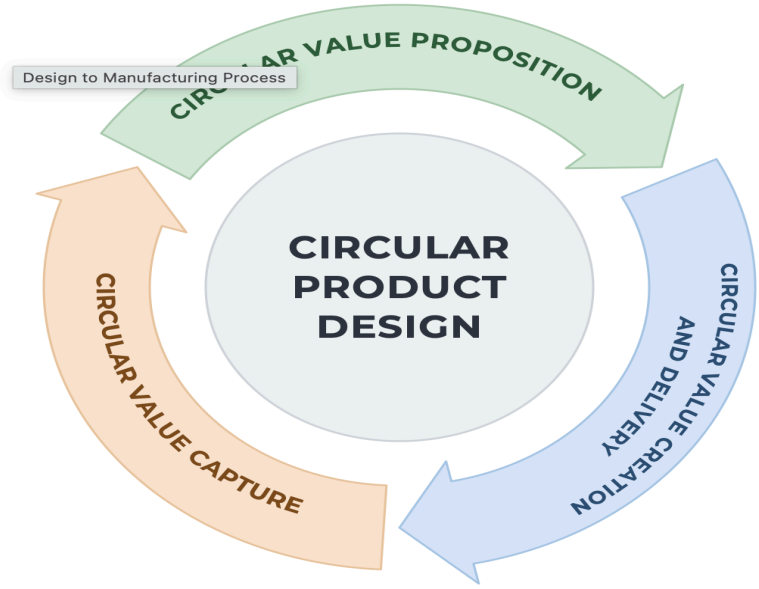


Figure 2.1: The framework for the role of Additive Manufacturing. Adopted from (Pradel et al., 2018)

2.3.3 Additive Manufacturing and Circular Economy

This review explores the interaction between AM technologies and CE, with particular attention to practical advances in developing additive materials from waste and to the emergence of smart, waste-derived materials that enable more responsible resource use. Alongside these material innovations, AM supports a move away from globalised supply chains towards local, on-demand production, helping to reduce transportation emissions while reinforcing local manufacturing networks (Ben-Ner & Siemsen, 2017). Moreover, AM facilitates the creation of complex, interlocking components that can be easily disassembled for repair or recycling. These lead to manufacturers equipped with AM for recycling facilities that could serve as community hubs for circular manufacturing practices. Additionally, AM supports CE by delivering tangible benefits, such as advancing resource efficiency and reducing waste (Despeisse et al., 2017; Hettiarachchi, Brandenburg, et al., 2022). Finally,

AM contributes to CE by assessing circularity in unique designs, guiding eco-friendly design practices, and evaluating existing operations for circularity (O'Grady et al., 2021).

AM has broad applications in CE across industries such as aircraft, medical implants, and fashion products (Haleem & Javaid, 2020; Strong et al., 2020). It reduces design iterations, material waste, and time by minimising printing errors (Wang et al. 2019). Moreover, AM offers an opportunity to significantly reduce material use and inventory levels (Kunovjanek & Reiner, 2020). AM directly contributes to CE goals through its inherent material efficiency, design flexibility for circular products, and ability to incorporate recycled materials in closed-loop systems (Ford & Despeisse, 2016; Garmulewicz et al., 2018). Additionally, AM enables CE adoption by facilitating localised production, extending product life through on-demand repairs, and supporting circular business models such as product-as-a-service (Jongeling, 2025; Singh et al., 2025). Thus, AM aids CE by enabling the progressive design of products, contributing to their repair, remanufacturing, recovery, redistribution, and maintenance (Ertz et al., 2022; Sauerwein et al., 2019).

2.3.4 Circular Economy and Circular Product Design

The concept of a circular economy (CE) strategically incorporates processes of restoration and regeneration within the industrial framework (Ellen MacArthur Foundation, 2013). Within this paradigm, the CE framework significantly influences decisions in operations management, encompassing areas such as product design, production scheduling, logistics, and supply chain management (Hazen et al., 2021). Additionally, CE aims to conserve energy and resources while generating value by integrating economic, environmental, and social dimensions (Oliveira et al., 2021). From an operational perspective, product design is pivotal in facilitating the transition to a CE and addressing specific requirements and waste management challenges (Aguiar et al., 2022; Bocken & Ritala, 2022). This is due to the current emphasis on end-user needs over waste management in product design. However,

circular product design (CPD) endeavours to preserve both physical attributes and emotional integrity, thereby enabling multiple use cycles and introducing innovative strategies, such as emotional durability and biomimicry (Aguiar et al., 2022; Sinclair, 2015; Sumter et al., 2020).

CPD serves as a strategic design approach that reconfigures product lifecycles to minimise waste, enhance resource efficiency, and advance sustainability by embedding CE principles into product development (Alam et al., 2025). Unlike traditional linear design that follows a take–make–waste logic (Bakker et al., 2014; Reike et al., 2023), CPD systematically applies value retention strategies such as reuse, repair, remanufacturing, and recycling to overcome design barriers that constrain circular transitions (Den Hollander et al., 2017). This is achieved through modular architectures that enable repair (Bovea & Pérez-Belis, 2012), standardised components that facilitate remanufacturing (Hatcher et al., 2013), and mono-material selection that enhances recyclability (Lieder & Rashid, 2016). CPD further addresses systemic limitations of traditional approaches, including multi-material assemblies that complicate disassembly (Wang et al., 2021), exclusion of end-of-life stakeholders in design processes (Hapuwatte & Jawahir, 2021), and centralised production models misaligned with distributed circular systems (Li et al., 2023). Technological advances such as AM strengthen CPD by enabling digital spare part inventories and extending product lifespans (Ford & Despeisse, 2016). Moreover, CPD implementation is evident in circular business models (value proposition, value creation & delivery and value capture) where Patagonia embeds durability and repairability within its value proposition (Farra, 2021), Philips advances circular value creation and delivery through its Pay-per-Lux service that incentivises long-lasting design, and IKEA captures circular value via leasing programs that reclaim and refurbish products (Ikea, 2025). Together, these practices demonstrate how CPD provides an integrative framework (Figure 2.2) that aligns economic performance with environmental

sustainability while systematically dismantling barriers inherent in linear product design (Den Hollander et al., 2017; Lieder & Rashid, 2016).

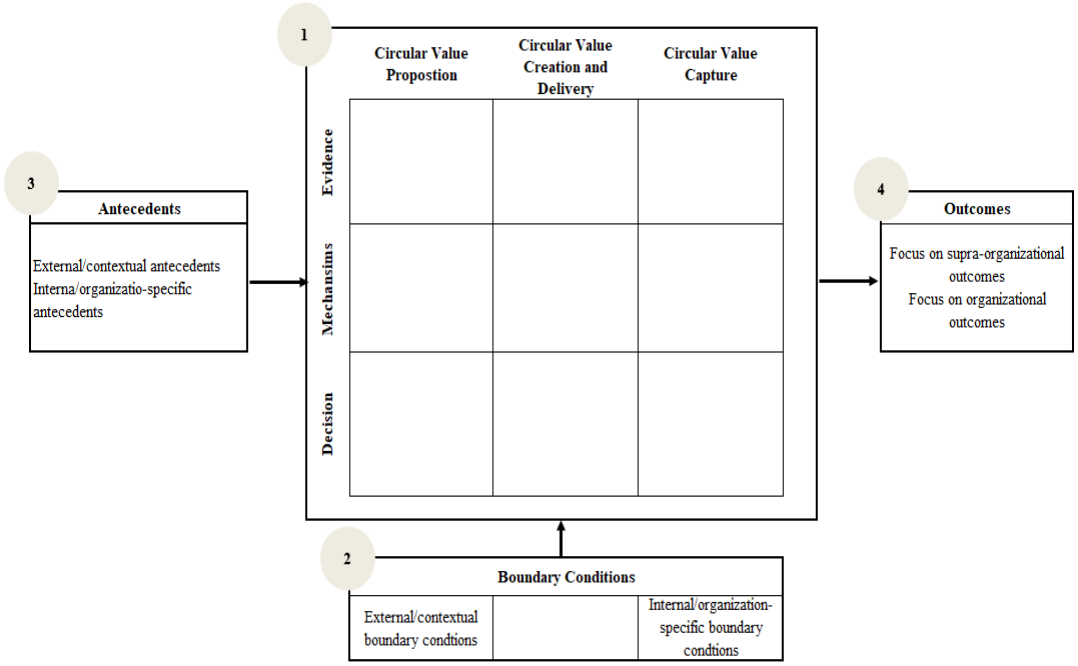


Figure 2.2: Circular Product Design (De Vasconcelos Gomes et al., 2023)

2.3.5 Contradiction in AM's role in CPD

The extant literature identifies significant contradictions regarding the role of additive manufacturing (AM) in the circular economy (CE) and circular product design (CPD). Despite its theoretical potential, AM can hinder CE goals due to energy-intensive processes, particularly in metal printing, and challenges in recycling multi-material prints (Huang & Schmid, 2018; Jung et al., 2023; Telenko & Seepersad, 2014). Its design freedom often results in overly complex products that complicate repair, disassembly, and material recovery, undermining closed-loop principles (Formentini et al., 2022; Gebler et al., 2014; Rejeski et al., 2018). High rejection rates, need for support structures, and material degradation issues further exacerbate waste and reduce the efficacy of AM in CE and CPD contexts (Jung et al., 2023; Sutton et al., 2017). Scalability constraints, including production speed, cost-effectiveness, and material limitations, restrict its large-scale implementation (Hettiarachchi, Brandenburg, et al., 2022). Additional barriers arise from misaligned business

models that favor linear systems, insufficient institutional frameworks, and technological constraints related to material recyclability, all of which impede the systemic adoption of AM for circular practices (de Mattos Nascimento et al., 2022; Despeisse et al., 2017; Kohtala et al., 2021). These disparities between theoretical promise and practical implementation highlight a critical need for interdisciplinary research integrating technical, economic, and policy perspectives to mitigate contradictions and optimise AM for CE and CPD objectives (Tukker, 2015; Wang et al., 2022).

2.3.6 Strategic Management Framework for Circular Product Design

Strategic management theories offer a robust theoretical foundation for understanding both traditional supply chain practices and the transition to CE and CPD. Among the strategic management theories, transaction cost economics clarifies governance for reverse logistics and closed-loop flows, a rationale extended to AM, where firms strategically choose between in-house capabilities and outsourced networks for production and remanufacturing (Williamson, 2008). From a resource-based perspective, AM functions as a design and manufacturing technology that enhances lightweighting, modularity, and material efficiency, thereby supporting eco-design competencies and reconfigurable production systems, which are central to CPD (Bromiley & Rau, 2016; Teece et al., 1997). Institutional theory further highlights how regulatory and normative pressures, including extended producer responsibility, drive firms to adopt follow product repairability and longevity requirements (Bhakoo & Choi, 2013; Zhu et al., 2013). Collectively, AM is recognised as a strategic enabler of waste minimisation, closed-loop material cycles, and design for disassembly, making it integral to sustainable product lifecycles (Diaz et al., 2022; Roy, Akbar, et al., 2025; Samadhiya et al., 2023).

Building on these concepts, a strategic management framework for CE and CPD can be structured across four interrelated dimensions. At its core is the focal organisation, the central

unit of analysis in which resources are mobilised to implement circular principles (Bromiley & Rau, 2016; Teece et al., 1997). Surrounding this are boundary conditions, including internal factors such as organisational structures and resource configurations, as well as external factors such as regulatory environments, market conditions, and institutional contexts, which reflect the importance of strategic fit (Sousa & Voss, 2008). Antecedents, the third dimension, encompass internal drivers such as leadership orientation and capability accumulation, alongside external drivers including stakeholder pressures, global challenges, regulatory mandates, and inter-firm relationships, as emphasised by institutional theory and the relational view (Bhakoo & Choi, 2013; Dyer & Singh, 1998). Finally, outcomes capture the operational and strategic consequences of adopting CE and CPD, including performance improvements, legitimacy, and long-term competitiveness (Diaz et al., 2022; Ketchen Jr & Hult, 2007). Within this framework, AM functions as a cross-cutting enabler that shapes circular value propositions, influences boundary conditions, responds to antecedents, and contributes to outcomes (Bromiley & Rau, 2016; Williamson, 2008; Zhu et al., 2013), demonstrating how strategic management provides a coherent lens for integrating circular practices across product design and supply chains (Figure 2.3).

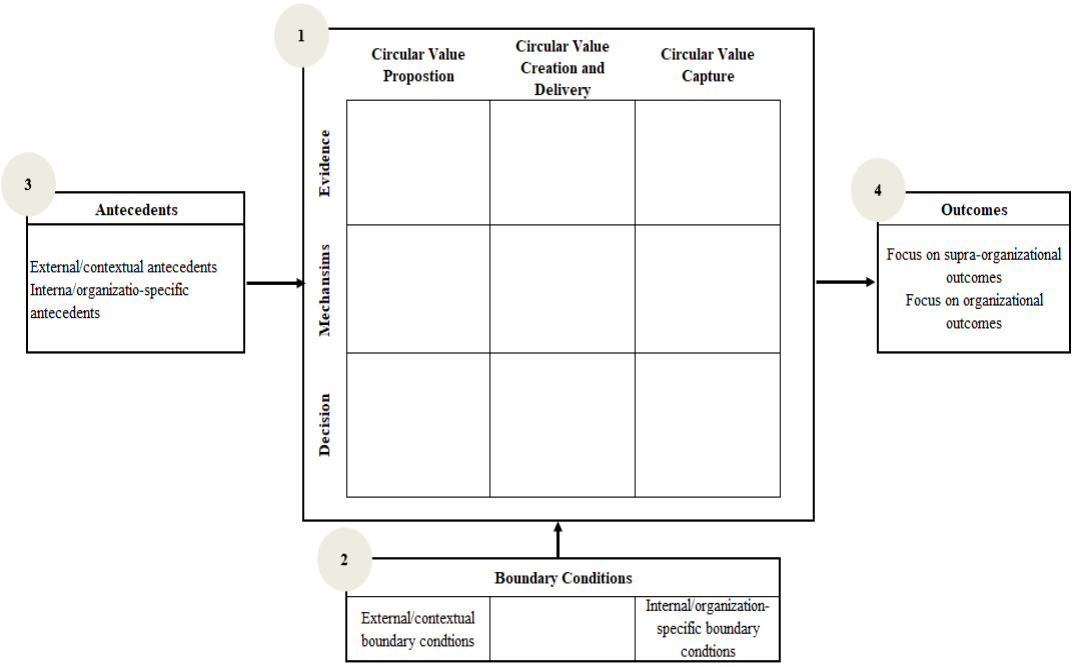


Figure 2.3: Strategic Management Framework for Circular Product Design

The next section explains the methodology adherence to a systematic literature review procedure.

2.4 Methods

This study specifically focuses on AM technology to support product design and manufacturing, to streamline the contradiction, and to establish the actual role of AM in CPD, unlike extant systematic reviews that have investigated a narrow phenomenon in a split way. To synthesises research on the role of AM on the CPD and minimise contradictions, this study is based on systematic literature review (Palmié et al., 2025; Torraco, 2016). A systematic literature review (SLR) is research endeavour that provides guidelines in management and in OM that summarises and synthesises representative literature on a topic in an systematic way such that new frameworks and perspectives on the topic are generated (Thomé et al., 2016).

A SLR begins with the systematic selection of relevant and representative literature in the chosen field of research (Tranfield et al., 2003). For this purpose, the study focused solely on publications from 2013 onwards. The study further justifies the choice of this timeframe

(2013-2025) based on the limited literature available before this period on key terms such as AM, product design, and CE.

2.4.1 Steps of SLR

The process of conducting SLR is still fragmented. Over time, many institutions have established and integrated guidelines for developing an SLR model. To conduct this SLR, the study followed a three-step process based on prior research: Planning, Conducting, and Reporting (Tranfield et al., 2003), to make sure that the process is transparent, accurate, rigorous, and reproducible. During the planning phase, the authors conducted a non-systematic review of relevant literature by reading recent articles to identify key terms and match them with the search database. Then the search criteria are identified. Subsequently, the search is conducted, results are screened, and data are extracted, analysed, and synthesised. Finally, in the reporting phase, the investigated outcomes are presented in a structured, organised manner. The above three processes are presented in Figure 2.4 based on eight different steps guided to elaborately explain the SLR process (Xiao & Watson, 2019).

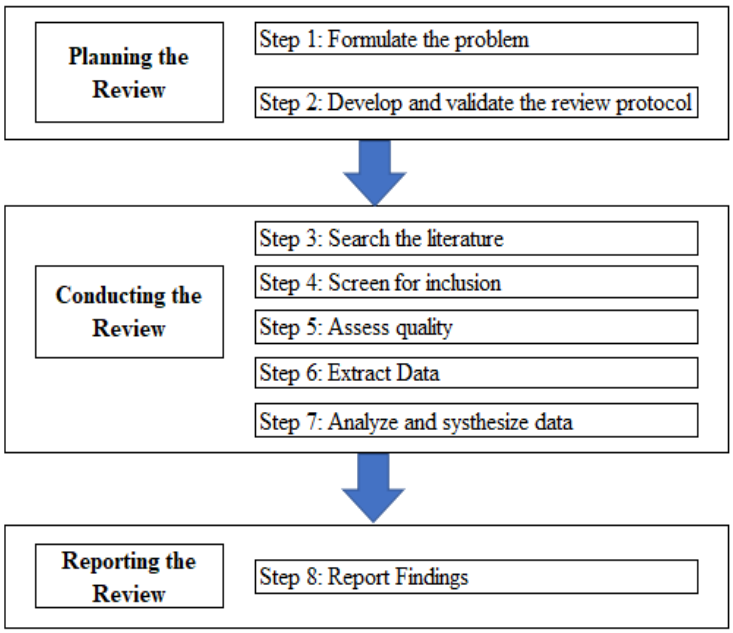


Figure 2.4: Steps of SLR

Step 1: Formulate the problem

Formulating the problem is the first step in conducting an SLR. After problem formulation, three research questions were identified to define the study's scope accurately and unambiguously (Denyer & Tranfield, 2009). Research questions are the driving force behind an SLR, which aims to formulate the problem (Kitchenham et al., 2007). Considering the scope of the study, the main research question is: How can AM be systematically integrated into CE and CPD frameworks to enable sustainable performance?

Step 2: Develop and validate the review protocol

The research protocol is vital for systematic literature reviews. The research protocol is a predetermined plan outlining the methods used to conduct the review (Xiao & Watson, 2019). This research followed a predefined protocol to thoroughly review all relevant articles on the subject. The SLR protocol followed in this study is shown in Figure 2.5.

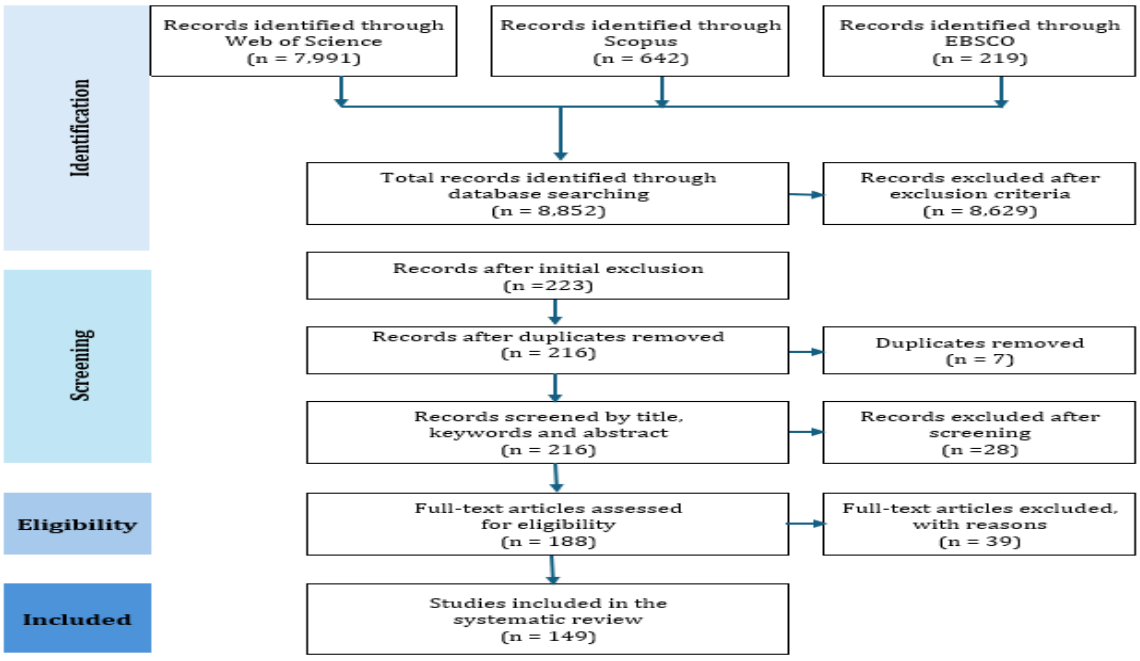


Figure 2.5: SLR Protocol (PRISMA Flow Diagram)

Step 3: Search the literature

This study adopted multiple steps to minimise potential bias. More specifically, the study incorporates feedback from a panel of academics, leverages the expertise of academic supports, involves multiple screenings, searches three databases, and avoids restricting itself to specific publications.

Moreover, the study used three of the most comprehensive databases, Scopus, EBSCO, and Web of Science, to ensure the inclusion of the most relevant articles. These databases cover approximately 95% of all published research articles (de Oliveira et al., 2019). After identifying the search tools, the researchers select keywords to ensure that the relevant literature retrieved from databases meets the research objectives. The study aims to determine the extent to which AM supports PD in CE as a design and manufacturing technology. The title keywords are "Additive Manufacturing", "Product Design", and "Circular Economy". In line with other works in the field, the study identified 2 synonyms for the area of additive manufacturing (additive manufacturing** or 3D printing**); a list of 2 keywords for product design (product design** or design for manufacturing**) and a list of keywords for circular economy (reverse* or 'sustainable* or closed loop* or reverse* or refuse* or recycle*). In December 2025, the researcher conducted a database search using various search conventions, including truncation characters and Boolean operators (AND, OR), to group keywords and construct search terms. This process resulted in the creation of search items that were searched across all fields simultaneously. A total of 8,852 articles were found across the three databases (Web of Science: 7,991; Scopus: 642; EBSCO: 219). The details of these search items are presented in Table 2.2.

Table 2.2: Search Terms based on Key Concepts

Key Concepts	Database	Search String with key words
Additive manufacturing	Web of Science	('desig*' or 'product desig*' or 'embodiment desig*' or 'design for manufactur*' or 'product lunc*'or 'ergonomic*' or 'human factors' or 'design-evaluation-redesign' or 'regenerative design') and ('3D print*' or 'additive manufactur*' or 'rapid manufactur*' or 'rapid prototyp*') and ('circular economy*' or 'sustainable*' or 'closed loop*' or 'revers*' or 'refuse* 'or 'recycle*' or 'refurbishment*' or 'reuse*' or 'remanufacture*'
Product Design	Scopus	
Circular Economy	EBSCO (Business Source Ultimate)	

		or ‘reduce*’ or ‘repurpose*’ or ‘redesign*’or ‘repair*’ or ‘resell*’ or ‘rethink*’or ‘recover*’ or ‘industrial ecology*’ or ‘cradle-to-cradle*’or ‘product lifecycle design*’)

Step 4: Screen for inclusion

For screening the articles, all the inclusion and exclusion criteria applied by the authors the summarised below in Tables 2.3 and 2.4:

Table 2.3: Inclusion Criteria

Criteria for Inclusion	**Explanation**
Database: Scopus, Web of Science and EBSCO	These three data contribute more than 95% of total publications
Date of Publication between 2013 to December 2025	Few publications are available before 2013 based on the AM, PD, and CE combination.
Journal articles only	This is because all the articles are peer-reviewed and published in good-quality indexed journals.
Subject matter	From Scopus, articles related to Business, Management, Accounting, Social Sciences or Economics, Econometrics, and Finance are included.
	The Web of Science includes articles related to Business, Economics, Social Science Interdisciplinary, or Operations Research and Management Science. From EBSCO, all the key fields are included.
Articles that were published in English	For coding and research, only articles published in English were taken into consideration

Table 2.4: Exclusion Criteria

Criteria for Exclusion	**Explanation**
Not peer-reviewed	Articles identified using the keywords and found to be non-peer-reviewed should be excluded. This includes conference articles, which are generally classified as "grey literature.
Completely unrelated	Papers that are not related to the relationship between AM, PD, and CE.
Duplicates	Researcher used three databases, duplicating results must be excluded
Subject matter	Areas such as engineering, material science, environmental science, and many others were excluded from the study
Articles that were not published in English	Articles written in a language other than English were excluded from the literature review.

After applying the inclusion and exclusion criteria, the researcher independently generated a final list of papers for the SLR. To avoid confusion, the researcher made sure no relevant articles were excluded. A list of the papers excluded has been retained for the reference of future readers to ensure they can perform the same search (Kitchenham et al., 2007). A total of 269 papers were selected after considering exclusion and inclusion criteria (8,629 were excluded from the three databases). After getting 223, the duplicates were deducted from the final database. A total of 216 articles were then considered for further processing.

Step 5: Assessing quality

Ensuring quality and consistency was a primary objective during the SLR. Researcher assessed inter-rater reliability using Cohen's kappa. Researcher then independently evaluated study quality to ensure the relevance of the extracted papers. For this assessment, 30 articles randomly from the dataset and screened them by title and abstract. After reaching on a ground regarding inclusion and exclusion criteria, compared the coding decisions to determine inter-rater reliability using Cohen's kappa (κ) statistic. Cohen's kappa quantifies the degree of agreement between raters, based on the number of codes in the coding scheme and the value obtained (Tranfield et al., 2003). For instance, a kappa value between 0.40 and 0.60 is considered fair, 0.61 to 0.75 is good, and above 0.75 is excellent. After the critical evaluation, the kappa value was 0.632. Moreover, the rigour of each study was evaluated independently of the criteria based on the use of the Mixed Methods Appraisal Tool (Hong et al., 2018). Additionally, the MMAT rating is stated in relation to each individual criterion rather than a summary score. These ratings did not exclude any study from the analysis. This indicates good inter-rater reliability for coding the inclusion and exclusion criteria and consistency across the documents used for the analysis. This process enhanced data quality and minimised potential bias.

Step 6: Data extraction

All relevant articles to this study's objectives were downloaded. The researcher carefully screened each paper several times, which is crucial for providing article-specific data (Andresen & Bergdolt, 2017). This is carried out to prevent human error and to document the process for replication and transparency (Tranfield et al., 2003). The coded data were then entered into an Excel spreadsheet and categorised according to the SLR objectives. These categories included authors, year of publication, publication location, journal name,

keywords, paper methodology, major findings, and contributions of each article. Table 2.5 below shows the data extraction template.

Table 2.5: Data Extraction Template

Data	Explanation
Authors	Author's Name
Year	Publication year
Location	Lead author's affiliated institution
Journal	Journal Name
Keywords	Number of keywords
Methodology	Experimental design: An empirical study entails the manipulation of causal relationship variables and the observation of effects between the treatment and control groups. Qualitative Study: An empirical study based on people's experiences, perceptions, and behaviour. Quantitative Study: A quantitative study based on numerical data to validate the research hypothesis. Case Study: A case study entails a comprehensive analysis of one or multiple cases, delving into their details and characteristics. Conceptual Paper: An analytical study derives conclusions by establishing logical relationships and connections. Mixed Method: A combination of the quantitative and qualitative study.
Key findings	A concise overview of the main results aligned with the review questions.
Contributions	Main contributions of the articles based on AM, CE, and CPD

Step 7: Analysis and synthesis of data

Following a comprehensive analysis (Popay et al., 2006; Tranfield et al., 2003), the evaluation was conducted independently by the researcher. From the initial pool of 216 articles identified after applying inclusion and exclusion criteria and removing duplicates, each study was assessed for relevance to three core dimensions: additive manufacturing, product design, and the circular economy. Articles that did not align with any of these dimensions, a total of 28, were excluded, leaving 188 for full-text analysis.

The retained articles were then evaluated using a four-point scale with 1 indicating a very low extent or none at all, and 4 indicating a high extent or full representation (Keupp et al., 2021). Articles scoring 3 or 4 across all three dimensions were included in the subsequent analysis, whereas those rated 1 or 2 on at least one dimension were excluded. In cases where an article scored 3 or 4 on one dimension but 1 or 2 on another, the mean score was calculated, and

studies with an average above 2.5 were retained. This procedure yielded a final set of 149 articles deemed relevant for further analysis (See Appendix 5).

Step 8: Report findings

After screening and quality assessment, the literature search results are summarised in descriptive and content analysis perspectives. The next section comprehensively discusses the study's findings based on data extracted from the 149 research articles. In the data analysis phase, 149 articles were analysed using the content analysis method (Miles, 1994). A coding scheme was developed after discussion among the research team members. The study further focuses on the narrative integration of the qualitative content, which comprised a two-step debate (Popay et al., 2006). First, the researcher extracted and recorded descriptive information from the articles reviewed, including publication year, location, journal title, methods, and keywords.

Second, the study ensured that all 149 studies addressed at least one of the following elements: additive manufacturing (AM), product design, or the circular economy. To this end, the researcher applied a content analysis approach, which enabled us to systematically code and categorise the articles according to these content areas (Krippendorff, 2018). The analysis further distinguished studies by their primary objectives, including the role of AM in product design, the contribution of product design to CE, the conceptualisation of CPD, and the challenges of implementing AM within CE and CPD contexts. In addition, operational and strategic aspects were identified and classified from a strategic management perspective.

2.5 Findings and Discussion

This section offers a descriptive overview of the reviewed articles and is organised as follows. It first outlines when and where the articles were published, then presents a distribution of journals by title. examination of how they conceptualise circular product design, and the methodological approaches employed. The analysis then considers how AM

and circularity are operationalised, both independently and in relation to one another, with particular attention to the intersection of AM, circular product design, and sustainability. The results of this descriptive analysis are detailed in the subsequent discussion.

2.5.1 Publication Year: Since the literature search was completed in December 2025, all articles published in 2025 were included in the study. A summary of publications by year shows a trend in the number of studies on the study topic. An increasing trend is evident in the articles published over the last five years, with 80% appearing between 2020 and 2025, and, surprisingly, nearly one-sixth (16%) published in 2025 alone. Surprisingly, no published articles were found in the year 2015. This has shown that the topics AM, PD, and CE have gained increased attention and popularity in the scientific community (Figure 2.6).

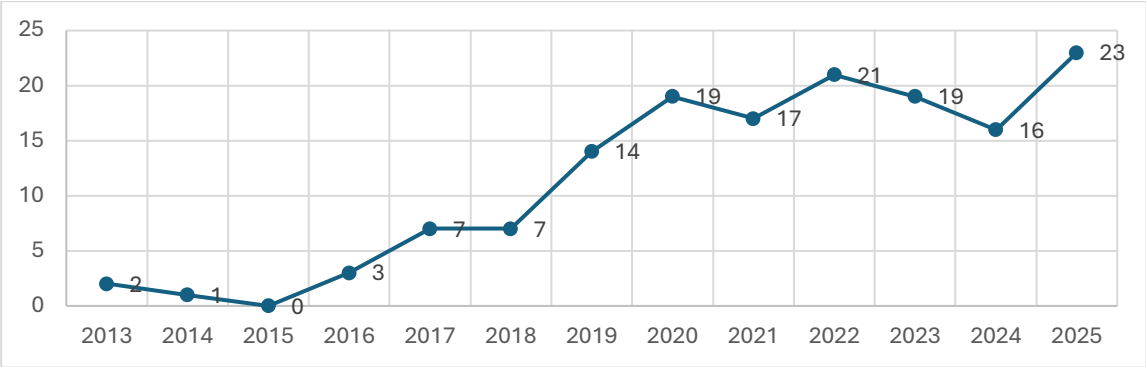


Figure 2.6: Publication of Articles by Years

2.5.2 Geographic Distribution: The objective of geographical distribution is to identify the country with the highest level of research publication relative to the affiliation of the first author. Figure 2.7 shows a graphical representation of the geographic distribution of publications by connection to the principal author.

The USA leads all other nations in scientific research and publications, with 28 articles on the integration of AM, PD, and CE. China published the second-highest number of papers in the field, with 14 articles. Among all continents, Europe published the most articles on the subject, totalling 75.

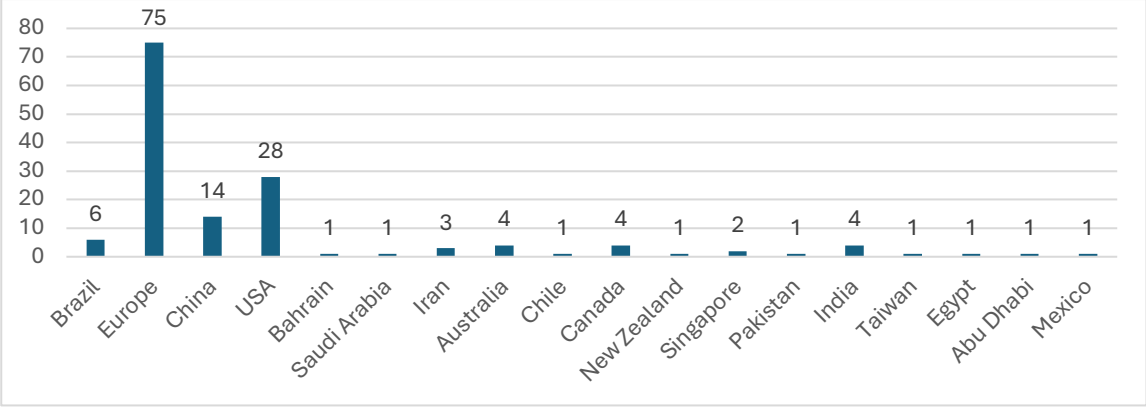


Figure 2.7: Geographic Distributions of Articles based on First Author's Affiliation

2.5.3 Distribution of Articles among Journals: While the publications breakdown provides information on the percentage of publications by the journal, the distribution of publications by journal aims to identify the journals most interested in the research theme. The International Journal of Production Research (15), Journal of Manufacturing Systems (13), Sustainability (12), International Journal of Production Economics (9), Journal of Cleaner Production (7), and International Journal of Computer Integrated Manufacturing (5) were the six top journals where more than 41% percent of the journal articles were published (Figure 2.8).

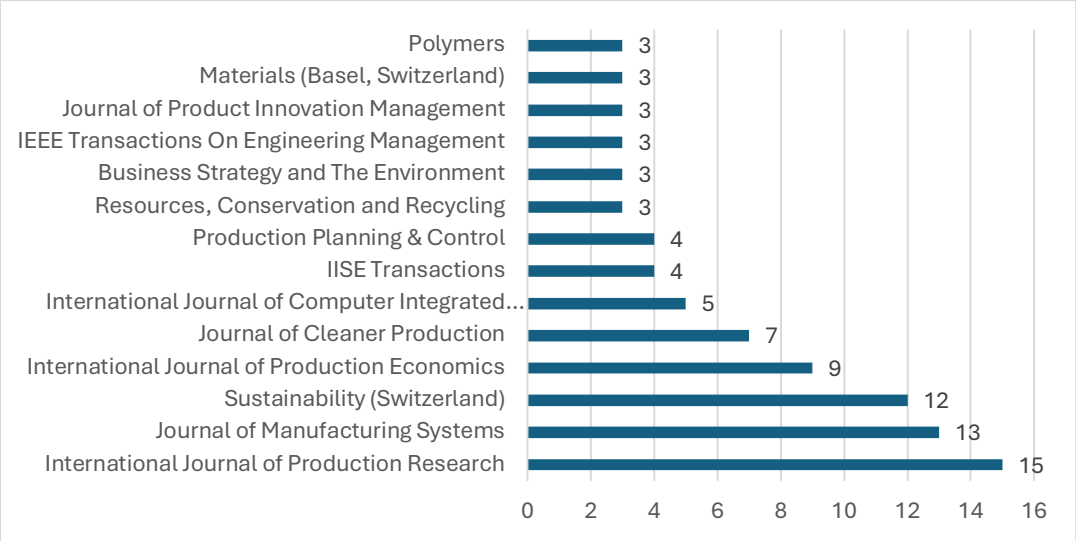


Figure 2.8: Distribution of Articles among Journals

2.5.4 Research Methods used in the Selected Studies: The articles are divided into several categories: case studies, experimental studies, empirical studies, qualitative and quantitative studies, model development, dynamic assessment approach, and miscellaneous. Figure 2.9 demonstrates that case studies were used in 39 articles, experimental studies in 35, and quantitative studies in 13. The remaining articles were focused on conceptual study 13, qualitative studies 11, model development and qualitative studies 9, and other methodologies.

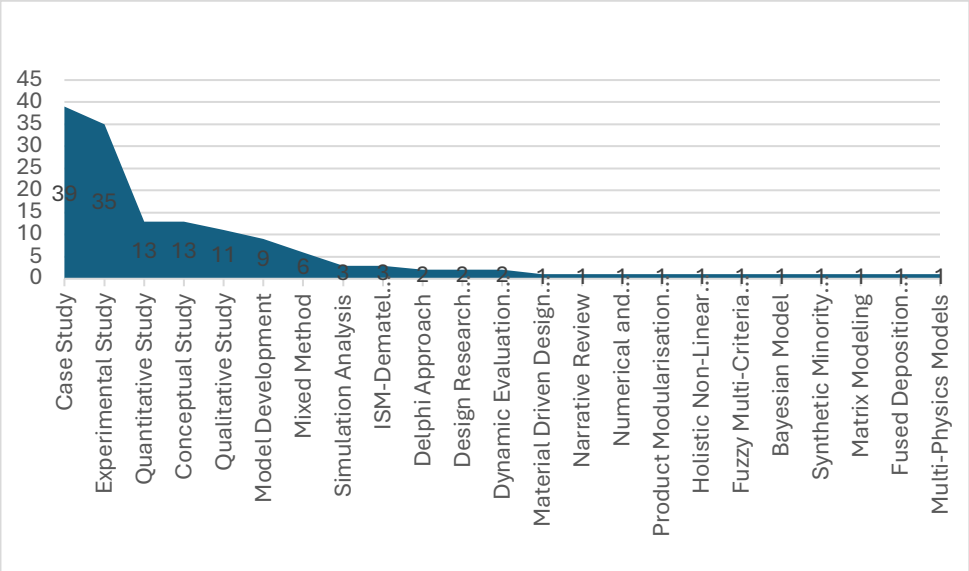


Figure 2.9: Distribution of Articles based on Research Methods

2.5.5 Keywords Statistics: The keyword statistics were analysed based on the selected papers. The most frequently identified keywords were additive manufacturing, circular economy, 3D printing, Industry 4.0, sustainability, and others. However, consider the context and relevance of these keywords in the research to ensure accurate representation and meaningful insights from the analysis. Further examination of how these keywords were used and interconnected in the papers would provide a more critical understanding of their significance in the field. Figure 2.10 shows the keyword statistics for the selected articles.



Figure 2.10: Keywords Statistics

2.5.6 Circular Product Design Conceptualisation

Of the 149 articles reviewed, only 89 (60%) explicitly articulate their conceptualisation of product design within the context of the CE or CPD. Drawing on the three dimensions of the circular business model, CPD is commonly framed around: (1) the circular value proposition, (2) circular value creation and delivery, and (3) circular value capture (Kuzma & Sehnem, 2023; Sjödin et al., 2020). Among these 89 contributions, 59 articles (66%) adopt a CPD model aligned with this tripartite structure (de Sousa Jabbour et al., 2019; Fehrer & Wieland, 2021). The remaining 60 articles employ the more granular nine-component conceptualisation of CPD, which can nevertheless be systematically mapped onto the three-dimensional framework in Table 2.6. Given its parsimony and broad applicability across the literature, the nine-component conceptualisation is adopted here as the analytical lens for examining the strategic frameworks advanced in the selected articles.

Table 2.6: Distribution of Articles based on Circular Product Design Conceptualisation

Three Components	Circular Value Propositions	Circular Value Creation & Delivery	Circular Value Capture
Nine Components	(1) Product offerings	(4) Key activities	(8) Cost structures
	(2) Customer segments	(5) Key resources	(9) Revenue flows
	(3) Customer relationships	(6) Key partners	
		(7) Channels	

2.5.7 Content Analysis

As shown in Table 7, most studies engage with AM, CE, CPD, and sustainability primarily through circular value propositions and circular value creation. In contrast, the dimension of circular value capture occupies the least position between these focal points.

Table 2.7: Distribution of Articles based on Key concepts

	Additive Manufacturing	**Circular Economy/Circular Product Design**	**Sustainability**
Circular value proposition	58	98	118
Circular value creation & Delivery	68	41	62
Circular value capture	59	34	45

Most articles on CBMs, with particular emphasis on underlying mechanisms, whereas the dimension of decision-making has received comparatively limited attention. Circular value retention strategies from AM to CPD and CE with sustainability is being positioned in the following subsection.

2.5.7.1 Additive Manufacturing role for Circular Value propositions

In the context of the circular economy, product design constitutes a critical stage in the progression from development to commercialisation. AM has emerged as a transformative technology in this regard, increasingly adopted by manufacturers to replace conventional design practices with more sustainable and adaptable solutions (Ford & Despeisse, 2016; Gardan, 2017). AM is distinguished from traditional methods by three principal characteristics that directly contribute to circular value propositions. First, it offers unprecedented design flexibility, enabling the creation of product configurations that would be unattainable using conventional techniques. Second, it allows for differentiated quality outcomes, as AM can achieve specific performance measures that diverge from those of traditional technologies. Third, AM offers unique operational adaptability, enabling capacity adjustments without compromising efficiency (Dong et al., 2022).

Empirical studies further demonstrate that AM enables new forms of design freedom and product innovation, thereby enhancing product development pathways (Canciglieri et al., 2019; Dahmani et al., 2021). Moreover, the capability of design remixing in AM introduces additional opportunities to extend product lifecycles and support circular objectives (Sauerwein et al., 2019). Collectively, these features position AM as a key enabler of circular value propositions by aligning product design with the principles of durability, adaptability, and resource efficiency. Beyond these technical features, AM contributes strategically to circular product design through mass customisation and customer participation. By enabling the tailoring of products to individual user requirements, AM reduces overproduction, enhances product relevance, and extends product lifespans, while customer involvement in the design process fosters stronger product attachment, which is widely recognised as a driver of durability and reuse. In addition, AM's ability to improve precision and quality further supports product longevity by reducing premature obsolescence. Empirical research highlights AM's ability to generate new design freedoms, facilitate product development, and integrate remixing practices that expand reuse and adaptation possibilities (Dahmani et al., 2021; Friesike et al., 2019; Mellor et al., 2014). Collectively, these attributes position AM as a central enabler of circular value propositions by advancing durability, adaptability, mass customisation, customer-driven innovation, and resource efficiency (See Appendix 6).

2.5.7.1.1 Mass Customisation for Circular Value Propositions

Mass customisation has been difficult to achieve with conventional manufacturing because high tooling costs make individualised production uneconomical (Hauser et al., 2021). In the circular economy, however, consumer demand for personalised products has grown as technology allows more active involvement in design. AM addresses this challenge by manufacturing customised items at a lower cost than traditional methods (Abdulhameed et al., 2019). Previous studies show that AM can support the production of medium-to large

volume, tailored goods, thereby reducing costs and enabling circular production systems (Attaran, 2017; Ponis et al., 2021). This happens because AM relies on digital design and rapid prototyping, which make it easy to create virtual models, adjust designs quickly, and customise products with limited use of materials, energy, or labour (Hu et al., 2019). Choosing AM for mass customisation enables firms to meet consumer needs while improving resource efficiency, flexibility, and product lifecycles, all of which are key goals of circular product design.

2.5.7.1.2 Complex Geometry for Circular Value Propositions

Additive Manufacturing (AM) distinguishes itself from traditional manufacturing technologies through its unique ability to produce products with complex geometries and patterns, a capability well documented in the literature (Geng et al., 2022; Vongbunyong & Kara, 2017). This advantage is enabled by its layer-by-layer material deposition in a controlled environment, which allows precise fabrication of both external and internal structures that are impossible to achieve with traditional methods (Chandima Ratnayake, 2019). By reducing material use and production time for intricate components, AM supports resource-efficient circular product development. Consequently, firms can leverage this flexibility to implement novel designs and optimise production processes, making AM a strategic tool for enabling complex geometries and advancing circular economy objectives (Paz et al., 2016).

2.5.7.1.3 Customer Participation for Circular Value Propositions

Operational managers frequently evaluate relocating or opening factories in response to shifting customer demand, seeking lower labour costs or proximity to key markets (Moradlou et al., 2021). AM facilitates this process by enabling production closer to customers while supporting resource-efficient manufacturing and free-form product designs (Khorram Niaki & Nonino, 2017). The most probable reason lies in AM's flexible, localised production

capabilities, which allow rapid adaptation to market needs and reduce dependence on large-scale, centralised facilities. As a result, AM not only streamlines production relocation but also encourages circular business models, such as involving consumers in the product design process, thereby enhancing both sustainability potential (Dong et al., 2022).

2.5.7.1.4 Enhancing Quality for Circular Value Propositions

AM is widely employed in circular economy applications because it improves product quality while remaining flexible and cost-effective for small-batch production (Geng & Bidanda, 2022). Evidence shows that AM can help meet quality standards even when using recycled or scrap materials, ensuring products conform to required specifications (Sun, Pedrielli, et al., 2020). The mechanism behind this lies in AM's precise, layer-by-layer fabrication process, which enables the production of high-quality, pollution-free products and reduces the inherent variability in traditional manufacturing (Dahmani et al., 2021). As a result, adopting AM enables firms to accelerate development timelines, reduce production costs, and enhance product quality, thereby supporting both circularity principles and consumer demand for sustainable, high-standard products (Liu et al., 2022).

2.5.7.2 Additive Manufacturing Role for Circular Value Creation and Delivery

Additive Manufacturing (AM) plays a pivotal role in enabling circular value creation and delivery by supporting sustainable product development practices across the product lifecycle. Empirical evidence demonstrates that AM facilitates the extension of product lifetimes through repair, remanufacturing, recovery, and maintenance, while simultaneously enabling resource-efficient production and industrial symbiosis by integrating waste streams into the value chain (Abd Aziz et al., 2021; Arian et al., 2021; Ertz et al., 2022). The mechanism underpinning this lies in AM's design flexibility, which enables modularity, and disassembly, standardisation, and optimisation of closed-loop supply chains, ensuring that products can be upgraded, repaired, or recycled with minimal environmental impact (Huang

et al., 2022; Singh, 2025). Furthermore, AM supports circular product design (CPD) strategies that incorporate sustainable end-of-life considerations and enable the efficient flow of product and material information, thereby facilitating coordinated reverse logistics and enhancing resource circularity (De Arroyabe et al., 2021). Through these capabilities, AM not only drives value retention by reducing material consumption and waste but also enables robust life-cycle assessments that quantify environmental impacts across the entire product lifecycle, reinforcing its central role in advancing sustainable, circular manufacturing systems (Elsacker et al., 2022; Ertz et al., 2022). Data coding for all dimensions is shown in Appendix 7.

2.5.7.2.1 Product Life-Time Extensions for Circular Value Creation and Delivery

Past literature provides evidence that a shift toward CE practices emphasises repair, remanufacturing, reuse, and repurposing, highlighting the importance of product lifetime extension for achieving higher circularity (Ertz et al., 2022; Wang et al., 2022). AM contributes to this goal through its design freedom, ability to create complex geometries, and capacity for customisation, personalisation, and localised production, which collectively enhance product durability and enable multiple reuse cycles (Ford & Despeisse, 2016; Sauerwein et al., 2019). The mechanism underpinning this lies in AM's ability to integrate reliability, maintainability, and repair-friendly features into product designs, allowing components to be replaced or upgraded efficiently, while supporting intelligent process monitoring, control, and optimisation across lifecycle stages (Liu et al., 2022; Sauerwein et al., 2019). Consequently, adopting AM enables firms to implement long-life product strategies that extend usability, reduce waste, and enhance resource efficiency, making it a strategic tool for sustainable performance (Salesa et al., 2025).

2.5.7.2.2 Industrial Symbiosis for Circular Value Creation & Delivery

Empirical evidence indicates that industrial symbiosis (IS) promotes circularity in manufacturing by encouraging collaboration among industries to share materials, energy, water, and by-products, thereby mitigating resource depletion, waste, and pollution while enhancing competitive advantage (Sgambaro et al., 2024). AM facilitates this process by enabling flexible, localised, and resource-efficient production, allowing the industries to adapt designs and utilise shared inputs effectively within an inter-organisational network (Yang et al., 2022). AM processes capacity to produce complex, customised components on demand, integrating recycled or secondary materials and supporting coordinated production flows across participating firms. Consequently, adopting AM in industrial symbiosis enables manufacturers to operationalise CE strategies, optimise resource use, and strengthen collaborative networks for sustainable value creation.

2.5.7.2.3 Design for Modularity and Disassembly for Circular Value Creation and Delivery

Past evidence confirms that modular design enables products to undergo easier repairs, remanufacturing, and upgrades, thereby maximising lifespan and supporting circular economy objectives (Mestre & Cooper, 2017). AM enhances this process by facilitating modular product design, enabling the efficient integration and replacement of components while accounting for factors such as core cleaning, serviceability, production, and transportation costs (Fadeyi & Monplaisir, 2022). The mechanism extends to design for disassembly, where AM's precision and layer-by-layer fabrication enable products to be constructed in ways that facilitate easy separation of parts for maintenance, reuse, or recycling, reducing end-of-life waste and resource consumption (Su et al., 2024). Consequently, adopting AM for modular and disassembly designs supports longer product

lifetimes, facilitates remanufacturing and recycling, and strengthens circular value creation across product lifecycles.

2.5.7.2.4 Closed-Loop Supply Chain for Circular Value Creation and Delivery

Extant literature supports the implementation of closed-loop supply chains (CLSCs) within CE frameworks by enabling the use of both virgin and recycled materials during product design and manufacturing, thereby promoting environmental sustainability (Sun, Pedrielli, et al., 2020). The mechanism by which AM achieves this involves its platform-based approach, in which 3D printing services integrate materials from suppliers and end users, while real-time diagnostics and automatic machine adjustments ensure consistent product quality and feedback (Liu et al., 2019). Consequently, incorporating AM into CLSCs allows firms to optimise resource utilisation, maintain high-quality production with recycled inputs, and enhance the overall efficiency and sustainability of supply chain operations, making it a strategic tool for circular manufacturing practices.

2.5.7.2.5 Life-Cycle Assessment for Circular Value Creation and Delivery

Life cycle assessment (LCA) provides a systematic framework for evaluating and monitoring the environmental impacts of manufacturing activities across the entire product lifecycle (Saade et al., 2020). Moreover, LCA enhances material efficiency, reduces emissions, and optimises resource flows (Lara et al., 2025). AM contributes to this process by enabling precise, resource-efficient production while allowing designers to incorporate environmental considerations directly into the manufacturing stage. The mechanism lies in combining AM with LCA to identify and quantify the environmental implications of design choices, material use, and production processes, creating a feedback loop for optimising sustainability (O'Grady et al., 2021). Consequently, integrating AM with LCA enables firms to advance circular-economy objectives, foster green technologies, and implement energy-conserving manufacturing practices, thereby ensuring environmentally responsible product development.

2.5.7.2.6 Reverse Engineering for Circular Value Creation and Delivery

Reverse engineering (RE) is widely applied in remanufacturing, particularly for producing legacy or spare parts in small batches, supporting the maintenance and extension of existing products (Geng & Bidanda, 2022). AM enhances RE by enabling the precise reproduction of complex geometries and customised components that would be difficult or uneconomical to manufacture using traditional methods. The mechanism involves scanning, modelling, and layer-by-layer fabrication, enabling firms to accurately recreate parts while integrating them into remanufacturing workflows. Consequently, leveraging AM for RE facilitates collaboration among stakeholders, supports the transition from a linear economy to a circular economy, and strengthens the efficiency and sustainability of product lifecycle management (Mishra et al., 2023).

2.5.7.3 Additive Manufacturing for Circular Value Capture

Manufacturing industries, nowadays, are increasingly pursuing CE objectives by adopting remanufacturing and restorative practices that extend product lifespans, reduce material consumption, and enhance economic returns (Saidani et al., 2019; Yang et al., 2022). AM plays a pivotal role in this context by enabling scalable production of modular, repairable, and reusable components, facilitating material circularity through recycling and upcycling, and allowing precise customisation that minimises waste and assembly complexity (Fadeyi & Monplaisir, 2022; Rosa et al., 2020). The mechanism lies in integrating circular product design with AM's flexibility, where early detection of failures, process uncertainties, and design optimisation directly reduce development costs, improve serviceability, and support industrial symbiosis, while simultaneously generating multiple revenue streams from repair, refurbishment, remanufacturing, and resale (Rosa et al., 2019; Wang et al., 2022). Consequently, leveraging AM for circular product design enables firms to capture value across the product lifecycle, optimise cost structures, enhance material efficiency, and create

new sources of revenue while strengthening long-term sustainability and competitiveness. Data coding for validating AM's role in circular value capture is shown in Appendix 8.

2.5.7.4 Boundary Conditions of Additive Manufacturing for Circular Product Design

AM provides support for product design in the field of CE but encounters various challenges during implementation. It initially gained prominence in specialised industries with similar components (Kunovjanek & Reiner, 2020). Nevertheless, AM will not make conventional factories obsolete (Attaran, 2017). The existing literature has diligently outlined the legal, ethical, organisational, strategic, and technological obstacles that impede the adoption of AM for CPD (Bilbao-Ubillos et al., 2025; Luthra & Mangla, 2018). Several other studies also categorised potential hurdles spanning design, safety, manufacturing, certification, and legal aspects (Wang, Lin, et al., 2019). Through a comprehensive content analysis, the study identified the subsequent challenges related to AM implementation in CPD. The literature for internal and external boundary conditions is summarised in Appendix 9.

2.5.7.4.1 Legal Challenges

The most formidable challenges in adopting AM for CE are centred around legal considerations, including the potential for intellectual property violations, brand dilution, and the looming threat of cyber-attacks (de Mattos Nascimento et al., 2022). Data and cybersecurity are major concerns in the adoption of digital technologies, such as AM (Deepu & Ravi, 2023; Sahoo & Lo, 2022). Besides these, a lack of informed strategies, governmental policies, and regulations is also hindering AM adoption for CE (Almahamid et al., 2023).

2.5.7.4.2 Operational Challenges

AM faces operational challenges related to energy use, including reducing electricity transmission losses and minimising material-processing energy consumption during product design (Arian et al., 2021). On the other hand, key challenges in AM implementation for CPD include limitations in mass production due to lower output rates (Shukla et al., 2025).

AM may incur higher production costs, greater planning and control complexity, and reduced capacity utilization (Chowdhury et al., 2019). AM requires integrated designs that hinder component changes, leading to increased costs and inefficiencies in remanufacturing (Abd Aziz et al., 2021; Geng et al., 2022). Moreover, delivering high product quality and consistency, detecting defects, and reducing waste generation are also other challenges during AM implementation (Borgue et al., 2019; Liu et al., 2019). Furthermore, balancing high throughput with the desired output level poses additional challenges (Geng & Bidanda, 2022). Figure 2.11 provides an overview of the challenges in AM implementation for CPD.



Figure 2.11: Challenges for Implementing Additive Manufacturing for Circular Product Design

2.5.7.4.3 Technical Challenges

From a technical viewpoint, AM offers design flexibility to optimise production constraints, such as reducing effort in assembly steps (Zhang & Zhao, 2022). However, it may lead to longer processing times and increased packing complexity (Hu et al., 2022). For achieving target accuracy, production units require more scans and parts (Geng et al., 2023), and configuring optimal spare parts can be complex (Cantini et al., 2022). On the other hand, ensuring manufacturability with selected AM printers is challenging (Zhang & Zhao, 2022)

and requires stocking expensive consolidated parts to anticipate random failures (Knofius et al., 2019). The industry's broad acceptance of AM is hindered by the lack of robustness and repeatability, due to complex relationships among material properties, design, process parameters, post-AM processes, and product quality (Liu et al., 2022).

2.5.7.4.4 Organisational Challenges

The organisational challenges in AM adoption include shortening supply chains, reducing the number of suppliers, and transforming the supply chain structure to enhance CE (Arian et al., 2021). Moreover, a sustainable supply chain structure can be achieved through closed-loop approaches (Santander et al., 2020). However, interdepartmental conflicts and communication barriers hinder AM implementation (Despeisse et al., 2017). Moreover, financial resources to afford technological investments pose critical challenges for equipment and infrastructure (Kerin & Pham, 2019). Similarly, managers face challenges in aligning implementation processes with the upstream and downstream supply chains (Chen, Li, et al., 2025; Yang et al., 2021). Hence, top-management commitment, visionary thinking, and a high degree of vertical integration are crucial for successful AM adoption for CE (Bressanelli et al., 2019; Luoma et al., 2022). Additionally, specific design skills are needed to fully exploit AM's design freedom (Verboeket & Krikke, 2019).

2.5.7.4.5 Socio-cultural challenges

Overcoming social-cultural challenges in implementing AM for CPD requires addressing operational skill gaps, enhancing knowledge, building trust, and upskilling personnel (Arian et al., 2021; Chowdhury et al., 2019). Human expertise and the low adoption rate of the technology play a decisive role in understanding machine behaviour and identifying optimal configurations for AM implementation (Almahamid et al., 2023; Jarrar et al., 2023). However, resistance from managers due to uncertainties on the upstream supply side and

reliability concerns impedes the actual implementation of AM (Alexopoulos et al., 2022; Feng et al., 2022).

2.5.7.5 Antecedents for the Adoption of Additive Manufacturing for Circular Product Design

The adoption of AM for CPD is shaped by a combination of external and internal antecedents that influence organisational strategies and capabilities. Externally, pressures such as resource scarcity, environmental degradation, and climate change drive firms to seek sustainable alternatives, while regulatory frameworks, including the European Union's Eco-design for Sustainable Products Regulation (ESPR), mandate compliance with environmental standards and incentivise circular practices (Ghisellini et al., 2016; Moraga et al., 2019). Market dynamics, including increasing consumer demand for eco-friendly, repairable, and recyclable products, further stimulate the adoption of circular manufacturing approaches (Pinheiro et al., 2019; Saidani et al., 2019). Internally, organisational values that emphasise sustainability and long-term environmental stewardship are pivotal in guiding firms toward circular initiatives (Liu et al., 2018). The integration of digital technologies, such as Industry 4.0 tools, enhances AM's feasibility by improving design precision, resource efficiency, and production flexibility (Burke et al., 2023; Ertz et al., 2022). Additionally, top management's commitment to sustainability and the allocation of resources toward circular innovation foster an organisational culture conducive to the adoption of AM for CPD (Abd Aziz et al., 2021; Tian et al., 2021). Together, these external and internal antecedents create a favourable environment for leveraging AM in CPD, enabling firms to align operational practices with sustainability imperatives and strategic objectives (See Appendix 10).

2.5.7.6 Outcome due to the Adoption of Additive Manufacturing for Circular Product Design

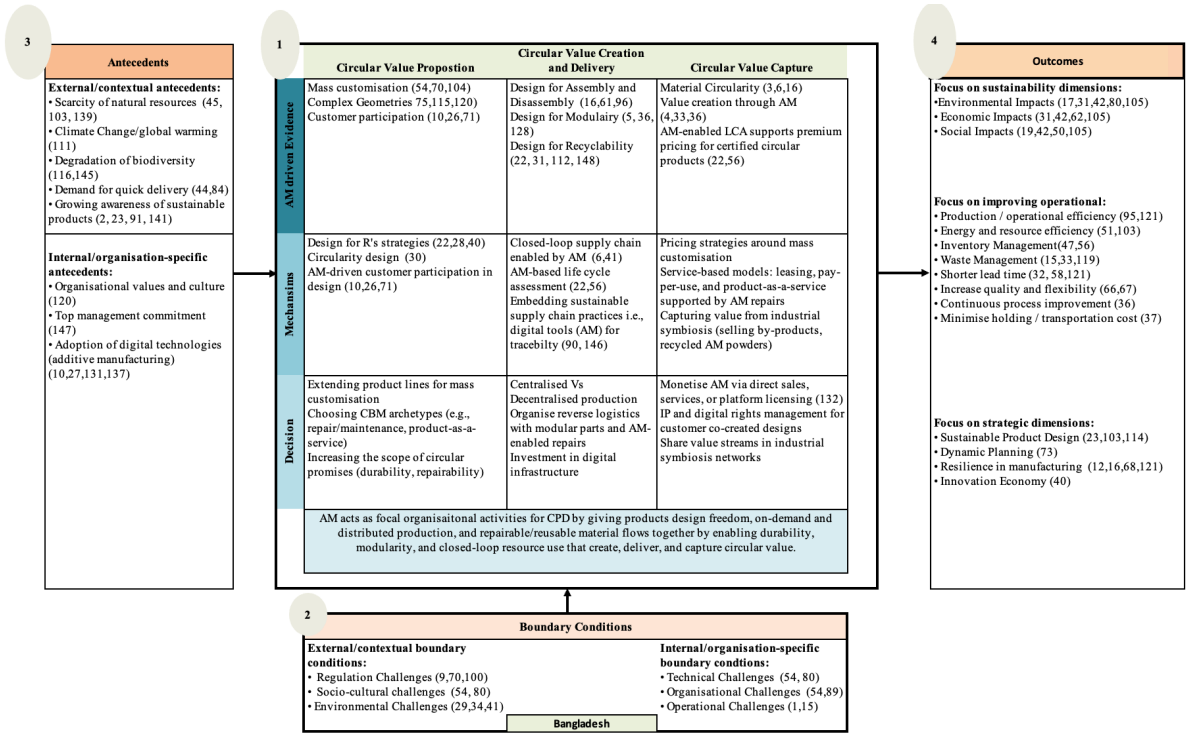
The adoption of AM for CPD has been shown to positively influence sustainability, operational efficiency, and strategic decision-making within manufacturing organisations. By facilitating practices aligned with the triple bottom line (people, planet, and profit), AM supports achieving broader sustainable development goals (Geng & Bidanda, 2022; Saidani et al., 2019). Operationally, integrating AM into CPD enhances production and process efficiency, reduces energy and material consumption, improves inventory management, minimises waste, shortens lead times, and increases product quality while maintaining design flexibility (Liu et al., 2022; Rosa et al., 2019; Sauerwein et al., 2019). Additionally, AM enables continuous process improvement, reduces transportation costs, and encourages active customer participation throughout the production cycle (Ford & Despeisse, 2016; Rogers et al., 2025). From a strategic perspective, AM facilitates sustainable product design, smart manufacturing, dynamic operational planning, resilience in production processes, and delayed product differentiation, thereby enhancing organisational competitiveness while advancing sustainability objectives (Ertz et al., 2022; Tian et al., 2021). In sum, the deployment of AM for CPD transforms traditional manufacturing practices, generating measurable benefits across operational and strategic dimensions while reinforcing sustainability commitments and achieving both environmental and economic objectives (See Appendix 11).

2.5.8 Integrative Strategic Management Framework

Building on the content analysis, this study proposed a framework (Figure 2.12) to explain how AM enables CPD by converting circular opportunities into value for customers, manufacturers, and the environment. The given framework connected three interconnected stages: circular value proposition, value creation and delivery, and value capture. Circular value propositions, including mass customisation and design freedom, are enabled by AM's

reduced tooling requirements and flexible production capabilities (Attaran, 2017; Ponis et al., 2021). These propositions are then realised through value creation and delivery mechanisms, namely lifetime extension (Sauerwein et al., 2019), modularity and disassembly (Kenger et al., 2021), closed-loop supply chains (Dong et al., 2022), life-cycle assessment (Ford & Despeisse, 2016), decentralised production (Khorram Niaki & Nonino, 2017), and reverse engineering (Geng & Bidanda, 2022). Circular value capture, by contrast, reflects how manufacturers appropriate economic value through material recovery (Johnson & Wang, 1995), cost reduction (Hailemariam & Erdiaw-Kwasie, 2023), premium pricing and small-batch cost-effectiveness (Geng et al., 2023), as well as sustainable business model, remanufacturing, and resale (Bauwens et al., 2020). The framework thus extends existing strategic management perspectives by positioning AM as a design-stage facilitator of value-retention strategies, rather than a mechanism confined to end-of-life recovery (Luoma et al., 2022).

This study further argue that the effectiveness of these value processes depends on both antecedents and boundary conditions. External antecedents, such as resource scarcity, climate change, regulatory pressures, customer demand, and sustainability requirements, create the incentives underpinning AM-enabled CPD (Yang & Zhao, 2015), while internal factors such as organisational values, top-management commitment, and digital capabilities support its adoption (Lee et al., 2025). Regulatory, socio-cultural, environmental, technical, organisational, and operational conditions, however, may constrain or facilitate this translation into circular value based within rubber and plastic (Ul Haq & Franceschini, 2020), and medical sector (Peron et al., 2025). However, variation in AM-enabled CPD across manufacturing contexts such as Bangladesh, can therefore be attributed to these boundary conditions and improvements in precision, efficiency, and flexibility (Mitić & Zdravković, 2025).



**** Numerical number indicates selected articles that cover the topic**

Figure 2.12: Strategic Management Framework for Circular Product Design

Strategic management further offers a comprehensive way of studying firms' strategy formulation and implementation of the CE in terms of value proposition, value creation and delivery, and value capture (Bocken et al., 2016; Geissdoerfer et al., 2023). This approach is compatible with theories of dynamic capabilities (DCT) and institutional theory (IT). According to DCT, a firm can sense opportunities, seize them, and reconfigure its resources and capabilities to implement its circular strategies (Teece et al., 1997), whereas IT provides the reasons and conditions of how regulatory, normative, and cognitive pressures impact organisational response (DiMaggio & Powell, 1983). Hence, the strategic management framework identifies what Bangladesh as a boundary condition needs to be managed strategically, whereas DCT and IT identify the organisational capabilities and institutional conditions that affect it.

The next section presents research propositions derived from the review findings, which guide future studies.

2.6. Research Propositions

The study's findings emphasised that AM technology has a significant influence on various aspects of product design and circularity, playing a fundamental role in shaping CPD's view to ensure sustainable, operational, and strategic benefits. In this section, the study outlines an upcoming research agenda that presents a series of research propositions derived from thematic analysis.

AM is primarily used as a digital tool for designing product components (Hettiarachchi, Seuring, et al., 2022). Because AM allows part consolidation, complex geometries, and modular interfaces, designers can plan value-retention strategies from the start of the product life cycles (Beltagui et al., 2020; Moussa & ElMaraghy, 2021). Value retention strategies, i.e., recycling, reusing, reproducing, reducing, refurbishing, and remanufacturing, offer chances for waste reduction and sustainable resource management that are embraced by AM adoption (Abd Aziz et al., 2021; Sun, Pedrielli, et al., 2020). AM also enables digital spare-part libraries and on-demand production, reducing the need for large inventories and allowing products to be supported for longer periods, thereby keeping components in use at higher value (Ford & Despeisse, 2016). For this reason, AM is increasingly recognised as a technological enabler that strengthens CPD rather than replacing it.

Value retention processes such as remanufacturing, refurbishing, and quality repair apply the CPD process by extending the lifespans of products, parts, and materials. Because all these involve reverse logistics, product recovery, and cooperation with suppliers and service providers and thereby value retention processes improve CSCM practices (Bressanelli et al., 2019; Romagnoli et al., 2023). In turn, CSCM practices result in TBL benefits. Environmentally, remanufacturing and repairing products produce significantly lower greenhouse gas emissions and material waste than manufacturing from virgin materials (Ardente et al., 2016; Wurst et al., 2023). Economically, second-life products generate

additional income and protect organisations from material market volatility (Wurst et al., 2023). Socially, inspecting and reassembling second-life products requires more labour and thus supports regional employment and technological expertise (Dubey, 2026). Furthermore, prior research confirms that sustainable supply chain practices improve environmental, economic, and social performance simultaneously (Sahoo & Upadhyay, 2024). Organisations can also achieve sustainability across all three dimensions by applying circular principles to their products and services (Lim et al., 2024). This study suggests:

Proposition 1: Increased adoption of AM in CPD leads to the value retention strategies.

Proposition 2: Value-retention strategies driven by CPD enhance CSCM practices, which in turn improve the triple bottom line of sustainability.

Upstream innovation within the circular economy paradigm occurs at the product design stage, where most decisions shape product sustainability throughout the life cycle (Dahmani et al., 2021). Material selection is critical in these decisions. Decisions on whether to use virgin or recycled materials influence not only the product's cost, quality, and recoverability but also the economics of the closed-loop supply chain (Sun, Wang, et al., 2020) and the logistics of raw material supply processes (Kunovjanek & Reiner, 2020). Recycled and reprintable materials ensure functional longevity across multiple life cycles (Mishra et al., 2023; Sharma et al., 2021). Bio-based materials create new pathways to sustainable design (Elsacker et al., 2022). Single-material product design facilitates recycling and helps reduce material consumption and emissions (Top et al., 2023). Material selection also supports downstream innovation, as recycled materials become feedstock for distributed recycling systems (Zhong & Pearce, 2018), while considerations of material origins support circular supply chains (Romani et al., 2021). Appropriate material selection thus connects upstream innovation with downstream circular practices. The study proposes:

Proposition 3: Suitable material selection enables CPD, for facilitating circular practices.

CE is often conceptualised as a means of increasing resource value through minimising waste It is essential to have a closed-loop supply chain (CLSC) and life cycle assessment (LCA) to ensure CPD. AM facilitates a PD and CLSC using recycled and new materials while minimising flaws by utilising automated detection (Liu et al., 2019; Sun, Pedrielli, et al., 2020). As an additional benefit, AM enables CPD through highly efficient, sustainable practices, reduces human error through autonomous machines or robots, optimises overall resource consumption, and meets customers' customised requirements (Sahoo & Lo, 2022). This is done through AM, which can process both virgin and recycled materials and reproduce components on demand, reducing the need for large inventories and enabling efficient product returns, repair, and remanufacturing within the CLSC (Sun, Pedrielli, et al., 2020). Automated inspection systems in AM also help detect flaws early, improving quality and reducing material waste (Liu et al., 2019). AM supports CPD through CLCS by keeping materials in a higher-value state, extending product lifespans, and reducing reliance on new resource extraction, aiming to achieve circular manufacturing.

Furthermore, AM contributes to the PD involved in the LCA process to improve production efficiency by reducing environmental impacts (Top et al., 2023). This occurs when AM allows products to be redesigned with less material, optimised geometries, and lower embodied energy, thereby reducing environmental burdens across the life cycle. AM technologies can also automate production tasks, lowering human error and resource inefficiencies, while enabling customisation without the waste associated with conventional tooling (Sahoo & Lo, 2022). The support of AM for CPD is that accurate LCA feedback and efficient material guide design decisions that prioritise durability, repairability, and reduced environmental footprint, which are fundamental pillars of circular product strategies. Hence, the study can posit the following:

Proposition 4: AM supports CPD through the implementation of CLSC.

Proposition 5: AM supports CPD through the proper application of the LCA process.

AM enhances CPD by facilitating modular design. It enables firms to manufacture and replace modules as they become obsolete, in low volumes, and without tooling, making repairs and upgrades easier (Borgue et al., 2019; Fadeyi & Monplaisir, 2022; Moussa & ElMaraghy, 2022). Moreover, AM supports design for assembly and disassembly. Through part consolidation and tool-free, single-material parts, AM eases assembly while saving materials (Maiyar et al., 2019; Top et al., 2023). Design for disassembly enables worn-out modules to be replaced instead of scrapping the entire product (O'Grady et al., 2021; van Oudheusden et al., 2024). In addition, AM enables design for recyclability through reusable and recycled materials that retain functionality across multiple life cycles (Sauerwein et al., 2019; Sharma et al., 2021; Zhong & Pearce, 2018).

AM also contributes to CPD through reverse engineering (RE), as RE helps replicate and enhance parts, especially when original designs need adaptation. This requires collaboration among supply chain actors and forces to facilitate small-batch production when needed and to replace original parts with existing parts through digital modification, replacement, and reproduction (Holmström & Partanen, 2014). This collaboration promotes CPD as a RE-limited product, ensuring it remains functional and enables continuous production even when traditional supply chains fail. Therefore, the study proposes the following:

Proposition 6: AM supports CPD through design for modularity, assembly and disassembly, and recyclability.

Proposition 7: AM supports CPD through reverse engineering.

Circular product design and circular supply chain activities raise issues that go far beyond technical design. From a legal perspective, the company must address liability for shared design information, the safety of secondary and recycled materials, and liability for repaired or remanufactured products (Ford & Despeisse, 2016). Regulatory compliance and the lack of

developed standards and certifications pose significant barriers to local and circular production (Kamble et al., 2018; Luthra et al., 2022). Technical challenges include maintaining recycled-material quality across multiple life cycles and designing products for disassembly (O'Grady et al., 2021; Sauerwein et al., 2019). Operationally, tracing parts becomes challenging in distributed and reverse flows. At the same time, these activities require coordination across design, procurement, supply, and services, as well as collaboration with new partners in the circular supply chain (Bressanelli et al., 2019; Cafforio et al., 2026; Upadhyay et al., 2021). Sociocultural challenges include customers' acceptance of repaired or remanufactured products as a criterion for adopting circular approaches (Hazen et al., 2021). Social conservatism and skill gaps also contribute to the process (Chaudhuri et al., 2025). Addressing these challenges requires more than technical solutions; it demands alignment among the company's design specifications, governance systems, and end-user participation. Top management is responsible for this alignment. Underlying factors include management challenges, a lack of long-term strategies, and bureaucracy (Chatterjee et al., 2022; Verma et al., 2025). Adopting a new business paradigm, driven by top management commitment, enables circular supply chains (Farooque et al., 2022). The study, hence, proposes:

Proposition 8: Top management commitment enables firms to overcome the interrelated legal, technical, operational, organisational and socio-cultural challenges of circular practices.

Table 2.8 presents a crosswalk of the propositions, linking each to its theoretical pathway and framework component and highlighting the relationships left for future research.

Table 2.8: Crosswalk for Propositions

No.	Proposition	Pathway	Framework link	Investigated in/ Scope for Future Research
P1	Increased adoption of AM in CPD leads to value-retention strategies	AM adoption in CPD → repair, refurbishment, remanufacturing	AM-driven evidence → R's Strategies	Paper 2 (Chapter 3)
P2	Value-retention strategies driven by CPD enhance CSCM practices, which improve the TBL	CPD → value retention → CSCM → TBL	Value capture → Sustainability outcomes	Paper 3 (Chapter 4)
P3	Suitable material selection enables CPD for facilitating circular practices	Material selection (virgin or recycled) → CPD → new product performance	Organisational capability →	Paper 2 (Chapter 3)
P4	AM supports CPD through the implementation of closed-loop supply chains (CLSC)	AM → CLSC (recovery, recycling, reuse loops) → CPD	Mechanism → Value delivery	Future research
P5	AM supports CPD through the proper application of the LCA process	AM → LCA / LCC → design decisions → CPD	Mechanism → Value capture	Future research
P6	AM supports CPD through design for modularity, assembly and disassembly, and recyclability	AM → design strategies → CPD	Dynamic design capability → Circular Product Design	Paper 2 (Chapter 3)
P7	AM supports CPD through reverse engineering	AM → reverse engineering + supply chain collaboration → CPD	Mechanism → Value delivery	Future research
P8	Top management commitment enables firms to overcome legal, technical, operational, organisational and socio-cultural challenges of circular practices	TMC → challenge mitigation → circular practices	Internal antecedent → Boundary conditions	Paper 3 (Chapter 4)

2.7 Conclusion, Limitations, and Future Research

Adopting additive manufacturing (AM) for circular product design (CPD) is a nascent area of scholarly inquiry. This paper presents a review of articles published in Scopus, Web of Science, and EBSCO that are related to AM, CE, and CPD over the past twelve years. The purpose of this SLR is to identify the role of AM in CPD minimise contradictions and achieve sustainability and operational dimensions within the existing literature. The study

reviewed 149 papers and used content analysis. The result shows that AM supports mass customisation, complex geometry, value retention, product differentiation, and customer engagement for product design. Moreover, AM supports value retention strategies (different R's), industrial symbiosis, and product lifetime extension for CE. Finally, AM supports CPD by properly initiating and implementing a closed-loop supply chain, sustainable manufacturing, life-cycle assessment, modular design, and reverse engineering. This study also offers two significant contributions. Firstly, it presents a strategic management framework (Figure 2.12) that provides a roadmap for understanding the role of AM in CPD, facilitating insights into its effective utilisation to support circular design principles. It establishes a solid foundation for future research in this field by examining the role of AM adoption in CPD and the subsequent challenges it poses. Secondly, the study supports managers in achieving operational efficiencies, sustainability, and strategic planning by adopting AM as a design and manufacturing technology for CPD. It emphasises the importance of considering various product design components and aspects of the CE framework for the design mechanism of CPD. It serves as a guide to circular product development focusing on durability, ease of use, and sustainability, and covering CE value retention strategies and upstream innovation within the supply chain.

There are certain limitations to this study, which should be acknowledged as part of any research endeavour. First, although the review is rigorous, no SLR can ensure the full representativeness of its literature sample. Second, the search term employed inflationary keyword like "sustainable*," which reduces the precision because many papers use sustainability merely as a side issue rather than a primary topic. Third, the data collection involved only journal articles from the Scopus, Web of Science, and EBSCO databases, excluding conference papers, books and grey literature. Fourth, the filtering of subject matter to exclude engineering and materials science literature, in which much of the AM literature is

published, was done deliberately. Fifth, the language of the articles searched is limited to English, excluding other languages. Sixth, the suggested strategic management framework (see Figure 2.12) was derived deductively from the content analysis conducted, and it is a post-hoc derivation rather than an a priori framework tested independently. Seventh, operationalising product design for the CE using AM remains a theoretical idea at this point, and empirical research is needed.

Therefore, future research is needed to address all the limitations. Future studies could benefit from expanding the coverage to other databases, subsequent literature, and other languages, including the engineering and materials science literature that was intentionally excluded from the current analysis. Moreover, the developed propositions should be tested empirically through large-scale surveys or case studies to transform a synthetic approach into a developed theory. The relationship between AM and CPD through the application of reverse engineering, sustainable manufacturing, life cycle assessment, and closed-loop supply chains across different manufacturing environments should also be examined, given the variability of this relationship by industry, materials, and production scale. Finally, implementation barriers should be studied to understand how organisations can derive greater benefits from the use of AM in CE and CPD.

The subsequent chapter empirically examined the proposed relationships, investigating how design capabilities, such as design for assembly, modularity, and recyclability, together with the adoption of digital technologies, particularly additive manufacturing, support the design of circular products and enhance overall new product performance.

Chapter 3: Dynamic Capabilities for Circular Product Design: The Mediating Role of Additive Manufacturing

3.1 Abstract

The transition from a linear to a circular economy depends on state-of-the-art product design that emphasises recycling, reusing, and remanufacturing, as well as reducing waste, costs, and energy use, and extending the overall life of a product. To facilitate this transformation, dynamic capabilities theory offers a framework for aligning organisational and capabilities for product design, specifically sensing, seizing, and transforming to unfold environmental challenges. This study investigates how manufacturing firms leverage organisational, and design capabilities connected with additive manufacturing to support circular product design (CPD) and enhance new product performance (NPP). A mixed-methods approach was employed, integrating surveys and qualitative interviews from manufacturing firms engaged in circular practices. The findings reveal that firms' dynamic capabilities, including design for assembly and disassembly, design for recyclability, organisational capabilities such as material selection, and manufacturing technology, e.g., additive manufacturing, are critical for implementing CPD and NPP. This study contributes to the dynamic capabilities literature by focusing on internal design and technology alignment and provides practical and policy implications for managers and policy makers to operationalise CPD.

Keywords: Circular Product Design, Material Selection, Design for Assembly and Disassembly, Design for Recyclability, Additive Manufacturing.

3.2 Introduction

The concept of circular economy (CE) has gained substantial momentum since 2014, replacing the traditional linear model (Domenech & Bahn-Walkowiak, 2019; Ellen MacArthur Foundation, 2013). CE is increasingly recognised across academic, economic, and

policy domains for its potential to address pressing environmental challenges such as climate change, biodiversity loss, and resource scarcity (Dagilienė et al., 2024; Hofmann & Jaeger-Erben, 2020). CE support organisations in optimising resource use, improving sustainability practices, and maintaining a circular resource flow enabled by technological innovation (Lu et al., 2024). Transitioning to CE thus necessitates the adoption of circular business models within organisations (Chen et al., 2020; Jugend et al., 2024; Stahel, 2019). These models emphasise extending, narrowing, and closing resource loops to enhance resource recovery and deliver greater value to consumers (Bocken & Ritala, 2022; Bocken et al., 2016). Consequently, circular product design (CPD) has emerged as a key enabler of the CE, aiming to implement CE principles at both the operational and supply chain levels (Burke et al., 2023).

CPD emphasises resource circularity through design choices that support material reuse, repair, recycling, disassembly, remanufacturing, and extending product life cycle (Bocken et al., 2016). Prior empirical studies revealed that CPD is imperative to eco-design strategies, such as multiple-use cycles and durability in design for the tactical dimension (Aguiar et al., 2022; Jugend et al., 2024), as well as product and waste management, modularity, and standardisation in design (Burke et al., 2023; Wang et al., 2022). These functions collectively induce manufacturers to adopt CPD, yielding both economic and environmental benefits (Kang et al., 2023).

Successful CPD implementation requires two tactical design strategies: (1) design for product integrity, minimising product and component obsolescence and increasing their lifecycle, and (2) design for recycling, focusing on minimising material obsolescence through efficient recycling mechanisms (Den Hollander et al., 2017). These strategies compel firms to innovate both upstream and downstream supply chains, particularly during early-stage product design (Ellen MacArthur Foundation, 2020). For example, these strategies include

developing new material sources (virgin or recycled), new product designs, or new business models.

Moreover, digital technologies (DTs) are propelling operations and decision-making by product traceability and lifecycle visibility, which are essential elements for product design in CE (Giovanardi et al., 2023). Consequently, DTs are instrumental in enabling the transition to CPD by ensuring material flows and use as well as reducing waste to support design for reuse, remanufacturing, and recyclability (Rosa et al., 2020; Seegrün et al., 2024). Empirical studies further highlighted DT's role in enabling material traceability, design optimisation, and closed-loop systems (Bocken et al., 2016; Kirchherr et al., 2017). Among all DTs, additive manufacturing (AM) is a design and manufacturing technology that offers unparalleled design flexibility and ultimately reduces waste and energy consumption, aligning with CE principles (Sauerwein et al., 2017). AM also supports CPD through design enhancements for remanufacturing, repair, and mass customisation (Kühl et al., 2023). Considering these, AM promotes circularity through resource efficiency, thereby supporting new product performance (NPP) by reducing costs, time, and improving quality and satisfaction (Despeisse et al., 2017; Ford & Despeisse, 2016).

Despite the growing emphasis on CE and AM, manufacturing companies face significant challenges integrating CE principles into product design, hindering their ability to achieve superior NPP (Lieder & Rashid, 2016; Pieroni et al., 2019). Empirical evidence indicates that product design is a capability that drives differentiation and competitive advantage by fostering innovation and growth (Sahakian & BenMahmoud Jouini, 2023). As things go, a growing number of manufacturing firms have integrated dynamic capabilities (DCs) to sense design opportunities, seize design strategies, and transform resources into circular design to improve NPP (Saari et al., 2024; Teece, 2007). Moreover, the extant literature identifies several design capabilities and material circularity for CPD. For example, design for

assembly and disassembly (DfAD), design for modularity (DfM), and design for recyclability (DfR), along with material selection based on circularity, are the key design and organisational capabilities for CPD (Mesa, 2023; Tian et al., 2023). AM is critical for circular product design because its digital, layer-wise production enables design for disassembly, manufacturing, and recycling by reducing material complexity, supporting modular architectures, and embedding end-of-life considerations at the design stage rather than treating them ex post (Ford & Despeisse, 2016; Gebler et al., 2014). On this basis, AM can be conceptualised as an integrating technology that links these dynamic design capabilities and CPD outcomes, translating firms' ability to reconfigure design and manufacturing routines into tangible circular design performance rather than leaving dynamic capabilities as abstract constructs (Despeisse et al., 2017; Teece, 2007). However, empirical evidence explaining how material selection capability and AM jointly strengthen these design capabilities to enhance CPD and, in turn, new product performance remains limited. Moreover, neither AM nor dynamic capabilities can deliver superior new product performance when firms pursue linear design strategies (Lu et al., 2024). Taken together, these limitations indicate that the mediating role of AM in linking dynamic capabilities to CPD and ultimately to new product performance has yet to be empirically examined, pointing to three persistent research gaps.

Limited Integration of DCs and CPD: While design for assembly and disassembly (DfAD), design for modularity (DfM), and design for recyclability (DfR) have been extensively investigated within the domains of product innovation and strategic management (Teece, 2018), their application within the CPD domain remains in its early stages (Rosa et al., 2019). Empirical research has not systematically investigated how the DfAD, DfM, and DfR capabilities collectively facilitate CPD (Kristoffersen et al., 2021).

Ambiguity in the role of AM: AM is increasingly seen as a core technology for the CE because its design flexibility improves material efficiency, enables component consolidation,

and supports longer product lifecycles (Ford & Despeisse, 2016; Gebler et al., 2014). These features mean that AM not only contributes directly to circular product design but also shapes how circular design capabilities, such as design for disassembly, manufacturing, and recycling, are enacted in practice. Although these capabilities are recognised drivers of CPD, their impact remains limited under linear manufacturing systems that restrict geometric freedom and modularity (Bocken et al., 2016). AM therefore functions as a mediating mechanism that translates dynamic design capabilities into realised circular design outcomes by embedding circular requirements into product architectures. Examining this mediating role is deemed valuable because it clarifies how design capabilities generate CPD outcomes, addressing a gap in the CE literature that has largely treated AM as a background enabler rather than an active mechanism.

L*ack of empirical studies on performance outcomes:* Although CPD and AM are associated with sustainability, their combined impact on NPP remains poorly documented (Bressanelli et al., 2019). This study addresses this gap by examining how AM mediates the relationship between DCs and NPP within a CPD context.

Based on the above gaps, this study addresses the following research questions: (i) How do organisational and design capabilities facilitate AM and CPD, and (ii) to what extent does CPD affect these relationships to enhance NPP? By drawing on organisations and design capabilities, this study explores the associations between DCs, i.e., design for assembly and disassembly, design for modularity, and design for recyclability, and AM, the prerequisite material selection that supports CPD, and their ultimate effects on NPP. DCs are unique among manufacturing organisations and contribute to improving their overall performance (Teece, 2014). This linkage is highly applicable to the context of CPD, as it shifts the focus from existing to transforming capabilities, best utilises resources in response to threats and opportunities, and thereby builds and captures NPP (Bag, Gupta, et al., 2021).

This study considers internal organisational capabilities, such as material selection and design, as well as AM design and manufacturing technology, which significantly impact CPD. The findings confirm that each of these capabilities positively influences CPD, highlighting their importance in enabling better product performance. AM plays a mediating role in this relationship by enhancing the implementation of these capabilities, and it is also directly associated with improved CPD outcomes. The findings of this study also suggest that the successful implementation of CPD, driven by material selection capability and other design capabilities such as design for assembly and disassembly, and design for recyclability, and mediated through AM, increases NPP. This result demonstrates that firms must combine these DCs to realise NPP across cost, time, quality, and customer satisfaction, thereby leading to sustainable development and increased competitive advantage.

This study makes a significant contribution to the literature on CPD and NPP in three ways. First, while previous research has primarily focused on the challenges and barriers to CPD implementation (Burke et al., 2023; Jugend et al., 2024; Schöggl et al., 2024), this empirical investigation advances the theoretical understanding by illustrating how firms can effectively operationalise some forms of DCs to achieve CE through product design. Second, this study elucidates the mediating role of AM in enhancing these capabilities, offering novel insights into how AM technologies strategically enable NPP through CPD, thereby fostering competitive advantage. Third, by exploring the mechanisms by which DCs affect CPD, they address a fledgling field in CE on improving product performance and sustainability and provide guidance on how firms could utilise and integrate DCs to effectively meet rapidly changing market requirements. This alignment is critical to accelerating the CE process through product design, which, in turn, increases a company's performance by reducing resource use (cost and time) and improving operational efficiency (quality and customer satisfaction).

The remainder of the chapter is structured as follows: Section 3.3 discusses the theoretical foundation of dynamic capabilities. It covers material selection, design for assembly and disassembly, design for modularity, and design for recycling, followed by a conceptual framework and hypotheses development in Section 3.4. Section 3.5 presents the research methods in detail. Section 3.6 reports the analysis and findings, and Section 3.7 discusses them. Section 3.8 provides a conclusion that outlines the theoretical, practical, and policy implications, identifies the limitations of this study, and presents several avenues for future research.

3.3 Theoretical Background

To transition to the circular economy (CE), firms must cultivate dynamic capabilities (DC) to facilitate product design. First, this section provides a detailed review of material selection as an organisational capability, emphasising the importance of preserving functional performance while reducing environmental impact (Hapuwatte & Jawahir, 2021). Subsequently, an analysis of the design for modularity, design for recyclability, and design for assembly and disassembly (DfAD) is performed as DCs to promote product longevity, component reuse, and efficient end-of-life recovery (Bocken et al., 2016). This study further explores the strategic role of CPD by examining the design for recyclability (Aguiar et al., 2022). A critical review of AM demonstrates its contributions to design flexibility, waste reduction, and localised production (Top et al., 2023). This study demonstrates how CPD, supported by AM and DCs, enhances NPP by developing hypotheses while ensuring competitiveness and sustainability (Sabale et al., 2025). Finally, dynamic capabilities theory (DCT) provides the theoretical foundation for examining the integration and interrelationships among MS, AM, CPD, and NPP.

3.3.1 Material Selection

Materials used across all production units do not always support a CE due to various technical and operational issues. Material selection (MS) is a critical requirement for implementing circularity and sustainability and significantly influences the product design process in CE (Steiner et al., 2024). MS in the CE reflects a firm's ability to ensure product longevity and recirculation by choosing virgin or used materials that support reuse, remanufacturing, refurbishment, or recycling, thereby enhancing processability and durability (Mesa, 2023). Moreover, manufacturers might consider material to reduce the use of hazardous (Ellen MacArthur Foundation, 2013) and virgin materials (Valentine, 2024) while ensuring the reuse of materials to extend the life of a product, which ultimately results in reduced use of new materials over time (Ipsen et al., 2024). Consequently, organisations should be able to use materials that are easy to recycle at their highest utility and value without losing their properties (Bai et al., 2024; Reike et al., 2023). Cost of materials is another important aspects of MS, as the capability of reducing the cost of materials allows continuous improvements in production without compromising quality and operational flexibility, the ability to prioritise locally or regionally sourced materials supports CE principles, as it allows for reducing transportation-related emissions, mitigating resource depletion, and strengthening regional closed-loop systems (Geissdoerfer et al., 2017). Such localised sourcing strategies enhance opportunities for cost efficiency, material reuse, recycling, and regenerative design by improving transparency among manufacturers and facilitating customer demands (Wu et al., 2014).

3.3.2 Design for Assembly and Disassembly

Design for Assembly and Disassembly (DfAD) is an essential driver of CE that emphasises the enhancement of reusability and recyclability by guiding the design of products and their components to be more easily reused or recycled at the end of life (EOL). DfAD enables the

products that can be efficiently assembled during production and effectively disassembled at the EOL (Ong et al., 2021; Steeneck & Sarin, 2013). DfAD also enhances operational efficiency by minimising material consumption, thereby reducing production costs and shortening lead times (Battaïa et al., 2018). Unlike design for manufacturing, DfAD enables recycling optimisation and material efficiency (Shahhoseini et al., 2023).

Based on the purpose of the study, the design for assembly and design for disassembly are considered as a single concept rather than separate concepts, despite having some dissimilarities. Design for assembly (DfA) is a well-established design option with tangible benefits, such as simplifying the design, lowering production and assembly costs, reducing overheads, improving quality, and decreasing time-to-market (Boothroyd & Alting, 1992). Intrinsically, DfA constitutes a strategic organisational capability aimed at simplifying design, improving quality outcomes, and increasing production efficiency (Kuo et al., 2001). In contrast with DfA, design for disassembly (DfD) is separated from other capabilities that are connected with components and/or subassemblies through non-destructive in-product (or, at most, semi-destructive) operations to facilitate their repair, upgrade, and reuse (Chouinard et al., 2009). Despite these differences, both DfA and DfD are considered, regardless of product and process differences, to ensure products are easy to assemble and disassemble (Boothroyd & Alting, 1992). In essence, DfAD is considered an organisational dynamic capability that supports the restoration of parts from EOL or rejected products to reduce pollution, satisfying repair, maintenance, and recycling considerations for a product (Battaïa et al., 2018).

3.3.3 Design for Modularity

Product modularity has emerged as a fundamental design element for the CE, which facilitates product longevity, repairability, and material recovery. Design for modularity (DfM) refers to an organisational dynamic capability to develop standardised,

interchangeable components that can be efficiently reconfigured or reused across product lines, enhancing adaptability and reusability in product development (Tu et al., 2004). Moreover, DfM can affect product development, lead times, demand-driven innovation, and process innovation (Reitsma et al., 2023). DfM demands that organisations cultivate a product design structure that makes products easy to maintain and reduces waste (Krikke et al., 2004). Furthermore, DfM effectively identifies standardised parts for creating various products by decomposing complex products into distinct parts and components. Unlike traditional linear design, which often leads to premature obsolescence, DfM allows components to be independently replaced, upgraded, or repurposed, thereby extending product lifecycles. Ultimately, DfM extends the traditional design problem of product recycling to consider the product's environmental impact (Tian et al., 2024). These capabilities help manufacturers to design products that are easier to make and easier to take apart, repair, or reuse, thereby reducing the negative environmental impacts, which are essential for a CE.

3.3.4 Design for Recycling

There is growing awareness about recycling that needs to be embedded in the fundamental reasoning during product design in CE. CE requires a reduction in both the input of virgin materials and the output of waste by closing economic and ecological loops of resource flows (Haas et al., 2015). Design for recycling (DfR) is an organisational dynamic capability that helps to develop a recycling-friendly product. These capabilities reflect the objectives of designers, consumers, recyclers, and suppliers by enabling effective information exchange and handshaking for cooperation (Kriwet et al., 1995). At the product design stage, designers should incorporate strategies to increase recycling rates. Previous studies found that simple low-energy, low-cost, eco-feedback, i.e., individual or group recycling behaviour practices, resulted in statistically significant recycling rates (Mozo-Reyes et al., 2016). DfR not only

supports manufacturers in minimising their dependency on first- and virgin resources but also lessens environmental impact (Bocken et al., 2016). Furthermore, DfR helps manufacturers improve the recoverability of closed-loop systems by focusing on recovery design at the end of a product's life (Ijomah & Childe, 2007).

3.3.5 Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing, is considered a design and manufacturing technology within manufacturing settings for its potential to produce either customised parts or produce at a variety of volumes (Baumers & Holweg, 2019). Organisations need to capitalise AM as technology that joins materials, usually layer by layer, to create objects from 3D model data. The benefits of this technology span many areas, including new design freedom, elimination of tooling requirements, and low-cost production (Mellor et al., 2014). Moreover, AM offers advantages across several strategic areas, including on-demand production, customisation, reduced waste, the ability to handle complex geometries, and increased strength-to-weight ratios (Tziantopoulos et al., 2019). AM also contributes to reducing material sourcing by rationalising inventory through reduced safety stock and excess capacity (Singh et al., 2024). Manufacturers generally use various types of printers, each with distinct characteristics and printing methods, such as selective laser sintering, selective laser melting, electron beam melting, laminated object manufacturing, and binder jetting (de Mattos Nascimento et al., 2022). In practice, companies employ a diverse array of printers, often without explicitly referring to them as AM. However, it is not always certain that the AM provides a positive result. Empirical studies have found no evidence of a positive effect of increased volume on unit cost while AM is at full utilisation (Baumers & Holweg, 2019).

Moreover, AM is well-suited to the CE framework for remanufacturing and reverse logistics in high-value industries such as defence and aerospace, due to its adaptable processing

capabilities and distributable manufacturing model (Ding et al., 2025). AM enhances circular practices by reducing dependence on external suppliers, thereby reducing the need for parts, materials, or components during production (Ligon et al., 2017). Additionally, AM supports sustainability and is consistent with CE principles, as it minimises waste and energy consumption while facilitating repair and refurbishment, thereby enhancing resource efficiency (Hettiarachchi, Brandenburg, et al., 2022). In the manufacturing practices, AM enhances closed-loop systems by enabling localised, on-demand production, thereby reducing inventory waste and transportation emissions (Kunovjanek et al., 2022). Its compatibility with recycled and organic materials fosters circularity of resources (Ferreira et al., 2023). An integration of AM with digital tools such as CAD and AI-driven design will allow firms to operationalise CE strategies, such as product life extension, remanufacturing, and modularity, as core competitive capabilities (Ford & Despeisse, 2016). To put it concisely, AM supports circular design strategies by creating capabilities to extend a product's lifespan, for example, by enabling reprocessing or upgrades, even if these products were not originally designed for ease of repair or upgrading (Sauerwein et al., 2019).

AM is used in this study as a design technology as well as a manufacturing technology. AM is a manufacturing technology because it is an additive process that builds parts layer by layer based on digital models (ASTM, 2012). AM is also designing technology due to its geometric freedoms, which affect the designs of products and enable the creation of complex structures that are not achievable through other production methods (Aboutaleb et al., 2017). Among AM technologies, DfAD, DfM, and DfR are considered the study's design components, each with a specific purpose. The goal of DfA is to minimise part numbers and facilitate part fitting (Boothroyd & Alting, 1992). DfD helps ensure products can be disassembled for repair, reuse, or recovery (Bocken et al., 2016). DfM entails designing a product in separate

modules joined by interfaces (Krikke et al., 2004). DfR involves selecting proper materials and making products separable at the end of their lifecycle (Ford & Despeisse, 2016).

3.3.6 Circular Product Design

Many companies, such as Ikea, Unilever, H&M, Adidas, and HP, adopted CE strategies for their product design to foster sustainability (Ellen MacArthur Foundation, 2020; Sharma et al., 2025). Historically, industrial product design has been based on increased resource consumption and waste, leading to environmental degradation (Sirkin & ten Houten, 1994). Circular product design (CPD) is an organisation's strategy to create durable, reusable, repairable, and recyclable products that generate zero waste, supporting a CE (IDF, 2023). Recently, experts and strategists have focused on designing products that positively impact climate change, reduce environmental degradation, and address resource scarcity to enhance CPD strategies.

To integrate CE principles into practice, manufacturers and practitioners must integrate these strategies into the product design process from the initial stages of product development (Burke et al., 2023). Operationally, there are distinctions between CPD and eco-design. CPD aims to preserve the economic and environmental value of materials for as long as possible through its design strategies (Den Hollander et al., 2017), whereas “eco-design refers to the systematic integration of environmental aspects into product design and development to reduce adverse environmental impacts throughout a product’s life cycle” (European Commission, 2015). Product design in the CE must undergo several stages. CPD is predicated on four multiple-loop strategies: (I) design to slow the loops, (II) design to close the loops, (III) design for bio-inspired loops, and (IV) design for bio-based loops, in addition to eco-design (Mestre & Cooper, 2017). Furthermore, CPD adapts to various circular strategies (i.e., recover, recycle, repurpose, remanufacture, refurbish, repair, re-use, reduce, rethink, refuse) to ensure better performance (Valentine, 2024), necessitating new

regulations, policies, and design methods for product design and development within manufacturing companies (Dekkers et al., 2013). Empirical studies have linked CPD strategies to eco-effective production systems across the product life cycle and to the design of sustainable capabilities (Dahmani et al., 2021; Nag et al., 2022). In recent years, diverse innovation capabilities, such as reinventing, rethinking, reconfiguring, recirculating, restoring, reducing, and avoiding (material and product), have been associated with CPD strategies (Blomsma & Brennan, 2017). Therefore, CPD is conceptualised as a critical design strategy for firms seeking advancements in product design, aiming to achieve material cost efficiency and extend the product life cycle (Jugend et al., 2024).

3.3.7 New Product Performance

Ensuring satisfactory performance is key to the success and sustainability of businesses. In a competitive, technology-driven market environment, product performance is typically measured by sales volume and market share, which provide immediate financial returns and market acceptance (De Vries et al., 2017; Edeling & Himme, 2018). For CE, profitability is a crucial indicator when combined with other indicators such as product and market performance (Linder et al., 2017). Beyond profitability, new product performance (NPP) in CE is also assessed by promoting products characterised by high durability and resource efficiency, which enables the use of long-lasting materials (Franklin-Johnson et al., 2016). CE objectives are realised by transforming organisational and design capabilities, thereby enhancing product performance through the integration of environmentally friendly and resilient design elements (Mishra et al., 2024). However, the NPP metrics for CE depend on the efficient use of resources, market share, or market growth, along with emphasis and assurance of customer satisfaction through offering sustainable products (Govindan & Hasanagic, 2018a; Tukker, 2015), which establishes a key indicator in creating consumer loyalty and sustainable market expansion.

3.3.8 Dynamic Capabilities Theory (DCT)

Dynamic capabilities theory (DCT) guides the theoretical framework to address the research questions. DCs refer to an organisation's ability to develop, expand, or transform its resource base, encompassing routines, processes, and tangible, intangible, and human assets, along with associated capabilities (Cepeda & Vera, 2007). These capabilities are characterised by their repeatability (Davies & Brady, 2000)(Davies & Brady, 2000). CPD demands distinct dynamic design capabilities that have not been previously analysed within organisations. These capabilities contribute to entrepreneurial initiatives for NPD and process development (Teece et al., 1997). Conventionally, capabilities are treated as distinct perceptible systems, skills, and management systems (Leonard-Barton, 1992). In this sense, DC's framework is useful for strategic decision-making for CPD and long-term business performance (Teece, 2007).

Moreover, the DCT framework is grounded in firm-specific resources, capabilities, and strategic processes, highlighting how business entities generate and capture value in rapidly evolving technological environments (Teece, 2018). Explicitly, DCT is supported by micro-foundations, which integrate skills, routines, methods, structures, and decision-making procedures that influence the processes of reconfiguring organisational capabilities related to organisational sensing, seizing, and transforming, which are inherently challenging to develop and replicate (Teece, 2007). In addition, empirical evidence indicates that in highly volatile, and competitive business environments, companies must continuously develop and strategically reconfigure their capabilities to maintain adaptability and competitiveness while ensuring sustainable value for the firm (Teece, 2018). Within this context, firms can design products to ensure NPP, which is widely acknowledged as a manifestation of dynamic capabilities (Winter, 2003). Thus, DCT posits that a firm's sustained success in developing

circular products and enhancing new product performance is contingent on its ability to leverage unique, inimitable resources and capabilities.

The following section develops the hypotheses based on the literature and proposes a conceptual framework at the end of the section.

3.4 Hypothesis Development and Theoretical Framework

3.4.1 Material Selection (MS) and Circular Product Design (CPD)

Material section (MS) supports CPD by minimising waste and environmental pollution during manufacturing, aligning with the global priority of environmental sustainability and the strategy of value creation (Mesa, 2023). Manufacturers are showing their responsibility to uphold the principles of CE and sustainability by developing their capabilities and functional attributes through MS (Diaz et al., 2021). For example, Microsoft developed its capability to eliminate single-use plastics from its product packaging. Products like the Surface Pro X were the first Microsoft products to use 100% recyclable packaging, significantly reducing plastic waste (Microsoft News, 2020). Additionally, the company has committed to using ocean-bound plastics in its hardware products, such as the Microsoft Ocean Plastic Mouse, which contains 20% recycled ocean plastic (Microsoft, 2021). These practices of MS enhanced CPD's core values of recyclability, reusability, and durability (Wang et al., 2022). Drawing on market dynamics and consumer demand, organisations' capabilities are being enhanced by reducing the use of harmful materials and opting for easily recycled or reused materials (Corona et al., 2019). These capabilities promote resource loops and reduce material flow, which are essential strategies for CPD (Victar et al., 2024). Given the previous remarks, it is evident that MS capability is technically related to CPD, as the entire product lifecycle and its potential for circularity are influenced. Such a capability of material choice is key to the development of actual circular products, which also enables the transition toward CE. Hence, the study proposes the following hypothesis:

H1: Material selection capability is positively associated with circular product design.

3.4.2 Design for Assembly and Disassembly (DfAD) and Additive Manufacturing (AM)

Design for assembly and disassembly (DfAD) is an organisational design capability that aims to simplify both joining and separating materials or components across a product's lifecycle by emphasising standard parts, accessible joints, and material compatibility (Battaïa et al., 2018). It connects the product's end-of-life lifecycle to the early stages of the design process, ensuring that assembly, maintenance, and waste recovery are possible by default. On the other hand, AM supports layer-by-layer fabrication, offering enormous design freedom and part consolidation capabilities to integrate complex geometries and functions that traditional processes cannot easily achieve (Schmitt et al., 2021). However, this type of integration cannot generate a repair and recycling facility if disassembly is not considered in the design. In contrast, several aspects of DfAD, such as part consolidation, reversibility, and material transparency, are directly linked to AM, which is known for its precise design and localised production. Additionally, AM is confirming the design features of DfAD to address aspects of buildings with adaptive reuse potential, such as interlocking modules. This cohesive integration mix-up adds to reconfigurable smart products and supports flexibility and adaptability across different product types (Monetti et al., 2025). Drawing upon DCT, organisations need to utilise their capability to sense which design components DfAD should adopt in response to rapid environmental change and customer demands, then capitalise on AM capability to grasp technological benefits, and mobilise processes and systems accordingly Thus, DfAD capability intensifies the use of AM by adding a unique design-level feature for joining and separation. Subsequently, DfAD and AM strengthen each other through the firm's DCs to reallocate resources and enhance design capacity considering current technological and environmental contexts. Hence, the study can hypothesise that:

H2: Design for assembly and disassembly capability is positively associated with additive manufacturing.

3.4.3 Design for Modularity (DfM) and Additive Manufacturing (AM)

Design for modularity (DfM) is conceptualised as the organisational design capability to produce separate and interchangeable modules, thereby reducing the lead time for product development (Osman et al., 2025). It enhances the organisation's ability to manage and improve the efficiency of both components and to decouple design and functionality (Sanchez et al., 2020). DfM reduces manufacturing complexity at the design stage to check whether the design fits with the specification (Krikke et al., 2004). In contrast, AM uses layer-by-layer manufacturing to build a part, consolidate it, and save on fabrication (Petrovic et al., 2012). While AM is often associated with part consolidation, its real potential lies in allowing modular ability, potentially using the same or different materials with the same machine iteratively, for allowing for customisation and personalisation (Yang et al., 2015). DfM thus complements AM by carrying the detailed design, providing the architectural logic through which AM's design flexibility can be implemented in a logical and organised fashion (Gao et al., 2020). Firms that integrate DfM principles with AM can design modules with a standardisation principle, yet improvements in design efficiency and cost savings accelerate building rates through customised features (Montazeri et al., 2025). This interplay aligns closely with the dynamic capability framework, which is the capability of designing products based on modularity by using AM's aptitude and transformations, and is an intensification of product market competition (Teece et al., 1997). Developing DfM capabilities enhances a firm's capacity to leverage manufacturing and design technologies, such as AM, to expand the scope of reducing manufacturing changeover costs through modular redesign and additive fabrication (Lei et al., 1996). Hence, it is proposed that:

H3: Design for modularity capability is positively associated with additive manufacturing.

3.4.4 Design for Recyclability (DfR) and Additive Manufacturing (AM)

Design for recyclability (DfR) is an effective organisational capability that improves a product's recyclability at the end of life (de Aguiar et al., 2017). DfR aims to enhance product design alignment so that products can be easily disassembled, sorted, and reintegrated into material loops (Wu et al., 2025). However, DfR is achieved through careful choices of materials, selection of joining techniques, and component design (Kumar & Putnam, 2008). AM fits into one or more of these goals because it allows precise positioning of the material, provides good-sized objects under construction, and reduces material waste (Smith & Ball, 2012). Moreover, AM enables designers to define exact material mixes that generate less scrap and material waste, thereby reducing material waste through precise deposition (Ford & Despeisse, 2016). Specifically, AM makes it easier to extend a product's lifespan, for instance, by enabling repair or upgrades, even complex parts that support design for recyclability, allowing quick changes to the material (Sauerwein et al., 2019). Moreover, DfR supports real-time monitoring of fabrication processes, mono-material components, and the connection detail machining, which connect closely with AM's ability to deposit materials locally and control digital fabrication (Mogas-Soldevila et al., 2025). Drawing upon DCT, DfR represents a higher-order organisational capability that enables firms to capitalise on organisational resources to optimise AM support and achieve greater environmental and competitive results (Teece et al., 1997). Firms that integrate DfR with AM are thus better positioned to reconfigure their resources, dynamically adapting design, materials, and production systems to meet the demands of the circular economy. Thus, the study proposes that:

H4: Design for recyclability capability is positively associated with additive manufacturing.

3.4.5 Additive Manufacturing (AM) and Circular Product Design (CPD)

The literature suggests that digital technologies (DTs) enable CE practices via circular procurement, design, recycling, and remanufacturing by increasing efficiencies and enabling value creation (Khan et al., 2022). Due to its potential to support resource reconfiguration within the CE, AM is a critical design and manufacturing tool for CPD (Hettiarachchi, Brandenburg, et al., 2022). AM delivers several benefits, including reduced material waste, modular designs, product customisation, and on-demand production. Companies can iterate on sustainable product design and improve resource efficiency while aligning with sustainable requirements and market demand (Naghshineh, 2024). However, DCT emphasises the development of organisational competence, which necessitates cultivating diverse skills, adopting innovative and environmentally sustainable processes, and establishing routines to implement AM for CE (Santa-Maria et al., 2022).

AM technology integrates with the firm's design capability by enabling reconfiguration exploration through rapid design chaining, quick reaction, and effective resource utilisation (Tziantopoulos et al., 2019). For instance, AM technology affects both cost and capacity in product design by improving the manifestation of product lifecycle properties (Baumers & Holweg, 2019). Moreover, AM facilitates CPD across various industries by minimising waste and optimising resource use. For instance, in the aerospace sector, GE Aviation's 3D-printed fuel nozzles exemplify production efficiency by consolidating 20 manufactured parts into a single component, thereby reducing material waste by 75% (GE Aerospace, 2020). The consumer goods industry has also witnessed similar innovations, with Adidas employing AM to produce 4D midsoles featuring optimised lattice structures that reduce material use while maintaining performance (Adidas Report, 2021). These applications underscore AM's role in advancing CPD through increased material efficiency, enhanced innovative lightweight designs, extended product longevity, and closed-loop material systems (Ellen MacArthur

Foundation, 2020). The contribution of AM to CE is expected to increase significantly as AM capabilities evolve with bio-based materials and improved recycling capabilities (McKinsey & Company, 2023). Hence, this study proposes the following hypothesis:

H5: Additive manufacturing technology is positively associated with circular product design.

3.4.6 Circular Product Design (CPD) and New Product Performance (NPP)

Because CE significantly influences sustainable design strategies and business models, leading to enhanced new product performance (NPP), it emphasises product longevity, resource efficiency, and customer value (Geissdoerfer et al., 2017). Moreover, NPPs based on easy repairability or recyclability reduce environmental impact and extend product life (Bocken et al., 2016). CPD also allows firms to decrease material dependency, adapt to the demands of consumers, and adhere to sustainability regulations, leading to the achievement of product performance (Rincón-Moreno et al., 2021) For example, empirical evidence from industry leaders such as Patagonia shows CPD has enhanced product performance in a variety of business metrics, such as 30% of revenue through its Worn Wear program (Patagonia, 2022), and Apple's self-service repair program satisfied 72% of customer requests, as the company enables customer and independent retail workers to fix their devices with genuine parts (Apple Incorporation, 2022), and closed-loop material flows have been demonstrated by Adidas's 100% recyclable thermoplastic polyurethane (TPU) footwear (Adidas Report, 2021), Consequently, Tesla's 92% material recovery rate in battery systems (Tesla Report, 2023) substantiates the NPP based on closed-loop material flows. These examples collectively promise NPP based on economic and environmental value creation, which aligns with the principles of the CE (Ellen MacArthur Foundation, 2020). Based on this, the study proposes the following hypothesis:

H6: Circular product design positively supports new product performance**.**

3.4.7 Mediating Role of Circular Product Design

The following subsection presents the mediating role of CPD for both material selection and additive manufacturing for enhancing new product performance.

3.4.7.1 The Mediating Role of Circular Product Design (CPD) on Material Selection (MS) for New Product Performance (NPP)

Circular product design (CPD) serves as an important bridge between the sustainability of the materials chosen and the improved performance of new products by integrating life-cycle considerations, recyclability, and functionality into the design process. MS is estimated and integrated into product design to improve resource and product performance (Schoormann et al., 2025). MS depends on how organisations integrate a product design process that values the performance attributes of durability, modularity, and end-of-life recoverability, while enhancing product performance by using sustainable materials, such as recyclable or biological materials, that are environmentally suitable and ensure sustainability (Bocken et al., 2016). However, CPD moves the circularity principles of the material that creates customer value through reliability and ease of maintenance, or aesthetics to enhance customer satisfaction, leading to an expected increase in sales, profitability, brand loyalty, and market attractiveness (Galvão et al., 2020; Lieder & Rashid, 2016). Additionally, CE strategies enhance sustainability performance by improving financial and operational outcomes, particularly through increased material and energy efficiencies; CPD thus serves as a key pathway for revalorising and innovating design based on MS to secure better product performance (Kirchherr et al., 2017; Ranta et al., 2021). Hence, the study proposes that:

H1a: Circular product design mediates the relationship between material selection capability and new product performance.

3.4.7.2 The Mediating Role of Circular Product Design (CPD) on Additive Manufacturing (AM) for New Product Performance (NPP)

While AM supports CPD by enabling new product innovations that deliver superior value to firms, for example, AM enhances design flexibility, customisation, and material efficiency. This leads to tangible and marketable benefits in the form of lightweight, resource-efficient, and complex products with high added value (Nyamekye et al., 2024). However, these benefits alone do not guarantee improvements in profitability, market share, or customer loyalty unless they are integrated into design strategies that emphasise durability, repairability, and end-of-life recyclability (Bocken et al., 2016; Ford & Despeisse, 2016).

CPD provides mechanisms for creating user-friendly, standardised products that maximise customer experience, extend product life, and reduce resource use, attributes that are essential for building brand trust, retaining customers, and differentiating products (Geissdoerfer et al., 2023). AM adoption is further supported by manufacturing capabilities, which can shorten time-to-market and meet CE requirements, leading to growth and profitability (Sun, Wang, et al., 2020). CPD bridges the technological promise of AM and enhances product performance. Hence, this study hypothesises that:

H5a: Circular product design mediates the relationship between additive manufacturing and new product performance.

3.4.8 Mediating Role of Additive Manufacturing

3.4.8.1 The mediating role of Additive Manufacturing on Design for Assembly and Disassembly (DfAD) for Circular Product Design (CPD)

Additive manufacturing (AM) enhances design for assembly and disassembly (DfAD) by enabling integrated yet separable product designs that optimise joining mechanisms (e.g., snap-fit connections) and reduce component counts, thereby improving production efficiency and end-of-life recovery (Ford & Despeisse, 2016). The geometric freedom of AM facilitates disassembly-friendly structures, such as standardised components and embedded identifiers, which simplify component separation and recycling (Kumke et al., 2016; Watson &

Taminger, 2018). The compatibility nature of AM with recycled feedstocks and customised production supports CE objectives (Despeisse et al., 2017; Gebler et al., 2014). Empirical studies across the automotive, medical, and textile industries demonstrate that AM improves reuse rates by 35–60% through the use of standardised components and minimised material mixing (Butt et al., 2024; Ellen MacArthur Foundation, 2020). Manufacturing firms that use AM can overcome geometric constraints in eco-design, enabling the practical implementation of circular strategies such as remanufacturing and refurbishment (Hmamed et al., 2024). Thus, AM serves as a critical digital tool transforming DfAD principles into tangible CPD outcomes. Thus, this study hypothesises the following:

H2a: Additive manufacturing mediates the relationship between design for assembly and disassembly and circular product design.

3.4.8.2 The Mediating Role of Additive Manufacturing (AM) on Design for Modularity (DfM) for Circular Product Design (CPD)

Research suggests that integrating design for modularity (DfM) with CPD enables adaptable product architectures, such as standardised interfaces and functionally graded materials, to enhance repairability and recyclability (Ford & Despeisse, 2016). In contrast to DfAD, which prioritises efficiency in assembly and disassembly, DfM enables AM to focus on adaptable product architectures, such as the replaceable components of electronic devices (Bocken et al., 2016), that extend product lifespans through modular replacements, thereby reducing electronic waste (Ellen MacArthur Foundation, 2016). AM adds value to DfM in two ways. First, AM supports DfM by reconfiguring supply chains for localised, on-demand module production (Hettiarachchi, Brandenburg, et al., 2022), and second, it enables post-design modifications, such as the integration of smart components, even in originally non-modular designs (Pinheiro et al., 2019; Sauerwein et al., 2019). Based on DCT principles, organisations must possess and capitalise on integral capabilities to understand how AM-

driven modular architectures support product design for CE that are resistant to imitation and capable of product design upgrades (Davies et al., 2022). From the above discussion, the study hypothesises that:

H3a: Additive Manufacturing mediates the relationship between design for modularity and circular product design.

3.4.8.3 The Mediating Role of Additive Manufacturing (AM) on Design for Recycling (DfR) for Circular Product Design (CPD)

Design for Recycling (DfR) aims to recycle end-of-life materials (Bocken et al., 2016), and focuses on design tools that support the traceability of materials used, reduce waste generation, and improve design flexibility, while ensuring that products are more recyclable (Gebler et al., 2014). In contrast, AM supports DfR by enabling accurate material selection (Kumke et al., 2016), facilitating automated material identification through embedded markers or QR codes, and enabling complex geometries that are not possible with traditional manufacturing methods (Ford & Despeisse, 2016). Simultaneously, CPD encourages products to last longer, be reused, remanufactured, or recycled (Stahel, 2019). For instance, AM translates DfR into CPD results through material purity requirements that must be compatible with digital tracking for identification and with the potential for material recycling in closed-loop material systems (Ford & Despeisse, 2016; Kellens et al., 2017). Based on the above, the study hypothesises that:

H4a: Additive Manufacturing mediates the relationship between design for recyclability and circular product design.

Figure 3.1 presents the theoretical framework for this study, representing the relationships among the key constructs.

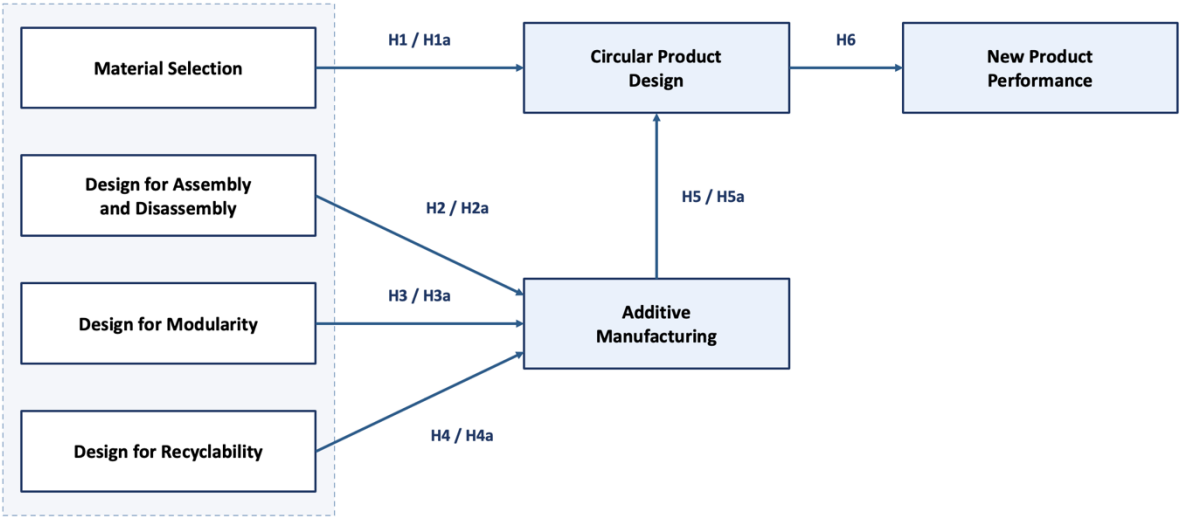


Figure 3.1: Theoretical Framework

3.5 Methods

A mixed-methods approach was used in the study, which comprised both interviews and a survey. Given the study's context, a mixed-methods approach was useful. The mixed-method approach was appropriate in two ways within the context of investigating how dynamic capabilities impact CPD and, in turn, the performance of new products. First, mixed methods offer a strong approach for researching context when the field is relatively new, such as the slow adoption of product design within CE, which is complex and only partly understood. Second, integration at the interpretation and reporting levels occurred through explanation, data transformation, and sequential joint display of qualitative and quantitative findings (Fetters et al., 2013).

In this study, a qualitative study was used for triangulation to better understand the findings of the quantitative study (Onwuegbuzie & Collins, 2007). The inclusion of executives' opinions was particularly important in CPD, which was made possible by qualitative interviews. Executives' opinions add insights into qualitative and quantitative data and approaches as one considers most, if not all, research questions (Johnson et al., 2007). The mixed-methods strategy adopted in this study was also aligned with past empirical studies that used mixed methods with underserved populations to comprehend sustainable product

design (Ma et al., 2024). Semi-structured interviews, as a qualitative method, helped validate the quantitative findings, guided the interpretation of the interview results (McIntosh & Morse, 2015), and offered insights into the most effective ways to plan and execute CPD, given the limited scholarly research on its operational aspects.

The following subsections discuss the two phases of the mixed methods research (survey and interviews) adopted in this study.

3.5.1 Phase 1: Quantitative Study

3.5.1.1 Research Design

The focus of the quantitative study was to investigate the relationships among the attributes of overall organisational capabilities, i.e., material selection and design capabilities for assembly and disassembly, design for modularity, design for recycling for circular product design, and the direct and mediating role of design and manufacturing technology, like additive manufacturing, for new product performance.

To establish a research design for this study, appropriate measures and models were considered. The study used a two-step process to select measures for the research model. First, the study reviews existing literature to identify measures proposed by previous studies. Second, the study further used cross-sector illustrative triangulation. Triangulation is perceived as a methodological approach that incorporates numerous methods or data sources to enhance a comprehensive understanding of phenomena (Patton, 1999). The intent of using triangulation was to decrease, negate, or counterbalance the deficiency of a single strategy, thereby increasing the ability to interpret the findings (Thurmond, 2001). Among the four types of data triangulation (Patton, 1999), the study used data source triangulation in this study. In this connection, the study first conducted a pilot study with academics, supply chain professionals, and executives working in the research and manufacturing fields. Triangulations offered two benefits in this study. Firstly, triangulations support belief and

perception, which are essential for accurately interpreting results (Harris, 2000). Secondly, the items of the questions were more concrete, based on the triangulation process, as they were clear in the responses and interviews.

During the pilot study, a copy of the questionnaire was sent to eight respondents, of whom five responded (two academics and three industry professionals), and they were encouraged to evaluate the items thoughtfully. The study then held subsequent discussions to clarify any ambiguities and obtain more detailed feedback regarding the wording, format, and applicability of the questions. During these discussions, some respondents indicated that a few items could be potentially confusing or ambiguous, which ultimately led to changes and improvements in the questionnaire to enhance clarity and accuracy. Furthermore, based on their practical experience, it was suggested that the study exclude certain types of manufacturing firms (such as the paint industry), where a recycling process is not traditionally appropriate. The feedback from the study participants noted above was carefully considered and integrated into the final design to improve focus, relevance, and methodological integrity. Based on the pilot study results, the survey instruments were revised to gather more detailed information on the variables.

To ensure data quality, the research first generated the English version of the questionnaire, along with a Bangla (the mother tongue of Bangladesh) translation, to ensure the items' understandability to the respondents. Bangla translation was appropriate within the context of the study. Forward and back-translation have been used to translate the English questionnaire into Bangla. The Bangla version was then independently back translated into English, and the backtranslation was checked against the original English version to identify inconsistencies in wording and meaning. Researcher then reviewed and resolved all detected inconsistencies to ensure meaning and concepts were equivalent across both languages. Thus, although steps

were taken to make the versions linguistically and conceptually equivalent, measurement equivalence cannot be guaranteed.

Finally, the study refined the questionnaire based on the feedback from the pretesting of 37 items representing 7 different constructs. Table 3.1 summarises the constructs and measurement scales retrieved from different literature.

Table 3.1: Literature Used in Scale Development

Construct	Source	Measurement Scale
Material selection	(Bai et al., 2024; Kriwet et al., 1995; Mesa, 2023)	Likert scale (1-5)
Design for assembly and disassembly	(De Fazio et al., 2021; El Jalbout & Keivanpour, 2024; Kriwet et al., 1995; O'Grady et al., 2021)	Likert scale (1-5)
Design for modularity	(Duray et al., 2000; Lin, 2003; Worren et al., 2002)	Likert scale (1-5)
Design for recycling	(El Jalbout & Keivanpour, 2024; Gallagher et al., 2019; Kriwet et al., 1995)	Likert scale (1-5)
Additive manufacturing	(El Jalbout & Keivanpour, 2024; Gupta et al., 2022)	Likert scale (1-5)
Circular product design	(Aguiar et al., 2022; Bocken et al., 2016; Den Hollander et al., 2017; Halstenberg et al., 2019; Selvefors et al., 2019; Sinclair et al., 2018)	Likert scale (1-5)
New product performance	(Ellinger et al., 2000; Song & Parry, 1999; Ward & Duray, 2000)	Likert scale (1-5)

3.5.1.2 Control Variables

This study included two types of factors as control variables. First, individual factors such as gender, age, academic background, and work experience (Riketta, 2005). Second, organisation characteristics, such as the age of the company, number of employees (as a measure of the company's size), and industry types that may be strategically important and vary in circular practices (Rodríguez-Espíndola et al., 2022). The number of employees measures firm size. To keep it simple, the study labels them (less than 50 = small size, 50-249 = medium size, and more than 250 = large size). Large and long-lived companies may have more resources to gain desirable performance in business and operations (Miller & Le Breton-Miller, 2005). The study further included experiences within the current company that might have impacted circular product design.

3.5.1.3 Sample Selection

A non-probability sampling was employed, supplemented by snowball sampling seemed appropriate for this research to ensure relevant responses from practitioners (Ritchie et al., 2003). Moreover, it is quite common to select industry types for data collection based on research objectives (Flynn et al., 1990). This study focused on the manufacturing sector in Bangladesh, where circular and sustainable practices were likely to have significant implications for circular product design, except in financial services such as banks and telecommunications. This is because manufacturing companies play a significant role in CE practices that impact sustainability and product performance outcomes (Schoormann et al., 2025). The target sample encompasses both male and female professionals covering different age groups, educational backgrounds ranging from hight to master's degrees working in different functional departments, and varying levels of work experience; they incorporated individuals with varying lengths of experience, covering periods of 1-6 years, between 7-12 years, between 13-18 and over 18 years of involvement in the professional domain.

3.5.1.4 Data Collection

An online survey was used in this study to collect information from Bangladeshi manufacturing companies that produce steel, plastics, clothing, textiles, glass, and other products. This is an appropriate and significant context for the current study for two main reasons. First, Bangladesh is an ideal context for CE research because its dominant manufacturing companies, especially ready-made garments and textiles, generate significant industrial waste and face mounting global pressure to adopt sustainable production models (Ahmed et al., 2022; Salman et al., 2025). Second, the country has begun implementing national policies and industry initiatives to promote circular practices, creating a supportive environment for studying how firms transition from linear to circular systems (Circular Economy Hotspot, 2023).

A single survey dataset was collected specifically to measure the seven constructs examined in this study. More than 750 people were selected at random to serve as samples from the industry database and from other professional bodies, such as the Institute of Cost and Management Accountants of Bangladesh (ICMAB), the Chittagong University Management Association (CUMA), and the Chittagong University MBA Association (CUMBA). All these professional platforms are suitable for data collection, as they are circular practices. Most respondents were available through their formal organisational or alumni channels, making it convenient to collect detailed contact information (name, email, phone number) and to ensure reliable responses from executives actively working in relevant manufacturing and capability development activities. Thus, Google Forms links to the designed questionnaires were distributed to the appropriate respondents. Data arrived in several batches in 2024, collected between May and October where overlap the period of major political disruption in Bangladesh. Questionnaires were then provided to them. All items were developed using a five-point Likert scale (1=strongly disagree, 5=strongly agree). The survey instrument is presented in Appendix 3.

An online survey instrument was distributed for the first time in the middle of May 2024 to prospective respondents from various manufacturing firms and professional associations. All respondents were asked to tick a consent form before continuing with the survey. The researcher received 120 filled-out questionnaires within 4 weeks of initiating this survey. The researcher then kindly reminded those on the online platform to complete the survey questionnaire 8 weeks later, in mid-July 2024. The researcher received another 73 completed questionnaires over the next 10 weeks. After 10 weeks, the last week of July 2024, the researcher again sent the online questionnaire links to the sample respondents who had not responded previously. Within 14 weeks, the researcher received 69 filled-out questionnaires. A gentle reminder was issued to the remaining prospective respondents at the end of

September 2024, 4 weeks later, to fill out the survey questionnaire. The researcher received another 59 within two weeks. A total of 321 responses were received after 18 weeks, and the researcher decided not to collect any further responses, as the data were adequate for the planned analysis. Six service-based organisations, which were not the focus of this study, were then removed from 321 responses, and responses from two small firms were deleted. Finally, 313 responses were used for the analysis from more than 12 different types of manufacturing industries. This shows a response rate of 41.7%, that is within the range reported in organisational settings, where response rates may differ across social science studies and respondent populations (Baruch & Holtom, 2008). For this, non-response and common method bias text have been done throroughly.

Demographic profile of the respondents is presented in Table 3.2 after deleting 6 responses from service organisations.

Table 3.2: Demographic Profile of the Respondents

Gender	**Frequency**	**Percentage**	**Types of Industry**	**Frequency**	**Percentage**
Male	267	85.3	Garments	83	26.5
Female	46	14.7	Textiles	73	23.3
Age			FMCG	28	8.9
18-25 Years	5	1.6	Steel	25	8.0
26-33 Years	144	46.0	Plastics	49	15.7
34-41 Years	113	36.1	Dyeing and Thread Manufacturing	3	1.0
42-49 Years	39	12.5	Food and Beverage	10	3.2
50 and more	12	3.8	Ship Building	4	1.3
Academic Qualification			Pharmaceuticals	4	1.3
Degree/Honours/Bachelor	129	41.2	Tyre and Leather Industry	3	1.0
Masters/MBA	181	57.8	Power Plant	3	1.0
Others	3	1.0	Paper and Packaging	10	3.2
Working Department			Glass	9	2.9
Marketing and Sales	14	4.5	Others	9	2.9
Production Engineering	64	20.4	**Total Job Experiences**		
Supply Chain	103	32.9	1-6 Years	143	45.7
General Management	70	22.4	7-12 Years	88	28.1
Commercial	18	5.8	13-18 years	60	19.2
Quality and Research Team	13	4.2	19 and more	22	7.0
Merchandising	9	2.9	**Experiences within the Current Company**		

Others	22	7.0	1-6 Years	194	62.0
Age of the Company			7-12 Years	86	27.5
1-6 Years	15	4.8	13-18 Years	17	5.4
7-12 Years	26	8.3	19 and more	16	5.1
13-18 years	83	26.5	**Size of the Company**		
19 and more	189	60.4	Medium Size (50 -249 employees)	31	9.9
			Large Size (More than 250 employees)	282	90.1

N= 313

3.5.1.5 Non-Response Bias and Common Method Bias

Non-response bias may arise when data are collected over different periods, as respondents who participate earlier may differ systematically from those who respond later. To assess the reliability of the collected data, the study first examined potential non-response bias by comparing early and late respondents. The researcher assessed differences between the two groups and found no statistically significant differences (Werner et al., 2007). This finding suggests that non-response bias is unlikely to have materially affected the study's results (See Appendix 12a).

Common method bias (CMB) is a type of measurement error that frequently arises and threatens the validity of behavioural research by inflating or deflating the relationships among variables (Bagozzi & Yi, 1991; Nunnally, 1978). CMB usually happens with social desirability when items may be written in such a way as to reflect more socially desirable attitudes, behaviours, or perceptions or context-induced mood when the first question (or set of questions) encountered on the questionnaire induces a mood for responding to the remainder of the questionnaire (Podsakoff et al., 2003).

As data is collected from different manufacturing units over a period and from diverse respondents, CMB could be possible. To mitigate this risk, multiple measures for each variable were considered (Podsakoff et al., 2003). First, during questionnaire design, all items for the constructs were separated onto a page, creating a temporal, proximal, or psychological

separation that should reduce biases in responses. Second, organisational and dynamic design capabilities (MS, DfAD, DfM, DfR), AM, and CPD were designed using measures with different commonalities in scale endpoints, as the same endpoints can create CMB (Podsakoff et al., 2003). All design capabilities were measured using a 5-point Likert scale with endpoints ranging from "1= Disagree" to "5= Strongly Agree", whereas circular product design was measured using a 5-point Likert scale with endpoints ranging from "1= Strongly Disagree" to "5= Strongly Agree". Third, a single-factor technique was conducted to identify whether any individual factor was responsible for most of the variance. The factor analysis confirmed that the variance accounted for by a single factor (34.58%) is well below the common threshold of 50%, indicating that CMB is not an issue in this study (Podsakoff et al., 2003). Moreover, confirmatory factor analysis (CFA) based on a marker-variable technique was used for CMB. Using correlational technique, the smallest marker correlation (r_M = .315) was partially out of all construct correlations; 19 of the 21 correlations remained significant ($p < .05$), which indicates no substantial bias that will affect further study (Lindell & Whitney, 2001). The following table 3.3 presents the CFA analysis based on marker-variable technique.

Table 3.3: Marker Technique for Common Method Bias

Model	χ^2	df	CMIN/DF	CFI	TLI	RMSEA	SRMR
CFA with marker (all factors correlated)	891.526	436	2.045	0.921	0.910	0.058	0.052
Baseline (no method paths)	979.507	449	2.182	0.908	0.898	0.062	0.122
Method-C (equal marker paths)	875.083	448	1.953	0.926	0.918	0.055	0.055
Method-U (free marker paths)	848.660	420	2.021	0.926	0.912	0.057	0.048
Method-R (Method-C, correlations fixed to Baseline)	886.085	469	1.889	0.928	0.924	0.053	0.086

Finally, the study also tested multicollinearity between the constructs (Kock, 2015). The study performed a variance inflation factor (VIF) test. The results show that all VIF scores are lower than 2.117 and the collinearity tolerance is greater than 0.472, suggesting that our study is not affected by common method bias. Despite the use of Harman's one-factor test, CFA common latent factor test, and VIF test, common method variance cannot be ruled out since the study utilises a single source in Appendix 12c, although self-reporting and cross-sectional data could lead to methodological and response biases (Fuller et al., 2016; Podsakoff et al., 2003). Reusing the same dataset in two chapters (3&4) makes independent testing even harder; therefore, such tests should be viewed as diagnostic rather than confirmatory (Podsakoff et al., 2024).

3.5.1.6 Data analysis

Data collected for this study were analysed using SPSS and AMOS software. This analysis included descriptive statistics to summarise essential characteristics of the constructs, confirmatory factor analysis (CFA) in Table 3.5 to assess construct validity, correlation analysis to investigate relationships, and hypothesis testing to determine the nature of these relationships. The selected analytical approach was designed to comprehensively understand the research questions while contributing meaningful insights to the relevant field. Table 3.4 displays the descriptive statistics for various variables associated with MS, DfAD, DfM, DfR, AM, CPD, and metrics for new product performance. Although the correlation between DfAD and CPD was relatively high (r = 0.664), the HTMT values were below the recommended threshold of 0.85, confirming adequate discriminant validity among the constructs.

Table 3.4: Mean, Standard Deviations, and Intercorrelations among the Variables

Construct	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Gender	1.147	0.355	-															
2. Age	2.709	0.848	**.188****	-														
3. Education	1.597	0.510	0.098	**.158****	-													
4. Working	3.636	1.742	0.040	0.032	**.213****	-												

Department																	
5. Industry Types	3.962	3.538	-0.075	-.140*	0.055	**0.001**	-										
6. Total Job Experiences	1.875	0.958	.182**	.874**	.192**	0.059	**-0.103**	-									
7. Tenure with Current Company	1.537	0.816	-.118*	.647**	0.097	-0.022	-.117*	**.660****	-								
8. Age of the company	3.425	0.837	0.048	.157**	0.027	0.012	0.013	.142*	**.205****	-							
9. Company Size	2.901	0.299	-0.044	0.076	0.053	-0.014	-.137*	0.080	.113*	**.322****	-						
10. MS	3.736	0.883	0.017	0.040	.190**	0.025	0.014	0.082	.132*	-0.094	**0.001**	-					
11. DfAD	3.643	0.900	0.004	-0.076	.184**	0.061	0.043	-0.051	-0.006	-0.070	-0.060	**.583****	-				
12. DfM	3.557	0.907	0.080	-0.053	.214**	0.025	0.045	-0.047	-0.036	-0.014	0.019	.369**	**.572****	-			
13. DfR	3.892	0.850	0.028	0.034	0.016	-.162**	0.049	0.045	.180**	0.012	-0.029	.414**	.531**	**.481****	-		
14. AM	3.982	0.826	0.014	0.006	0.111	0.033	-0.075	0.003	0.091	-0.017	0.019	.486**	.465**	.442**	**.540****	-	
15. CPD	3.756	0.780	0.046	-0.016	.204**	0.033	0.019	0.020	0.044	-0.006	-0.059	.497**	.664**	.582**	.603**	**.524****	-
16. NPP	4.014	0.820	-0.065	0.035	.127*	0.010	0.022	0.049	.113*	0.004	-0.066	.399**	.427**	.379**	.409**	.442**	**.429****	-

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The dataset comprises a variety of variables, each characterised by its mean and standard deviation (SD). The reliability and validity of the constructs were also tested (Table 3.6). Descriptive and inferential statistics were used to examine the relationships among CPD, AM, and DCs, and to identify direct and indirect relationships using structural equation modelling. AMOS-29 and SPSS-29 were used to analyse the dataset.

The following section discusses the interview approach as the second phase of the mixed methods.

3.5.2 Phase 2: Qualitative Study

3.5.2.1 Research Design

The qualitative study aimed to explore the organisational and dynamic design capabilities to identify critical attributes of circular product design and understand their implications on new product performance. It emphasises the importance of contextual features in organisational involvement in CPD, addressing identified research gaps. The study involved in-depth, semi-structured interviews with key business professionals from 25 manufacturing companies in

Bangladesh. This approach enabled a flexible exploration of participants' insights and experiences regarding circular product design to ensure new product performance.

3.5.2.2 Data collection procedures

The study employs an interpretive analysis approach, utilising qualitative data collected from interviews conducted via Zoom and in person. The interviews were also recorded for future use and ranged from 35 minutes to 1.5 hours. The interviews focused on the participants' experiences during various stages of the production, procurement, and supply chain functions. The topics covered included material selection, design for assembly and disassembly, design for modularity and standardisation, design for recyclability, and the impacts of AM/3D on these practices. For many cases, the respondents consider 3D and AM as a same technology although the know the difference. Moreover, a separate question asked how to implement different R's strategies to ensure circular practices during product design and how these strategies enhance performance during new product development. Using these criteria, this method allows researchers to uncover prevailing processes and practices regarding companies' CPD practices. The interview protocol is presented in Appendix 4.

3.5.2.3 Participant Demographics

The participants included 25 males aged 28-57 years, all holding managerial positions in manufacturing companies in Bangladesh. This indicates that low presence of female in decision-making roles at management and executive levels in Bangladesh's manufacturing industry (Islam & Jantan, 2017). Their selection was based on their knowledge and experience in operations and supply chain management. Most of the respondents were professionally renowned personnel in their respective fields. The communication mechanism with the respondents was email and phone communication. Among them, merchandisers, supply chain professionals, founders, CEOs, general managers, mechanical engineers, textile

engineers, industrial product engineers, and computer and electrical engineers participated in this study. Table 3.5 shows the participants' demographics.

Table 3.5: Demographic Profile of Interview Participants

S.L	Age	Education	Position	Types of Industry	Years of Experience	Company Age	No of Employees
Part_001	41	Bachelor	Lead Merchandiser	Garments Retailer	20 Years	50 Years	1,000
Part_002	37	Master's	Head of Supply Chain	Sea Food Processing	10 Years	42 Years	1,200
Part_003	32	BSc	Textile Engineer	Denim Manufacturer	7 Years	40 Years	35,000
Part_004	33	BSc	Mechanical Engineer	Shoe Manufacturer	8 Years	12 Years	40,000
Part_005	45	Master's	General Manager	Garments Manufacturer	20 Years	24 Years	20,000
Part_006	28	Bachelor	Supply Chain Executive	Textile Manufacturer	2 Years	33 Years	1,200
Part_007	58	Master's	Chief Executive Officer	Garments and Textile	33 Years	44 Years	35,000
Part_008	38	Master's	Head of Supply Chain	FMCG	14 Years	25 Years	800
Part_009	48	Master's	General Manager	Plastics	20 Years	27 Years	500
Part_010	52	Master's	General Manager	Garments and Textile	26 Years	20 Years	28,000
Part_011	28	BSc	Production Engineer	Plastics	3 Years	10 Years	400
Part_012	42	Master's	Head of Supply Chain	FMCG	18 Years	27 Years	600
Part_013	42	BSc	Production Engineer	Automobile	20 Years	8 Years	250
Part_014	32	Bachelor	Quality Controller	Plastics	6 Years	10 Years	300
Part_015	38	Master's	Corporate Strategy Team	Steel	12 Years	72 Years	4,000
Part_016	46	BSc	General Manager	Garments	18 Years	34 Years	5,000
Part_017	52	Master's	General Manager	Steel	24 Years	15 Years	450
Part_018	46	Master's	Production Director	Sewing Thread Manufacturer	17 Years	24 Years	2,000
Part_019	42	Master's	Merchandiser	Garments	15 Years	25 Years	5,000
Part_020	33	Master's	Factory HR Administrator	Label Manufacturer	7 Years	11 Years	1,600
Part_021	32	Master's	Merchandiser	Garments and Textile	6 Years	25 Years	12,000
Part_022	56	Master's	Chairman and Director	Garments and Textile	29 Years	23 Years	11,000
Part_023	43	MSc	Mechanical Engineer	Steel	15 Years	8 Years	250
Part_024	45	MSc	Chemical Engineer	Sewing Thread Manufacturer	16 Years	11 Years	1,560
Part_025	40	Master's	Head of Supply Chain	Cement	13 Years	22 Years	2,500

N=25

3.5.2.4 Data Analysis

Microsoft transcription software was used to transcribe the interviews that were gathered. To verify correctness, the transcripts were compared to the audio recording. NVivo was used to code and analyse the transcripts. When gathering and analysing data, constant comparison techniques were applied (Glaser, 1965). The researcher moves from data gathering to interpretation through an iterative process called constant comparison, continuing until

"newly analysed data do not prompt further changes to concepts" (Tracy, 2024). The researcher then analysed the important concepts that arose from the data through comparative and interactive coding procedures (Brooks et al., 2015).

First, researcher read the entire data set to familiarisation of the concepts. Coding is the second step in the emergent process of qualitative data analysis. Coding generally comprises a set of processes that enable collected data to be assembled, categorised, and thematically sorted, providing an organised platform for the construction of meaning (Williams & Moser, 2019). In this study, a deductive-based approach was used to see which question, or just a part of the interview data, related and validated with the quantitative data (Brooks et al., 2015; Gale et al., 2013).

The coding strategy is based on one of the coding process: open, axial, and selective coding (Williams & Moser, 2019). In this connection, the study used open coding. Open coding is the initial phase of qualitative data analysis, in which raw data is broken down into discrete parts to identify key concepts and patterns. This process is fundamental to organising and interpreting qualitative data, as it enables researchers to assemble, categorise, and thematically sort information, laying the groundwork for constructing meaningful insights (Williams & Moser, 2019). Based on open coding, the researcher organised interviewees' responses by grouping similar words, phrases, and concept indicators within the broad initial variable's domain. For example, "indicators are symbols or conventional signs; thus, a man and woman are concepts. So are love, mate selection, divorce, death, and depression" (Strauss & Corbin, 1998). Each stage of the coding process progressively integrates the theory and concepts acquired during data collection and continually refines the concepts, culminating in the creation of new items (Williams & Moser, 2019).

This method enabled the study to systematically examine how specific interview responses relate to predefined concepts, thereby enhancing the integration and validation of qualitative

and quantitative data (Wieland & Creutzig, 2025). For categorisation, iterative categorisation (IC) is a suitable technique that can support a constant comparison developed within the research field (Neale, 2016). IC further generates categories and their properties rather than being based on the researcher's hypotheses and preconceptions. This is because every category must earn its way into the analysis, i.e., it must be grounded in the data rather than being generated from the researcher's hypotheses and preconceptions (Hallberg, 2006). The study applies the process of identification and verification for emerging categories and their properties in the data to ensure that these conceptual relationships are grounded in the data. Identification of a core category is central to integrating other categories into a conceptual framework or theory grounded in the ''core category'' of grounded theory data. This core category determines and delimits the theoretical framework (Williams & Moser, 2019).

During the analysis, the study includes detailed memos to record ideas, assumed associations, and theoretical reflections for each emerging variable. Finally, the researcher concludes the qualitative data collection when saturation based on cross-sectors is reached. Saturation is a critical concept in grounded theory; no further interviews would give noble information (Hallberg, 2006). The following section presents the analysis of the survey and interview data. The data analysis protocol has been summarised in Table 3.6.

Table 3.6: Data Coding Protocol

Step	What is Coded	Type of Coding	Coding Procedure	How Codes are Developed Inductively
1	Entire dataset	Familiarisation	Data are read repeatedly to gain an overall sense of content and context	No codes are applied at this stage
2	Meaningful data segments	Open coding	Line-by-line coding is applied to identify salient ideas and actions	Codes are created directly from the data, using participants' language where possible
3	Significant codes	Inductive code refinement	Codes are reviewed, merged, split, or discarded	Refinement occurs through iterative comparison
4	Related codes	Categorisation	Codes are grouped based on conceptual similarity and relational meaning	Categories emerge through pattern recognition across codes

5	Categories and analytic insights	Memo writing	Analytical and reflexive memos are written throughout coding and categorisation	Memos capture emerging interpretations, analytic decisions, and shifts in understanding
6	Categories in relation to research questions	Analytic integration	Categories are revisited considering memos and research aims	Deductive insights are synthesised based on research aims

3.6. Data Analysis and Findings

3.6.1 Quantitative Data Analysis and Findings

The current study employed a covariance-based Structural Equation Modelling (SEM) technique using AMOS to examine the reliability, validity, and interrelationships among latent variables. Covariance-based SEM using AMOS is suitable for theory testing and confirmation, as it allows researchers to evaluate the overall model fit and the relationships among latent constructs (Hair Jr et al., 2020). This technique is widely used in behavioural and social sciences due to its ability to handle measurement error and provide robust model fit indices that provides: (i) it enables more complex and comprehensive analysis with the evaluation of mediating effects (Hair Jr et al., 2014), and (ii) allows for the elimination of large error terms and/or indicators with low loadings, thereby improving the quality of modelled latent constructs. The results of AMOS-SEM are organised into the following two sub-sections: 'Measurement Model' and 'Structural Model Testing."

3.6.1.1 The Measurement Model

The measurement model describes the conceptualisation of latent variables in terms of observed items. In the measurement model, the study has 7 latent variables, each with 37 items. The measurement model provides a good fit based on fit indices (χ^2 (574.769, df=354, $p<0.001$) and χ^2/df of 1.626; RMSEA=0.045; SRMR=0.0450; GFI=0.893; IFI=0.959; TLI=0.949; CFI=0.958), indicating an excellent fit (Hu & Bentler, 1999). The study also tests the measurement model regarding individual item reliability, internal consistency, and convergent validity (See Tables 3.7 and 3.8).

The study assesses the reliability using Cronbach's alpha and composite reliability. First, the researcher calculates Cronbach's alpha reliability coefficients and compares them to the minimum acceptable level of 0.70 (Nunnally, 1978). The alpha values for each construct exceed this threshold. Next, the researcher computes composite reliability (CR) scores for each variable. This is done by dividing the squared total of the standardised loadings by the sum of the squared total of the loadings and the variance of the associated error terms (Fornell & Larcker, 1981). The results show that the values of the two indices for each construct are all above the threshold of 0.70, and the exploratory factor loading of 0.6 is acceptable (Nunnally, 1978). Thereby suggesting adequate internal consistency for the measurement model.

Table 3.7: Confirmatory Factor Analysis, Composite Reliability, and Cronbach's Alpha

Construct	Items	Standardized Loading	Composite Reliability	Cronbach Alpha
Material Selection (MS)	MS1	0.317*	0.812	0.817
	MS2	0.625		
	MS3	0.674		
	MS4	0.806		
	MS5	0.769		
Design for Assembly and Disassembly (DfAD)	DfAD1	0.559*	0.788	0.770
	DfAD2	0.499*		
	DfAD3	0.642		
	DfAD4	0.811		
	DfAD5	0.772		
Design for Modularity (DfM)	DfM1	0.547*	0.750	0.747
	DfM2	0.564*		
	DfM3	0.691		
	DfM4	0.612		
	DfM5	0.810		
Design for Recyclability (DfR)	DfR1	0.753	0.817	0.814
	DfR2	0.832		
	DfR3	0.732		
Additive Manufacturing (AM)	AM1	0.611	0.861	0.858
	AM2	0.854		
	AM3	0.777		

	AM4	0.707		
	AM5	0.737		
Circular product Design (CPD)	CPD1	0.502*	0.909	0.896
	CPD2	0.728		
	CPD3	0.702		
	CPD4	0.756		
	CPD5	0.777		
	CPD6	0.790		
	CPD7	0.583*		
	CPD8	0.703		
	CPD9	0.693		
	CPD10	0.811		
New Product Performance (NPP)	NPP1	0.827	0.915	0.917
	NPP2	0.826		
	NPP3	0.893		
	NPP4	0.870		

* Item dropped for further Analysis

The measurement model was evaluated to determine the extent to which it achieves convergent and discriminant validity. "Convergent validity was confirmed using two criteria: each factor had loadings above 0.5 (Bagozzi & Yi, 1988), and all average variance extracted (AVE) values were greater than 0.5 (Fornell & Larcker, 1981). Discriminant validity was established when the square roots of the AVEs were higher than the correlations among constructs (Fornell & Larcker, 1981).

Table 3.8: Fornell & Larcker Convergent Validity

		Correlations between latent variables (square root of AVE in the diagonal)						
	AVE	**1**	**2**	**3**	**4**	**5**	**6**	**7**
(1) DfM	0.503	**0.709**						
(2) MS	0.521	0.474	**0.722**					
(3) DfAD	0.555	0.706	0.709	**0.745**				
(4) DfR	0.598	0.637	0.511	0.674	**0.774**			
(5) CPD	0.557	0.689	0.591	0.784	0.687	**0.746**		
(6) AM	0.555	0.501	0.572	0.540	0.657	0.587	**0.745**	
(7) NPP	0.730	0.441	0.461	0.510	0.472	0.491	0.488	**0.854**

AVE: Average Variance Extracted

3.6.1.2 Structural Model

The structural model in this study was analysed using AMOS-29 with a 5000-bootstrap subsample setup, as strongly recommended for reliable results (Hair et al., 2022). The model showed a good fit based on all indices. Specifically, χ^2 (779.599, df = 371, $p < 0.001$) and the χ^2/df ratio (2.155; below the threshold of 3) met the criteria (Arbuckle, 1999). Other model fit measures (RMSEA = 0.067, SRMR = 0.0727, GFI = 0.851, IFI = 0.903, TLI = 0.886, CFI = 0.902) also indicated an excellent fit (Hu & Bentler, 1999).

The structural model involves six direct effects and five mediation effects. The six direct effects are (1) the direct effect of MS on CPD, (2) the direct effect of DfAD on AM, (3) the direct effect of DfM on AM, (4) the direct effect of DfR on AM, (5) the direct effect of AM on CPD, and (6) the direct effect of CPD on NPP. Figure 3.2 illustrates all hypothesised relationships and corresponding standardized regression coefficients.

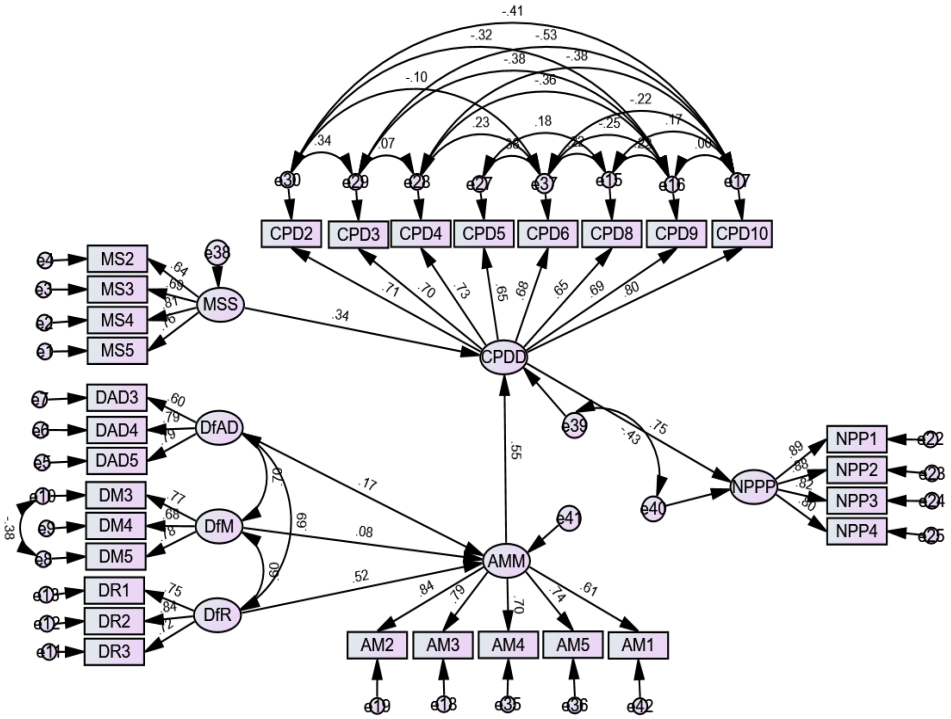


Figure 3.2: Structural Model

The regression results confirm that material selection (MS) has a positive and statistically significant effect on CPD (β =.295, p = .000), thereby supporting H1. The findings also support H2, H3, and H4, showing that dynamic design capabilities positively influence AM, with design for assembly and disassembly (DfAD) exerting a modest but significant effect (β =.144, p < .10), design for modularity (DfM) demonstrating a weaker and not significant influence (β =.070, p > .10), and design for recyclability (DfR) emerging as the strongest predictor of AM (β = .506, p < .001). In addition, AM has a strong, highly significant positive effect on CPD (β = .561, p < .001), providing empirical support for H5 and underscoring its central role in enhancing circular product design. Finally, CPD positively and significantly affects NPP (β =.804, p < .001), confirming H6. Overall, all hypothesised direct effects are statistically significant, offering robust empirical support for the proposed research model.

The mediating effects of AM and CPD on the relationships among material selection, dynamic design capabilities, and NPP were examined using bootstrapping (Preacher & Hayes, 2008). The results indicate positive direct effects for organisational and design capabilities, with statistically significant indirect effects for H2a, H3a, and H4a, confirming that design for assembly and disassembly and recyclability design influence CPD fully through AM. In contrast, although material selection shows a significant direct effect, its indirect effect via CPD is not significant (β = .210, p = .236), leading to the rejection of H1a. Likewise, H5a is not supported, as neither the direct nor the indirect effect was significant (β = .690, p = .142), indicating that CPD does not mediate the relationship between AM and NPP. Overall, the findings highlight AM as a key mediating mechanism linking dynamic design capabilities to CPD, while CPD does not consistently mediate effects on new product performance. Table 3.9 summarises the hypothesised direct and mediating effects among DCs, AM, CPD, and NPP.

Table 3.9: Hypothesis Testing based on Survey

Hypothesis	**Direct effects**	**Estimate**	**S.E.**	**C.R.**	**P Value**	**Comments**
H1	MS →CPD	.295	.050	5.946	***	Supported
H2	DfAD→AM	0.144	.084	1.710	.087*	Supported
H3	DfM→AM	0.070	.072	.974	.330	Not Supported
H4	DfR→AM	0.506	.089	5.664	***	Supported
H5	AM→CPD	0.561	.072	7.831	***	Supported
H6	CPD→NPP	0.804	.123	6.548	***	Supported
Mediation Effects		**Total Effects**	**Direct Effects**	**Indirect Effects**	**P Value**	
H1a	MS →CPD →NPP	0.210	0.210	0.078	0.236	No Mediation
H2a	DfAD →AM →CPD	0.362	0.012	0.350	0.006***	Full Mediation
H3a	DfM →AM →CPD	0.184	0.081	0.103	0.002**	Full Mediation
H4a	DfR→AM →CPD	0.244	0.113	0.131	0.004**	Full Mediation
H5a	AM→CPD→NPP	.690	0.690	0.000	0.142	No Mediation

*****<.001, **<.01, *<.10**

MS= Material Selection. AM= Additive Manufacturing

DfAD= Design for Assembly and Disassembly DfM= Design for Modularity

DfR: Design for Recyclability CPD= Circular Product Design

NPP= New Product Performance

3.6.1.3. Control variables

Considering the study objectives, the research used the control variables meaningfully (Hult et al., 2007). Hence, correlation and regression analyses for this study revealed that the chosen relevant control variables, taken from the literature, were not significantly associated with circular product design. This study, therefore, does not include control variables in the further analysis due to context. Previous studies have shown that in Bangladesh, the labour market payoffs of education are not uniform; they differ by geographical location, gender, and economic sector (Asadullah, 2006).

3.6.2 Qualitative Data Analysis and Findings

The results from the interview data on MS, DfAD, DfM, DfR, AM, CPD, and NPP, along with their relationships, are reported in the following section. This section also highlights the matching of the different items collected from the interview quotes from the qualitative

survey. The study then categorised the collected qualitative interviews into three dynamic design capabilities and organisational capabilities. First, organisations need to be aware of identifying resources for material selection, then sensing capabilities: design for assembly and disassembly, design for modularity, and design for recyclability, and of adopting additive manufacturing as a design and manufacturing technology. Second, seizing capabilities, organisations need to mobilise their resources for circular product design. Finally, the established resources and operations are transformed to improve new product performance.

3.6.2.1 Material Selection

Based on the qualitative data, the study identified routine capabilities that are significant contributors to CPD. First, material selection is the primary contributor to CPD. Material selection is a basic manufacturing activity based on production needs and customer demands, not on strategic change. For this reason, it is an everyday operational decision rather than a dynamic capability, which involves adjusting resources when conditions change. Table 3.10 provides a complete overview of factors related to MS based on the deductive approach and quantitative items. The results also confirmed that almost all participants focused on MS for CPD, with more than 10 participants (8 from garments, textiles, and 2 from plastics) emphasising recycled, reprocessed, and reutilised raw materials, followed by using non-hazardous or harmful materials. Organisations are aware of emissions when using materials.

Table 3.10: Participants' Responses for Material Selection (MS)

Organisational Capabilities	Material Selection Measures		Interview Quotes
	MS1	Our company doesn't use any dangerous or environmentally harmful materials	No environmentally sensitive or harmful material is used by maintaining proper compliance regulation (Participants from Garments, Textile, Plastic, Cement, FMCG, and Label Manufacturers)
	MS2	Our company uses raw materials to be recycled, reprocessed, or reutilised into	We use recycled and reused material, which has less impact on the environment (Participants from Garments Retailer, Denim, Textile, Plastic,

		new raw materials	Automobile, Steel, Sewing Thread, Label, and Cement Manufacturers)
	MS3	Our company uses materials and chemicals broken down into natural, safe substances through biological processes	We use ZDHC (Zero discharge of hazardous chemicals) certified chemicals (Participants from Denim and First Moving Consumer Goods Manufacturers)
	MS4	Our company uses material that protects against environmental factors like water, UV light, and chemicals	We used materials that help to reduce the chemical impact and carbon emission (Participants from Garments Retailer, Textile, Plastic, Steel, and Cement Manufacturers)
	MS5	Our company uses material that stays the same in high and extreme temperatures without losing its properties	The quality of the recycled yarn for producing the yarn will not be hampered or deteriorated (Participants from Seafood Processing, Denim and Plastics Manufacturers)

3.6.2.2 Dynamic Capabilities: Sensing

The first dynamic factor influencing CPD is the design of the assembly and disassembly. Table 3.11 illustrates organisational awareness of incorporating design for assembly and disassembly principles into product development. 11 participants including automobile, furniture, plastics and garments recognised DfAD as a critical design component. Most respondents emphasised the importance of ensuring that products can be easily assembled and disassembled without requiring any special tools or requirements post-purchase.

Table 3.11: Participants' Responses for Design for Assembly and Disassembly (DfAD)

Dynamic Capabilities	Design for Assembly and Disassembly Measures		Interview Quotes
Sensing	**DfAD1**	Our company can design products that can easily be assembled and disassembled	There is not a single chemical that cannot be disassembled (Participants from Shoes, Garments, Textile, Plastics, and Automobile Manufacturers)
	DfAD2	Our company can design products that do not require any special people or tools/equipment to join/move components	We produce a product that is easily assembled and disassembled and that does not need any special tools. Customers can join by seeing the instruction manuals (Participants from Seafood Processing and Plastic Manufacturers)

	DfAD3	Our company can design products that use joining elements that easily disassembled between subassemblies of incompatible materials	We can easily assemble or disassemble the products. After collecting the yarn, we cut it, sew it, and we can even easily disassemble it (Participants from Garments and Textile Manufacturers)
	DfAD4	Our company can design products based on components that can easily be reused and refurbished	From the garment section, when the fabric is passed, not all the fabric can be used for design purposes; some can be wasted, or some can be left over from the cutting table due to marking and designing. So, this is what we bring to our factory with the recycling. So, this is the reusing concept (Participants from the Shoe Manufacturer)
	DfAD5	Our company can design products that can be easily repaired and replaced	The material that will be used in the new design should be available or easy to repair, or recycle (Participants from the Plastic Manufacturer)

Second, organisations must recognise the significance of modularity in initiating CPD. Table 3.12 illustrates the participants' modularity capability during the product design phase. Notably, 16 participants from automobile, plastics, garments and textiles acknowledged the critical role of modularity in design principles. Participants placed considerable emphasis on the utilisation of standardised components and their reuse across various products to achieve design modularity. Furthermore, the participants highlighted the importance of modifying designs without necessitating the redesign of other components, advocating for a high degree of component carryover within the modular design framework.

Table 3.12: Participants' Responses for Design for Modularity (DfM)

Dynamic Capabilities	Design for Modularity Measures		Interview Quotes
Sensing	**DfM1**	Our company can design products that can be decoupled into separate modules	We design 20-litre bowls based on modularity; full products might not be rejected. Only some of the parts can be rejected, and the remaining will be good. In that case. Only rejected parts need to be reproduced or remanufactured (Participants from Textile and Plastic

			Manufacturers)
	DfM2	Our company designs products that use standardized components	To reduce the time for production, we have common materialism in adding the pig down every purchase of 3 to 5 MT of pig, and some padding like Yahoo padding, and some downtime padding will be stocked (Participants from Garments, Automobile and Plastic Manufacturers)
	DfM3	Our company can design products that can make changes without redesigning others	We produce versatile garments, so men and women can use them, and husbands can use them. Relatively, men are a little bit bigger with greater respect for their wives' bodies (Participants Garments, Plastic and Textile Manufacturers)
	DfM4	Our company can design a product that has a high degree of component carry-over	If a customer wants 1-inch elastic, we use this for every customer (Participants from Plastic and Sewing Thread Manufacturers)
	DfM5	Our company can design products that can be reused in various products	We recover some components and then use them for spare parts (Participants from Garments, Textile, and Automobile Manufacturers)

Third, in the qualitative interviews, participants are very much aware of recyclability. Table 3.13 presents the design for recyclability. 15 participants from garments, plastics and steel were convinced that designing products based on recyclability is a crucial design component. In the qualitative study, it was found that many organisations already have recycling facilities on their factory premises or are planning to introduce new design dimensions for recyclability. Recyclability is not only a requirement from manufacturers but is also highly valued by buyers. Hence, firms aim to ensure recyclability of their products during the design stage so they can easily recover materials at end-of-life without polluting the environment.

Table 3.13: Participants' Responses for Design for Recyclability (DfR)

Dynamic Capabilities	Design for Recyclability Measures	Interview Quotes

Sensing	**DfR1**	Our company can design a product that increases recycling rates for raw materials	We use a completely recyclable material (Participants from Denim, FMCG, Garments, and Textile Manufacturers)
	DfR2	Our company can design products based on the reuse of recycled components	We design products based on recycled fiber/packaging/Scrab (Participants from Denim, Shoe, FMCG, Steel, Garments, and Textile Manufacturers)
	DfR3	Our company can design a product that could be easily recovered at end-of-life	We have a recycling plant only for reusing and remanufacturing, where we produce pants for export, but for certain reasons are being rejected. Then, it will go into the new factory, crash, and make new fiber yarn, which will be used to make new denim pants. That is recovered at the end of life (Participants from Steel and Denim Manufacturers)

3.6.2.3 Design and Manufacturing Technology: Additive Manufacturing

Moreover, within the era of Industry 4.0 and the beginning of Industry 5.0, organisations need to be aware of using digital technology to improve their efficiency. Table 3.14 highlights qualitative quotes from interviewees to identify the roles of additive manufacturing/3D printing in circular product design. 15 participants from garments, furniture, plastics and automobile agreed to receive support from AM for design and manufacturing within their organisations to support CPD. Interestingly, 3D printing is widely used in garments and textiles, whereas additive manufacturing is used in injection moulding for plastics and the automotive industry. Participants also urge 3D/AM to maintain a competitive position because it enables precise designs, is more energy- and time-efficient, and supports sustainable recycling. In Bangladesh, 3D printing is used in almost all manufacturing firms, where design is the main factor in attracting customers. On the other hand, AM is being adopted for design and manufacturing, with large companies often upgrading their organisational capabilities.

Table 3.14: Participants' Responses for Additive Manufacturing (AM)

Technology	Additive Manufacturing/3D Printing Measures		Interview Quotes
	AM1	Our company uses 3D software to improve the design process	3D helps us to make exact designs (Participants from Garments Retailer, Denim, Plastic, and Label Manufacturers)
	AM2	AM or 3D printing contributes to less time/energy consumption in the manufacturing	3D printing helps us to make the operations more efficient, more energy-saving, and more timesaving (Participants from Garments Retailer, Textile and Denim Manufacturers)
	AM3	AM can reduce transportation costs and improve the lead time	3D helped us to reduce lead time for the sample approval and the sample design (Participants from Garments, Textile, and Plastic Manufacturers)
	AM4	We need to keep very little inventory due to the AM manufacturing facility	3D printing helps us to keep little inventory (Participant from Sewing Thread Manufacturer)
	AM5	AM improves the product development time and contributes toward the Circular Product Design	The 3D design is helping with the sustainable and recycling process (Participants from Garments Retailer and Automobile Manufacturers)

3.6.2.4 Dynamic Capability: Seizing

In line with the principles of dynamic capability, organisations must leverage their resources for operational activities. Circular Product Design (CPD) represents a critical strategic activity (seizing) that contributes to firms' long-term success. Table 3.14 succinctly presents the participants' statements endorsing CPD. Nearly all participants agreed to use any of the R strategies to enhance the circularity of products and operations in their companies. Among these strategies, participants placed greater emphasis on recycling, reusing, remanufacturing, and reducing costs, energy use, and waste.

Table 3.15: Participants' Responses for Circular Product Design

Dynamic Capabilities	Circular Product Design Measures		Interview Quotes
Seizing	**CPD1**	Our company can produce products that allow recycling	We are using recycled materials and energy to produce new products (Participants from Garments, Textile, and Plastic Manufacturers)
	CPD2	Our company can produce	We focus on the reuse of materials like zippers and

		products that allow the reuse of components	buttons (Participants from Textile, Garments, and Denim Manufacturers)
	CPD3	Our company can produce products that allow remanufacturing	In the automobile/plastic sector, remanufacturing is common practice (Participants from Plastic, Automobile, and Sewing Thread Manufacturers)
	CPD4	Our company can produce products that are easy to recover	We recover exhaust and send it to the cement industry by not throwing it into the land. We have a contract with a cement company (Participants from the Garment Retailer)
	CPD5	Our company can produce products that are easy to assemble/disassemble	We can easily assemble or disassemble the products (Participants from the Shoe, Plastic, Garments, Textile, and Automobile Manufacturers)
	CPD6	Our company can develop products whose components can be easily refurbished	We refurnish the products, and sometimes we refurbish a certain percentage of our products, and that's not degrading the product quality, not degrading any product applications' performance (Participants from Automobile and Plastic Manufacturers)
	CPD7	Our company designs products based on the reduction of waste	If we use the recycled materials, they ensure less wastage (Participants from Garments, FMCG, and Sewing Thread Manufacturers)
	CPD8	Our company designs products based on the reduction of material usage	If we use recycled materials, there is less material and water consumption (Participants from Garments, Plastic, Label, and Sewing Thread Manufacturers)
	CPD9	Our company designs products based on the reduction of money and energy	If we use recycled materials, we need less energy and electricity, and reduce cost (Participants from Textile, Steel, Plastic, Garments, and Sewing Thread Manufacturers)
	CPD10	Our company designs products based on the repetition of the process	The waste we gather, keep in one place, and give to a spinning mill to reprocess these materials, and the process is repeated (Participants from Garments and Textile Manufacturers)

3.6.2.5 Dynamic Capability: Transforming

Organisational resources are presumed to be utilised to transform organisational capabilities into practice. Table 3.16 shows how firms can transform their circular product design capabilities to achieve better performance through new products. 13 participants from FMCG, plastics, garments and textiles agreed that good business is based on sales, profits,

market share, and customer satisfaction when they provide circular products or are willing to offer sustainable products. Additionally, becoming a CPD ensures better customer satisfaction.

Table 3.16: Participants' Responses for New Product Performance (NPP)

Dynamic Capabilities	New Product Performance Measures		Interview Quotes
Transforming	**NPP01**	The new/circular product has achieved our sales target	Our company is the best seller in the respective market (Participants from Garments, Plastic, Steel, and Cement Manufacturers)
	NPP02	The new/circular product has achieved our profit goal	We achieved and most of the time exceeded sales targets (Participants from Plastic, Steel, Sewing Thread, and Cement Manufacturers)
	NPP03	The new/circular product ensures an increase in market share	We are the market leader (Participants from Denim, FMCG, Plastic, Steel, and Cement Manufacturers)
	NPP04	Customers are satisfied with the new/circular product performance	Customers are happy to use recycled materials, considering the environmental impact (Participants from Garments and First Moving Consumer Goods Manufacturers)

3.7 Discussion

The study results confirm that a set of organisational and design capabilities can significantly contribute to the transition to CPD, thereby improving product performance. The results also confirm that organisational and design capabilities are not the only actors in CPD; design and manufacturing technology, such as AM, also play a direct and mediating role in strengthening the relationship with CPD. In doing so, it examines the direct impact of design capabilities like DfAD, DfM, and DfR on AM, as well as the impact of AM on CPD and CPD on NPP, and the mediating impact of AM on CPD and CPD on NPP. Based on the quantitative and qualitative data, the results indicate a positive and significant impact of MS and AM on CPD and of CPD on NPP. The following subsections highlight qualitative narratives, compare them with quantitative results, and discuss these results in the context of existing literature.

3.7.1 Direct Effects

First, the direct effects provide sufficient evidence of the positive impact of adopting organisational capabilities, as shown based in the material section and AM, on CPD. This suggests that firms with circularity principles based on MS and AM have shown positive effects in CPD. In manufacturing settings, the materials section is a foundational capability for designing products that fit circular business models, particularly in achieving longevity, modularity, and end-of-life recovery (Bocken et al., 2016). The existing empirical literature has also found a positive effect of material selection on CE (Bai et al., 2024; Cainelli et al., 2020) and CPD (Dey et al., 2022). The study's results contrast with Stahel's findings, who claimed that circular material selection cannot be effectively implemented unless embedded in a more systemic approach alongside strategies such as performance-based business models and extended producer responsibility (Stahel, 2019). Finally, the study demonstrates that material selection can directly affect CPD, even when no comprehensive systemic approaches are employed. The quantitative findings are consistent with the qualitative findings. Participant 23 from steel manufacturing interviews mentioned that "*We try to focus on different factors for material selection. ...material availability, supplier's location, their industry practices…sustainable techniques, how we can recycle those things after finishing our production process… we can reuse them, which will minimise our costs. So, I'll say ...the safety of the materials and our processes and the quality…need to have very good delivery within our lead time, and then the basis should be cost-effective*". In addition to these factors for material selection, Participant 24 from sewing thread manufacturer also states that "*Material selection is based on recycled materials or biodegradable materials or organic materials and their sources if sustainable or not".* Firms with a circular focus on material selection can support circular product design. This, in turn, suggests that material selection positively influences circular product design, thus supporting H**1**.

The results further support the notion that the design for assembly and disassembly (DfAD) is significantly related to AM. In practice, DfAD enables many capabilities to design products that are easy to assemble and disassemble, not only for process customisation but also to support the technology. Previous empirical research provides validation for the study findings. Past studies found that AM facilitates part consideration and reduces the number of parts, thereby facilitating easy assembly and disassembly, which aligns directly with the principles of DfAD (Vaneker et al., 2020). Moreover, DfAD relates to assembly efficiency and disassembly feasibility, which are enabled by the complex geometry and integrated functions of AM (Oh et al., 2020). Consequently, DfAD optimises the AM design option for product remanufacturing and reuse (Oh et al., 2020). Consequently, DfAD optimises the AM design option for product remanufacturing and reuse (Battaïa et al., 2018). However, in some cases, DfAD faces some challenges with integrating modern technologies. Evidence shows that AM parts consolidation may be problematic during part maintenance, limiting the principles of DfAD (Oh et al., 2018). Consistent with the survey results, the study finds similar evidence in the qualitative interview data. Participant 10 from the garments and textiles companies posits that "*We can easily assemble or disassemble the products. After collecting the yarn, we cut it, sew it, and even disassemble it. We can separate the material as well. There is no single material that cannot be disassembled".* Another plastic manufacturer participant confirmed that DfAD supports the technology of AM. In response to DfAD capabilities, Participant 9 from plastic manufacturing companies argued that "*We design our products based on assembling and disassembling. For example, we assemble and disassemble wardrobes, kitchen drawers, and shoe racks. Even our door can also be easily assembled and disassembled*". These findings align with the conclusion of the current study that DfAD has a significant and positive influence on AM. Hence, it is confirmed that DfAD has a positive effect on AM, thus **H2** is confirmed.

Based on a quantitative study, the study findings posit that design for modularity (DfM) does not affects AM. Although DfM is often viewed as a design capability because it enables products to be more easily interchanged, repaired, and upgraded. Empirical evidence shows a positive relationship between DfM and AM. For example, Yang and Zhao (2015) confirmed that the modular design of a product enables product customisation and part replacement, which aligns well with the design flexibility of AM. Moreover, DfM promotes product adaptability by enabling rapid design iterations and facilitating easier modifications and upgrades (Lindemann et al., 2015). Similarly, AM enables the unlimited production of modules without tooling restrictions, thereby reducing assembly time and cost (Ruffo & Hague, 2007). However, some studies provide similar outcomes. For instance, Lehmann stated that excessive modularisation can hinder AM's design freedom by constraining integration opportunities (Lehmann et al., 2022). The qualitative findings are likely from participants at the plastic manufacturer. The participants mentioned that "*We can produce many products with greater flexibility by following the same structure or design. For example, say we use the same recipe for bowls and buckets. If some bowls are rejected, it is not necessary to produce bowls. We can also produce buckets based on market demand. In that case, we just melt and then compound to make the buckets"*. The results suggest that DfM supports AM and must be managed to address potential trade-offs between efficiency and flexibility. Despite positive intent of qualitative findings, the **H3** is not confirmed.

Further, the results confirm that the direct relationship between design for recycling (DfR) and AM is positive. DfR is considered an important capability for facilitating product design that focuses on product end-of-life, material recovery, and reduction of environmental waste. Empirical results also confirmed that DfR can support manufacturers in selecting materials and designing components that are easier to disassemble and separate, thereby enabling greater recycling and improved closure of material loops (Bakker et al., 2014; Thakuri et al.,

2025). AM supports the design principle of recyclability by enabling the reuse of metal and polymer powders, thereby enhancing material efficiency (Su et al., 2024). Moreover, AM enables product designs to incorporate principles of recyclability, minimising waste through controlled material use (Ferreira et al., 2020). Similarly, other findings demonstrated that AM can reduce environmental impacts by promoting closed-loop material cycles and enabling the recycling of printed components (Gebler et al., 2014). However, fewer studies provide distinct findings that recycling of AM materials can be inadequate due to contamination and degradation after multiple print cycles, which limit the recyclability benefits (Ford & Despeisse, 2016). In fine, the interview findings further confirm the survey findings, despite the contrasting evidence in the literature. Participant 4 from the shoe manufacturing companies also confirmed that DfR is an urgent and necessary capability for manufacturers. One of the participants claimed that *"We are focusing on recycled items. The world is facing limited resources that we are using. So, our world can be safe if we do not use it repeatedly. This is our main factor, and our buyers are thinking about the same thing".* Overall, DfR is a valuable design capability for AM but relies on interactions and principles for much larger systemic alignment. Hence, **H4** is accepted.

Results also provide evidence that AM significantly supports CPD. Prior research suggests that AM is a design and manufacturing technology for product design, which is crucial for achieving sustainable development in the CE (Hettiarachchi, Brandenburg, et al., 2022). The extant literature also suggests that AM has the potential to save significant amounts of material, energy, and time in manufacturing by utilising additive layer-to-layer processes and its near-net-shape capabilities (Ford & Despeisse, 2016; Gebler et al., 2014). Moreover, AM utilises decentralised, on-demand design and production, which improves process flexibility and can help mitigate excess inventory and overproduction, both of which are essential positive benefits of a circular product design (Khajavi et al., 2014). However, there are

contradictions to these findings. Although AM manufacturing can reduce waste, it can have the opposite effect on energy, making energy consumption problematic in some cases, particularly in metal-based printing (Faludi et al., 2015). On the other hand, AM can promote sustainability; the benefits depend on the materials used, the scale of production, and whether production is integrated into a closed-loop supply chain (Hettiarachchi, Seuring, et al., 2022). Participant 3 from a denim manufacturing company confirmed that "*3D printing helps us to make the operations more efficient, more energy-saving, and more timesaving in comparison to any other industry*." Therefore, it is apparent that AM offers significant potential as a trend for encouraging CPD; hence, hypothesis **H5** is supported.

Finally, CPD ultimately supports sustainable performance by advancing the development of new products that support business performance improvement metrics, including sales, revenue, market share, and customer retention. Extensive literature demonstrates that design approaches based on the principles of recycling, reuse, reduction, and remanufacturing contribute to the CE by providing customers with greater or additional value and enhancing overall business performance (Pinheiro et al., 2019). CPD is a strategic approach to business continuity and sustainability that builds environmental and economic value while reducing external resources, dependencies, and environmental impacts, and provides companies with the competitive advantages of improved customer loyalty and differentiation in the marketplace (Bocken et al., 2016; Geissdoerfer et al., 2023). Furthermore, CPD responds to a shift in consumer preferences towards sustainable products, which can increase revenue as consumers increasingly demand sustainable values and guidelines (Moyle et al., 2018). However, there is no guarantee of achieving advantageous financial outcomes with CPD. Huge costs can be incurred from an initial investment without achieving the desired efficiencies, or from reliance on appropriate technology that may not be available at the time of production (Kirchherr et al., 2018). The quantitative findings are like the responses from

the qualitative interviews. Participant 11 from the plastic manufacturing company states, *"We practice Kaizen very effectively. We sometimes design to reduce plastic or material use. We always try to bring a design with less material to satisfy our customers and ensure environmental sustainability*". Finally, the findings reflect that CPD holds strong potential for NPP. Therefore, **H6** is supported.

3.7.2 Indirect Effects

3.7.2.1 Mediating effects of AM on Design capabilities and CPD

In this subsection, the study presents the mediating role of AM in the relationship between organisational design capabilities (DfAD, DfM, and DfR) and CPD. The quantitative study found positive and full mediation effects of AM as a design and manufacturing technology for CPD and DfAD. The results confirm that AM serves as a mediating mechanism between DfAD and CPD. This illustrates the progression of digital technologies in facilitating sustainable design practices. AM not only provides tools for feedback-driven iteration or real-time processing but also enhances prototyping flexibility, which can foster modularity, part standardisation, and disassembly that serve as effective elements of DfAD necessary for advancing CPD (Weller et al., 2015). Empirical evidence indicates that AM improves adaptability and responsiveness in product, process, and supply chain contexts, helping firms better respond to heterogeneous markets and advance innovation cycles (Tziantopoulos et al., 2019). Moreover, the highly customised nature of AM may inhibit reuse and remanufacturing efforts if they are not part of a larger CE framework (Holmström & Partanen, 2014). The interview results further confirm the quantitative results. Participant 14 from the plastics manufacturing company mentioned that *"When we consider any household items that are one or two parts and need to be assembled. Before we move to mass production, we need to assess whether assembly is feasible. So, design tools and software, like CAD, give us this opportunity. It can be adjusted easily".* Based on the findings, the results suggest that AM

may be a promising mediator of technological capability in product design within a systemic CE framework. Hence, hypothesis **H2a** is supported.

The results also indicate that AM mediates the modular design (DfM) and, consequently, contributes to CPD. AM facilitates the production of modular components that can be easily substituted, enhanced, or repaired, delivering durable products that embody circularity (Ford & Despeisse, 2016; Kamble et al., 2018). Moreover, AM enables decentralised, just-in-time production, which supports the development of modular systems for reuse and remanufacturing, fundamental elements of CPD (Gebler et al., 2014). Additionally, AM enables the production of complex geometries through flexible methods that do not require tooling and reduce design constraints, thereby making it easier to implement a modularity strategy during the early design phases (Weller et al., 2015). The extant literature also confirms that AM provides evidence that products with interchangeable components can be designed to support intergenerational modularity, in which components are compatible across product versions or generations (Sauerwein et al., 2019). Design based on standard components is also an effective capability for many manufacturing companies. Participants 13 from the plastics and furniture company suggested that "*If any parts are broken, you must send them to the workshop. So, we make the drawing in CAD and give the dimensions. And elevate the damaged parts. We sent the backup so the machine shop could do the work as per the drawing. So, it's for maintenance and repair purposes"*. In conclusion, AM serves as a design and manufacturing technology that mediates the DfM and CPD, potentially offering a pathway for further sustainable adaptive manufacturing models. Hence, **H3a** is supported.

The study further provides strong evidence to support that AM is a positively and significantly mediating factor in the relationship between DfR and CPD. In practice, AM encourages the sustainable use of materials and the extension of product life. Moreover, AM enables a unique capability to control the specific amount of material used, reduce waste, and

make the process easier to adhere to DfR, achieved through material recovery and recyclability (Ford & Despeisse, 2016). The ability to utilise recyclable and bio-based materials encourages closed-loop systems, which are vital in circular design strategies (Sauerwein et al., 2019). Additionally, AM supports layer-by-layer processing, leading to better material tracking and separation, thereby making recycling and disassembly easier (Gebler et al., 2014). In addition, evidence exists that confirms AM as both a design and manufacturing technology that supports CPD through recollection, material recycling, and reusability via reuse extensions on the product life (Hettiarachchi, Brandenburg, et al., 2022). The qualitative results also confirmed that AM has a direct mediating effect on DfR and CPD. Participant 5 from a garment manufacturing company claimed that "*If we use 3D design for cotton, then of course it's easy to recycle. So, these kinds of things we are doing. But the design based on cotton-polyester ratio is difficult to recycle"*. Taken together, these contributions and discussions show that AM is a potential mediator of DfR for CPD outcomes. Thus, **H4a** is supported.

3.7.2.2 Mediating Relationship of CPD for Material Selection, AM, and New Product Performance

The indirect effect on H1a, where MS ability influenced NPP through CPD, was insignificant ($\beta = 0.210$, $p = .236$). This may be due to the short-term costs of using circular materials, including high sourcing and qualification costs, longer development times for new products, and variable quality and mechanical properties of recycled materials (Bocken et al., 2016). Furthermore, circular designs may lack the necessary capabilities and consumer interest (Kirchherr et al., 2018). Although CPD could create long-term value through designing more durable, modular and easily recyclable products, these advantages might manifest themselves throughout the product life cycle rather than at the time of launch (Geissdoerfer et al., 2018; Lieder & Rashid, 2016). However, the interview findings differ slightly from the survey

findings. Participants from the interviews stated that MS is an essential ability for CPD to ensure NPP. One of the participants from a steel manufacturing company stated, "*For material selection, we try to focus on many different factors. ...material availability for continuous production, so that the materials are available on demand. A supplier's location in the country is also considered. Moreover, industry practices... how they are applying sustainable techniques to ensure we do not use any contaminated materials in our production processes. Another factor is how we can recycle those materials after completing our production process. So, we can reuse those things and minimise our costs. So, we'll say the main factors are around the safety of the materials and our processes, and the quality. Now, they need to deliver very well within our lead time, and the focus should be on cost-effectiveness* (Participant-23). This shows that interview results provide significant mediation of CPD for MS and NPP. This is because many professionals acknowledge the importance of MS for CPD, which supports NPP. Although empirical evidence provides that MS does not directly improve short-term performance outcomes, under specific strategic and technological conditions, it may contribute positively to the long term. However, the study results do not support **H1a.**

Finally, indirect relationship postulated in H5a, which posits that AM affects NPP via CPD, was not significant ($\beta = 1.490$, $p = .142$), and thus H5a was not supported. This is likely because of the short-term limitations of AM, such as high cost, longer production time, poor productivity, and a lack of economies of scale (Baumers & Holweg, 2019; Ford & Despeisse, 2016). Furthermore, AM's environmental performance depends heavily on its processes and materials, and the circularity of outcomes depends on incorporating AM into product design (Kellens et al., 2017; Sauerwein et al., 2017). Despite the fact that AM facilitates repair, customisation, on-demand spare parts and efficient use of materials, these aspects of AM are likely to influence product life and efficient use of resources rather than cost, time and quality

associated with the launch stage that NPP represents (Despeisse et al., 2017; Sauerwein et al., 2019). However, the interviewees provided positive responses. Participant 1 from a garment retailer mentioned that "*Previously, manufacturers needed to submit samples four to five times. But when they go with the 3D design, they can reduce this process by 2 or 3. So, means out of five. It reduces 3 designs. It means 40% is a saving of material and resources*". Overall, these findings suggest that while AM supports CPD in theory, its practical contribution to new product performance remains limited. Based on these findings, hypothesis **H5a** is not supported.

Drawing on interview results, Table 3.17 illustrates the conceptual framework in which dynamic capabilities (sensing) and the mediating role of additive manufacturing support circular product design (seizing) to ensure new product performance (transforming). In addition to the quantitative items, participants in the qualitative interviews also mentioned material availability for continuous production, recycled materials instead of virgin materials, biodegradable or organic materials, nearby suppliers (longer distances mean higher carbon emissions), quality and price, cost, and safety during material selection for CPD

Table 3.17: Qualitative Model: Themes and Supporting Quotes

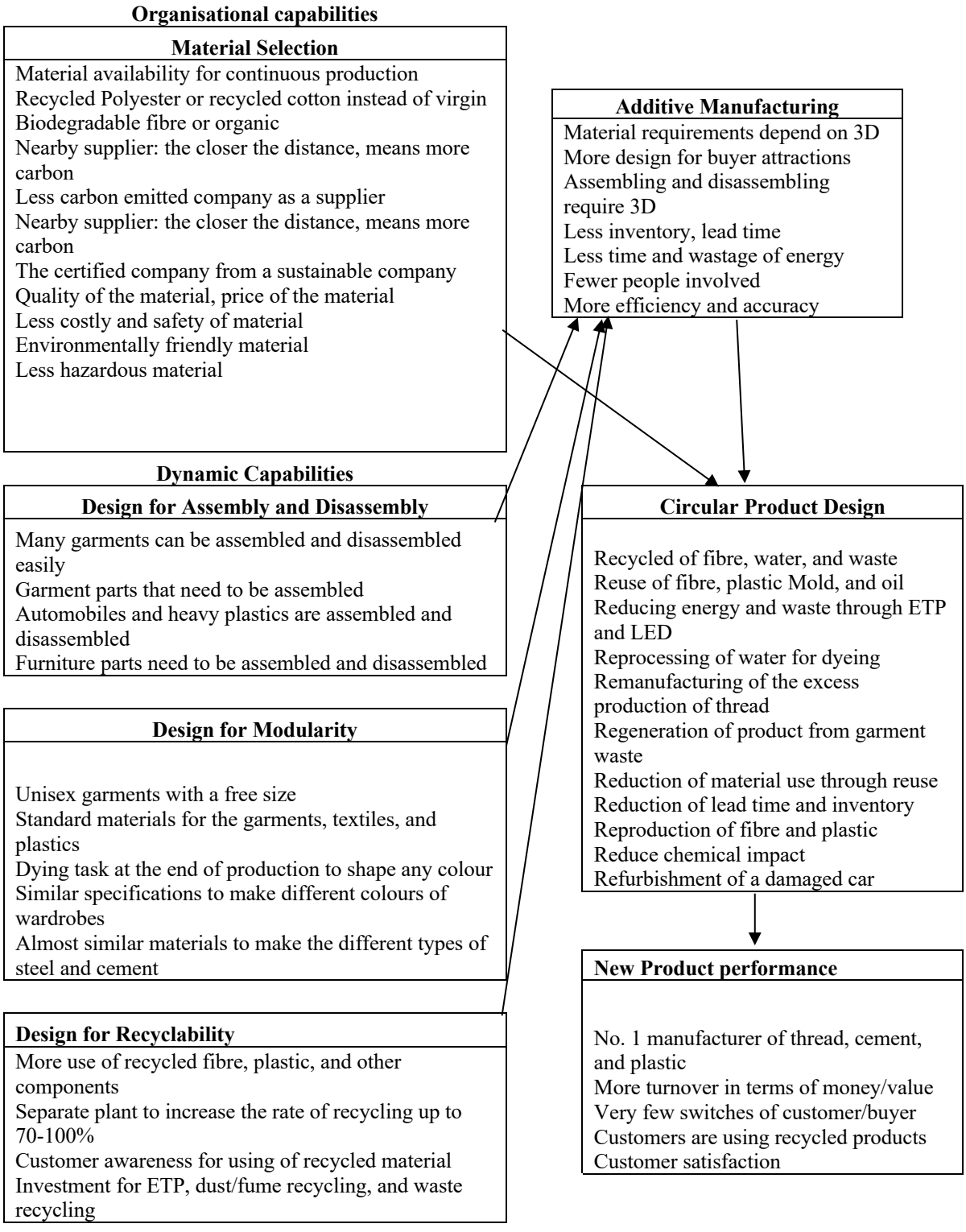


Figure 3.3: Qualitative Model: Themes and Supporting Quotes

In the qualitative analysis, the study found that many products require assembly and disassembly due to the technical specifications for garments, plastics, furniture, and automobiles. The study also found universal garment sizes and standard materials for producing different types of products. A colouring task should be performed at the end of the production process so that different colours can be delivered to make the products more modular. Modular practices are common in garment, textile, plastic, steel, and cement companies, where the same components are used across multiple products.

To ensure recyclability, most garments use recycled fibers, plastics, and other components as per buyer requirements. Customers are now very aware of recycled materials. Keeping this in mind, management invests heavily in installing an Effluent Treatment Plant (ETP) and establishing new recycling plants. The quotes noted that additive manufacturing supports the mediating role of dynamic design capabilities in the relationship with CPD. Finally, manufacturing firms can strategically operationalise circularity (CE) in product design (seizing) to ensure sustainability (NPP). Firms then satisfy their customers with more vibrant designs and sustainable products, thereby ensuring their own long-term success (transformation).

3.8 Conclusion

While circular product design is widely recognised as the initial thinking for the circular economy globally and in Bangladesh, little is known about it or the capabilities required for its effective transformation. This study provides a first-of-its-kind investigation of the relationship between the organisational and dynamic capabilities of material selection and design and digital technologies that may facilitate a systemic transition toward circular product design to ensure new product performance. The study analysed quantitative data from 313 respondents and qualitative data from 25 executives working in manufacturing firms, using SEM and content analysis to investigate the proposed hypotheses. Data were

collected only from employees who have either worked or are working in manufacturing firms that have adopted circular practices (R's strategies) for their routine operations. Based on a mixed-method study using a survey questionnaire and interviews in manufacturing companies in Bangladesh. The study findings revealed a novel extraction between different types of organisational and dynamic design capabilities to facilitate the transition towards product design in CE: (i) material selection, (ii) design for assembly and disassembly, and (iii) design for recyclability, with the design and manufacturing technology of additive manufacturing needed to accomplish the new product performance. However, the mediation results show that CPD did not mediate the relationship between MS, AM, and NPP, indicating that these three factors alone cannot enhance new product performance. This study makes several noteworthy contributions to the theory, practices, and policy.

3.8.1 Theoretical Contributions

Based on the findings, this study makes four key theoretical contributions.

First, it responds to the limited integration of dynamic capabilities and circular product design by extending DCT to explain how firms utilise sensing, seizing, and transforming processes to embed circular principles within product development. Prior studies have examined design capabilities mainly in relation to competitive advantage and strategic adaptation, yet few have explicitly linked them to circular product design practices. By integrating organisational capabilities such as material selection and design capabilities, including design for assembly and disassembly and design for recyclability, this study demonstrates how dynamic capabilities enable firms to reconfigure internal resources and routines to achieve circularity in product design and development (Eisenhardt & Martin, 2017; Teece et al., 1997).

Second, it addresses the ambiguity surrounding AM's role in CE product design. Previous research in developed contexts has explored AM as a form of technological innovation but has rarely examined its function as a design and manufacturing technology that facilitates

CPD (Sauerwein et al., 2019). This study clarifies that AM enhances product and material life cycles through product and process redesign, improvements in material input processing, make-to-order component and product manufacturing, and loop closure, all of which contribute to extending product lifecycles and reducing waste. By linking AM to DCs, the study conceptualises it not merely as a technological enabler but as a design and manufacturing technology that supports the transition toward circular manufacturing systems.

Third, this study aims to contribute to the research on connecting CPD with NPP. Past literature has studied CPD through systematic reviews, qualitatively, or narrowly focused on environmental or cost-related impacts (Aguiar et al., 2022), overlooking how CPD affects new product performance based on multiple dimensions (Nakata & Sivakumar, 1996). The empirical investigation of this study shows that CPD, driven by materials, DCs, and manufacturing technology, enhances NPP in terms of time, cost, quality, and customer satisfaction. All these results extend DCT by integrating all DCs within the CE context and by demonstrating how integrating material, design capabilities, and technological adoption drives both circular product design and greater product performance.

Fourth, this study contributes to the field of AM-driven CPD by foregrounding the role of dynamic (design) capabilities. It provides empirical evidence from a developing-country context, where such perspectives remain underexplored. However, the nonsignificant mediation effects in H1a and H5a indicate that neither MS nor AM improves NPP through CPD. This suggests that these capabilities require complementary skills, processes and resources to generate performance benefits (Sirmon et al., 2007; Teece, 2007). Additionally, MS appears more operational than dynamic because its effect does not occur through CPD-based reconfiguration, while AM may enable circular design without improving launch-stage cost, time or quality (Winter, 2003). Study findings further reinforce that dynamic capabilities are necessary but not sufficient for performance (Eisenhardt & Martin, 2017).

Finally empirical evidence from Bangladesh extends existing knowledge beyond dominant Western and advanced industrialised settings.

3.8.2 Managerial Implications

This study also provides valuable insights for practitioners, offering specific, useful information to support circularity and sustainability in product design within the manufacturing sector.

First, manufacturers should prioritise organic and recycled materials over virgin materials. Lowering environmental pollution and protecting natural resources can help achieve SDG 12 (Responsible Consumption and Production) and prevent pollution of land, air, and water, as CO2 emissions have increased substantially, with the manufacturing sector as the largest contributor. Furthermore, resource conservation and the protection of natural resources encourage more circular and sustainable practices of material selection and promote the overall objectives of SDG 13 (Climate Action), which aims to safeguard and protect against global warming (United Nations, 2015).

Second, managers can operationalise circular product strategies that can be easily assembled and disassembled. For this, they should determine the main factors influencing assembly and disassembly operations, whether the product can be easily repaired and replaced, or can be easily reused and refurbished. This will reduce disassembly time and, by increasing the economic feasibility of product lifetime extension, increase the viability of a CE in the manufacturing industry (Vanegas et al., 2018).

Third, despite non-significant effects, modular designs are closely related to circular product design and the development of new products. When designing a product based on modularity, managers should use standardised components, that is, the same components for different types of products, be flexible in terms of the use of components, ensure reuse in various types of components, and have a high degree of component carryover. For this, managers should

build or acquire specialised knowledge (e.g., product design, component selection, and implementation) to support the design of modular systems and adopt a comprehensive assessment to consider different factors when designing modularity-based strategies.

Fourth, managers generally extract materials from the environment, then use them to produce goods, and sell them in the market. After consumption and use, many recycling activities are needed before landfilling to reduce environmental damage. Keeping these activities in mind, a product can be designed to be recyclable, increasing recycling rates for raw materials, reusing recycled components, and allowing easy recovery at the end of its life.

Fifth, design is a sophisticated task in the manufacturing process. Managers take advantage of using additive manufacturing, which enables designers to think beyond traditional design for manufacturing. AM supports companies in improving the design process, reduces time and energy during manufacturing, and requires minimal or no inventory, thereby improving product development time and contributing to the CE.

3.8.3 Policy Implications

The study's results suggest several noteworthy policy implications for Bangladesh's manufacturing sector. Policymakers should adopt renewable energy systems and optimise energy consumption by integrating solar systems into industrial facilities. All these could significantly reduce production costs and carbon emissions to foster CPD and enhance NPP, while improving energy efficiency could result in long-term competitiveness (Islam & Hossen, 2025). Waste reduction, recycling, and remanufacturing must be incorporated into the policy, while optimising resources across the product's whole life cycle, consistent with the country’s emerging CE agenda (Ahmed et al., 2022).

For CE to CPD, product design innovation is central to this transition. Reward and inclusive policies for such as design for assembly and disassembly (DfAD), and design for recyclability (DfR), as these enhance maintainability, reuse, and material recovery (Johnson

& Wang, 1995; Sehnem et al., 2023). Furthermore, government-led schemes for carbon emissions and tax incentives should support firms adopting AM technologies to reduce waste and increase product repair and remanufacturing by accelerating design flexibility, all of which contribute to improved time, cost, and quality performance (Samford et al., 2017).

Policies regarding environmental compliance remain a critical agenda item. The mandatory installation and proper operation of Effluent Treatment Plants (ETPs) in all factories to treat wastewater should be rigorously enforced to reduce industrial waste, promote wastewater reuse, and prevent pollution (Islam et al., 2024; World Bank, 2021). Adopting these requirements aligns with Bangladesh's National Environmental Policy to achieve Sustainable Development Goals 12 and 13, ensure productivity and quality, and reduce costs within manufacturing operations (Salman et al., 2025). By integrating material selection capability with design and manufacturing technology, and CE and product design principles, policymakers can help manufacturing firms achieve both improved environmental performance and enhanced product competitiveness. Implanting circular design criteria in national industrial policies, tax incentives, and export standards will support the shift from traditional linear production to an environmentally friendly manufacturing ecosystem.

3.8.4 Limitations of the Study

Although the study made several contributions from both theoretical and practical perspectives, it also had several limitations. First, dynamic capabilities (DCs) themselves can vary considerably across contexts, particularly in more tech-driven contexts than in low-tech ones, influencing how firms leverage DCs for CPD (Teece, 2018), limiting the generalisability of the study. Second, the study mainly focuses on specific organisational capabilities, such as material selection and design capabilities, including design for assembly and disassembly, design for modularity, and design for recyclability, as well as design and manufacturing technology, such as additive manufacturing for CPD. These are not the only

DCs relevant to CPD, as other digital, design, and organisational capabilities may also contribute to CPD (Del Giudice, Scuotto, et al., 2021). Third, new product performance was assessed primarily through time-to-market, cost, quality, and customer satisfaction, although additional performance dimensions, such as environmental sustainability and innovation outcomes, could further support the NPP (Song & Xie, 2000). Fourth, the study collected data from more than 12 manufacturing industries. Therefore, differences in the measurement identifiers across industries could not be fully assessed, particularly given the relatively small subsample sizes and no measurement variance based on translation. Lastly, the study is based on a single dataset for paper 3 & 4, with the interview sample comprising only male respondents and few or no female respondents among the executives, which may limit the diversity of perspectives. Furthermore, the study has concentrated only on the large manufacturing sector, and data collection disrupted due to major political crisis that caused regime change in Bangladesh.

3.8.5 Directions for Future Research

Future research should extend the given theoretical framework and examine whether other theoretical lenses reveal further exploration capabilities, such as end-of-life thinking in product design, CSCM, business model innovation, sustainable organisational values (Burke et al., 2023), waste management, eco-design business models, product leasing, and collaborative commerce (Sehnem et al., 2023), to help understand how contextual like material selection and institutional differences influence the development and integration of DCs for CPD. As this study is the one of the beginning empirical study for study, further study advocates for exploration in other context (developing and developed) manufacturing and service firms to clarify how contextual and institutional differences, including (1) various industries and geographical locations, (2) partnerships with NGOs, industry associations, universities, and consultancies, and (3) distinct formal and informal governance mechanisms

to enhance inter-industrial and inter-sectoral capabilities for CPD. Future research should broaden the assessment of new product performance by incorporating additional dimensions such as environmental sustainability, innovation outcomes, and social impact. Expanding these metrics would provide a more comprehensive understanding of how CPD contributes to long-term product success and organisational competitiveness. Other digital technologies, along with additive manufacturing, could be examined in future empirical studies to better establish their roles in supporting CPD and new product performance. As data collected from more than 12 different manufacturing industries, future research should conduct multi-group CFA and measurement-invariance testing across manufacturing industries and translation to examine whether the measurement properties and relationships are consistent across industry contexts. In addition, future research could involve participants of various genders (male-female) and the investigation of additional manufacturing organisations in developing and developed nations. Moreover, expanding the research across industries and countries will allow us to examine the generalisability of the results.

The next chapter examines how three types of external pressures drive the implementation of circular supply chain management through top management commitment. It further analyses how these pressures influence three dimensions of sustainability performance, namely economic, environmental, and social.

Chapter 4: Adopting Circular Supply Chain Management for Sustainable Performance: The role of Top Management Commitment

4.1 Abstract

Due to transformation inertia, change is rarely initiated without external pressure, as individuals and organisations often resist voluntarily altering established practices despite the benefits. Therefore, transitioning the supply chain to a circular model necessitates not only overcoming challenges and barriers but also strategically aligning with institutional pressures, such as coercive, normative, and mimetic, and top management commitment to overcome resistance and address systemic challenges. The objective of this study is to examine how institutional pressures and top management commitment support the operationalisation of circular supply chain management (CSCM) practices and secure sustainability performance. In this study, a mixed-methods approach is used to investigate research questions about manufacturing firms in a developing country such as Bangladesh, with a focus on sustainable practices. The results confirm that top management commitment and all three types of institutional pressures positively support the successful implementation of CSCM and the achievement of all key sustainability performance indicators. Moreover, it directly reflects coercive, normative, and mimetic forces and indirectly reflects top management commitment in adopting CSCM to bolster sustainability performance. The study identifies the effects of institutional pressure and the visionary role of top management in securing the first-mover advantage to promote circular practices in the supply chain and achieve sustainability outcomes. Finally, the study discusses the theoretical and practical implications and provides directions for future study.

Keywords: Institutional Pressures, Circular Supply Chain Management, Manufacturing Companies, Developing Countries, Sustainability Performance.

4.2 Introduction

Over the past decade, research and practices in operations management (OM) have gradually experienced a paradigm shift from the traditional to a sustainability orientation (Gunasekaran & Ngai, 2012). Historically, OM has systematically focused on operational frameworks designed to enhance firms' effectiveness and profitability (Mouzas, 2006), promptly respond to customer needs (Kim et al., 2007), and the adoption of technology (Gunasekaran & Ngai, 2012). However, these practices often overlook essential measures to reduce carbon footprints, improve resource efficiency, and engage stakeholders in sustainable practices (Chan, 2021). Traditional practices also fall short in addressing global challenges, such as environmental degradation, resource scarcity, and food insecurity (Tashman, 2021). Circular mode of production has thus evolved as a distinctive field of study within the OM domain to address the limitations of traditional business models (De Angelis et al., 2018). These leads to the adoption of circular economy (CE) framework that replaces the old-fashioned model, is widely accepted in theory and practice (Kristoffersen et al., 2021; Masi et al., 2017) and has been officially adopted in China through the CE promotion law (Xue et al., 2010), and in Europe through the CE package (Hughes, 2017). Consequently, CE collaborates with supply chain management (SCM) principles to establish circular supply chain management (CSCM) and enhance resource utilisation by reducing waste (Zhang et al., 2021).

Integrating CE principles into SCM, referred to as CSCM, enables a circular business model and realises potential sustainability benefits (Alghababsheh, 2024). CSCM provides a practical way to apply CE principles within supply chains (Farooque et al., 2019). It focuses on closing material loops, reducing waste, and promoting the reuse and recycling of materials across the supply chain. The key elements of CSCM include product design, resource recovery, reverse logistics, and collaboration among supply chain partners (Farooque et al., 2019; Genovese et al., 2017). Moreover, adopting CSCM requires major changes in company

processes and structure. These changes can improve environmental, social, and economic outcomes (Hutchins & Sutherland, 2008; Klassen & Vereecke, 2012). However, implementing CSCM is challenging due to several barriers, including high costs, limited CE knowledge, resistance to change, and limited financial resources (Mangla et al., 2018). Additionally, the implementation of the CSCM depends on many factors. Among them, factor includes government regulations (de Lima et al., 2024), geographic context (Farooque et al., 2022), and technological readiness (Huang et al., 2022). External pressure and strong support from top management are also critical factors for CSCM. Managers' attitudes influence the extent to which a firm adopts circular practices (Alghababsheh, 2024; Udin et al., 2014). Additionally, top management commitment (TMC) helps secure investments, set goals, and overcome resistance (Geng & Sharpley, 2019). CSCM systems require time and money to build. In addition, not all firms see the same level of sustainability benefits (Hailemariam & Erdiaw-Kwasie, 2023; Tseng et al., 2023). In developing countries, adoption is slower owing to weaker infrastructure, skills, and policies (Mangla et al., 2018). Although CSCM is valuable for research, practice, and policymaking, its results depend on the developed and developing context, given its varied practices (Karim et al., 2022). This may stem from the fact that developed countries have the institutions to enact regulatory policies, thereby forcing the adoption of technological know-how and providing infrastructure for CSCM, in comparison to developing countries (Mangla et al., 2018). Transition towards CSCM is increasingly vital for developing context to address shortages of natural resources and excessive generation of industrial waste, particularly in manufacturing companies, where closed-loop material flows and reverse logistics are shown to improve sustainable performance, especially in the environmental dimensions, while supporting economic performance (Ellen MacArthur Foundation, 2016; World Bank, 2018).

Although CSCM is gaining momentum in both developed and developing contexts, few empirical studies examine how it is implemented under multiple pressures and with varying levels of top-management commitment. Empirical studies examine the role of institutional pressures on the adoption of CE in supply chains rather than full commitment from the management, i.e., the deeper internalisation and organisational routines (Calzolari et al., 2025; Farooque et al., 2019). Moreover, past literature identified the drivers and barriers to CE operationalisation, but with a limited focus on integrating the role of strategic leadership (top management) in shaping these pressures (Ouro-Salim & Guarnieri, 2023). Institutional theory (IT) is important to explain different pressures on CSCM. This may stem from the notion that redesigning the supply chain to a CSCM is impractical without addressing the different pressures from the parties in the supply chain. Drawing on the principles of institutional theory, external forces shape company behaviour, including the adoption of CE practices (Bag, Pretorius, et al., 2021; DiMaggio & Powell, 1983). These forces, called institutional pressures, can be coercive (laws and regulations), normative (social and professional norms), or mimetic (copying others). Such pressures push companies to act similarly (DiMaggio & Powell, 1983). Moreover, external forces help firms adopt CSCM, which improves sustainability by saving resources, reducing waste, and promoting reuse (Centobelli et al., 2020; Geng et al., 2023). Extant research has looked at how suppliers and customers influence firms, especially SMEs, to adopt circular practices (Agyabeng-Mensah et al., 2022; Jabbour et al., 2020). However, many studies combine supply chain actors with other stakeholders, like governments and NGOs. This makes it convincing to see the specific impact of institutional actors (internal and external) on CSCM (Jain et al., 2020).

Achieving sustainable performance relies heavily on effective CSCM practices. This aligns with circular modes of operation and ambitious long-term performance targets. However, little is known about how institutional pressures and top management commitment interact to

promote the adoption of CSCM for sustainable performance. A few studies have focused on the external pressures on firms (Zhu & Sarkis, 2007) and the influence of leaders on change (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019). Limited studies directly examine the performance and sustainability outcomes of TMC and CSCM (de Lima et al., 2024; Genovese et al., 2017). Past research has largely focused on the individual issues of institutional pressure and leadership in isolation. These analyses give limited consideration to how the two relate and to how the adoption of CSCM supports the application of circular practices across firms (Kirchherr et al., 2017). Furthermore, the extent to which CSCM mediates, in whole or in part, the association between institutional pressures and sustainability has not been empirically examined (Zeng et al., 2017). Institutional pressures have been identified in green supply chains (Zhu et al., 2013) and supply chain integration (Calzolari et al., 2025), yet their direct and indirect effects are not well established, particularly regarding top management commitment to adopting CSCM (Marculetiu et al., 2023). Existing research has yet to provide a comprehensive understanding of how firms can successfully implement CSCM. This study fills this knowledge gap by empirically examining TMC and institutional pressures in CSCM, seeking to address the following research questions (RQs):

RQ1: Does institutional pressure influence the adoption of circular practices in the supply chain, and how does the CSCM impact the sustainability performance?

RQ2: How does the commitment from top management support the execution of CSCM strategies and sustainability?

RQ3: How does top management commitment mediate the relationship between institutional pressure and CSCM for enhancing sustainability?

To get the answer to the RQs, the study investigate three institutional pressures (coercive, mimetic, and normative) based on IT (DiMaggio & Powell, 1983) and how these pressures

can significantly impact firms' decisions to adopt CSCM practices (Calzolari et al., 2023) and the interactive role of top management commitment for CSCM, and their impact on sustainability dimensions, i.e., social sustainability, economic sustainability, and environmental sustainability (Sahoo & Upadhyay, 2024).

This research makes three theoretical contributions to the CSCM literature. First, it offers a unified model that demonstrates the effects of both institutional pressures and top management commitment on effective CSCM adoption and, consequently, on sustainability performance. The effects of internal and external enablers occur one at a time rather than as separate components, thereby explaining the relationships in CSCM (Chen et al., 2022). This result contrasted with past empirical studies, which emphasised the pivotal mediating role of CSCM in transforming external pressure and internal leadership into a sustainable outcome (Genovese et al., 2017). Second, his study's results empirically show that institutional pressure's effectiveness depends on contextual factors, including economic rationale and policy convergence (Kirchherr et al., 2018). The results indicate that regulations are most likely to be effective when complemented by market opportunities (for instance, tax rebates), especially at an early stage of CSCM. This aligns with previous research on material sourcing, advancing our understanding of how policy design affects adoption (Agyabeng-Mensah et al., 2022). Third, the current study identifies TMC as a vital mediator that amplifies the influence of institutional pressures, especially under confined circumstances. The current study adds new insights into the interaction between leadership and institutional pressures in facilitating circular transitions by showing how leadership commitment and strategic intent can overcome implementation barriers by taking a couple of steps back (Geissdoerfer et al., 2017). From a practical perspective, the results provide practitioners with the guidance needed to design localised, context-dependent incentives and help managers

leverage leadership commitment to accelerate the implementation of CSCM across diverse industry contexts (Marculetiu et al., 2023).

The rest of the section is structured as follows. Section 4.3 provides the theoretical background with a comprehensive literature review. Section 4.4 theorised the development of research hypotheses and the proposed conceptual framework. Section 4.5 presents the research methods, and Section 4.6 presents the findings from the data analysis. Section 4.7 provides a detailed discussion of the findings. Finally, section 4.8 concludes the paper by outlining the theoretical, practical, policy implications, limitations, and possible avenues for future research.

4.3 Theoretical Background

Supply chains are genetically dynamic, forcing firms to adopt circular practices to enhance sustainable performance (Lu et al., 2024). Despite this growing transition, the underlying forces of CSCM remain insufficiently investigated or fully explained the practices of supply chains and their management, it is therefore necessary to examine CSCM practices as articulated in this empirical research; accordingly, the following sections synthesise the literature on CSCM, top management commitment, sustainability performance, and institutional theory to establish a robust theoretical foundation for this study.

4.3.1 Circular Supply Chain Management

Circular Supply Chain Management (CSCM) represents a production paradigm aimed at sustainable development. Within this framework, production systems perpetually acquire materials through recycling, remanufacturing, and reuse (De Angelis et al., 2018; Mangla et al., 2018). CSCM facilitates the continuous flow of raw materials, minimise waste, and safeguards the environment (Luthra et al., 2022). Moreover, CSCM enhances both economic and operational efficiency while offering substantial environmental benefits (Lieder & Rashid, 2016). However, effective implementation of CSCM requires alignment with

ecological imperatives and consensus among supply chain partners on decisions regarding recycling, remanufacturing, and reuse (De Angelis et al., 2018). Circular product flow is another critical component of the CSCM and can deliver strategic value across all company departments (Mollenkopf et al., 2011). The selection of appropriate suppliers is also pivotal for the success of CSCM, as suppliers must endorse the "R's" strategies (reduce, reuse, recycle, etc.) to ensure CSCM efficacy (Rizos et al., 2016). Furthermore, the development of human capacity is a significant factor in CSCM, as training enables employees to fully comprehend circular principles and their benefits, thereby fostering motivation and championing sustainability innovation (Ishaq et al., 2025).

4.3.2 Top Management Commitment

Top management significantly influences an organisation's strategy, alignment with sustainability goals, and the development of a culture that supports CE practices. This impact extends to other areas, such as financing for CE initiatives (Sharma et al., 2021). Top management acts as an indispensable facilitator of sustainability practices by providing strong support for circular projects and adopting improvements to CE practices across the company (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019). This commitment pays off through grants to explore technological innovations in circular production systems, such as digital tracking devices and recycling technologies (Lieder & Rashid, 2016). In addition, an attitude of openness to new sustainable management practices should be fostered among all future employees. A circular attitude from management encourages employees to adopt CE practices as a new way of life. This attitude also permeates and generalises throughout their entire work environment and family life. Moreover, top management's contribution to the development and discourse of CE concepts and activities in the organisation promotes employee health (Hofmann & Jaeger-Erben, 2020). Top management also provides the necessary training facilities to ensure that employees thoroughly understand circular practices

(Bocken et al., 2016). Furthermore, CSCM also demands coordinated action with suppliers. Hence, top management plays a key role in integrating relationships across the entire value chain, including supplier links and arrangements, thereby contributing to a more systemic approach to supply chain management in CE (Alghababsheh, 2024). Although extant studies acknowledge that top management commitment is a significant driver of sustainable supply chain practices (Dubey et al., 2017), empirical investigations specifically linking top management commitment to the adoption of CSCM for sustainability performance have not been explored (Farooque et al., 2019).

4.3.3 Sustainability Performance

Most prior literature suggests that CSCM enhances sustainability performance, but findings remain inconsistent and context dependent. Empirical studies confirm that CSCM practices positively influence environmental, social, and economic performance by improving resource efficiency and reducing waste (Farooque et al., 2019; Liu et al., 2023). However, evidence from other studies does not reliably confirm the sustainable benefits of CSCM. For example, although circular initiatives can improve environmental outcomes, this initially reduces financial performance due to high investment and operational costs (Yin et al., 2024). Similarly, firms need to make a trade-off between circular implementation and short-term profitability, particularly when technological and institutional infrastructures are underdeveloped (Del Giudice, Scuotto, et al., 2021). Moreover, firms should exercise greater caution to achieve sustainable performance from CSCM, as this integration is highly contingent on managerial commitment and contextual readiness; circular practices may even lead to inefficiencies if institutional or leadership support is not confirmed (Farooque et al., 2019). These mixed results highlight the need for further empirical research to clarify whether CSCM improves triple-bottom-line sustainability outcomes with a focus on the top

management commitment. The following sub-section delineates three key aspects of sustainability.

4.3.3.1 Environmental Performance

Over the past two decades of industrialisation, environmental performance (EnvP) has emerged as a central strategy within the manufacturing sector. This strategy focuses on the efficient utilisation of resources and the mitigation of adverse environmental impacts associated with production processes (Sarkis & Zhu, 2018). To this end, manufacturers are striving to minimise their environmental footprint and reduce operational costs by reducing waste, enhancing recycling efforts, and improving energy efficiency (Seuring & Müller, 2008). Nevertheless, manufacturers face significant challenges in addressing environmental issues, particularly in reducing solid waste accumulation. This necessitates the optimal use of energy resources, including water and raw materials, in production processes to curtail carbon emissions and pollution (Lieder & Rashid, 2016). For instance, EnvP significantly reduces waste through eco-design, energy-efficient machinery, and renewable energy sources (Sarkis et al., 2011). As the market increasingly prioritises environmental considerations, firms that adhere to environmental standards and regulations are better positioned to sustain their operations, enhance their public perception, and avoid penalties (Banerjee, 2001). Moreover, environmentally compliant companies effectively manage regulatory risks, achieve corporate advantages by fostering improved stakeholder interaction, and cultivate a positive reputation (Zhu et al., 2012).

4.3.3.2 Social Performance

Social performance (SocP) has emerged as a significant component of business success, and research has indicated its necessity for long-term viability. This compels companies to transcend mere financial outcomes by adopting ethical labour practices, engaging stakeholders meaningfully, and supporting community well-being to achieve sustainable

long-term growth (Carroll & Shabana, 2010). Empirical evidence demonstrates that companies prioritising ScoP enhance their reputations and gain greater stakeholder trust, thereby becoming more resilient to social and environmental challenges (Carroll & Shabana, 2010; Kramer & Porter, 2011). This highlights the notion that integrating social objectives, such as worker safety, equitable community relations, and improved quality of life, into business models, including CSCM, confers a competitive advantage. It also ensures compliance and legitimacy in society (Elkington, 1998; Howard-Grenville et al., 2019). CSCM enhances workplace safety through automation, improved waste management, and IoT-based hazard detection, significantly mitigating occupational risks (Genovese et al., 2017). Furthermore, it promotes cleaner production methods and involves employees in sustainability initiatives, resulting in healthier, more ergonomic, and satisfying work environments (Ghisellini et al., 2016). Beyond internal benefits, CSCM strengthens external relationships through recycling partnerships, transparent CSR activities, and collaboration with diverse stakeholders, thereby building trust and reinforcing a company's social license to operate (Bocken et al., 2016). Additionally, the CSCM enhances waste systems and creates local employment opportunities through remanufacturing and recycling, thereby improving living standards, air quality, infrastructure, and economic stability in nearby communities (Ellen MacArthur Foundation, 2020). Taken together, ScoP augmented by CSCM is not merely an ethical obligation but a strategic imperative for businesses seeking enduring success in an increasingly sustainability-conscious world.

3.3.3.3 Economic Performance

Manufacturing firms usually strive for economic performance (EcoP) by developing and increasing their market share (Szymanski et al., 1993). EcoP can be achieved through operational efficiency, attained by reducing costs through waste reduction and the consumption of virgin materials, the use of resource recovery, remanufacturing, extended

product use, and the extension of product lifecycles (De Angelis et al., 2018; Govindan & Hasanagic, 2018a). Additionally, EnvP can be improved if companies maintain and resell circular products to extend their lifecycles or enhance customer satisfaction (Bocken et al., 2016; Urbinati et al., 2017). CSCM helps managers during price changes and resource shortages. It also protects businesses from supply chain disruption (Rizos et al., 2016). Within the CE framework, profits may take longer and require high investment in infrastructure and product design (Batista et al., 2023). Companies that apply circular practices can gain an advantage over those that apply traditional practices. These practices help them lower costs, improve their market position, and meet the rising demand for sustainable products (Geissdoerfer et al., 2018; Kirchherr et al., 2018). Consequently, firms can measure their EcoP by how well they use CSCM and meet customer needs without losing product quality or value (Hofmann & Jaeger-Erben, 2020).

4.3.4 Institutional Theory

Institutional theory begins with the basic assumption that organisations do not adopt practices simply because they are efficient. Instead, organisations adopt such practices because of expectations in their broader operational environment either from domestic or international communities, and complying with those expectations ensures legitimacy, resource availability, and, ultimately, continued operations (DiMaggio & Powell, 1983; Meyer & Rowan, 1977). Institutional theory offers a strong framework for understanding CSCM. For most businesses, shifting from the linear approach carries high risks and costs, and the business case may not be evident at first. Under such circumstances, external forces from regulatory agencies, customers, industry associations, and rival organisations carry more weight in influencing the adoption process (Murray et al., 2017; Urbinati et al., 2017).

These pressures take three broad forms. Coercive pressure comes from both formal and informal pressures applied by those who influence the organisation, namely the state.

Coercive pressure operates through legal mandates, financial sanctions, and contracts (DiMaggio & Powell, 1983). In the EU, policies have focused on transforming production systems from linear models to product-life extension, reuse, remanufacturing, and recycling (Stahel, 2019). This regulation requires companies to reduce material use and integrate circularity into procurement, production, and product design (Lacy & Rutqvist, 2015), thereby supporting EPR implementation and waste reduction. Similar findings for Chinese companies operating in eco-industrial parks, where policies require them to adopt sustainable supply chains and CE capabilities (Zeng et al., 2017). Large customers can impose coercive circularity demands on suppliers through their codes of conduct and contracts (Glover et al., 2014). On the other hand, in cases where regulation and government involvement are either weak or ineffective, sustainability performance at firms is negatively affected (Kazancoglu et al., 2021).

Normative pressure (NP) arises through professionalisation that is a set of shared values, standards, and expectations generated by professional organisations, industry bodies, educational institutions, and certification systems (DiMaggio & Powell, 1983). Chambers of commerce and business federations are among the organisations that share knowledge on environmental responsibility in innovation and shape their members' behaviour (González-Benito et al., 2012; Popa et al., 2017). Environmental management standards and certifications, such as ISO 14001, and reporting guidelines, such as the Global Reporting Initiative (GRI), standardise such behaviour and make compliance visible to external stakeholders. Therefore, adopting CSCM becomes legitimate. Moreover, normative pressure increases awareness of the need for CSCM and helps turn practices that owners and managers initially view with scepticism into appropriate business behaviour (Scott, 2010). However, since certifications can be implemented without altering the underlying material flows, NP has a special potential for ceremonial implementation (Wijen, 2014).

Lastly, mimetic pressure (MP) describes how organisations imitate peers they see as successful or legitimate, especially amid uncertainty, ambiguous goals, or unclear technological processes (DiMaggio & Powell, 1983). Because circular economy models are new, technically sophisticated, and associated with uncertainty about benefits, these circumstances clearly apply to CE adoption. Organisations will find it easier to adopt the CE model by imitating success stories, as this offers a relatively risk-free way to adopt it, alleviate cost concerns, and demonstrate its value (Zhu & Sarkis, 2007). However, mimetic adoption can be superficial.

All these pressures are analytically distinct, but they tend to coexist and even conflict (Zhu et al., 2013). With recent innovations in IT, these changes' impact on CSCM is neither automatic nor universal. Rather, it is affected by the way in which the organisation views and reacts to the conflicting pressures (Greenwood et al., 2011; Williamson, 2008), the nature of implementation (substantive vs. ceremonial) (Bromiley & Rau, 2016), and the institution where the supply chain is positioned (Paluri & Mishal, 2020). Therefore, this research treats institutional pressures as antecedents whose influence on CSCM, as well as the phenomenon of decoupling, should be investigated.

4.4 Conceptualisation and Hypothesis Development

The following sections conceptualise the direct and indirect effects of institutional pressures and top management commitment on circular supply chain management practices, and, based on these, propose the relevant hypotheses.

4.4.1 Direct Effects

4.4.1.1 Coercive Pressures (CP) and Circular Supply Chain Management (CSCM)

The implementation of revolutionary changes typically requires such coercive pressures (CP). In practice, government regulations and policies are enacted to induce and encourage

businesses to influence manufacturing behaviour and supplier practices, particularly regarding sustainability. CP originates from external stakeholders and regulators to uphold environmental guidelines, compliance requirements, and legal frameworks that impose rules and standards on organisations (DiMaggio & Powell, 1983). These rules provide a clear framework and direction for businesses to adopt innovation and manage resources efficiently (Jabbour et al., 2019).

Consequently, regulatory authorities are responsible for establishing policies and procedures that promote the use of sustainable materials, waste reduction, and CO2 decarbonization practices, which are essential for closing the loop in the CE (Oladapo et al., 2024). Regulators also encourage investment in cleaner production processes through government initiatives such as environmental taxes, green subsidies, and cleaner production incentives that foster environmentally friendly practices (Li et al., 2022). These financial incentives inspire businesses to reduce environmental pollution and harmful CO2 emissions, thereby stimulating pro-environmental behaviours (van Valkengoed et al., 2022). Furthermore, these pressures are perceived as necessary to enhance and secure purchasing and supply chain practices for the widespread adoption of green practices and to assist firms in transitioning to a CSCM perspective (Hoejmose et al., 2014). Additionally, CP induces manufacturers to integrate circularity into their supply chains and contributes to the standardisation of sustainable practices across manufacturing companies. Moreover, regulatory requirements shape the manufacturer's mindset to implement green supply chain practices that improve eco-design (Royo et al., 2023) and promote circularity (Zhu & Sarkis, 2007). These pressures help businesses align with broader sustainability goals, thereby creating strategic advantages (Farooque et al., 2022). Thus, coercive pressure is a critical driver of systemic change and enables CSCM adaptation in the manufacturing industry. Hence, the study hypothesises the following:

H1: CP has a positive effect on improving the circular supply chain practices.

4.4.1.2 Normative Pressures (NP) and Circular Supply Chain Management (CSCM)

Theoretically, normative pressures (NP) are a significant social norm that governs institutional behaviour through the practices and expectations of trade associations (DiMaggio & Powell, 1983). These norms facilitate trade associations in implementing circular practices, such as resource recovery and waste minimisation in manufacturing firms, thereby fostering cooperation and advancing the CE (Singh & Joshi, 2024). Moreover, NP positively influences organisational engagement in innovation by transitioning from traditional to contemporary practices (Caprar & Neville, 2012). Transformation occurs when diverse groups adopt sustainable practices through programs and training. Global induction programs and employee education schemes increasingly incorporate sustainability into their practices alongside industry-specific requirements, thereby raising awareness among prospective employees and cultivating a workforce committed to sustainability (Santos & Silva Bastos, 2021). This initiative not only encourages businesses to adopt CE and promote sustainable business practices but also supports the development of sustainable products and future employees who carry their commitment to sustainability into the workplace and beyond (Delmas & Toffel, 2004). Consequently, by aligning organisational norms with broader societal and environmental goals, NP play a key role in promoting the widespread adoption of circular supply chain methods (Bocken et al., 2016). For example, CSCM seeks firms that meet sustainability standards and provide access to their resources, such as special training to adopt circular strategies (Kazancoglu et al., 2021; Rizos et al., 2016). Empirical findings reveal that NP facilitates the incorporation of green innovation and stakeholder engagement, paving the way for the creation of closed-loop supply chain models necessary for CSCM (Zhang et al., 2023). This leads firms to adopt sustainable practices to enhance their legitimacy and competitiveness, as well as to meet the expectations of trade associations

and industry norms (Quairel-Lanoizelée, 2011). Hence, NP creates a stronger promise for greater CE practice (Calzolari et al., 2023). Based on the literature, the study proposes the following hypothesis:

H2: NP has a positive effect on improving the circular supply chain practices.

4.4.1.3 Mimetic Pressures (MP) and Circular Supply Chain Management (CSCM)

Mimetic pressures (MP) emerge when organisations attempt to imitate successful firms' adoption of circular components for CSCM (DiMaggio & Powell, 1983). Manufacturing firms facing strong competition in environmental and sustainability are often led by executives who have successfully adopted CSCM strategies, including recycling, remanufacturing, and resource recovery (Agyabeng-Mensah et al., 2022). This transformation helps firms meet stakeholder expectations while simultaneously improving their market competitiveness by strengthening their circularity reputation. However, the adoption of CSCM under MP depends on how easily a company can adopt and follow the practices of leading companies in its domain. Firms whose competitors are highly proactive allocate resources to integrating circularity into their supply chains, thereby strengthening alteration principles and yielding positive sustainability benefits for subsequent companies. Furthermore, when strong support for supply chain integration and cross-functional collaboration is required, MP can accelerate the diffusion of circular practices across companies (Calzolari et al., 2023). Thus, MP serves as an external institutional driver of CSCM adoption. Thus, the study hypothesises the following:

H3: MP has a positive effect on improving the circular supply chain practices.

4.4.1.4 Top Management Commitment (TMC) and Circular Supply Chain Management (CSCM)

Top management commitment (TMC) drives strategic alignment, resource allocation, and organisational change that support CSCM implementation. Circular practices encompass the

redesigning of the existing supply chain based on CE principles such as resource efficiency, product durability, recycling, and closed-loop logistics (Geissdoerfer et al., 2017). The successful adoption of such practices requires not only operational adjustments but also strategic shift, both of which are largely influenced by top management. TMC to the circular use of resources, as well as allocating the necessary financial and human resources, and embedding circular goals that align with corporate strategy and decision-making processes (Zhu & Sarkis, 2004). Management also supports the internal functioning of CSCM initiatives by facilitating departmental collaboration and employee engagement. However, a lack of leadership commitment often results in fragmented efforts and symbolic compliance, undermining the effectiveness of such initiatives (Bourdin & Jacquet, 2025). Therefore, we can conclude that TMC may be seen as a foundational force that mobilises the organisation toward the successful and sustained implementation of CSCM. Hence, the study can propose:

H4: TMC has a positive effect on improving the circular supply chain practices.

4.4.1.5 Circular Supply Chain Management (CSCM) and Sustainability Performance

The CSCM procedure is grounded in the process of recycling, reusing, and remanufacturing materials and resources to ensure the circular flow of products and improve environmental performance (EnvP) by enabling firms to align with circularity that promotes sustainability (Alghababsheh, 2024). Moreover, environmental regulations have increased owing to increased consumer demand for green practices and pressure from other stakeholders. Consequently, operating firms are adopting circular strategies, including resource recovery, product life extension, and waste minimisation (Wang et al., 2022). These practices minimise the use of virgin resources and reduce environmental degradation by promoting R strategies (Geissdoerfer et al., 2017). Consequently, firms that operationalise circular practices must meet external environmental expectations and achieve lower emissions, reduced landfill use, and improved overall sustainability outcomes (Kirchherr et al., 2018). For example,

Kingfisher transformed its existing value chain into a circular value chain as part of its environmental strategy and set targets to reduce Scope 1 & 2 emissions by 68% by 2030 and Scope 3 by 46% by 2030 (Kingfisher, 2024). Thus, circular practices serve as a strategic response that enhances EnvP while aligning with the evolving societal and regulatory demands. Based on the literature, the study proposes the following hypothesis:

H5: CSCM has a positive effect on improving environmental performance.

CSCM also boosts social performance (ScoP) by fostering ethical responsibility, employee engagement, and community development. This is because of growing societal concerns regarding maintaining labour standards, environmental fairness, and corporate clarity. Therefore, firms are increasingly adopting circular practices that prioritise resource acquisition and social impact by localising materials sourcing and increasing employment opportunities through reverse logistics and remanufacturing (Dowlatshahi, 2010). Kingfisher, for example, emphasises social goals by showing commitment towards colleagues and communities (apprenticeships, inclusivity) (Kingfisher, 2024). Moreover, circular practices help reduce negative social externalities and promote equitable supply chain performance (Murray et al., 2017). ScoP generally occurs by improving company reputation, fostering trust among employees, and contributing to broader social well-being (Batista et al., 2023). Thus, circular practices are a strategic approach that aligns business operations with societal values, leading to stronger social performance. Hence, the study proposes the following hypothesis:

H6: CSCM has a positive effect on improving social performance.

CSCM is not only positively related to environmental and social performance but also positively associated with economic performance (EcoP) when firms integrate circular practices. The extant literature indicates that CSCM has a significant positive effect on costs and financial performance (Farooque et al., 2022). CSCM instigates EcoP by reducing

material and input costs through reusing, remanufacturing, and recycling strategies, which ultimately reduces the use of virgin materials (Farooque et al., 2019). CSCM also boosts the profitability and financial performance by improving resource productivity (Genovese et al., 2017). Additionally, EcoP not only meets firms' external expectations but also leads to tangible economic benefits. For example, the Nike footwear company reuses manufacturing scraps and end-of-life footwear during production, reducing input costs and improving resource efficiency (Nike, 2025). However, the study considers the short-term negative economic performance of CSCM. Therefore, CSCM contributes to enhanced EcoP in the long run through operational improvements and circular practices. Thus, the study proposes the following hypothesis:

H7: CSCM has a positive effect on improving economic performance.

4.4.2 Indirect Effects

4.4.2.1 The Mediating Role of Top Management Commitment (TMC) on the Relationship between Coercive Pressures (CP) and Circular Supply Chain Management (CSCM)

The study already highlighted that coercive pressures (CP) arise from regulatory frameworks and legal procedures to accommodate sustainable practices, but these external forces might not yield meaningful change if top management lacks commitment. Understanding these challenges, turning them into strategic initiatives, and investing the required funds for circular supply chain processes depend on top management commitment (de Lima et al., 2024). Additionally, new business models, such as CE practices, require incorporating the organisation's goals and long-term vision into top management's commitment to overcome organisational resistance (Jain et al., 2020). Therefore, CE requires top management support for resource allocation (Govindan & Hasanagic, 2018a) and companies' intent to implement innovative supply chain management (Alaskar et al., 2021). Furthermore, CE philosophy is greatly influenced by interactions among different supply chain actors and by the handling of CP, which is facilitated by TMC (Calzolari et al., 2025). Therefore, CP can facilitate CSCM adoption, which relies heavily on top management commitment to convert external demands into internal actions and resource allocation (Zhu & Sarkis, 2007). This is because top management often acts as a vital mediator, allowing firms to respond proactively to CP and engage in CSCM. Thus, the following hypothesis is proposed:

H8a: TMC mediates the positive relationship between CP and CSCM.

4.4.2.2 The Mediating Role of Circular Supply Chain Management (CSCM) on the Relationship between Coercive Pressures (CP) and Sustainable Performance

Manufacturing firms typically adopt many measures to achieve sustainable performance, not only voluntarily but also because of regulatory and institutional pressure (Scott, 2010). These external pressures do not always support circular practices, as their implementation also

depends on senior leadership's attitude and involvement. When top management fails to invest in or prioritise circular activities, circular practices do not occur, and circular operations remain stagnant (Geissdoerfer et al., 2023). Moreover, circular practices improve environmental performance by reducing waste, increasing resource efficiency, and enforcing environmental regulations (Genovese et al., 2017). Consequently, these external pressures indirectly influence companies to adopt more efficient production processes, reduce waste, and reuse and recover materials, which, in turn, improves the efficiency and profitability of the industry and promotes social welfare through ethical sourcing, closed-loop systems, and waste reduction, helping firms meet regulatory standards and improve the working environment, employee benefits, and overall social protection (Geissdoerfer et al., 2018; Zhu & Sarkis, 2007). Additionally, circular practices help reduce the cost of producing materials, use them economically, and convert waste into valuable resources by promoting sustainable supply chain management through resource efficiency and reverse logistics practices (Genovese et al., 2017; Kazancoglu et al., 2021). Based on the above, it can be concluded that circular practices are mainly influenced by external pressures to adopt structurally circular practices to achieve environmental, social, and economic performance. Therefore, the following hypotheses can be proposed:

H8b: CSCM mediates the positive relationship between CP and environmental performance.

H8c: CSCM mediates the positive relationship between CP and social performance.

H8d: CSCM mediates the positive relationship between CP and economic performance.

4.4.2.3 The Mediating Role of Top Management Commitment on the Relationship Normative Pressures (NP) and Circular Supply Chain Management (CSCM)

Normative pressures (NP) consist of professional norms and social pressures that influence firms to adopt sustainable and circular practices (DiMaggio & Powell, 1983). External pressure doesn’t always lead to circular practices. A lot depends on whether senior managers

care about them and get involved. If top managers don't spend money on circular activities or make them a priority, nothing happens and progress not moving forward (Zhu & Sarkis, 2007). Moreover, a lack of top management commitment (TMC) can derail NP and pose a significant obstacle to the operationalisation of circular practices (Kirchherr et al., 2018). TMC is vital for interpreting and prioritising industry expectations, allocating resources, and integrating sustainability into operations (Wijethilake & Lama, 2019). Therefore, NP may not lead to circular practices alone unless support comes from the top and top management provides positive commitment. When top management does not commit to the change process, firms will not obtain a strategic direction for change and will not shape organisational norms to implement various practices in their circular practices. Thus, the study can propose the following hypothesis:

H9a: TMC mediates the positive relationship between NP and CSCM.

4.4.2.4 The Mediating Role of Circular Supply Chain Management (CSCM) on the Relationship between Normative Pressures (NP) and Sustainability Performance

Circular practices serve an essential mediating function in converting normative pressures (NP) into improved environmental, social, and economic performance. NP generally sets expectations for associations that influence organisations to align their operations with sustainability principles (Scott, 2010). Nonetheless, these efforts alone will not result in significant business performance unless operationalised through strategies such as circular practices by ensuring resource recovery, closed-loop systems, and remanufacturing. Moreover, circular practices allow companies to reduce waste and emissions and transform normative responsibility into quantifiable environmental performance (Geissdoerfer et al., 2017). In addition to environmental performance, social performance is achieved by following proper labour practices, focusing on local employment, community engagement, and sourcing from nearby locations when companies work with reverse logistics and CE

(Batista et al., 2023; Murray et al., 2017). From an economic perspective, increased cost efficiency and new revenue streams from standard practices, such as material reuse and lengthened product life cycles, are considered standard economic benefits for sustainable growth and competitiveness through circular practices (Genovese et al., 2017). Thus, it illustrates that circular practices are relied on as a strategic means to transform external NP into value in the form of social, environmental, and economic benefits. Hence, the study suggests the following hypotheses:

H9b: CSCM mediates the positive relationship between NP and environmental performance.

H9c: CSCM mediates the positive relationship between NP and social performance.

H9d: CSCM mediates the positive relationship between NP and economic performance.

4.4.2.5 The Mediating Role of Top Management Commitment (TMC) on the Relationship between Mimetic Pressures (MP) and Circular Supply Chain Management (CSCM)

Top management initiatives provide fundamental momentum in shaping how organisations handle MP during CSCM execution. MP generally prompts enterprises to replicate the successful practices of industry leaders or rivals, particularly in contexts characterised by uncertainty, to acquire legitimacy and maintain their competitiveness (DiMaggio & Powell, 1983). These pressures often push firms to adopt sustainability practices, such as resource recovery, closed-loop systems, and product life extension. However, the extent to which these pressures translate into meaningful change depends largely on top management's commitment and willingness to act. Top executives set the vision and strategic direction that prioritise sustainable practices within the organisation, aligning them with both internal goals and external expectations (Bocken et al., 2016; Zhu & Sarkis, 2004). TMC is essential for ensuring that MP leads to substantive actions rather than superficial compliance. Moreover, support from top-level management facilitates the successful adoption of CSCM by fostering a culture of sustainability, securing investments in green technologies, and aligning

performance metrics with those of other leading companies (Govindan & Hasanagic, 2018a). Additionally, top management allocates essential resources, including financial backing and human resources, to proficiently execute circular practices. In this context, TMC acts as an intermediary between MP influences and the internal mechanisms necessary for the effective adoption of circular practices, thereby ensuring that imitated practices culminate in enduring sustainability outcomes (Kemp et al., 2005). Thus, firms can adopt CSCM to implement meaningful circular practices based on the MP, but their impact is amplified only when internal enablers, such as TMC and organisational capability, are in place. Hence, the study proposes the following hypothesis:

H10a: TMC mediates the positive relationship between MP and CSCM.

4.4.2.6 The Mediating Role of Circular Supply Chain Management (CSCM) on the Relationship between Mimetic Pressure (MP) and Sustainability Performance

Manufacturing firms also face mimetic pressures (MP), which occur when firms imitate the practices of successful competitors to maintain their legacy (DiMaggio & Powell, 1983). Firms that face MP usually implement sustainable practices to conform to the environmental and social responsibilities of their market leaders and stakeholders. Drawing on IT, firms often imitate industry leaders to gain legitimacy, particularly in sustainability-driven markets. By implementing circular practices (e.g., recycling, remanufacturing, and green procurement), firms can systematically convert external imitation pressures into measurable environmental gains, such as reduced emissions, lower resource depletion, and improved eco-efficiency (Sarkis et al., 2011). Firms facing strong MP are likely to adopt CSCM practices by emulating competitors who have successfully implemented CE initiatives (Zhu et al., 2013). This imitation occurs particularly in industries that improve worker safety and labour conditions in supply chains (Ghisellini et al., 2016). Moreover, CSCM implementation enhances economic performance by driving resource productivity gains (Ellen MacArthur

Foundation, 2017) and generating cost savings through waste reduction and byproduct utilisation. Additionally, it creates new revenue streams via circular business models (e.g., product-as-service), improves resilience to resource price volatility (Genovese et al., 2017), and facilitates access to green financing and investments. Accordingly, the study suggests the following hypotheses:

H10b: CSCM mediates the positive relationship between MP and environmental performance.

H10c: CSCM mediates the positive relationship between MP and social performance.

H10d: CSCM mediates the positive relationship between MP and economic performance.

4.4.2.7 The Mediating Role of Circular Supply Chain Management on the Relationship between Top Management Commitment and Sustainability Performance

CSCM serves as a mediating mechanism between TMC and sustainability performance in the economic, social, and environmental dimensions. For environmental performance (EnvP), the relationship between TMC and CSCM is strong, as circular practices support sustainability commitments and ecological benefits. Circular practices can be instituted via eco-design requirements, supplier sustainability and circularity standards, and purchasing guidelines (Rizos et al., 2016). TMC supports circular practices through eco-design directives, supplier sustainability guidelines and circularity performance (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019). Circular practices bring environmental benefits through closed loops of material flows that decrease resource extraction, energy-efficient reverse logistics networks that reduce carbon footprints, and industrial symbiosis relationships that decrease waste (Ghisellini et al., 2016). Prior studies have concluded that EnvP improvements when using CSCM are superior to alternative linear strategies, as evidenced by reductions in emissions, water use in remanufacturing, and hazardous waste generation across all industries (Khan et al., 2021).

Regarding social performance, TMC's impact on circular practices is reflected in three ways: through ethical supply chain management practices, stakeholder collaboration, and investment in human capital (Murray et al., 2017). Circular practices build on this by institutionalising fair labour practices and extending community involvement to include activities such as recycling and take-back systems. It also fosters inclusive growth through circular value, in part formed by small and medium-sized enterprises (De Jesus & Mendonça, 2018). Prior research has demonstrated the contribution of circular practices to various social indicators. This includes ensuring workers' health and safety during recycling operations, fair sharing of benefits in reverse logistics, and fostering consumer awareness through the creation of cycle-proof product designs (Masi et al., 2017). Through such mediation, TMC's concept of TMC within circular innovation creates value beyond the scope of traditional CSR initiatives (Jabbour et al., 2020).

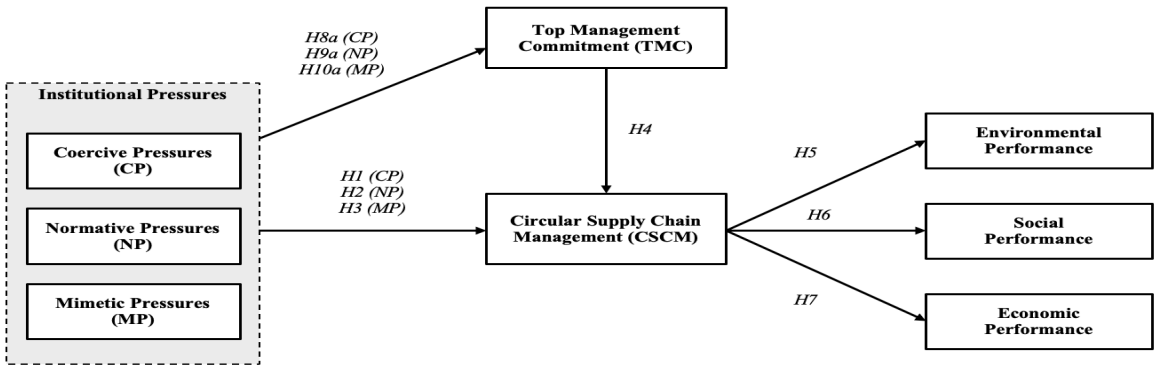
To improve economic performance, TMC promotes the adoption of CSCM by providing the support needed to encourage innovation in circular business models (CBMs) (Kirchherr et al., 2018; Lieder & Rashid, 2016). These innovations now embody circular practices: remanufacturing and waste-to-value conversion with a focus on product life extension and designs for all (Geissdoerfer et al., 2017; Genovese et al., 2017). Furthermore, as the existing literature indicates, circular practices can foster managerial sustainability intentions when linked to economic benefits, rising above such interests to support CE principles (Jabbour et al., 2019; Mangla et al., 2020). Based on the above analysis, the study proposes the following hypotheses:

H11a: CSCM mediates the positive relationship between TMC and environmental performance.

H11b: CSCM mediates the positive relationship between TMC and social performance.

H11c: CSCM mediates the positive relationship between TMC and economic performance.

Drawing on the literature and proposed hypotheses, Figure 1 (a,b) presents a theoretical framework that highlights the direct and indirect relationships between the variables.



Note. CP = Coercive Pressures; NP = Normative Pressures; MP = Mimetic Pressures; TMC = Top Management Commitment; CSCM = Circular Supply Chain Management. Mediation hypotheses (H8b–d, H9b–d, H10b–d, H11a–c) are shown in Figure 1b.

Figure 4.1 (a): Theoretical Framework (Direct Path)

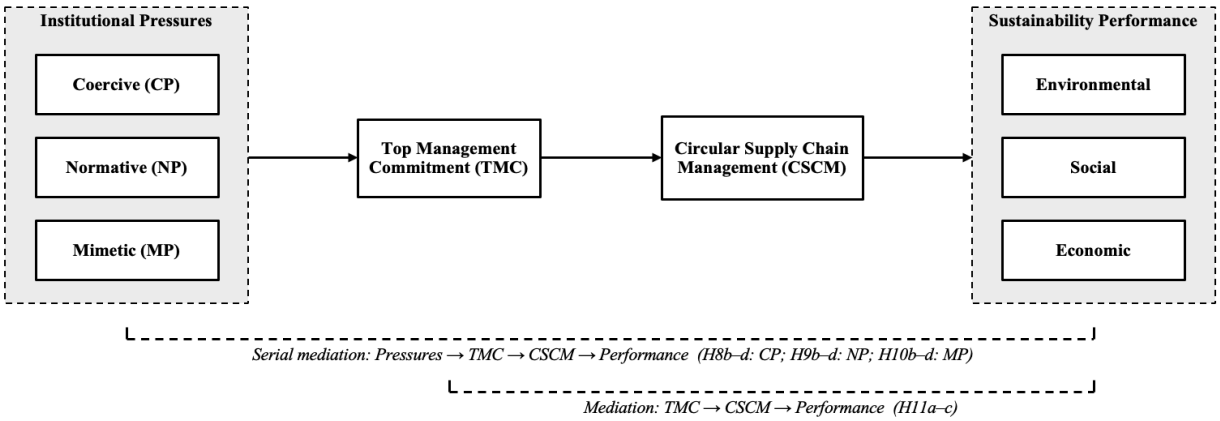


Figure 4.1 (b): Theoretical Framework (Indirect Path)

4.5 Methods

The literature on CSCM, which is distinguished by its complexity and encompasses a range of environmental, economic, and social variables, is best investigated using a mixed-methods approach (Heaton et al., 2022). As this context is constantly evolving, using a single approach to study it is unlikely to provide a comprehensive perspective. Mixed methods provide a broader perspective that includes surveys and other quantitative data alongside interviews.

Using a mixed-methods approach, the study begins with a quantitative phase to identify statistical patterns and test the proposed relationships. The subsequent qualitative phase will then be used to probe these results in greater depth, allowing for triangulation and stronger interpretive validity (Creswell, 2013; Tashakkori & Teddlie, 2010). Moreover, mixed-method techniques further yield more thorough and trustworthy results, as ideas around CSCM are still evolving (Bryman, 2016).

While the qualitative method is based on collecting data from a manufacturing perspective (e.g., professionals) to explain the reasons behind these trends and to demonstrate what is required for CSCM, including suppliers, necessary investments, human resources, and digital technologies. This knowledge is crucial in developing fields such as CSCM, where developing realistic, well-founded plans requires a better understanding of how to implement these motives (Tashakkori & Teddlie, 2010). Due to the limited focus of CSCM existing literature, mixed methods can fill these gaps by combining qualitative insights with quantitative data, thereby providing theoretical and practical contributions to further research (Kumar & Rahman, 2016). Additionally, this method facilitates the development of practical, context-sensitive solutions, in which qualitative data informs tailored interventions or policy recommendations and quantitative data yields quantifiable outcomes (Creswell & Creswell, 2017). Using quantitative methods first provides a structured foundation for the inquiry, while the qualitative stage helps triangulate results, clarify unexpected findings, contextualise observed patterns, and enhance the robustness of the overall interpretation (Bryman, 2016; Creswell & Creswell, 2017).

4.5.1 Quantitative Study

4.5.1.1 Research Design

This quantitative study aimed to explore the connections between the characteristics of overall institutional pressures, namely, coercive, normative, and mimetic pressures related to

circular supply chain practices, and the mediating influence of top management's commitment to achieving sustainability performance. To test the research framework for this study, suitable measures and models were considered and selected. The researcher first conducted a pilot study with academics, supply chain professionals, and executives in the research and manufacturing companies. During the pilot study, a copy of the questionnaire was sent to eight participants, and one participant was contacted to discuss the study matter and encourage them to evaluate the items thoughtfully. Five participants provided feedback and suggested clarifying ambiguities in the wording, format, and applicability of the questions. During these discussions, some participants noted that a few items were confusing or ambiguous, prompting changes and improvements to the questionnaire to enhance clarity and accuracy. Additionally, based on their practical experience, it was suggested that the study exclude certain types of manufacturing firms (such as the paint industry), where a recycling process is not traditionally suitable. The feedback from the study participants was carefully considered and incorporated into the questionnaire study design to improve its focus, relevance, and methodological integrity. Based on the pilot study results, the survey instruments were revised to collect detailed information about the variables. The revision was done to make the questions easier to understand and to adapt them to their practical terms.

Then the study employed a two-step approach to select the measures for the research model. Initially, the measures started with a thorough review of the existing literature to identify measures suggested by previous research. Based on the collected measures and results, the study utilised cross-sector illustrative triangulation as data from more than 12 different industries, a methodological approach that integrates multiple methods or data sources to enhance the comprehensive understanding of phenomena (Meydan & Akkaş, 2024; Patton, 1999). The purpose of using triangulation was to minimise the limitations of a single strategy, thereby enhancing the ability to interpret the findings (Thurmond, 2001). Among the four

types of data triangulation (Patton, 1999), the study employed data source triangulation. Triangulation provided two advantages in the present study. First, it supports validity and reliability, which are crucial for accurately interpreting results (Thurmond, 2001). Second, the questions became more concrete through the triangulation process, as they were clear to respondents during the interviews.

4.5.1.2 Scale Development

The measurement items in this study are based on established scales from existing literature (See Appendix 3). Coercive pressures (CP1–CP5) are measured using the instruments from Prieto-Sandoval et al., (2018). Normative pressures (NP1–NP4) are measured using questions from Zhu & Sarkis (2007). Mimetic pressures (MP1–MP3) are measured using scales derived from Zhu & Sarkis (2007). Top management commitment (TMC1–TMC5) is measured using questions from Despeisse et al. (2017). Circular supply chain management (CSCM1–CSCM4) is assessed using the instrument developed by De Lima & Seuring (2023). Finally, economic performance (EcoP1–EcoP4), environmental performance (EnvP1–EnvP3), and social performance (SocP1–SocP4) are measured using scales from Abdul-Rahid et al., (2017). All constructs are operationalised using a five-point Likert scale (1-5). Table 4.1 summarises the details and references for each variable.

Table 4.1: Literature Used in Measurement Development

Construct	**Source**	**Measurement Scale**
Coercive Pressure	(Prieto-Sandoval et al., 2018; Zeng et al., 2017)	Likert scale (1-5)
Normative Pressure	(Colwell & Joshi, 2013; Dubey, Gunasekaran, Childe, Blome, et al., 2019; Wang, Wang, et al., 2019; Zhu & Sarkis, 2007)	Likert scale (1-5)
Mimetic Pressure	(Colwell & Joshi, 2013; Wang, Wang, et al., 2019; Zhu & Sarkis, 2007)	Likert scale (1-5)
Top Management Commitment	(Colwell & Joshi, 2013; Despeisse et al., 2017; Lopes de Sousa Jabbour et al., 2018)	Likert scale (1-5)
Circular Supply Chain Management	(De Lima & Seuring, 2023; Del Giudice, Chierici, et al., 2021)	Likert scale (1-5)
Environmental Performance	(Abdul-Rashid et al., 2017; Adebanjo et al., 2016; Dey et al., 2020)	Likert scale (1-5)
Social Performance	(Abdul-Rashid et al., 2017; Adebanjo et al., 2016; Dey et al., 2020)	Likert scale (1-5)
Economic Performance	(Abdul-Rashid et al., 2017; Adebanjo et al., 2016; Dey	Likert scale (1-5)

	et al., 2020)	

To maintain data quality, the researcher initially created the questionnaire in English and then translated it into Bangla to ensure that the items were comprehensible. The English instrument was translated into Bangla using a forward-and-back translation process. First, a bilingual translator familiar with the study context translated the original English version of the instrument into Bangla. Another bilingual translator who did not participate in the initial translation independently back translated the Bangla version into English. The researcher then compared the original English version with the back-translated version to identify meaning differences and assess conceptual equivalence. Finally addressed all differences found to achieve conceptual and semantic equivalence between the two versions.

4.5.1.3 Control Variables

In this study, several variables related to individual and organisational factors have been controlled. Individual factors included gender, age, academic background, and work experience (Riketta, 2005). Organisational factors encompassed company age, industry type, and firm size, measured by the number of employees: small (<50), medium (50–249), and large (>250) (Braun & Clarke, 2006). Larger and older firms may have more resources to enhance business and operational performance (Miller & Le Breton-Miller, 2005). Additionally, the study accounted for experience within the current company, which may influence circular supply chain management practices. Controlling for organisational and individual factors helped the study combine circular practices despite their differences, which typically do not influence circular-related behaviour (Podsakoff et al., 2012). These variables also reflected factors that earlier research had shown to shape the uptake of environmental and circular practices, which strengthened the internal validity of the analysis (Delmas & Pekovic, 2018).

4.5.1.4 Sample Selection

In this study, a survey-based method is being used within Bangladeshi manufacturing companies for two reasons. First, Bangladeshi manufacturers typically implement circular practices only when mandated by international buyers, as most firms lack the internal motivation or resources to voluntarily adopt such sustainability measures (Nath et al., 2025). Second, the capital-intensive nature of CE transitions creates significant barriers for Bangladeshi manufacturers, who operate on thin profit margins (Salman et al., 2025). For the sample selection, manufacturing firms with experience in sustainability practices were selected due to the nature of their operations, i.e., working with sustainable suppliers. Two criteria were used to select potential respondents of the questionnaire: (1) those who have at least one year of experience, and (ii) only manufacturing firms that have circular types of production (R's Strategies), except service organisations like banks. Circular-based manufacturing practices involve recycling, reusing, or reducing resource use. Based on the above two criteria, a list of garments and textiles, and professional bodies such as the Institute of Cost and Management Accountants of Bangladesh (ICMAB), the Chittagong University MBA Association, and the Chittagong University Management Association, was selected as the proposed sampling population. The researcher selects professional bodies and networks to gain access to executives whose professional backgrounds align with the study objectives, thereby strengthening the relevance and validity of the sample. These organisations also tended to attract experienced and engaged members, increasing the likelihood of informed, accurate, and credible responses.

4.5.1.5 Data Collection

For data collection, single cross sectional data set driven by online survey links were distributed to more than 750 respondents using Google Forms. Respondents were initially approached via purposive non-probability sampling supplemented by snowball within the

selected organisations, after which snowball, sampling was used to distribute the questionnaire to relevant and knowledgeable participants. Purposive non-probability sampling improves representativeness and minimises selection bias, whereas snowball sampling is particularly effective for identifying knowledgeable or experienced respondents through referral networks (Saunders et al., 2009). Data arrived in several batches in 2024, collected between May and October where overlap the period of major political disruption in Bangladesh. The researcher collected the distributed questionnaires at various phases. In May 2024, a researcher distributed an online survey to participants from different manufacturing companies and professional groups. Before proceeding with the survey, the researcher requested all participants to sign a consent form and shared a participant information sheet (See Appendix 1 and 2). Within four weeks of launching the survey, the researcher received 120 completed questionnaires. Eight weeks later, in July 2024, the researcher gently reminded participants on the online platform to complete the survey. By the tenth week, the researcher collected an additional 73 completed questionnaires. Last week of July 2024, the researcher sent the survey links again to those who had not yet responded. Within 12 weeks, the researcher received an additional 69 completed questionnaires. Later, in the last week of September 2024, the researcher issued another gentle reminder to the remaining potential respondents to complete the survey. This resulted in 59 more responses within two weeks.

Table 4.2: Demographic Profile of the Respondents

Gender	**Frequency**	**Percentage**	**Types of Industry**	**Frequency**	**Percentage**
Male	267	85.3	Garments	83	26.5
Female	46	14.7	Textiles	73	23.3
Age			FMCG	28	8.9
18-25 Years	5	1.6	Steel	25	8.0
26-33 Years	144	46.0	Plastics	49	15.7
34-41 Years	113	36.1	Dyeing and Thread Manufacturing	3	1.0
42-49 Years	39	12.5	Food and Beverage	10	3.2
50 and more	12	3.8	Ship Building	4	1.3
Academic Qualification			Pharmaceuticals	4	1.3
Degree/Honours/Bachelor	129	41.2	Tyre and Leather Industry	3	1.0

Masters/MBA	181	57.8	Power Plant	3	1.0
Others	3	1.0	Paper and Packaging	10	3.2
Working Department			Glass	9	2.9
Marketing and Sales	14	4.5	Others	9	2.9
Production Engineering	64	20.4	**Total Job Experiences**		
Supply Chain	103	32.9	1-6 Years	143	45.7
General Management	70	22.4	7-12 Years	88	28.1
Commercial	18	5.8	13-18 years	60	19.2
Quality and Research Team	13	4.2	19 and more	22	7.0
Merchandising	9	2.9	**Experiences within the Current Company**		
Others	22	7.0	1-6 Years	194	62.0
Age of the Company			7-12 Years	86	27.5
1-6 Years	15	4.8	13-18 Years	17	5.4
7-12 Years	26	8.3	19 and more	16	5.1
13-18 years	83	26.5	**Size of the Company**		
19 and more	189	60.4	Medium Size (50 -249 employees)	31	9.9
			Large Size (More than 250 employees)	282	90.1

N= 313

After 18 weeks, in the last week of October, the researcher collected a total of 321 responses and decided to stop accepting further responses, as the responses received were sufficient for analysis. The researcher then excluded responses from six service-based organisations that were not the focus of the study and removed responses from two small companies. Small firms were excluded because they were unaware of CE principles and their long-term benefits (Khan et al., 2024). Ultimately, 313 responses were included in the analysis, yielding a response rate of 41.7% (approximately 42%). This response rate is considered reasonable within organisational research, where response rates vary considerably across studies and respondent populations (Baruch & Holtom, 2008). The demographic details are shown in Table 4.2 after excluding the six responses from service organisations. The target sample comprises both male and female professionals across different age groups.

4.5.1.6 Non-Response Bias and Common Method Bias

Non-response bias may occur because data is gathered over varying periods. To assess data reliability, the study began by examining non-response bias. However, the researcher

computed disparities between early and late responders, under instructions to reduce the probability of non-response, and found no significant differences between the groups (Werner et al., 2007). In terms of gender, educational background, company size, and age, the study compared respondents to a random sample of 100 respondents. According to the t-test results, there was no statistically significant difference in the company's size ($t = -0.943$, $p > 0.10$), age ($t = -0.313$, $p > 0.10$), gender ($t = -0.545$, $p > 0.10$), or academic background ($t = -1.993$, $p > 0.10$). Non-response bias was therefore not an issue in this instance. The dataset showed a higher response rate from men, respondents working in the RMG and textile industries, and those employed in large organisations. The reason is that executive roles in these industries were predominantly held by men, and companies in these industries commonly exceed 250 employees, making large firms the norm. The nonresponse analysis is shown in Appendix 13a.

To reduce common-method bias, the study employed a two-step approach. First, the researcher took preventive measures before distributing the questionnaire. Second, the researcher conducted post-data collection analyses to assess and address potential bias. In the first step, the researcher conducted a pilot study with 5 individuals as a preventive measure, including academics and industry professionals with experience in supply chain management and the operational field (Podsakoff et al., 2003). Based on the suggestions and comments, the questionnaire was subsequently revised to ensure it was easy to understand. Second, the study conducted a common latent factor using confirmatory factor analysis (CFA), where the calculated chi-square value ($1.198 < 3.84$) is less than the tabulated value (Harrington, 2009). The exploratory principal components factor analysis showed no factor exceeded a maximum cut-off of 50%. Although the CFA based common-latent-factor (CLF) test and the VIF results suggest that common method bias is not a serious concern, however, these tests cannot fully rule it out (Podsakoff et al., 2003; Kock, 2015). As the data come from a single-source, self-

reported, cross-sectional dataset, shared method variance may still partly inflate the observed relationships (Podsakoff, MacKenzie and Podsakoff, 2012). Based on marker variance technique, method variance averaged 12.1% of item variance, and construct correlations changed by only .04–.113. Taken together, CMB based on CLF is not a serious threat to further analysis in Appendix 13c. The following table 4.3 presents the results of CMB based on CFA using marker technique.

Table 4.3: Market Technique for Common Method Bias

Model	χ^2	df	CMIN/DF	CFI	TLI	RMSEA	SRMR
CFA with marker (all factors correlated)	832.521	491	1.696	0.950	0.943	0.047	0.040
Baseline (no method paths)	943.517	505	1.868	0.936	0.929	0.053	0.113
Method-C (equal marker paths)	861.492	504	1.709	0.948	0.942	0.048	0.057
Method-U (free marker paths)	789.387	474	1.665	0.954	0.946	0.046	0.037
Method-R (Method-U, correlations fixed)	803.809	502	1.601	0.956	0.951	0.044	0.080

4.5.1.7 Reliability and Validity

Cronbach's Alpha and composed dependability were used to evaluate the reliability. To assess the components' internal consistency, the study used a reliability analysis. According to Fornell and Larcker, the Cronbach's Alpha coefficient should be higher than 0.7 (Fornell & Larcker, 1981). Every Cronbach's Alpha coefficient in the analysis was higher than 0.7. The study's composite reliability and Cronbach's Alpha are shown in Table 4.4.

Table 4.4: Reliability and Factor Loading

Construct	Items	Standardised Loading	Composite Reliability	Cronbach Alpha
Coercive Pressure (CP)	CP1	0.693	0.884	0.881
	CP2	0.770		
	CP3	0.872		
	CP4	0.879		
Normative Pressure (NP)	NP1	0.696	0.890	0.883

	NP2	0.905		
	NP3	0.834		
	NP4	0.830		
Mimetic Pressure	MP1	0.854	0.894	0.886
	MP2	0.918		
	MP3	0.799		
Top Management Commitment (TMC)	TMC1	0.690	0.916	0.916
	TMC2	0.858		
	TMC3	0.876		
	TMC4	0.868		
	TMC5	0.834		
Circular Supply Chain Management (CSCM)	CSCM1	0.810	0.903	0.900
	CSCM2	0.757		
	CSCM3	0.884		
	CSCM4	0.877		
Economic Performance (ECOP)	ECOP1*	0.598	0.764	0.763
	ECOP2	0.663		
	ECOP3	0.806		
	ECOP4	0.757		
Environmental Performance (ENVP)	ENVP1	0.770	0.840	0.843
	ENVP2	0.821		
	ENVP3	0.806		
Social Performance (SOP)	SOCP1	0.830	0.873	0.858
	SOCP2	0.739		
	SOCP3	0.807		
	SOCP4	0.802		

Both discriminant and convergent validity were used in this study. Convergent validity was assessed using an exploratory factor analysis (EFA). All the measurement items' factor loadings, as shown in Table 4.4, were greater than 0.50, indicating sufficient convergent validity (Hair et al., 2012).

This study compared the average variance extracted (AVE) and squared inter-construct correlations to assess discriminant validity. Based on Table 4.5, discriminant validity was supported because the AVEs exceeded the inter-construct correlations and were above 0.50 (Fornell & Larcker, 1981). Although EcoP, SocP, and EnvP are correlated, the heterotrait–monotrait ratio of correlations (HTMT) values should fall well below 0.85- 0.90 in Appendix

13b (Henseler et al., 2015). That's me, all three sustainability dimensions are distinct and separated. Therefore, discriminant validity is supported.

Table 4.5: Fornell & Larcker Validity Test

Constructs	AVE	1	2	3	4	5	6	7	8
1. Top Management Commitment	0.520	**0.721**							
2. Circular Supply Chain Managem	0.701	0.570	**0.837**						
3. Coercive Pressures	0.657	0.471	0.511	**0.810**					
4. Normative Pressures	0.671	0.489	0.545	0.709	**0.819**				
5. Mimetic Pressures	0.739	0.456	0.423	0.475	0.478	**0.860**			
6. Economic Performance	0.687	0.537	0.514	0.645	0.636	0.582	**0.829**		
7. Environmental Performance	0.637	0.683	0.598	0.468	0.531	0.458	0.593	**0.798**	
8. Social Performance	0.632	0.615	0.515	0.543	0.576	0.484	0.621	0.715	**0.795**

AVE: Average Variance Extracted

Variance inflation factors (VIFs) were also calculated to assess potential multicollinearity among the explanatory variables. The VIF scores, ranging from 1.27 to 2.56, remain well below the threshold of 4 (Hair et al., 2011), indicating that multicollinearity is not a concern.

4.5.1.8 Data Analysis

For data analysis, AMOS-based structural equation modelling (SEM) was used, as the sample size was adequate to meet the SEM criteria suggested by researchers (Felix, 2015). First, the sample size should be 10 times the number of items listed in the construct with the highest number of items (Hu & Bentler, 1999). Second, the sample size should be 10 times the number of paths directed to any endogenous variable in the model (Felix, 2015). Finally, bootstrapping techniques were performed with 5,000 samples using AMOS (Version 29.0), and structural equation models to assess the relationships among the constructs.

4.5.2 Qualitative Study

4.5.2.1 Research Design

The triple bottom line of sustainability (economic, environmental, and social results) is the goal of this qualitative study, which uses an institutional theory framework to examine how

businesses implement circular supply chain management (CSCM) techniques. Institutional theory serves as an effective tool for understanding how normative, regulatory, and cognitive pressures influence corporate engagement with circular supply chain practices (DiMaggio & Powell, 1983).

Moreover, the qualitative findings triangulate the quantitative results, which examined the role of institutional dynamics in shaping orientations towards circular supply chains and sustainable performance outcomes. The qualitative study was based on semi-structured interviews with participants from 25 Bangladeshi manufacturing companies, enabling triangulation and a systematic exploration of participants lived experiences, organisational practices, and contextual factors shaping their adoption of circular practices (Kallio et al., 2016). Semi-structured interview methods are appropriate for exploring complex socio-technical issues in which institutional contexts, informal practices, and policy interpretations vary across sectors (Bryman, 2016). Finally, the interview quotes validate how companies navigated institutional contexts to include circularity ideas in their supply chains and promote sustainable performance.

4.5.2.2 Data collection procedures

In the study, interview data were collected through in-person and Zoom platforms using semi-structured questions (Appendix 4). The interviews lasted between 35 minutes and 1.5 hours and were recorded for future transcription. The study focused on participants' experiences with their expertise in supply chain, procurement, and production processes. Interviewer were asked about various pressures, such as normative, mimetic, and coercive pressures for circular supply chain practices and their consequences. A specific question was also raised about whether top management encourages circular supply chain management techniques and how these tactics affect the attainment of various sustainability goals. By

conducting one-to-one interviews, researchers can uncover common procedures and practices in businesses' operations related to CSCM (Flynn et al., 1990).

4.5.2.3 Participant Demographics

Out of 30 individuals, only 25 male participants voluntarily consented after receiving an interview invitation, with ages ranging from 28 to 57. Although a substantial number of females are working at the operational level in manufacturing industries in Bangladesh, only a few female executives are working at the executive level (Islam & Jantan, 2017). Every participant had an experience working in different supply chain and operational roles in a Bangladeshi manufacturing company. Their supply chain management and operations knowledge and experience were the main factors in their selection. Most participants were well-known experts and held top positions in their fields. Phone calls and emails were used to communicate with the participants. Supply chain specialists, operations managers, founders, CEOs, general managers, and engineers with expertise in the electronics and electrical sectors were among the participants. Table 4.6 shows the demographics of the participants.

Table 4.6: Demographic Profile of the Interview Participants

S.L	Gender	Age	Education	Position	Types of Industry	Years of Experience	Company Age	No of Employees
Part_001	Male	41	Bachelor	Lead Merchandiser	Garments Retailer	20 Years	50 Years	1,000
Part_002	Male	37	Master's	Head of Supply Chain	Sea Food Processing	10 Years	42 Years	1,200
Part_003	Male	32	BSc	Textile Engineer	Denim Manufacturer	7 Years	40 Years	35,000
Part_004	Male	33	BSc	Mechanical Engineer	Shoe Manufacturer	8 Years	12 Years	40,000
Part_005	Male	45	Master's	General Manager	Garments Manufacturer	20 Years	24 Years	20,000
Part_006	Male	28	Bachelor	Supply Chain Executive	Textile Manufacturer	2 Years	33 Years	1,200
Part_007	Male	58	Master's	Chief Executive Officer	Garments and Textile	33 Years	44 Years	35,000
Part_008	Male	38	Master's	Head of Supply Chain	FMCG	14 Years	25 Years	800
Part_009	Male	48	Master's	General Manager	Plastics	20 Years	27 Years	500
Part_010	Male	52	Master's	General Manager	Garments and Textile	26 Years	20 Years	28,000
Part_011	Male	28	BSc	Production Engineer	Plastics	3 Years	10 Years	400
Part_012	Male	42	Master's	Head of Supply Chain	FMCG	18 Years	27 Years	600
Part_013	Male	42	BSc	Production Engineer	Automobile	20 Years	8 Years	250
Part_014	Male	32	Bachelor	Quality Controller	Plastics	6 Years	10 Years	300
Part_015	Male	38	Master's	Corporate Strategy Team	Steel	12 Years	72 Years	4,000
Part_016	Male	46	BSc	General Manager	Garments	18 Years	34 Years	5,000
Part_017	Male	52	Master's	General Manager	Steel	24 Years	15 Years	450
Part_018	Male	46	Master's	Production Director	Sewing Thread	17 Years	24 Years	2,000

					Manufacturer			
Part_019	Male	42	Master's	Merchandiser	Garments	15 Years	25 Years	5,000
Part_020	Male	33	Master's	Factory HR Administrator	Label Manufacturer	7 Years	11 Years	1,600
Part_021	Male	32	Master's	Merchandiser	Garments and Textile	6 Years	25 Years	12,000
Part_022	Male	56	Master's	Chairman and Director	Garments and Textile	29 Years	23 Years	11,000
Part_023	Male	43	MSc	Mechanical Engineer	Steel	15 Years	8 Years	250
Part_024	Male	45	MSc	Chemical Engineer	Sewing Thread Manufacturer	16 Years	11 Years	1,560
Part_025	Male	40	Master's	Head of Supply Chain	Cement	13 Years	22 Years	2,500

N=25

4.5.2.4 Data Analysis

Microsoft transcription software was used to transcribe the interviews, and the accuracy of the results was confirmed by comparing them to the original audio recordings. The transcripts were coded and analysed using NVIVO software. Constant comparative methods in the study are based on the progressive focusing principle (Braun & Clarke, 2006). Progressive focusing, as part of the iterative process, ensures the analysis brings an accurate and coherent understanding of the research context (Sinkovics & Alfoldi, 2012). The principles of interactive coding and comparative coding were applied to explore the main themes and ideas indicated in the data (Vaismoradi et al., 2016). Table 4.7 summarises the data coding protocol for data analysis.

The first step in analysing qualitative data was coding, which is classifying, organising, and thematically ordering data to make meaning (Williams & Moser, 2019). Open coding is a qualitative research technique and does not focus on other techniques such as interpretive research, sensemaking, socio-materiality, actor-network theory, ethnography, action research, discourse analysis, narrative research, or historical research. These techniques showed promise when applied to complex issues such as supply chain management (Wieland & Creutzig, 2025).

Table 4.7: Data Coding Protocol

Step	What is Coded	Type of Coding	Coding Procedure	How Codes are Developed Inductively

1	Entire dataset	Familiarisation	Data are read repeatedly to gain an overall sense of content and context	No codes are applied at this stage
2	Meaningful data segments	Open coding	Line-by-line coding is applied to identify salient ideas and actions	Codes are created directly from the data, using participants' language where possible
3	Significant codes	Deductive code refinement	Codes are reviewed, merged, split, or discarded	Refinement occurs through iterative comparison
4	Related codes	Categorisation	Codes are grouped based on conceptual similarity and relational meaning	Categories emerge through pattern recognition across codes
5	Categories and analytic insights	Memo writing	Analytical and reflexive memos are written throughout coding and categorisation	Memos capture emerging interpretations, analytic decisions, and shifts in understanding
6	Categories in relation to research questions	Analytic integration	Categories are revisited considering memos and research aims	Deductive insights are synthesised based on research aims

This study adopted a grounded theory to explore connections between specific interview questions or data segments. The three coding processes of grounded theory coding strategies, i.e., open, axial, and selective coding provide a way to analyse qualitative data (Charmaz, 2014). Based on open coding, the researcher initially organised interview responses by identifying common words, phrases, and indicators of concepts under broad headings of initial variables. This process, derived from data collection, is gradually included throughout each stage of the coding process, leading to the refinement of existing categories and the creation of new theoretical items (Williams & Moser, 2019).

Iterative categorisation (IC) is a suitable approach for categorisation that can support ongoing comparisons created within the study setting (Neale, 2016). Without depending on the theoretical prior beliefs and hypotheses, researcher derive categories and their characteristics. This method guarantees that every category is supported by the facts rather than the researcher's preconceived notions and assumptions (Hallberg, 2006). To ensure that these conceptual linkages are grounded in the data, the study used a process of identification and

verification to establish the emergent categories and their attributes. This core category informs and defines the theoretical framework (Williams & Moser, 2019).

After this, the researcher systematically recorded memos during the analytic process, recording concepts, theoretical insights, and hypothesised relationships about the developing variable items. This iterative procedure guarantees that the data's changing interpretation was fully recorded. the data analysis ends when all the data have been analysed, and saturation points are reached. A key idea is saturation, which denotes that no new information is substantially added by any more respondents (Charmaz, 2014). It is crucial to refrain from starting theoretical sampling too soon to maintain rigour.

4.6 Findings

4.6.1 Quantitative Results

The results of AMOS-SEM are organized into the following two sub-sections: 'Measurement Model' and 'Structural Model Testing'.

4.6.1.1 Measurement Model

The measurement model explains how latent variables are conceptualised in terms of observed items. The study model has 8 latent variables and 31 items. The measurement model shows excellent fit based on fit indices χ^2 (552.254, df=367, $p<0.001$) and the χ^2/df ratio of 1.505 (below the threshold of 3), meeting the criteria (Arbuckle, 1999). Other model fit measures (RMSEA=0.040, SRMR=0.0370, GFI=0.897, NFI=0.917, IFI=0.971, TLI=0.965, CFI=0.970) also indicated an excellent fit (Hu & Bentler, 1999).

4.6.1.2 Structural Model

In the structural model, path coefficients, t-values, and p-values were computed using bootstrapping across 5000 subsamples to investigate the hypothesised connections among the research variables. Structural model fitness indices (χ^2 (592.180, df=376, $p<0.001$) and χ^2 /df

of 1.574), RMSEA=0.043, SRMR=0.0690, GFI=0.890, NFI=0.911, IFI=0.965, TLI=0.959, and CFI=0.965 show good fits (Hu & Bentler, 1999).

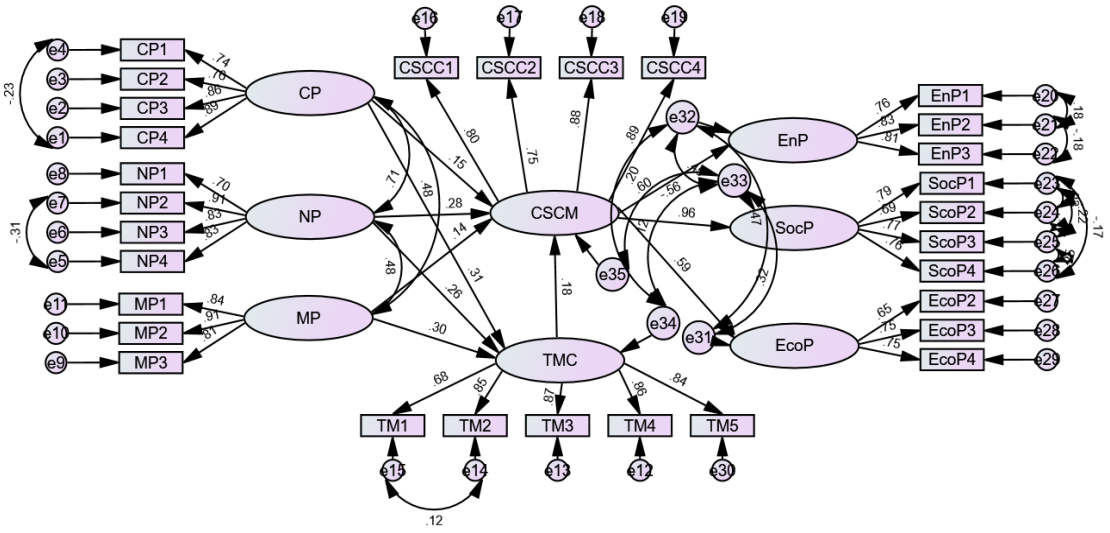


Figure 4.2: Regression Results based on Structural Model

The path coefficients and p-values of our suggested hypotheses are shown in Table 4.8. Path analysis revealed a positive correlation between CP and CSCM (β = 0.149, p = 0.003). Additionally, the results demonstrated a positive and substantial relationship between NP and CSCM (β = 0.282, p = 0.000).

Additionally, there is a positive and substantial correlation between CSCM and mimetic pressures (β = 0.142, p = 0.000). CSCM is likely to be positively and strongly correlated with top management commitment in the name of TMC (β = 0.151, p = 0.006). EcoP, EnvP, and ScoP are all positively and strongly correlated with CSCM. The three sustainability dimensions are EcoP (β = 0.405, p = 0.000), EnvP (β = 0.491, p = 0.000), and ScoP (β = 0.856, p = 0.000). Although the path coefficient between CSCM and ScoP is unusually high, however, it indicates CSCM practices are strongly connected with ScoP. Thus, all hypotheses (H1, H2, H3, H4, H5, H6, and H7) based on direct relationships are supported.

Table 4.8: Hypothesis Testing based on Survey Data

Hypothesis	Paths	Estimate	S.E.	C.R.	P Value	Comments
H1	CP →CSCM	.119	.056	2.132	.033*	**Supported**
H2	NP → CSCM	.252	.065	3.871	***	**Supported**
H3	MP →CSCM	.122	.050	2.448	0.025*	**Supported**
H4	TMC →CSCM	.151	.067	2.246	.025*	**Supported**
H5	CSCM → EnvP	.491	.056	8.771	***	**Supported**
H6	CSCM →ScoP	.856	.100	8.593	***	**Supported**
H7	CSCM → EcoP	.405	.051	7.874	***	**Supported**

*****<.001, **<.01, *<.05**

CP = Coercive Pressures **NP =** Normative Pressures **MP** = Mimetic Pressures
TMC Top Management Commitment **CSCM=** Circular Supply Chain Management
EcoP= Economic Performance **EnvP=** Environmental Performance
ScoP= Social Performance

4.6.1.3 Mediation Analysis

The dependent, mediator, and independent variables were used to illustrate the mediation results in Table 4.9. The link between CP and CSCM was partially mediated by TMC, according to the results (β =.046, p <.05). Additionally, the association between NP and CSCM was fully mediated by TMC (β = .049, p <.001). The link between MP and CSCM was fully mediated by TMC, as indicated by the results (β = .042, p < .001). Moreover, the relationship between CP and EcoP was also fully mediated by CSCM (β = .068, p < .005). In addition, the relationship between CP and EnvP was fully mediated by CSCM (β = .087, p < .05). Likewise, the relationship between CP and ScoP was fully mediated by CSCM (β = .079, p < .05).

In the same way, the path between NP and EcoP was fully mediated by CSCM (β =.110, p <.05). Additionally, the path between NP and the EnvP was partially mediated by CSCM (β = 0.141, p < 0.05). Moreover, the connection between NP and ScoP was fully mediated by CSCM between the two constructs by CSCM (β =.128, p <.05). Accordingly, the association between MP and EcoP was fully mediated by CSCM (β =.055, p <.001). Furthermore, the association between MP and EnvP was fully mediated by CSCM (β = .070, p < .001).

Moreover, the association between MP and ScoP was fully mediated by CSCM (β = .064, p < .001). Therefore, H8a, H8b, H8c, H8d, H9a, H9b, H9c, H9d and H10a, H10b, H10c, H10d are all supported and validated.

Table 4.9: Mediation Analysis

Hypothesis	Paths	Total Effects	Direct Effects	Indirect Effects	Comments
H8a	CP →TMC → CSCM	.192	.146	.046 *	**Partial Mediation**
H8b	CP → CSCM → EnvP	.087	.000	.087*	**Full Mediation**
H8c	CP →CSCM → ScoP	.079	.000	.079*	**Full Mediation**
H8d	CP → CSCM → EcoP	.068	.000	.068***	**Full Mediation**
H9a	NP →TMC → CSCM	.309	.260	.049***	**Full Mediation**
H9b	NP →CSCM → EnvP	.141	.000	.141*	**Full Mediation**
H9c	NP →CSCM → ScoP	.128	.000	.128*	**Full Mediation**
H9d	NP →CSCM →EcoP	.110	.000	.110***	**Full Mediation**
H10a	MP →TMC → CSCM	.154	.112	.042***	**Full Mediation**
H10b	MP → CSCM→ EnvP	.070	.000	.070*	**Full Mediation**
H10c	MP → CSCM →ScoP	.064	.000	.064*	**Full Mediation**
H10d	MP →CSCM→ EcoP	.055	.000	.055***	**Full Mediation**
H11a	TMC →CSCM→ EnvP	.048	.013	.035***	**Full Mediation**
H11b	TMC→ CSCM→ ScoP	.035	.017	.018***	**Full Mediation**
H11c	TMC→ CSCM → EcoP	.058	.035	.023***	**Full Meditation**

*****<.001, **<.01, *<.05**

CP = Coercive Pressures **NP =** Normative Pressures **MP** = Mimetic Pressures
TMC Top Management Commitment **CSCM=** Circular Supply Chain Management
EcoP= Economic Performance **EnvP=** Environmental Performance
ScoP= Social Performance

Final mediation was based on circular supply chain management, with top management commitment and three types of sustainability performance. The relationship between TMC and EnvP was fully mediated by CSCM (β = .035, p < .001). Accordingly, the association between TMC and ScoP was predominantly mediated by CSCM (β = .018, p < .001). In addition, the relationship between TMC and EcoP was fully mediated by CSCM (β = .023, p < .001). Thus, all the other mediations, such as H11a, H11b, and H11c, are confirmed.

4.6.1.4 Control variables

In this study, control variables were used meaningfully. The regression analyses revealed that employees' total experience has a negative and significant effect on CSCM (β = -.229, p < 0.05). This means that when the years of experiences increases the use of CSCM practices decreases. Additionally, more experienced employees may be less likely to adopt or engage

with newer CSCM practices than less experienced employees. Moreover, employees working within the same company show a positive and significant association with CSCM ($\beta = .149$, $p < 0.05$). Finally, employees' academic qualifications are positively and significantly associated with environmental performance ($\beta = .206$, $p < 0.05$). The other control variables are not significantly associated with CSCM and the sustainability domain. The study, therefore, did not include the other control variables in the further analysis to avoid measurement errors.

4.6.2 Qualitative Results

Interview data were used to triangulate the survey findings. Specifically, interview data is being used to cross-check and boost the credibility of the quantitative findings. The next section discusses the qualitative data analysis of constructs such as CP, NP, MP, TMC, CSCM, and their relationships with the associated sustainability performance. The section then explains how the pressures identified in the interviews were consistent with basic statistical trends in the survey data. The qualitative interview data were coded and classified by institutional theory to gain additional analytical depth. The data classification identified three major aspects: (i) the three types of institutional pressures that drive the CSCM; (ii) the role of the top management commitment to pursue advanced CSCM; and (iii) how institutional pressures, CSCM activities, and TMC combinedly improve environmental, social, and economic sustainability performance.

The following section explains and demonstrates the interview data to explain the different hypotheses.

4.6.2.1 Institutional Pressures and CSCM

In the study, the manufacturers who are working in the garments, textiles, plastics, and steel industries speak about compliance, which is the set of standards and regulations regarding work conditions, product quality, environmental impact, and human rights. Moreover, firms

mainly engage in circular practices not only because of regulations but also to achieve economic incentives and recycling pressure from the buyers. Three figures (4.3a, 4.3b, and 4.3c) were used to conduct the content analysis of institutional pressures, TMC, and CSCM. Figure 4.3(a) presents the first- and second-order quotes to determine the institutional pressures for CSCM.

To validate the survey findings, the study identified distinct quotes from the interview transcripts. The interview quotes support the different items taken from the literature to represent the coercive pressure under institutional pressure. Table 4.9 summarises interview quotes to define how three types of institutional pressures help implement sustainability practices that support and facilitate CSCM.

From the interview results, all participants confirmed that coercive pressures have a positive effect on the successful implementation of CSCM. This indicates that the firms are compliant with government laws, and regulations are more adaptive to sustainable and circular practices. Also, all respondents noted that regulatory policies and mandates are influential in shaping and motivating environmental practices within organisations and their suppliers' organisations. Additionally, all participants in the interview agree that manufacturers comply with government standards, not just regulatory requirements, but also to access economic incentives, including tax rebates.

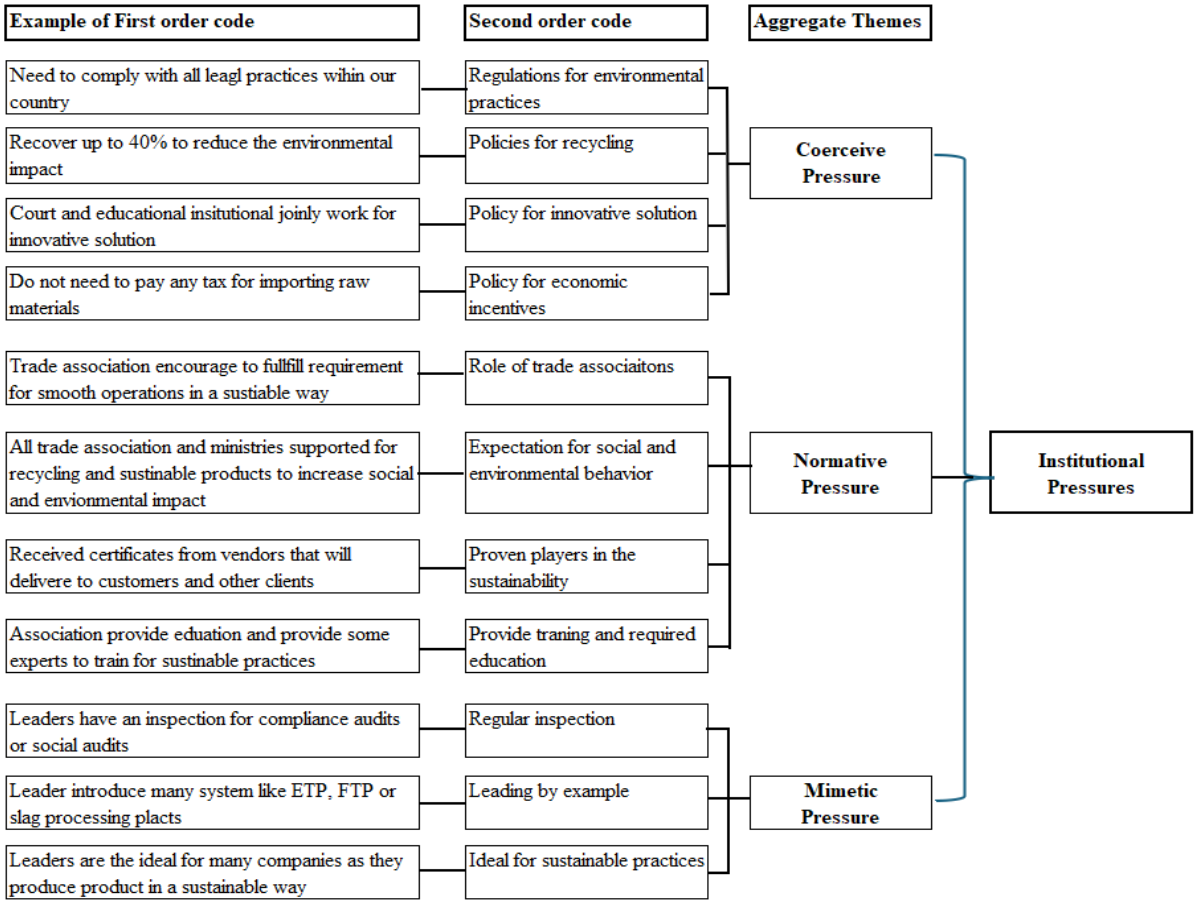


Figure 4.3 (a): Interview Data Visualisation for Institutional Pressures

The interview results also show that normative pressure positively supports CSCM, mainly by maintaining environmental and social responsibility and fostering a culture across the industry. 3 of 25 participants argue that companies are strongly supported by industry trade associations and external bodies (for example, BGMEA, BKMEA, and the European Union) and are encouraged to be environmental stewards and to abide by environmental regulations. Moreover, 3 participants confirm that companies support recycling and sustainability initiatives in response to customer and societal demand to deliver positive socio-economic returns. Additionally, 8 participants focus on getting a certificate from the authorities, and sustainability documents are required to become a member of the concerned body. More than 5 participants claimed that education programs from schools and universities, and in-house training, contribute to sustainable behaviour and create a common set of values that enhance the implementation of CSCM across the supply chain. Table 4.10 presents a summary of the

quotes from the interviews to identify how normative pressures help to implement circular practices in the supply chain.

Table 4.10: Institutional Pressures based on Interview Quotes

Types of Pressure	Responses	Interview Quotes
Coerceive Pressure	Regulations for environmental practices	We need to comply with all legal practices within our country (All participants)
	Policies for recycling	Now we are 40% recovered, but later, probably we'll be recovering 80% 70%, so the government is working with us, working with this and this industrial community, to reduce the environmental impact (Part_3; Part_7; Part_16; Part_18;Part_23)
	Policy for innovative solution	Regulatorsalso monitoring the leverages; you know formerly a court and now the RSC is jointly working with the teacher to implement the compliance, social compliance, structural compliance (Part_4; Part_16; Part_18; Part_25)
	Policy for economic incentives	There is a provision for getting incentives from the government for export. We do not need to pay any tax to import raw materials. It increases our competitive advantage as the production cost is minimal (All participants)
	Role of trade associaitons	Negotiate with association like BGMEA, BTMEA, BKMEA, Government commercial, or European Union supporting to fulfill the requirement to ensure their business sustainable way (Part_1 Part_5; Part_6; Part_7; Part_13;
Normative Pressure	Expectation for social and environmental behavior	All organizations and ministries are supported to do this kind of recycling or sustainable products to satisfy the customer and to ensure the economic impact on the business (Part_1; Part_12; Part_20)
	Proven players in the sustainability	we have certificates from our vendors as well, and through that, we are providing proof to our clients (Part_4; Part_5; Part_6; Part_7; Part_12;Part_13; Part_14; Part_20)
	Provide traning and required education	They educate us and we have some teams also there, we are sustainable on the product (Part_12;Part_13; Part_14; Part_19)
	Regular inspection	Market leader have an audit every week, It is related to compliance audits, and social audits. POE audit (Part_3; Part_7; Part_11; Part_19)
Mimetic Pressure	Leading by example	Parket leader have introuduced slag processing plat or water treatement plant to reduce the environmental harm (Part_1; Part_3; Part_6; Part_11; Part_15;Part_17)
	Ideal for sustainable practices	They are ideal and at the at the at the moment in the market and many of the companies are following their trend and they are one of the customer who give. A very short time new product to their customer in a sustainable way (Part_1; Part_6; Part_15)

*** **Part- Participants**

Table 4.9 above also confirms that mimetic pressure (MP) directly supports circular CSCM. MP encourages firms to adopt circular practices as industry leaders have shown the way. Based on the scale items, 5 participants confirm that their motivation to engage in sustainable practices stems from the leader's firm's actions in successful environmental practices. 8 participants agree that sustainable actions, such as obtaining certifications, recycling, and reusing materials, depend on replicating market leaders' initiatives. Similarly, 5 participants argue that a manufacturing firm develops its sustainability credentials for implementing CSCM practices by adopting acceptable industry practices from leading companies.

4.6.2.2 Top Management Commitment and CSCM

Bangladeshi manufacturers are not keen to adopt the CE due to infrastructure issues, lack of policy support, and market pressures that often prioritise cost over sustainability. Furthermore, cost pressures on SMEs and the demands of fast fashion also inhibit any willingness to pursue this path. Figure 4.3(b) summarises how top management commitment supports the implementation of CE in the supply chain and helps overcome many difficulties.

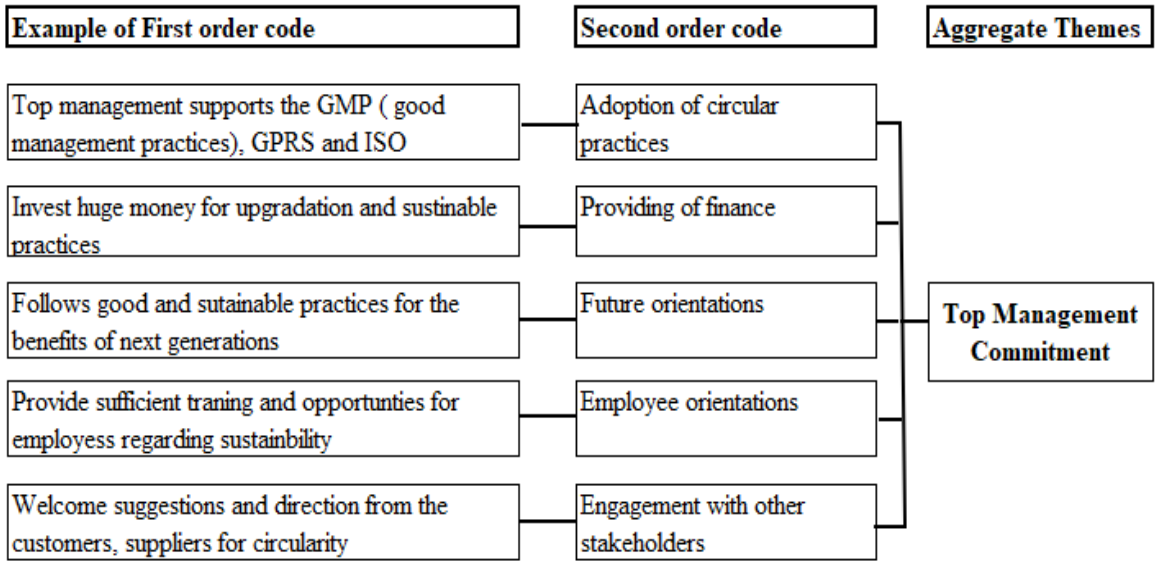


Figure 4.3 (b): Data Analysis Visualisation of Top Management Commitment

Based on the interview quotes, all participants confirmed that top management commitment (TMC) is crucial for CSCM, as it provides strategic direction for compliance with existing international standards, including GMP and ISO 9000. 8 participants confirm that firms invest heavily in sustainability and sustainability-based infrastructure, and provide the finances and tools needed to develop circularity practices. Moreover, 25 participants agree that top management needs to nourish a culture that embraces innovation and opportunities for sustainability practices, and they allow for adequate training for employees to develop a sustainable or circular cultural capacity. Additionally, 10 participants agree that top management plays a significant role in mobilizing with suppliers on jointly financed projects, promoting information exchange through competitive benchmarking, and responding to

brand and other stakeholder feedback to support aligned, holistic approaches towards circular supply chain management. Table 4.11 summarises the survey interview quotes to identify how normative pressures help implement CSCM.

Table 4.11: Top Management Commitment and CSCM

Management Support	Responses	Interview Quotes
Top Management Commitment	Adoption of circular practices	Top management supports the following the GMP (good manufacturing practices) as as well as the GPRS standard we are also following for recycling, the global recycling standard, and we have the ISO 9001 (All participants)
	Providing of finance	Top management invests huge money fnor upgradation and sustainable practices (Part_1; Part_2; Part_3; Part_4; Part_9; Part_10; Part_13; Part_19)
	Future orientations	Our management follow goods and sustainable practices for our benefit and the next generation (All participants)
	Employee orientations	Our management and most of our senior people have experience of visiting many places and factories outside, and visiting their factories, and experiencing the health, hygiene, and safety issues that we experience (Part_1; Part_3; Part_4; Part_6; Part_8; Part_10; Part_11; Part_12; Part_20)
	Engagement with other stakeholders	As a manufacturer, we get directions from the brands, right. So the same direction we follow, OK, but sometimes we add our comments, we suggest that yes this need to be done because the circularity (Part_1; Part_2; Part_6; Part_9; Part_12; Part_21; Part_25)

*** **Part- Participants**

4.6.2.3 CSCM and Sustainability Performance

The interview quotes demonstrate positive environmental performance with and through CSM by reducing waste through ETP (Effluent Treatment Plant), FTP, and other techniques, as mentioned by most participants, who also noted good practices and adequate material flow. Figure 4.3 (c) demonstrates how different actions based on CSCM support achieving economic, social, and environmental performance that, combined, achieve sustainability performance.

The interview findings provide clear evidence that CSCM positively influences economic performance by improving turnover, reducing operational costs, and fostering growth and customer loyalty. 10 participants argued that companies are switching to LED lighting, using rainwater harvesting, and adopting sustainable materials such as natural cotton to reduce

costs and improve operational efficiency. Furthermore, 11 participants believed that sustained attention to sustainability has contributed to business growth and increased market share.

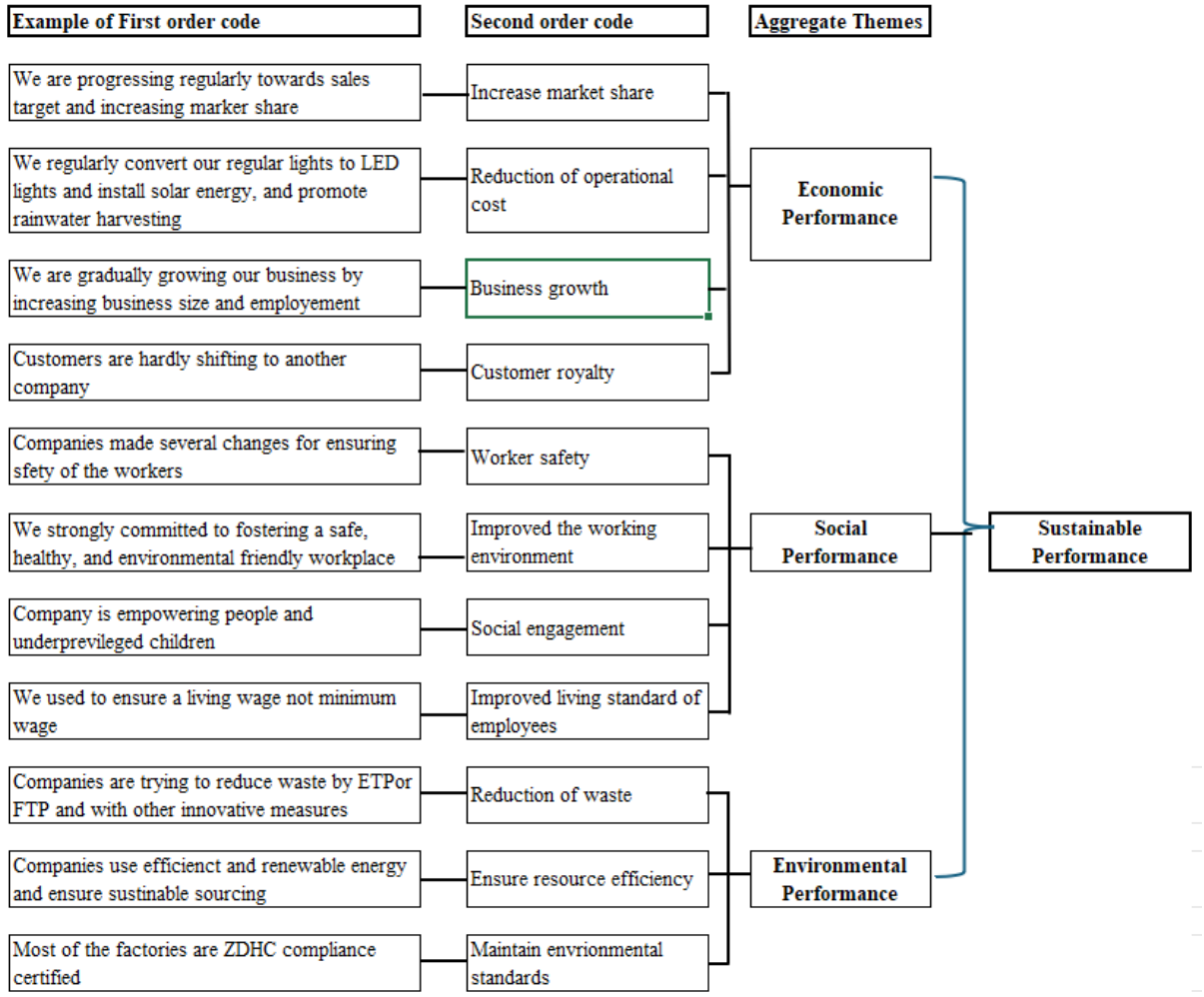


Figure 4.3 (c): Data Analysis Visualisation how CSCM effect Sustainability

8 participants believed that their company has secured increased customer loyalty, as evidenced by limited customer drift to competitors, further supporting the economic benefits of CSCM. Finally, sustainability-led practices within the circular supply chain have enabled firms to develop a long-term financial and competitive advantage. Table 4.12 presents a quote from an interview that summarises how CSCM facilitates sustainable performance.

Table 4.12: CSCM and Sustainability Performance

Management Support	Responses	Interview Quotes
Economic Performance	Increase market share	We are progressing regularly in terms of market share, growth and sales (Part_3; Part_4; Part_7; Part_9; Part_11; Part_14; Part_20; Part_22; Part_23; Part_24; Part_25)
	Reduction of operational cost	We converted our regular Lights to LED lights, rainwater harvesting, and using natural cotton to reduce cost (Part_1; Part_2; Part_4; Part_5; Part_15; Part_20;
	Business growth	We are developing ourselves for our sales our business growth. The main reason for the growth of our business is that we always focus on sustainability (Part_1; Part_14)
	Customer royalty	There is hardly any shifting of our customers to another company (Part_1; Part_10; Part_11; Part_14; Part_16; Part_17; Part_20)
Social Performance	Improved worker safety	All these changes is made keeping in mind that compliance and safety are at its highest priority (Part_6; Part_9; Part_10; Part_11; Part_12; Part_15; Part_18; Part_20; Part_21; Part_23)
	Improved working envirobment	We strongly committed to fostering a safe, healthy, and environmentally friendly workplace for both our employees and valued customers (Part_9; Part_10; Part_11; Part_18; Part_21)
	Improved community netowrks	We are empowering people and underprivileged children. So by doing this, we are contributing to society as well (Part_3; Part_4; Part_15; Part_21; Part_25)
	Improved standard of living	We don't mention the minimum wage. We used to mention a living wage, not a minimum wage ((Part_3; Part_10; Part_16; Part_18; Part_21)
Environmental Performance	Reduced waste	Our company is trying to reduce waste by ETP, FTP and other measures (All participants)
	Resource efficiency	We use energy efficient and renewable energy, and maintain waste management and sustainable sourcing (Part_1; Part_2; Part_4; Part_9; Part_10; Part_11; Part_13; Part_15; Part_18; Part_19; Part_20; Part_21; Part_23; Part_24)
	Improved compliance	All the factories must be ZDHC compliance certified (All participants)

*** **Part- Participants**

Based on the survey data, all participants confirmed that the company emphasised reducing resource consumption, improving efficiency and energy efficiency, adopting renewable energy, and promoting sustainable resource use, including compliance with sustainable supply chain standards and waste minimisation aligned with sustainable supply chains at multiple levels. Manufacturers are also trying to improve compliance and adherence to sustainable standards due to a requirement from the company's environmental standards, ZDHC (Zero Discharge of Hazardous Chemicals). Coordination across different levels of the supply chain, involving various companies and standards, reflects adherence to global protocols and demonstrates a commitment to sustainability. 25 participants believed that

integrative thinking and actions provide greater circularity in business operations and greater sustainability performance in the supply chain.

It is also noted here that CSCM supports the company as a strong performer in social performance, as it has made workplace safety a priority and improved the work environment over the last few years. 10 participants confirmed that maintaining compliance and safety has been the organisation's main priority. Moreover, 5 participants agreed that the manufacturer aims to ensure a safe, healthy, and environmentally friendly workplace for both employees and customers. For many years, manufacturers improved their relationships with the community and their stakeholders and enhanced the living conditions of their surrounding area. More than 20% of participants report making significant social contributions, including empowering underprivileged children and contributing to society, which has given them a broader sense of responsibility. Many companies are no longer based on minimum wage, but did, at one point, stress that they were providing their employees a living wage, which reflects their awareness of employee welfare to CSCM.

4.6.2.4 The Mediating Role of Top Management Commitment on the relationship between Institutional Pressures and CSCM

The interview findings also reveal that top management commitment acts as a key mediating factor in translating institutional pressures (coercive, normative, and mimetic) into effective CSCM practices. The qualitative data show that while external institutional forces create a regulatory and social environment that encourages circularity, translating these pressures into organisational action is not automatic. It requires internal alignment, which is primarily driven by top management. For instance, coercive pressures such as environmental regulations and tax incentives encourage firms to adopt circular practices. However, without top management's support for good management practices (GMP), sustainable technology investments, and policy implementation, these regulations often result in symbolic

compliance rather than genuine change. Here, top managers play a critical role in allocating resources, shaping compliance strategies, and embedding sustainability goals into the business model. Similarly, normative pressures are more effectively internalised when top leaders cultivate a culture of sustainability, provide employee training, and adopt long-term orientation strategies. This not only reinforces organisational legitimacy but also enhances employee engagement and stakeholder trust.

Lastly, mimetic pressures, such as following industry leaders or adopting best practices, are amplified when top management actively benchmarks successful firms, promotes knowledge transfer, and encourages innovation in circular strategies. Without managerial vision and strategic adaptation, mimicry can result in ineffective or misaligned implementation. Figure 4.4 demonstrates TMC's mediating role in supporting the positive relationships between IT and CSCM. Participants from garments and textiles manufacturing companies stated that *"Our company cannot do anything by violating any laws. Besides the laws, we also work closely with the government/BGMEA/BKMEA. If we follow the legal issue, the practices will be minimal. Beyond the law, we practice more in line with top management's goals. Our management has already invested 50-60 crore taka in a biological treatment plant to treat the water. In the future, we will also implement measures to reduce CFC gas emissions. We use the generator's exhaust to run the air cooler instead of the AC. We try to save the generator's exhaust by using the seller. We replace electricity and other items with 232 tonnes of AC support. We have a plan to harvest rainwater for the dying factory. So that we can reduce the use of groundwater."*

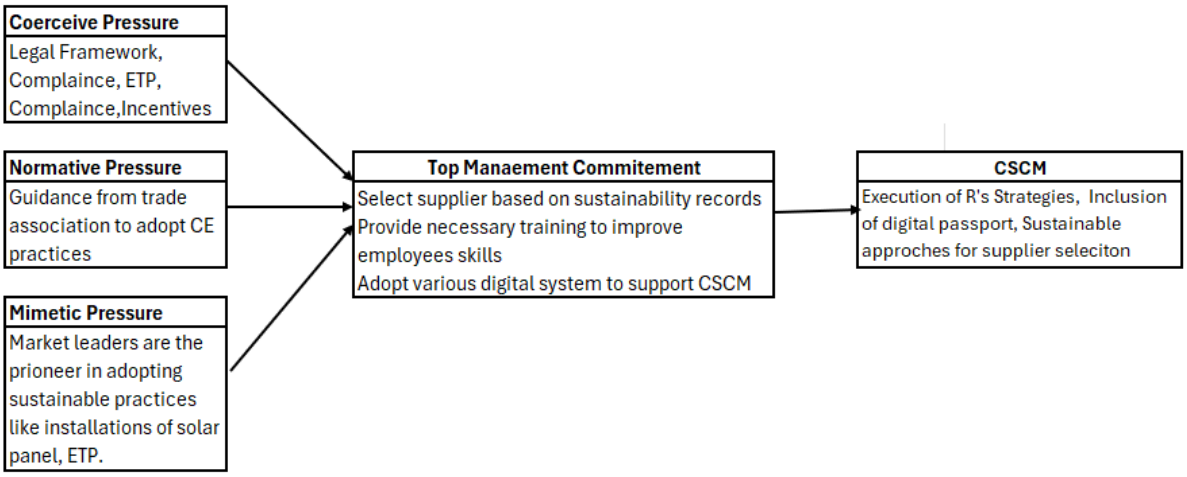


Figure 4.4: Mediating effects of TMC on TC and CSCM based on Qualitative Quotes

4.6.2.5 The Mediating Role of CSCM on the relationship between Institutional Pressures and Sustainability Performance

The mediating effects of CSCM on IT and sustainable performance are depicted in Figure 4.5. CSCM serves as the primary external driver of organisations' adoption of sustainable practices. Among the institutional pressures, coercive pressures arise from legal regulations and government policies that mandate environmental compliance and recycling practices, and that also provide economic incentives. Normative pressures stem from societal expectations, industry associations, and professional standards that promote social and environmental responsibility. Mimetic pressures emerge when organisations emulate successful peers in adopting recognized sustainable systems, compliance audits, or best practices. These institutional forces create a strong impetus for organisations to initiate sustainability measures, yet, by themselves, they may not directly lead to measurable performance outcomes unless effectively operationalised within the firms.

To translate institutional expectations into practice, CSCM encompasses a range of strategic and operational initiatives, including managerial processes for reuse and recycling strategies, digital tracking systems for material circularity, sustainable supplier selection, and investment in skilled human resources for sustainability. These initiatives enable firms to systematically

incorporate sustainability principles throughout their supply chains. CSCM acts as the critical link that internalises external institutional demands, equipping organisations with the tools, processes, and capabilities to meet regulatory standards, align with industry norms, and effectively emulate best practices.

The successful implementation of CSCM directly contributes to sustainability performance, the dependent variable outlined in the first figure. This performance is multidimensional, comprising economic, social, and environmental aspects. Economic performance benefits from increased market share, reduced operational costs, and business growth through resource-efficient practices. Social performance is improved by ensuring worker safety, enhancing employee well-being, and engaging in community development. Environmental performance is achieved through waste reduction, efficient resource use, and adherence to environmental standards. Thus, CSCM mediates the relationship between institutional pressures and sustainability performance by enabling organisations to operationalise external expectations into internal actions, ultimately resulting in comprehensive and measurable sustainability outcomes. Four respondents from garments and textile manufacturing companies confirmed that "*We keep a worker who cannot work. But we keep him not for legal requirements. It's our social responsibility. "We think that if he works with us, he will be good, and his family and children will have a good life." Two respondents from plastics manufacturing companies state that "we are following due to social and environmental standards and regulations, which are not affecting the users." Sometimes we follow some standards for the export markets, right for the European markets, we must follow some standards to get a certificate of GMP (good manufacturing practices), as well as the GPRS standard."*

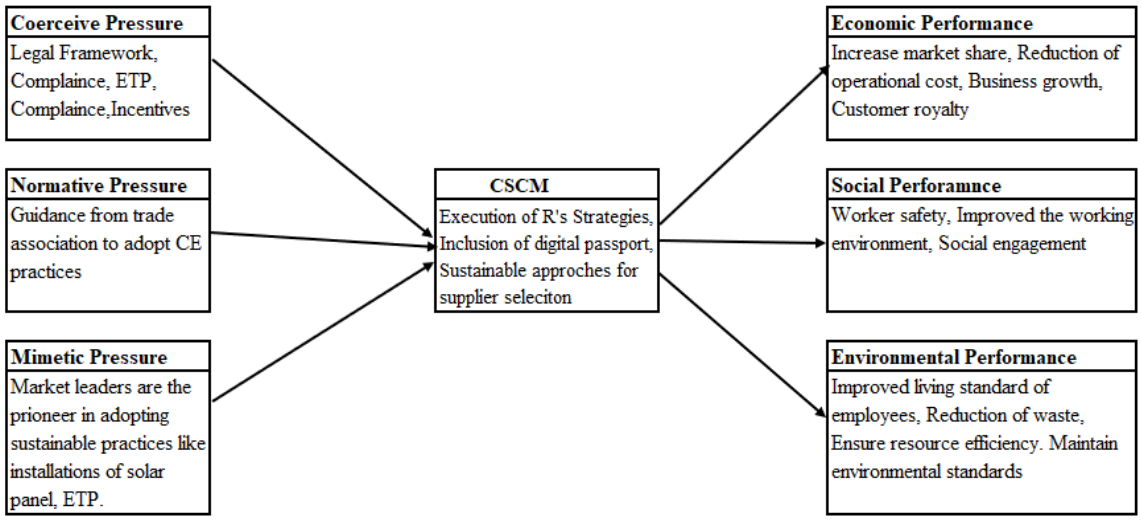


Figure 4.5: Mediating effects of CSCM on IT and Sustainability Performance based on Qualitative Quotes

4.6.2.6 The Mediating Role of CSCM on the relationship between Top Management Commitment and Sustainability Performance

Figure 4.6 shows that CSCM serves as a mediating mechanism between top management commitment and the three dimensions of sustainability performance: economic, social, and environmental. When top leadership actively integrates CE practices into strategic decisions, selects suppliers based on sustainability credentials, invests in employee training, and adopts digital tools, it creates the foundation for effective CSCM implementation. CSCM operationalises this commitment through practices such as implementing 3R strategies (reduce, reuse, recycle), using digital product passports, and selecting sustainable suppliers. These circular practices, in turn, lead to tangible performance outcomes: improved economic performance through cost reduction and market growth, enhanced social performance via better working conditions and worker safety, and stronger environmental performance through waste reduction and resource efficiency. In essence, CSCM translates managerial intent into measurable sustainability gains. One participant from an apparel company echoes these findings. The participants mentioned "*The top management has both growth and a*

sustainability mindset by how we can ensure recycling and remanufacturing of products and focus on sustainable operation, like training and zero printing. That's all, reduce cost, time, and improve efficiency." Other participants stated, "*We are a certified lead company. To become a lead company, we need to fulfil all sustainable criteria. The criteria make me committed. Sometimes it's better than commitment from our management*".

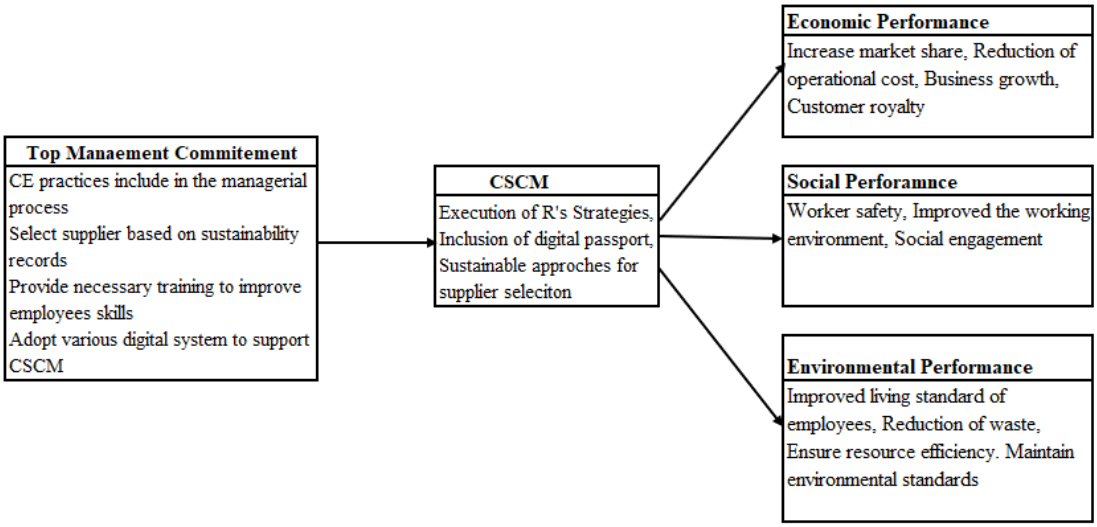


Figure 4.6: Mediating effects of CSCM on TMC and Sustainability Performance based on Qualitative Quotes

4.7 Discussion

This study examines the impact of institutional pressures and top management commitment on CSCM practices and on the enhancement of triple-bottom-line sustainability. This section draws on empirical evidence to discuss the connections among institutional pressures (coercive, normative, and mimetic), top management commitment, and the implementation of CSCM. Through the quantitative and qualitative findings, the study simultaneously places itself within the theoretical frameworks of institutional studies and introduces supporting and conflicting evidence from previous studies. Moreover, this section's discussion draws upon survey findings and interview statements by industry practitioners to show how external

pressures and internal leadership positively influence circular supply chain practices. In the indirect effects, the study emphasises that top management commitment plays a positive mediating role between institutional influence and operational CSCM practices, and CSCM mediates the institutional pressures and TMC with sustainability performance. This is a contribution that allows environmental performance, one of the three state benefits for environmental, social, and economic performance. The analysis verifies the conceptual framework and highlights critical boundary conditions and implications for organisations in their transition towards a circular supply chain.

4.7.1 Direct Effects

4.7.1.1 Coercive Pressures and Circular Supply Chain Management

The results show that institutional pressure has a statistically significant impact on CSCM adoption, with coercive pressures (CP) being the most influential. These findings are consistent with prior studies on CE and CSCM, which found that regulations drive sustainable supply chain practices (Zhu et al., 2013). Firms tend to respond to such pressures by adopting isomorphism to maintain legitimacy and avoid sanctions (DiMaggio & Powell, 1983), as they attempt to match the levels of competitiveness in their industries (Genovese et al., 2017). Empirical studies have shown that manufacturers in China were driven to adopt circular supply chains by tightening environmental regulations, as mandated by legislation and sanctions (Liu et al., 2018). However, extant research has also shown mixed results. CP occasionally induces resistance (especially for SMEs) due to high compliance costs or inadequate financial incentives (Ghisetti & Montresor, 2020). Furthermore, CP alone may lead to superficial compliance rather than genuine circular transformation (Walker et al., 2021). To further elucidate this relationship, two interview excerpts are presented. Respondents from all manufacturing firms unanimously agree that CP positively supports sustainable practices, thereby facilitating more circular operations. All respondents

emphasised the necessity of complying with all legal practices within their respective countries. Respondents from the garments, textile, denim, and sewing thread manufacturing companies stated, "*Currently, we have achieved a 40% recovery rate, but in the future, we anticipate reaching 70% to 80%. The government is collaborating with the industrial community to mitigate environmental impact."* Therefore, government regulations and monitoring positively support the implementation of CSCM. Consequently, Hypothesis **H1** is supported.

4.7.1.2 Normative Pressures (NP) and Circular Supply Chain Management

Our findings reveal a highly significant positive correlation between normative pressures (NP) and the adoption of CSCM, consistent with institutional theory and prior research (Kirchherr et al., 2018). Extant studies emphasised that NP from industry associations and influential buyers, such as multinational corporations imposing sustainability requirements on suppliers, significantly drive circular practices (Walker et al., 2021). Furthermore, academic institutions, sustainability training, and shifts in corporate culture establish normative expectations for CSCM adoption. Several studies confirmed that sustainability education and cultural norms in Scandinavian firms have accelerated the adoption of the CE (Geissdoerfer et al., 2017). However, NP alone is insufficient to promote CSCM without robust industry enforcement, as firms may disregard CSCM practices without repercussions. Previous studies also found that voluntary sustainability norms often fail without regulatory or economic incentives (Bocken et al., 2016). The survey findings are also consistent with the interview results. Respondents from garment retailers, FMCG companies, and label manufacturers argued that *"All associations and ministries are supported to do this kind of recycling or sustainable products to satisfy the customer and to ensure the economic impact on the business."* This indicates that NP from trade associations and relevant agencies is positively supporting CSCM. Thus, hypothesis **H2** is supported.

4.7.1.3 Memetic Pressures (MP) and Circular Supply Chain Management

In examining the hypothesis H3, the study confirms a statistically significant positive correlation between mimetic pressures (MP) and CSCM. This finding aligns with empirical evidence suggesting that manufacturing firms tend to adopt circular practices upon observing their competitors' successes (Zhu & Sarkis, 2007). Firms frequently implement CSCM practices by emulating successful competitors or sustainability leaders to achieve legitimacy and competitive advantage. Drawing on IT, mimetic isomorphism compels organisations to imitate their peers under conditions of uncertainty, a concept applicable to the adoption of CE practices (DiMaggio & Powell, 1983). However, circular strategies that prove successful in one region may not be effective elsewhere due to variations in regulations, infrastructure, or market demand. Past studies confirmed that the uncritical imitation of European circular models in developing economies often fails (Goyal et al., 2018). This observation is consistent with findings that mimetic pressure alone rarely facilitates substantial circular transitions (Geng & Sharpley, 2019), particularly among Small and Medium-sized Enterprises (SMEs) with limited resources (Agyabeng-Mensah et al., 2022). The results also resonate with responses from interview participants. Representatives from the garments, textile, and steel manufacturing sectors confirmed that "*Market leaders are treated as an ideal in the market, and many companies are following their trend. They are among the customers who provide new products to their customers in a sustainable manner within a very short time.*" In practice, market leaders influence other competitors rather than exerting pressure to act. Thus, hypothesis **H3** is supported.

4.7.1.4 Top Management Commitment (TMC) and Circular Supply Chain Management

Like in many cases in the study, top management commitment (TMC) is likely to drive statistical levels of significance for CSCM. The current finding corroborates empirical evidence demonstrating that committed leadership facilitates resource allocation and the

strategic prioritisation of circular initiatives (Agyabeng-Mensah et al., 2022). Moreover, firms with strong leadership commitment were more successful in integrating CE principles into supply chains (Luthra et al., 2022). However, even with the TMC, CSCM implementation might fail if middle managers resist change due to operational complexities or a lack of incentives (Mangla et al., 2018). Interview quotes strongly support the survey findings. Four participants from garment, textile, plastic, steel, and sewing thread companies confirmed that *"Top management invests huge money and provides training to employees in upgradation and sustainable practices,"* which is the key to implementing CSCM within the manufacturing context. Thus, **H4** is supported.

4.7.1.5 Circular Supply Chain Management and Environmental Performance

The result confirmed a highly significant positive relationship between CSCM and environmental performance. This finding supports the principles of the CE, demonstrating that closed-loop systems effectively reduce resource extraction and waste generation (Geissdoerfer et al., 2017). Empirical evidence also highlights CSCM's role in enhancing energy efficiency (De Angelis et al., 2018), reducing carbon footprints (Genovese et al., 2017), and conserving water (Agyabeng-Mensah et al., 2022). However, certain limitations exist when applying CSCM for EcoP. Previous studies found diminishing returns when CSCM prioritises easily recyclable materials (Kirchherr et al., 2018). Participants from almost all manufacturing companies stated that "*We use energy efficient and renewable energy and maintain waste management and sustainable sourcing*". These findings collectively emphasise that while CSCM drives measurable environmental gains, its efficacy depends on strategic implementation and its prioritisation. Thus, **H5** is supported.

4.7.1.6 Circular Supply Chain Management (CSCM) and Social Performance

The study confirms that CSCM has a highly significant positive impact on social outcomes. Empirical evidence confirmed that circular practices ensure green jobs, improve worker

safety, and engage marginalised communities in waste management sectors in Brazilian waste-picker cooperatives (Schroeder et al., 2019; Velenturf & Purnell, 2021). Additionally, past studies found that ethical sourcing in CSCM reduces reliance on exploitative mining practices (Geissdoerfer et al., 2017). However, the empirical findings are contradictory. Several studies revealed that circular practices often create hazardous conditions due to informal e-waste recyclers and often favour large corporations, exacerbating inequality (Corvellec et al., 2022; Lepawsky, 2022). Furthermore, other studies found that circular urban initiatives led to gentrification, displacing vulnerable communities (Checker, 2020). Moreover, interview quotes from the qualitative data confirmed that circular practices enhance employees' well-being and that of the broader community. Participants from denim, garments, textile, and sewing thread manufacturers confirmed that "*We don't mention the minimum wage. We used to mention a living wage, not a minimum wage*." These mixed findings suggest that while CSCM can enhance social sustainability, it can also undermine it. Thus, **H6** is supported.

4.7.1.7 Circular Supply Chain Management (CSCM) and Economic Performance

The findings demonstrate that CSCM highly significantly enhances environmental performance (EcoP) by minimising resource depletion and waste generation. Empirical evidence reveals that closed-loop systems in Chinese manufacturing reduced material consumption while cutting industrial waste, highlighting CSCM's potential to decouple economic growth from resource extraction (Sarkis & Zhu, 2018; Wang, Du, et al., 2019). Similarly, other studies confirm 25% improvement in energy efficiency through product-life extension in the electronics sector, reinforcing the role of circular strategies in lowering carbon footprints (Genovese et al., 2017). These outcomes align with the principles of a regenerative economy, where waste is redesigned as a resource (Mangla et al., 2020). Interview findings also echo the same. All the participants confirmed that "*We use energy*

efficient and renewable energy and maintain waste management and sustainable sourcing". Both the survey data and interview quotes suggested that CSCM positively supports economic performance. Hence, **H7** is supported.

4.7.2 Indirect Effects

4.7.2.1 Mediating Role of Top Management Commitment on the Relationship between Institutional Pressures and Circular Supply Chain Management

The results of this study also reveal that top management commitment (TMC) mediates the positive effect of institutional pressures (coercive, normative, and mimetic) on the adoption of CSCM. This is consistent with previous findings in institutional theory and supply chain sustainability, which show that external pressures lead to organisational change, but that their effectiveness is contingent on internal management support.

Firms, through coercive mechanisms such as regulations and penalties, are partially mediated by TMC to improve CSCM practices. The literature also empirically demonstrates that TMC exerts coercive pressures on strategy through budget allocation, setting sustainability goals, and compliance (Agyabeng-Mensah et al., 2022). TMC was found to partially mediate the influence of environmental regulations on green supply chain practices (Liu et al., 2010). However, empirical findings have shown that loose TMC may result in window dressing rather than real changes in firm circular practices (Zhu et al., 2013). The empirical results were also validated by the interview results. All participants from the manufacturing companies argued that "*Top management supports the following GMP (good manufacturing practices) as well as the GPRS standard we are also following for recycling, the global recycling standard, and we have the ISO 9001".* Thus, **H8a** is supported.

Normative pressures are partially mediated by TMC in the adoption of CSCM practices. Previous research indicates that TMC is crucial for aligning these pressures with long-term sustainability strategy. Empirical studies found that firms with high TMC were more likely to

adopt CE practices in response to industry norms, as managers actively sought certifications (e.g., ISO 14001) and engaged with sustainability-related stakeholders (Dong et al., 2024). Similarly, other studies confirmed that TMC strengthens the link between normative pressures and sustainable supply chain initiatives by fostering a culture of continuous improvement (Walker et al., 2021). This is also supported by the interview data. Participants from denim, garments, and label manufacturing companies stated that "*As a manufacturer, we get directions from the brands, the same direction from BGMEA or BKMEA, and ministries, and suggest that this needs to be done because of the circularity*". Thus, hypothesis **H9a** is confirmed.

Mimetic pressures are further mediated by TMC, forcing firms to emulate their competitors' effective CSCM. However, some research suggests that mere mimicry without managerial dedication creates implementation uncertainty (DiMaggio & Powell, 1983). The extant literature supported the idea that TMC enables mimetic pressures by changing how best practices are used (not simply replicated) in their organisation's context (Yang & Kang, 2020). Past literature also provides evidence that business units with high TMC tend to invest in circular supply chain practices, as historical leaders in the field have done, whereas those with low TMC tend not to invest (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019). Interview results from all participants confirmed this, as they stated, "*Our management follows good and sustainable practices for our benefit and the next generation*." Thus, **H10a** is validated.

4.7.2.2 Mediating Role of Circular Supply Chain Management between Institutional Pressures and Sustainability Performance

The findings indicate that coercive pressures (e.g., legislation, fines, and legal obligations) are fully mediated by circular supply chain management (CSCM) practices, which positively contribute to sustainability performance across all three pillars (environmental, social, and

economic). Compelling environmental regulations effectively force firms to adopt circular-based approaches (e.g., closed-loop supply chain) to minimise waste and emissions (Zhu & Sarkis, 2007), and circular practices have been empirically proven to fully mediate firms' regulatory intensity and carbon footprint (Chen, Jiang, et al., 2025). On the social aspect, the enforcement of labour and safety legislation encourages ethical sourcing for a CSCM practice, leading to better worker welfare (Yildiz Çankaya & Sezen, 2019)(Yildiz Çankaya & Sezen, 2019). Research indicates that enhanced social sustainability under institutional pressure depends on the implementation of circular practices (Zhou et al., 2024). Regarding the economic dimension, although regulatory compliance incurs initial costs, practices such as remanufacturing enable circular practices to recover these costs and address regulatory expenses (Lieder & Rashid, 2016), thereby converting them into economic benefits (Genovese et al., 2017). As a part of customer requirements, participants from garment manufacturing companies confirmed that "*We introduced digital passport based on the regulatory requirement from customers to get a clear idea, so we will make this feel safe to make our products sustainable with production and delivery, and everything can be aligned with a specific timeline*". This extensive body of evidence emphasises the significance of CSCM as a mediating variable that translates regulatory mandates into performance enhancement across all three sustainability performance domains. Consequently, **H8b**, **H8c**, and **H8d** are substantiated.

Normative pressures arising from industry norms, certifications, and trade association influences are fully mediated by CSCM, thereby enhancing sustainability performance. In the context of environmental performance, the implementation of certifications such as ISO 14001 encourages entities to engage in CSCM activities, including reverse logistics, thereby improving recycling rates (Roy, Ali, et al., 2025). CSCM mediates the relationship between industry norms and resource efficiency (Walker et al., 2021). Regarding social performance,

the development of large-scale fair-trade CSCM models, driven by consumer and NGO demands, is guided by a community well-being approach (Miemczyk et al., 2016). Extant studies suggest that ethical subjectivist preferences mediate the impact of normative pressure on social equity (Touboulic & Walker, 2016). In terms of economic performance, normative pressures may directly drive CSCM-based innovation for competitive advantage (Ghisellini et al., 2016), with mediating analyses supporting the centrality of CSCM in transforming industry best practices into tangible profit gains (Kristensen & Mosgaard, 2020). Moreover, interview quotes from the participants also support the findings. Participants from garment retail, label, and FMCG manufacturers stated that "*All organisations and ministries are supported to do this kind of recycling or sustainable products to reduce waste, satisfy the customer, and ensure the economic impact on the business*". Overall, these findings demonstrate how CSCM serves as a crucial mechanism mediating the influence of normative institutional pressures on the emergence of new sustainability initiatives in environmental, social, and economic performance. Thus, **H9b**, **H9c**, and **H9d** are confirmed.

The result confirms that mimetic pressures are fully mediated by CSCM for achieving sustainable performance. Firms usually adopt CSCM by observing and replicating competitors' successful sustainability strategies, a process that drives meaningful improvements across all three performance pillars. When companies emulate industry leaders in transforming waste into valuable resources, they dramatically reduce their dependence on landfills (Laari et al., 2018). Previous research confirms this link: CSCM acts as a critical bridge between imitation and actual gains in eco-efficiency (Chen, Jiang, et al., 2025). The benefits extend beyond the environmental outcomes. By adopting these practices, businesses measurably upgrade working conditions (Kumar et al., 2022), proving that circular practices effectively convert peer influence into social progress (Seuring & Müller, 2008). The financial advantages are equally compelling. H&M's garment recycling program

demonstrates how circular business models reduce operational costs (Bressanelli et al., 2019). Further studies show that CSCM mediates up to 60% of MP's impact on sustainability return on investment (ROI) (De Jesus & Mendonça, 2018). Participants from the denim, steel, plastics, garments, and textile manufacturing companies suggested that "*Market leaders have introduced slag processing plants or water treatment plants to reduce the environmental harm and introduce best practices to ensure efficiency and customer satisfaction*". Together, these findings validate CSCM's role as the operational engine that transforms competitive imitation into holistic sustainability wins, confirming **H10b**, **H10c**, and **H10d**.

4.7.2.3 Mediating Role of Circular Supply Chain Management between Top Management Commitment and Sustainability Performance

The study findings demonstrate how CSCM fully mediates the crucial connection between TMC and all three aspects of sustainability performance. When leaders truly commit by investing resources and setting clear strategic priorities, companies see real environmental benefits, such as reductions in waste or improvements in energy efficiency (Zhu et al., 2020). Extant research shows that firms excelling in green supply chain management achieve significantly greater reductions when implementing closed-loop practices (Wang et al., 2022). However, it is not just about the environment. Almost all participants in the interview agreed that "*Our management is trying to reduce waste by ETP, FTP, and other measures.*" Strong TMC also drives social progress. By prioritising stakeholder relationships, committed leaders implement ethical sourcing through CSCM, directly improving worker conditions and community well-being (Sahoo & Upadhyay, 2024). In manufacturing, nearly 50% of TMC's impact on social equity over five years came from CSCM practices such as fair wages and safe recycling (Li et al., 2025). Participants from denim, plastics, garments, textile, and plastic manufacturing confirmed that "*Our management is strongly committed to fostering a safe, healthy, and environmentally friendly workplace for both our employees and valued*

customers". The economic performance is equally compelling. When TMC backs CSCM, companies do not just cut costs; they uncover new revenue streams through circular business models (Saccani et al., 2023). In fact, for sustainability-focused firms, CSCM mediates most of TMC's positive effects on profits (Genovese et al., 2023). These powerful results position CSCM as an essential link transforming leadership commitment into concrete triple-bottom-line results. Participants from the garment, steel, plastic, and textile manufacturing companies stated that "*The Company has converted their regular lights to LED lights, rainwater harvesting, and uses natural cotton to reduce cost"*. With comprehensive evidence across all dimensions, the study confirms **H11a**, **H11b**, and **H11c**.

4.8 Conclusion

Circular supply chain management (CSCM) is widely regarded as a solution for addressing climate change, waste management, and resource scarcity while ensuring economic, social, and environmental performance throughout the supply chain (Mangla et al., 2018). However, research on the implementation of CSCM in manufacturing companies in developing countries such as Bangladesh is limited. This study is grounded in institutional theory, encompassing coercive, normative, and mimetic pressures, along with the direct and mediating roles of top management in influencing manufacturing companies to adopt circular practices for economic, social, and environmental sustainability. This study employed a mixed-method approach, comprising a quantitative analysis of 313 participants and a qualitative study involving 25 top-level executives committed to sustainability. The regression analysis indicates that all three institutional pressures (coercive, normative, and memetic) positively and significantly affect the implementation of circular practices. Furthermore, top management commitment (TMC) positively supports circularity in supply chain management (SCM). The findings also suggest that coercive, normative, and mimetic pressures are mediated by both CSCM and TMC, contributing to overall sustainability

performance in the economic, social, and environmental domains. Although circular supply chain practices are still in the nascent stages within the manufacturing industry in Bangladesh, the exploratory results provide valuable insights for theory, policy, and practice.

4.8.1 Contributions of the Study

CSCM is widely promoted by governments and organisations worldwide and serves as a strategic approach to advancing circular supply chains. However, CSCM is still in its nascent stage in Bangladesh. The research examines and empirically tests the effects of institutional pressures and management commitment on CSCM practices and sustainable performance. The study also uses causal links to explain the relationships among different types of institutional pressure, which require relevant strategic responses that lead to the successful adoption of CSCM. Therefore, the research investigation contributes to theory and practice by offering recommendations for managers and practitioners. More specifically, the research provides recommendations on how to respond to institutional pressures to facilitate the development of circular supply chains. While governments across the world continue to explore opportunities and activities linked to CE, the appropriate application of robust CSCM models is essential to deliver these activities and enhance an organisation's ability to respond, efficiently utilise resources, and develop circular supply chains.

Achieving these goals will require collaborative engagement with stakeholders to support essential CSCM practices, including recycling, material remanufacturing, the use of renewable energy sources, top management commitment, sustainable work environments, and waste reduction. Collective collaborative efforts are necessary for a successful transition toward sustainable, circular supply chains.

4.8.1.1 Theoretical contributions

This study has contributed to the literature in several ways. First, this study identifies CSCM as a strategic pathway to promote circular supply chains and sustainability in developing

countries such as Bangladesh. External pressures and internal support are required for achieving zero waste, which is crucial to effective CSCM (Zhu et al., 2013). Internal stakeholders, such as top management, employees, and operational teams, drive strategic decision-making, resource optimisation, and the integration of circular practices within organisational processes. External stakeholders, including suppliers, customers, regulatory bodies, and community partners, influence CSCM through compliance demands, market expectations, collaborative partnerships, and policy support. Together, these actors create a synergistic environment that enables the adoption and success of circular initiatives.

Second, the study contributes to IT by examining the influence of coercive, normative, and mimetic pressures. Consistent with prior research (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019), these findings underscore the significant role of institutional pressure in shaping sustainable supply chain practices. The study further extends institutional theory by revealing the mediating role of CSCM, through which institutional pressures are translated into tangible economic, environmental, and social outcomes. In contrast to empirical studies that report inconsistent or negative effects on CSCM (Geng et al., 2009). The findings align with empirical findings, which state that regulatory pressure without proper support can result in superficial adoption of circular practices and may create organisational tensions when standard norms are absent (Kazancoglu et al., 2021). Moreover, blind imitation of circular practices without strategic fit or resource capability may lead to inefficiencies, cost overruns, or implementation failures (Geng et al., 2009). Based on the findings, this study reinforces the strategic potential of circular practices in leveraging institutional pressures and top management commitment to drive sustainable performance.

Third, the study also investigated the mediating effects of top management commitment and institutional pressures on relationships related to CSCM. Prior research used distinctive theoretical frameworks, such as social identity theory and institutional and resource

orchestration theory, to identify how and when CSCM associates with sustainable performance (Agyabeng-Mensah et al., 2022; Farooque et al., 2022). The inconclusiveness of how these factors differ across contexts, and empirical studies do not yield the most insightful conclusions. The current study addresses some of these constraints by systematically considering the varying adoption of CSCM across cultural contexts and economic types (Mangla et al., 2018).

Finally, the study found that CSCM not only improves environmental performance but also social and economic performance. Regarding the research question, it's interesting that adopting CSCM leads to social performance before environmental and economic performance. This result is consistent with the findings that influence the firm, i.e., cost, financial, and operational performance, and then on social and economic performance (Alghababsheh, 2024; Farooque et al., 2022). However, they are counter to empirical results, which found that improvements in circular practices had ambiguous effects on carbon emissions (Lomas et al., 2025). The effects could be positive, negative, or no impact on environmental performance (Hailemariam & Erdiaw-Kwasie, 2023), and high initial investment and transformation costs of circular supply chains may negatively affect economic performance, especially in the short term (Tseng et al., 2023). Moreover, the extant literature suggests that CSCM is primarily focused on environmental and economic aspects rather than social performance, especially in developing country contexts (Mangla et al., 2018; Sudusinghe & Seuring, 2022). Hence, the integrative empirical evidence enriches academia and clarifies the ambiguity in sustainable performance (de Lima et al., 2024; Hailemariam & Erdiaw-Kwasie, 2023).

4.8.1.2 Practical Contributions

This research provides a guide for supply chain and operations managers in developing countries like Bangladesh on how to apply institutional pressures as strategic facilitators of

CSCM. Instead of viewing these pressures as restrictions, manufacturing firms should aim to adopt sustainability agendas that align with regulatory expectations, industry norms, and market-leading trends. Moreover, top management plays a crucial role in responding to these pressures by committing to adopting CSCM, allocating human and financial resources, and fostering a culture and digital mechanisms for circularity.

Moreover, CSCM requires wholehearted support from supply chain leaders who ensure proactive participation from employees, middle management, and cross-functional teams in accepting and executing the concept. This is because the goal of CSCM, when improving internal capabilities, should include employee skill development, cross-department collaboration, and training that would increase employees' awareness of circular practices to improve internal communication. Therefore, the manager should understand the impact executives' attributes (e.g., educational background, professional experience) have on decision-making capabilities and leadership abilities, to develop innovative approaches for zero-waste initiatives or sustainable supply chain practices that incorporate CSCM.

Additionally, Bangladesh's export-based industries (particularly the garment industry) are under greater pressure than ever from international buyers, regional/non-governmental organisations, and regulatory bodies to adopt more sustainable practices. This pressure is only partly compliance-related, but also market-access-related. Managers will need to meet with stakeholders across the supply chain (customers, suppliers, regulatory bodies, and so on) to help provide mutual support for certification programs, replicate successful CSCM practices from other leading organisations, and stay competitive and engage with international markets.

Finally, this study reinforces the multiple benefits of CSCM beyond its environmental benefits, which play an important role in social and economic performance. As global warming and resource scarcity become increasingly important worldwide, adopting CSCM enables firms to pursue long-term sustainability strategies while simultaneously addressing

the socio-economic development priorities of developing economies to achieve SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). Regulatory pressures require firms to comply with environmental standards on waste reduction, sustainable urban production, and responsible resource use, while strong top management commitment ensures these requirements are translated into sustainable operations. Together, these forces drive firms to adopt resource-efficient production systems, minimise waste generation, and support sustainable urban supply networks, thereby directly contributing to achieving SDGs 11 and 12.

4.8.2 Limitations of the Study

This study acknowledges certain limitations that need to be acknowledged and summarised in the following:

First, this study was conducted within the theoretical framework of institutional theory (IT). Although IT theory is widely accepted and used to understand organisational conformity and legitimacy, it may not apply to all phenomena (Tina Dacin et al., 2002). Additionally, decisions influenced by NPs and MPs may be inefficient, potentially leading to bandwagon behaviour (Kauppi & Luzzini, 2022).

Second, this study considers institutional pressures and top management commitment for implementing circular supply chain practices. However, other operational and strategic factors are equally significant to CSCM, such as, internal process alignment, integration of supplier and customer and real time visibility (Pellegrino et al., 2025).

Third, the study duration was based on a single data set and experience of a major political crisis, which limits the researcher's ability to observe changes over an extended period. Moreover, due to the disruption which leads to restricting the researcher’s ability to collect follow-up data, trust and openness with participants, or explore new themes in detail, which

may jeopardise reliability and validity. Moreover, no analysis on measurement variances for the work of translation.

Fourth, this study is based on only 25 interviews from male respondents to triangulate the survey results from manufacturing firms. Therefore, the study's findings may not adequately reflect the full diversity of perspectives in the target population, thereby risking insufficient data saturation due to more than 12 industries and threatening the depth and trustworthiness of the analysis.

Finally, the study focuses mainly on large manufacturing firms, often overlooking the practices of small and medium-scale firms. Additionally, Bangladesh experienced a political crisis during data collection. This political upheaval could have affected the response rate and respondents' perceptions, reducing the generalisability of the results.

4.8.3 Directions for Future Research

The above-mentioned limitations provide a direction for future research. The research directions are summarised as follows:

First, future research should incorporate alternative theories, such as contingency theory (Donaldson, 2001) and stakeholder theory (Freeman & Phillips, 2002), which may offer additional opportunities to enhance circular implementation and further contribute to the literature.

Second, future research should examine collaboration across the supply chain (Govindan & Hasanagic, 2018a), innovation and technological capabilities (De Jesus & Mendonça, 2018), strategic alignment, eco-friendly product systems based on closed and open biological and technology cycles (De Angelis et al., 2018), and business model innovations that incorporate environmental degradation, product design, and organisational values that support CSCM and sustainability performance (Burke et al., 2023).

Third, future research could benefit from longitudinal studies that examine actual changes in circular practices within supply chains over time. Longitudinal studies are crucial because circular practices rarely take hold through one-off decisions but through gradual alignment with shifting norms and expectations. By tracking these dynamics, future researchers can see how sustained leadership support translates into stable progress across the triple bottom line rather than short-term or symbolic gains.

Future studies could focus on additional interviews from cross-sectional data both male and female or focus group studies to compare findings across similar firms in nature. Cross-sectional interviews or focus groups offer a snapshot of how people understand and enact circular practices, giving a detailed understanding of the phenomenon.

Finally, while this study was conducted in Bangladesh, a South Asian country, future research could expand on the findings by exploring emerging countries in other developing countries.

The next chapter presents the final chapter of the thesis, which summarises the study's findings and discusses their theoretical, practical, and policy implications. These implications are examined in relation to circular product design, additive manufacturing, design capabilities, institutional pressures, and top management commitment in supporting the implementation of circular supply chain management practices to enhance sustainable performance.

Chapter 5: Conclusion

This chapter brings together the key findings of this thesis, demonstrating the contributions to theory, practice, and policy in the areas of circular product design, circular supply chain management, and sustainability performance. The study has been structured and presented in three connected research papers. Each paper addressed a distinct aspect of the overarching research aims of the role of additive manufacturing (AM) in advancing circular product design, the contribution of dynamic capabilities and design and manufacturing technologies in supporting transformation toward circularity, and the influence of institutional pressures and top management commitment in driving circular supply chain management for sustainability performance.

The chapter is structured into five main sections. Section 5.1 synthesises the key findings, offering both an integrated perspective and a breakdown of contributions from each of the three papers. Section 5.2 discusses the theoretical contributions of the research, showing how this study advances existing debates on additive manufacturing, circular product design, institutional theory, and the role of technology in sustainability transitions. Section 5.3 focuses on the practical contributions and draws out implications for managers. Section 5.4 highlights policy implications for government agencies, policymakers, and industry practitioners tasked with implementing circular strategies in real-world contexts. Section 5.5 outlines the study's limitations, and Section 5.6 provides directions for future research that can further enrich knowledge in this field.

5.1 Key Findings

All three papers collectively demonstrate that the circular transformation of the manufacturing sector is a multidimensional process that relies on appropriate technology, organisational and design capabilities, and effective leadership. AM is a design and manufacturing technology adopted and utilised with the subsequent manufacturing process in

mind, which means it is not only for advancing design flexibility and mass customisation but also for mediating broader shifts toward circularity in product design. However, achieving a CSCM necessitates a comprehensive approach, in which firms must address pressures to adapt, and this further requires top management commitment. Firms need to develop a group of dynamic design capabilities (DfAD, DfM, DfR) for circular product design, which must be integrated with external factors, such as institutional pressures for circular practices within the supply chain. However, CSCM cannot be operationalised solely because of product design principles. Implementation of CSCM requires alignment between design and manufacturing tools (AM), strategic leadership (top management commitment), and design capabilities across the entire supply chain, demonstrating that transformation is a joint effort between internal resources and external forces. All these key findings are elaborated below based on the three papers and context:

5.1.1 Design Capabilities and AM Enable Circular Products (Papers 1 and 2)

Existing research provides mixed evidence on whether AM supports the circular economy (CE), with studies highlighting its potential for material efficiency and design flexibility while also showing that AM does not inherently produce circular outcomes (Ford & Despeisse, 2016; Gebler et al., 2014; Sauerwein et al., 2017; Sauerwein et al., 2019). Paper 1 demonstrates that AM can support CE principles as both a design and manufacturing technology by enabling mass customisation, complex geometries, value retention through R-strategies and closer customer engagement, thereby supporting product longevity and resource recovery (Bocken et al., 2016; Geissdoerfer et al., 2017; Kirchherr et al., 2017). Given framework links the antecedents, boundary conditions, mechanisms and outcomes of AM-enabled CPD, emphasising that AM can facilitate the integration of circularity into product design. Paper 2 provides empirical support by showing that dynamic design capabilities, particularly design for assembly and disassembly (Battaïa et al., 2018; O'Grady

et al., 2021), modularity and recyclability (Lau et al., 2011; Mozo-Reyes et al., 2016), contribute to CPD, while material selection represents an organisational capability because it does not necessarily follow dynamic capability principles (Den Hollander et al., 2017; Winter, 2003). AM mediated the relationship between these capabilities and CPD, while CPD improved new product performance in terms of cost, efficiency, quality and customer satisfaction. These findings indicate that AM does not independently guarantee circularity but helps firms translate circular design capabilities into manufacturable products and strengthen the practical implementation of repair, reuse, remanufacturing, recycling and waste reduction strategies (Goyal et al., 2018; Hettiarachchi, Brandenburg, et al., 2022).

5.1.2 Institutional Pressures Operate Through Top Management Commitment for Circular Supply Chain Management (Paper 3)

Paper 3 investigated the impact of external institutional pressures and top management commitment on CSCM adoption. The results showed that coercive, normative and mimetic pressures have an important impact on the adoption of circular supply chain among Bangladeshi manufacturing companies (DiMaggio & Powell, 1983), which is similar to the results from previous studies on the relationship between institutional pressures and circular practices (Calzolari et al., 2023; Testa et al., 2016). However, external pressures alone were not enough to incorporate institutional expectations into CSCM practices, because top management commitment mediated this effect. These findings imply that regulatory, market, and industry expectations can be embedded in organisations' practices only if top management pays the required attention, dedicates the necessary resources, and commits to circularity (Dubey et al., 2017; Farooque et al., 2022). These findings align with the idea that firms respond strategically to institutional pressures rather than simply following them (Zeng et al., 2017). At the same time, these findings again highlight the importance of top management commitment in establishing CSCM practices (Farooque et al., 2019).

Bangladesh is considered for empirical evidence that reinforces this connection, especially in the garment industry, as the growing number of LEED-certified manufacturing facilities indicates compliance with regulations and managers' concern for resource use, water conservation, and carbon emission reductions (Financial Express, 2025). In general, institutional pressure appears to strengthen the drive toward CSCM when top management views these demands as strategic concerns.

5.1.3 Connecting Dynamic Capabilities, Institutional Pressures, CSCM and Sustainable Performance (Papers 1–3)

Papers 1-3 show that institutional pressures and internal capabilities are interconnected rather than independent determinants of circularity and sustainability performance. Paper 1 conceptualised institutional pressures as boundary conditions and design capabilities and digital technologies as antecedents of circular product design, while Papers 2 and 3 provide empirical evidence of how these elements operate within firms. Institutional pressures create incentives for circularity, top management commitment converts these pressures into strategic priorities and resources, and design capabilities supported by AM translate those resources into circular products (Hambrick & Mason, 1984; Teece, 2007). These integrations contribute to both product-level performance and broader environmental, social and economic outcomes (Elkington, 1998), supporting emerging research that integrates institutional pressures with organisational capabilities in explaining CE implementation (Castro-Lopez et al., 2023). In addition, Paper 3 shows that employee education and experience are associated with adopting circular design and supply chain practices, suggesting that workforce knowledge can strengthen the link between external pressures and internal organisational capability (Cohen & Levinthal, 2000; Felin et al., 2012). Finally, these findings establish empirical evidence of how external pressures, top management commitment, organisational dynamic capabilities and digital technologies interact to support

circularity and sustainability. The following figure the 5.1 connects the concept of AM, MS, DCT, IPs, TMC, CSCM and sustainability performance.

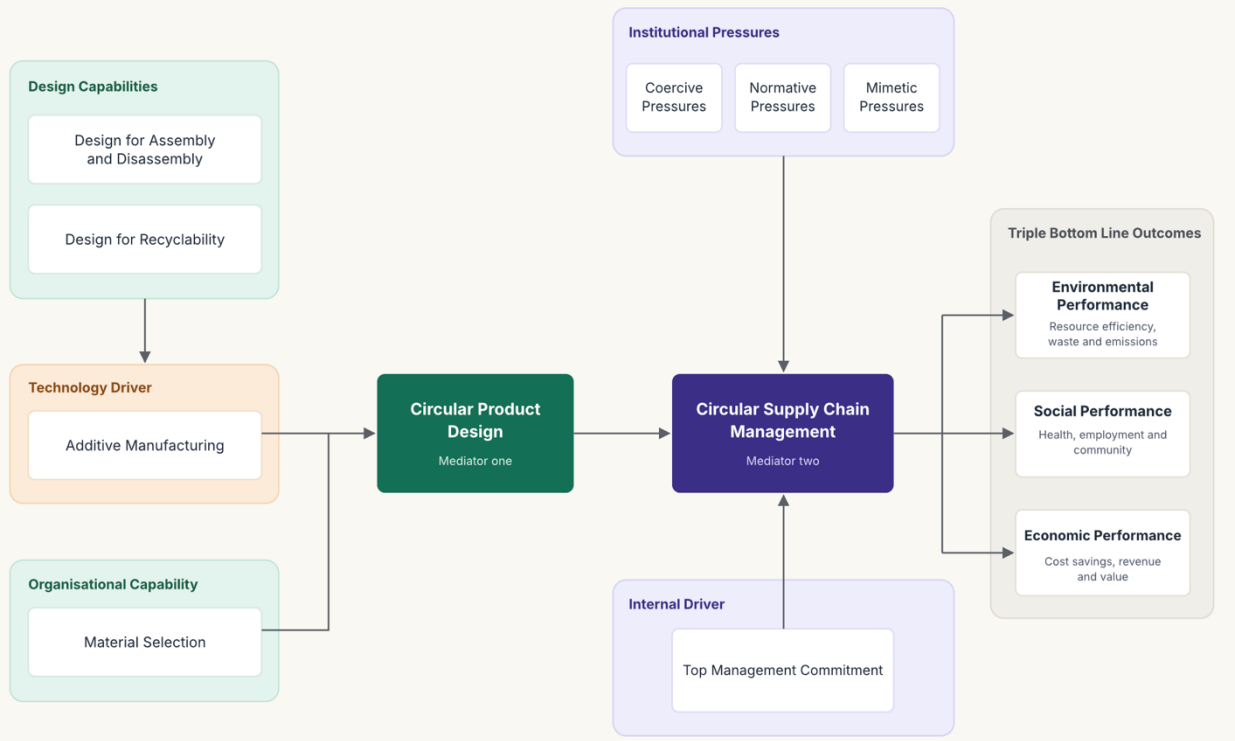


Figure 5.1: Integrative Framework

5.1.4 Contextual Findings: Bangladesh

This study offers the first empirical evidence from Bangladesh on how manufacturing firms are adopting circular practices to meet international standards and stay competitive in global markets. In the industrial domain in Bangladesh, the study found that circular supply chain practices (R's strategies) lead to sustainability performance. For example, in the garment sector, recycling, i.e., water and fabric, and reducing, i.e., energy and materials, has become a basic requirement, driven not only by regulatory requirements but also by buyer demand for circularity-oriented practices. The study also found that the textile industry's sustainability performance depends on meeting compliance with quality, social, and environmental standards, demands for both imported and locally produced raw materials, such as yarn, to meet international standards for quality management, social accountability, and environmental management, including ISO 9001, ISO 14001, and LEED.

In the steel industry, the study reveals that reducing fume generation and exhaust emissions is essential for minimising CO_2 emissions, and sourcing inputs from neighbouring countries can further reduce transport-related pollution and support smoother operational flows. The plastic section also put particular emphasis on environmental management through waste reduction strategies based on the 3Rs and the implementation of Extended Producer Responsibility, reflecting a growing focus on material recovery and extended product life cycle. In the automobile industry, circular and sustainable practices are primarily driven by regulatory compliance and industrial policy incentives. For this reason, the automobile industry meets environmental and safety regulations, local manufacturing requirements, and minimum levels of local value addition to qualify for tax incentives, thereby encouraging domestic production and component manufacturing through tax holidays. Similarly, the furniture industry relies on assembly and disassembly and localised production by using sustainable materials, an experienced workforce, and gradual adoption of advanced manufacturing technologies to meet export and environmental requirements. In the FMCG companies, the findings confirm that firms maintain strict legal compliance, ETP installations, social and labour standards (i.e., labour aged 18 or older), quality assurance, and investment in human capital, all of which contribute to circular sustainability practices. Collectively, qualitative quotes on these industry-specific practices illustrate how sustainability performance and circularity in Bangladesh are pursued through compliance-oriented yet progressively integrated operational approaches.

In addition to the above findings, the study contributes to the theory, practice and policy

5.2 Theoretical Contributions

This study considers both dynamic capabilities theory (DCT) and institutional theory (IT) as a lens to explain how external pressures and internal organisational and design capabilities shape CSCM adoption and sustainable performance. First, DCT explains how firms sense

opportunities, seize them, and reconfigure resources in response to external pressures (Teece, 2007; Teece et al., 1997). Institutional theory further explains how external pressures influence organisational behaviour and CSCM adoption (DiMaggio & Powell, 1983). The strategic management framework developed in Chapter 2 connects these two theories, with Bangladesh as the boundary condition; institutional pressures/top management commitment as antecedents; additive manufacturing as design capabilities within focal organisational activities; and the triple bottom line as outcomes (Elkington, 1998). On this basis, the study makes three theoretical contributions.

5.2.1 Dynamic capabilities for circularity originate in product design (Paper 2)

Drawing on supply chain literature, dynamic capabilities relate to managerial and organisational processes, including market scanning, investment decisions, and resource reconfiguration (Teece, 2007). Although prior research has examined managerial cognition and individual- and process-level micro-foundations, CSCM literature predominantly conceptualises sensing as identifying external market opportunities (Dubey et al., 2023; Helfat et al., 2009). Paper 2 extends this understanding by demonstrating that sensing also occurs during the product design stage for circularity. Design capabilities related to recyclability, assembly and disassembly, and organisational capabilities in material selection enable firms to anticipate material scarcity and end-of-life constraints before production begins, reinforcing the importance of upstream design in determining circular potential (Bocken et al., 2016; Den Hollander et al., 2017).

The study further shows that AM supports seizing and reconfiguring by reducing design constraints related to geometric complexity, material selection, and centralised production. This provides empirical evidence of how AM complements circular design capabilities and advances research linking digital technologies to circular economy capabilities (Despeisse et al., 2017; Ford & Despeisse, 2016; Gebler et al., 2014; Kristoffersen et al., 2021).

5.2.2 Leadership translates institutional pressure into circular performance (Paper 3)

Institutional theory explains how firms respond to external pressures through conformity or strategic adaptation (Castro-Lopez et al., 2023; DiMaggio & Powell, 1983). Previous research suggests that institutional pressures (IPs) can stimulate sustainability strategies, with coercive pressures often exerting a stronger influence than normative and mimetic pressures (Dubey, Gunasekaran, Childe, Papadopoulos, et al., 2019). Recent research further highlights IPs and supply chain integration constructs in CE practices (Calzolari et al., 2025). In this study, Paper 3 identifies TMC as an internal mechanism and mediates the relationship between coercive, normative, and mimetic pressures and CSCM. This finding highlights how IPs and commitment translate institutional expectations into organisational priorities and resource allocation, consistent with upper echelons theory and previous research on demanding management commitment in CSCM (Farooque et al., 2019). The thesis extends this previous explanation beyond practice adoption to sustainability performance, complementing research on supply chain integration by demonstrating the importance of TMC in translating IPs into sustainable outcomes (Calzolari et al., 2025).

5.2.3 Additive Manufacturing, dynamic capabilities, institutional pressures and top management commitment operate interdependently (Chapters 2–4)

Prior research has predominantly examined institutional pressures and organisational design capabilities separately, with limited attention to their integration in CE adoption (Castro-Lopez et al., 2023). This study mitigates these perspectives by claiming that institutional pressures stimulate CSCM, whereas TMC translates these pressures into strategic priorities along with design and organisational capabilities such as material selection, design for assembly and disassembly and design for recyclability, reinforced by AM, enable sustainability outcomes.

The proposed integrative framework distinguishes CSCM operationalisation from dyadic compliance, suggesting that institutional pressures without sufficient design and technological capabilities and TMC may decouple formal adoption from actual practices (Meyer & Rowan, 1977). Conversely, capabilities may remain underutilised without institutional incentives or leadership support. Employees' education and experience may further strengthen this integration by enhancing firms' capacity to acquire, assimilate, and apply knowledge to put relationships into practice (Cohen & Levinthal, 2000).

5.3 Practical Implications

The results from the studies presented in this thesis can guide companies and professionals seeking to implement CE principles in their operations. Across all three papers, the findings conclude that efficient CSCM requires four interlinked focus areas: incorporating AM into product development, enhancing circular design capabilities, translating institutional pressure into top management commitment, and aligning firm capabilities with those of the supply chain.

Specifically, managers should incorporate AM into the circular design and development process. In Paper 1, AM functions not only as a manufacturing technology but also as a design technology, while in Paper 2, it mediates the relationship between design capabilities and new product performance. Hence, managers should consider AM in the early product development stages rather than regarding it solely as a production technology. Facilities like design flexibility, reduced lead time, and on-demand/localised production possibilities that result from AM, which can support resource-efficient product development and reduce waste and inventory (Ford & Despeisse, 2016). However, because of high costs, low production speed, and limited materials, companies should use AM strategically before initiating its adoption process.

Secondly, firms need to consciously cultivate CPD capabilities. Paper 2 highlights assembly and disassembly design, recyclability, and material selection as dynamic and routine capabilities required for CPD. Managers need to integrate these capabilities into product design processes because they support repair, reuse, refurbishment, and material recovery (Bocken et al., 2016; Den Hollander et al., 2017; Vanegas et al., 2018). Material selection also gets managers' attention because it dictates the extent to which reuse, recycling, and recovery are possible. Firms need to articulate circular criteria and responsibilities for material selection. Building these capabilities alongside AM will help turn intentions into practice.

Third, companies need to translate external pressures into action through active top-management involvement. Paper 3 shows that IPs relate to CSCM adoption, but also that top management commitment can transform these external pressures into internal action. Hence, managers should use not only regulations, customers' demands, certifications, and industrial practices as compliance issues, but also as strategic tools for investing in the circular economy (Calzolari et al., 2025). Top management needs to set clear goals for circular activities, allocate resources, assign responsibilities, and monitor performance across the organisation's functional areas. Employee education and experience also affect circular adoption; therefore, investing in employee training and development can support circular implementation, although this is an exploratory finding, as these variables were introduced as control variables (Farooque et al., 2019).

Fourth, companies should integrate leadership, capability, and supply chain relationships to attain meaningful circularity. Empirical research indicates that external pressure, top management commitment, and design capabilities are interrelated, not independent, variables. Failing to build appropriate capabilities despite institutional pressure may lead to formality without meaningful action, and capabilities can be underutilised without management

involvement and resource allocation. Firms, in this case, should ensure that management's circularity goals are tied to developing design capability, AM, employee development, and partnership with suppliers and consumers. Integration is important for manufacturing firms in Bangladesh and other developing countries, where organisations face strong buyer pressure, regulatory requirements, and competition. It would help to advance SDG 12 by increasing responsible production and use of resources, while there may be some contribution to SDG 13 simultaneously.

5.4 Policy Implications

The research results show that policies can speed up the shift to CSCM practices by addressing both the technological and organisational prerequisites for implementation. There are four policy priorities of policies suggested by the results of the research.

First, policymakers must address barriers to adopting additive manufacturing technology for circular product development, as AM requires specialised expertise, materials, maintenance services, and technical support remain limited for many firms in Bangladesh. Papers 1 and 2 show that additive manufacturing can support circular product design and improve design outcomes. Initial investment costs and limited knowledge of the technology can be barriers to adoption, especially for small and medium-sized manufacturers in developing countries. Foreign direct investment, innovation grants from government, tax benefits, concessional loans, and AM hub can address this barrier by letting firms test the technology without making large investments. Policies must be related to concrete circular results in the form of modular, reparative, recyclable, or resource-efficient product design.

The second policy should initiate a mid and long-range plan for enriching design and human capabilities needed to facilitate circularity. Based on paper 2, capabilities such as design for assembly/disassembly, recyclability, and material selection are crucial in developing circular products. Therefore, policymakers need to complement the technological initiatives with

training and capacity-building programs that will help businesses to build these capabilities. Setting clear guidelines on recyclability, recycling rates, and material recovery can also promote better material selection. Extended producer responsibility can help establish economic incentives for companies to design products that can be easily recovered and recycled. Engineering/design education is important, given Findings from Paper 3's also stated the same policy implication in prior study where employee capabilities/experience were associated with circularity, although it was exploratory research (Cohen & Levinthal, 2000).

Third, policymakers should create an institutional environment that promotes the adoption of circular supply chains. Paper 3 indicates that coercive, normative, and mimetic pressure are linked to the adoption of CSCM. Thus, policymakers must welcome regulatory pressure with industry standards and demonstration effects. Policymakers can achieve regulatory pressure through clear, stable environmental regulations and disclosure. Collaboration with industry associations and professional bodies can create normative pressure. Demonstration effects can be achieved through public recognition and showcasing successful cases of circular practices. These aspects apply to export manufacturing industries, where company behaviours are shaped by regulation, buyer pressure, and industry standards (DiMaggio & Powell, 1983).

Fourth, policy must enhance accountability among managers and stimulate market demand for circular products. The findings in Paper 3 show that institutional pressures alone is not sufficient to facilitate the adoption of circular practices in companies and that top-level management commitment is an important mediator. Accordingly, policymakers can urge companies to set quantifiable circularity targets through sustainability reporting, accountability measures for company leaders, award schemes, and voluntary industry commitments. Meanwhile, public purchasing criteria should favour products with characteristics such as circular design, resource efficiency, reparability, and localised

production. Such a combined effort will help translate institutional pressures into organisational action and avoid superficial implementation (Farooque et al., 2022; Meyer & Rowan, 1977).

In summary, these four policy areas show that effective CE policies cannot be based solely on regulation or technology adoption. An efficient policy must combine technological solutions, capability-building, institutional coordination, and managerial accountability. By integrating all these policies, CE policies can contribute directly to SDG 12 by fostering responsible production and resource utilisation, and indirectly to SDGs 13 and 11 through resource-efficient manufacturing and localised production, respectively.

5.5 Limitations of the Studies

Although this study provides some novel findings in the fields of CE, CPD, CSCM, and sustainability performance, it is not without shortcomings. The following sub-section summarises the notable limitations.

First, this study focused solely on additive manufacturing. However, additive manufacturing is not the only technology directed toward circularity in practice. Moreover, there was semantic confusion between AM and 3D at the field level during data collection. Most respondents viewed both technologies as acting similarly, despite their differences in theory and practice.

Second, this study primarily used the theoretical lenses of dynamic capabilities and institutional theory to build and operationalise capabilities for CPD strategies to ensure the operationalisation of CSCM. However, the unusually high β and the size of the relationship between the CSCM and ScoP was not significant, since their strength may be an indication of construct overlap, suppression, or something unfamiliar about the sample or the measure used. While both these theories are criticised from conceptual and measurement perspectives. The capabilities of one firm may not match those of other firms, and there is a lack of

uniformity in the measurement of capabilities (Teece et al., 1997). Moreover, IT often underestimates the strategic choice and struggles to explain competitive advantage (Scott, 2010).

Third, the empirical analysis emphasised design capabilities (design for recyclability, assembly, and disassembly) and organisational capabilities, such as material selection. However, circular product design also encompasses broader aspects, such as design for durability, upgradeability, and emotional attachment (Bocken et al., 2016). Moreover, the lack of a considerable mediating effect of material selection and additive manufacturing would limit their role as valid mechanisms explaining the relationship between circular product design and NPP. Although MS is not considered a DCs in this study, there is a possibility of overlapping these two theoretically.

Fourth, the mixed-methods approach strengthened the analysis, yet the data for both Paper 2 and Paper 4 were collected at a single point in time and using same cross sectional data set, which may lead to common method bias. Moreover, the study is also limited by its sample of men only, which limits generalisability and replication. However, no measurement invariance between the English and Bangla versions was not formally tested in this study.

Fifth, the study highlighted the mediating role of top management commitment in amplifying institutional pressures but not considered the positive effect of employee education and experience for circular supply chain practices. However, organisational culture, leadership style, and inter-organisational collaboration were not deeply examined.

Finally, the readiness of different sectors to adopt circular product design and circular supply-chain practices varies considerably, making it difficult to generalise the findings across industries. In practical terms, the resources mobilised, and the nature of the firms differ in terms of adoption and practices.

5.6 Directions for Future Research

Acknowledging the above-mentioned limitations, this study offers opportunities for future research to strengthen and generalise the findings.

Future studies could explore other technologies, such as artificial intelligence for predictive maintenance, blockchain for traceability, and advanced recycling technologies, which may also significantly influence the effectiveness of circular product design. Comparative studies that examine multiple manufacturing technologies could deepen insights into how different digital and physical technologies complement or substitute for one another in circular supply chains (Kristensen & Mosgaard, 2020).

Future studies could integrate resource-based theory as a lens to explain how firms leverage unique tangible and intangible resources, such as proprietary additive manufacturing expertise and design knowledge, to gain a competitive advantage through circularity (Barney, 1991). Similarly, stakeholder theory could enrich the understanding of how multiple actors, i.e., customers, regulators, and supply chain partners, shape product design and supply chain decisions (Freeman & Phillips, 2002). Future studies may benefit from integrating such theoretical perspectives to broaden the explanatory power and improve generalisability.

Future studies could explore other design options, such as durability, upgradeability, and emotional attachment, for circular product design, and how these design approaches interact with supply chain strategies, such as industrial symbiosis or reverse logistics. These strategies can extend product lifespans and reduce resource intensity, which is overlooked in the current study. However, because no mediation was found between MS and AM with CPD, further studies should explore other mediating factors in the link between CPD and NPP.

Future studies could use separate datasets and include both male and female participants, or adopt a multi-country, multi-company approach, to generalise the findings. Longitudinal studies may also help capture the extended dimension of capability utilisation and how to

handle different internal and external pressures, providing a more comprehensive picture of how circular supply chain practices support sustainability performance.

Future research could investigate how workers' education and experiences support circular practices. Moreover, cultural context, i.e., innovation-oriented vs. compliance-driven, or governance mechanisms across supply chain networks, shape the adoption of circular practices. Supply chain network analysis may also reveal how collaboration and trust between supply chain partners enable or constrain the scaling of circular product design.

In light of the foregoing, while this thesis demonstrates the strategic role of circular product design in operationalising circular supply chain management with the help of dynamic design capabilities, additive manufacturing and top management commitment, future research can enrich, contextualise, and extend these insights by (i) applying alternative theoretical lens, (ii) exploring other manufacturing technologies, (iii) expanding the scope of design strategies, (iv) examining various organisational contexts and diverse firms, (v) longitudinal studies and (vi) considering cultural and organisational-level influences. Addressing these insights not only strengthens theoretical generalisability but also provides a more comprehensive foundation for practitioners seeking to drive circularity into supply chain management for achieving sustainable performance.

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Appendices

Appendix 1: Consent Form

Title of the Project: **Circular Supply Chain Management for Sustainability: Evidence from a Developing Country**

Research Team: **Mohammad Sharfuddin Rashed**

Dr Shamsul Karim
Dr Niraj Kumar

Please initial box

1. I confirm that I have read and understand the Information Sheet dated 27-09-2024 for the above study. I have had an opportunity to consider the information, ask questions and have had these questions answered satisfactorily.



2. I understand that my participation is voluntary and that I am free to withdraw from the project at any time without giving any reason and without penalty. I understand that any data collected up to the point of my withdrawal e.g. will be destroyed; cannot be withdrawn because it cannot be identified.



3. *Example of a risk statement:* I understand that, due to the nature of the interventions used in this research, those who have had epileptic seizures in the past may not be suitable as participants due to the risk of triggering such a seizure. I confirm that, to the best of my knowledge, I have never had an epileptic seizure.



4. I understand that the identifiable data provided will be securely stored and accessible only to the members of the research team directly involved in the project, and that confidentiality will be maintained.



5. I understand that my fully anonymised data will be used for research purposes

[*Provide details as listed in your participant information sheet, e.g. research publications*]



6. I understand that the data collected about me will be used to support other research in the future and may be shared anonymously with other researchers.



7. I give permission for the use of data

[*specify in which format the data will be deposited e.g. de-identified (anonymised) transcripts, audio/video recordings,*



survey database]

…. that I provide to be deposited in [either the name of data repository, if known and included on the PIS, or a research data repository] so that they will be available for future research and learning activities by other individuals.

8. I agree to take part in the above study.



Participant Name	Date	Participant Signature
_____	_____	_____

Researcher Name	Date	Researcher Signature
_____	_____	_____

Appendix 2: Participant Information Sheet

Participant Information Sheet for Research Project (ETH2324-1117): Circular Supply Chain Management for Sustainability: Evidence from a Developing Country
Dear participant,

I, **Mohammad Sharfuddin Rashed**, am currently carrying out a piece of research entitled, "The Role of Circular Product Design and Additive Manufacturing" under the supervision of **Dr. Shamsul Karim** and **Dr. Niraj Kumar.**

The study investigating the requirements for circular product design and additive manufacturing to support circular supply chain management. This questionnaire is a part of my PhD research study and will be used for academic purposes only. This study will take around 20-25 for a quantitative survey and one hour for a qualitative interview. The interview will be taken from separate individuals.

This information sheet provides you with information about the study and your rights as a participant.

What does taking part in the research involve?
The questionnaire will not include any personal information like name. Few demographic information will be surveyed like age, gender, academic background, positions and experiences, and related question items for each latent variable. The study will be collected through in-person and in some cases online survey platforms. The questionnaire will be for 20-25 and the interview session will be for 1 hour. Respondents for the survey will be different from interview participants. A sample of the questionnaire will be sent beforehand.

Do I have to take part?
Naturally, there is no obligation to take part in the study. It's entirely up to you. If you do decide to take part you will be given this information sheet to keep and be asked to give consent to take part. If publications or reports have already been disseminated, these cannot be withdrawn, however, these will only contain anonymised or aggregated data. If you decide to participate in the study and then change your mind in the future, you can withdraw at any point, even after the data has been collected. If you wish to withdraw from the study at any time, please contact the researcher at the details below.

Will my taking part in this study be kept confidential?
All information collected will be kept securely [password-protected computer] and will only be accessible by me and my supervisor. However, this research forms part of my studies at the University of Essex and therefore may be subject to scrutiny by other University staff in determining the outcome of my degree.
If I am mentioned individually in any publications or reports, then a participant number or pseudonym will be used and identifying details will be removed. A list may be kept linking participant numbers or pseudonyms to names, but this will be kept securely and will only be accessible to those listed above. A copy of the information that we record about you, but not other participants, will be provided, free of charge, on request.

I will not be asked to provide your name, but you may be asked to provide some demographic information for analysis purposes. Data collected through this questionnaire will be aggregated and you will not be individually identifiable in any reports or publications from this research.
I will retain this information only for my PhD studies and will destroy the data after my degree and acceptance of publication.

Are there any possible disadvantages or risks of taking part?

There will be no possible risk (physical, confidentiality, financial risk) associated for taking part in this risk.

What are the possible benefits of taking part?

Taking part in this research is a part of community welfare and is voluntary for university students. More importantly, as a professional, you will get a knowledge exchange program from a researcher and that will be practiced later for improving the different sustainability practices in your company.

What is the legal basis for using the data and who is the Data Controller?
The legal basis for processing the data collected from this project is informed consent. The Data Controller for his project is the University of Essex and the contact is the University Information Assurance Manager (dpo@essex.ac.uk).

What should I do if I want to take part?
Participants will "opt-in" in this research convenience snowball sampling. For this purpose, I will use University Alumni and personal referrals to approach as a participant for this study.

Who is funding the research?
This research is funded by the Commonwealth Scholarship Council to facilitate PhD studies in the member countries of the Commonwealth.

What will happen to the results of the research study?
The result of the survey or interview result will be mainly used for dissertation purposes, as one of the requirements of the degree program. After successful completion of the degree, there will be the possibility of publishing journal articles and presenting at conferences. I will be very happy to share the findings section with you if you want to see a copy of this. I will deposit all the responses both in soft and hard form so that no manipulation
ill happen.

Who has reviewed the study?
I have applied for ethical approval to undertake this study. My application was reviewed and approved by the Social Sciences Ethics Sub-Committee at the University of Essex.

What happens if something goes wrong?
If you are not satisfied with the response, you may contact the Essex Business School Research Ethics Officer, Dr Casper Hoedemaekers (choedem@essex.ac.uk) or Sarah Manning-Press (sarahm@essex.ac.uk) who will advise you further.

Name of the Researcher/Research Team Members

We would be very grateful for your participation in this study. If you need to contact us in the future, please contact me **Mohammad Sharfuddin Rashed** (mr22859@essex.ac.uk) or **Dr Shamsul Karim** (mskarim@essex.ac.uk). You can also contact us in writing at EBS, University of Essex, Colchester CO4 3SQ.

You are welcome to ask questions at any point.

Yours,
Mohammad Sharfuddin Rashed

Appendix 3: Quantitative Questionnaire

Dear Sir or Madam,

This questionnaire focuses on identifying "Circular Supply Chain Management for Sustainability: Evidence from a Developing Country**".** Your responses to this questionnaire will be used only in research about product design and circular supply chain capability. The questionnaires will not include your and your firm's addresses, names, and other information. I appreciate your cooperation. For each of the following statements and/or questions, please read each and give your comments that you feel are most appropriate in describing you or your firm.

Part A:

In Part A, all questions are related to the demographic information of the respondents.

A. Gender	**B. Education**	**C. Age**	**D. Industry**
I. Male	I. SSC	I. 18-25	I. Food/Beverage
II. Female	II. HSC	II. 26-33	II. Steel Manufacturing
	III. Bachelor	III. 34-41	III. Pharmaceuticals
	IV. Masters	IV. 42-49	IV. FMCG
	V. PhD	V. 50 and above.	V. Garments
	VI. Others		VI. Textile
			VII. Plastics
			VIII. Paints
			IX. Others (Specify)
E. Position	I. Entry-Level	II. Mid-Level	. III. Top Level
F. Experiences	I. 1-5 years of Experience	II.6-12 years of experience	III. More than 12 years of Experience
G. Company Size	I. Small Size Company (10-49 employees)	II. Medium Size Company (50-249 employees)	III. Large Size Company (More than 250 employees
H. Age of Company	I. 1-5 Years	II.5-10 Years	III. 10 Years and more

Part B:

In Part B, all the constructs and items are included to identify the requirements for circular product design. Based on the literature, the following four constructs are the most important requirements for circular product design. In the circular product development process, the company you work for: (Scale: 1. Totally disagree; 2. Partially disagree; 3. Neither agree nor disagree; 4. Partially agree; 5. Totally agree). Please put a tick (✓) that best describes your responses.

Material Selection						
MS1	Our company uses materials that are generally clear of dangerous and environmentally harmful materials.	**1**	**2**	**3**	**4**	**5**
MS2	Our company uses material that needs to be recycled, reprocessed, or reutilised into new raw materials.	**1**	**2**	**3**	**4**	**5**
MS3	Our company uses a material that can break down into natural, safe substances through biological processes.	**1**	**2**	**3**	**4**	**5**
MS4	Our company uses material that protects against environmental factors like water, UV light, and chemicals without losing its properties.	**1**	**2**	**3**	**4**	**5**

MS5	Our company uses material that stays the same in both high and extreme temperatures.	**1**	**2**	**3**	**4**	**5**
Design for Assembly and Disassembly						
DfAD1	Our company can design products that can easily be assembled and disassembled	**1**	**2**	**3**	**4**	**5**
DfAD2	Our company can design products that do not require any special people or tools/equipment to join/move components	**1**	**2**	**3**	**4**	**5**
DfAD3	Our company can design products that use joining elements which easily disassembled between subassemblies of incompatible materials.	**1**	**2**	**3**	**4**	**5**
DfAD4	Our company can design products based on components that can easily be reused and refurbished	**1**	**2**	**3**	**4**	**5**
DfAD5	Our company can design products that can be easily repaired and replaced	**1**	**2**	**3**	**4**	**5**
Design for Recyclability						
DfR1	Our company can design a product that improves recycling rates for raw materials	**1**	**2**	**3**	**4**	**5**
DfR2	Our company can design products based on the reuse of recycled components.	**1**	**2**	**3**	**4**	**5**
DfR3	Our company can design to allow for the use of recycled subassemblies/components	**1**	**2**	**3**	**4**	**5**
Design for Modularity						
DfM1	Our company can design products that can be decomposed into separate modules	**1**	**2**	**3**	**4**	**5**
DfM2	Our company can design products that can make changes in the key components without redesigning others	**1**	**2**	**3**	**4**	**5**
DfM3	Our company can design products that use components that can be reused in various products	**1**	**2**	**3**	**4**	**5**
DfM4	Our company can design a product that has a high degree of component carry-over	**1**	**2**	**3**	**4**	**5**
DfM5	Our company designs products that use standardized components	**1**	**2**	**3**	**4**	**5**
Additive Manufacturing						
AM1	Our company can design products using 3D software tools to improve the design process	**1**	**2**	**3**	**4**	**5**
AM2	For our company, AM or 3D printing contributes to less energy consumption in the manufacturing	**1**	**2**	**3**	**4**	**5**
AM3	AM can reduce transportation costs and improve lead time	**1**	**2**	**3**	**4**	**5**
AM4	In our company, we have very little inventory due to the 3D manufacturing facility.	**1**	**2**	**3**	**4**	**5**
AM5	AM improves the product development time and contributes to the Circular Product Design.	**1**	**2**	**3**	**4**	**5**

Part D:

In part D. all the items are used to know the circular product design and circular supply chain management. Please provide your rate from (1) Strongly disagree to (5) Strongly agree.

Circular Product Design						
CPD1	Our company can develop products that allow recycling.	**1**	**2**	**3**	**4**	**5**
CPD2	Our company can develop products that allow the reuse of components.	**1**	**2**	**3**	**4**	**5**

CPD3	Our company can develop products that allow remanufacturing.	**1**	**2**	**3**	**4**	**5**
CPD4	Our company can develop products that allow resource recovery	**1**	**2**	**3**	**4**	**5**
CPD5	Our company can develop products that allow product life extension through assembly or disassembly.	**1**	**2**	**3**	**4**	**5**
CPD6	Our company can develop products whose components can be easily refurbished.	**1**	**2**	**3**	**4**	**5**
CPD7	Our company designs products based on the reduction of waste.	**1**	**2**	**3**	**4**	**5**
CPD8	Our company designs products based on the reduction of material usage.	**1**	**2**	**3**	**4**	**5**
CPD9	Our company designs products based on the reduction of money and energy	**1**	**2**	**3**	**4**	**5**
CPD10	Our company designs products based on repetition of process or refurbishment of products	**1**	**2**	**3**	**4**	**5**

Part E

In part E, there are four constructs and associated items used for new product performance. It would be helpful if you put a tick based on your company performance in the following items: 1 – Strongly disagree, 2 – Disagree, 3– Neutral, 4 – agree, 5 – Strongly agree.

New Product Performance						
PP1	The new/circular product has achieved our sales target.	**1**	**2**	**3**	**4**	**5**
PP2	The new/circular product has achieved our profit goal	**1**	**2**	**3**	**4**	**5**
PP3	The new/circular product ensures a great market share	**1**	**2**	**3**	**4**	**5**
PP4	Customers are very satisfied with the new/circular product performance	**1**	**2**	**3**	**4**	**5**

Part F

In part C. all the items are used to institutional pressures and top management support for circular supply chain performances. Please provide your rate from (1) Strongly disagree to (5) Strongly agree.

Coercive Pressures (CP)						
CP1	Regulation and policy determinants influence and motivate consumers' and suppliers' environmental practices	**1**	**2**	**3**	**4**	**5**
CP2	Policymakers propose instruments to decrease resource demand, such as repairing or renovating products (including electronics) instead of purchasing new ones and encouraging a sharing economy	**1**	**2**	**3**	**4**	**5**
CP3	Regulation and policy determinants support the development of innovative solutions for waste collection	**1**	**2**	**3**	**4**	**5**
CP4	Regulation and policy determents support economic incentives for cleaner production	**1**	**2**	**3**	**4**	**5**
Normative Pressures (NP)						
NP1	Our industry has trade associations (FBCCI/COC) that encourage organisations to become more environmentally responsible.	**1**	**2**	**3**	**4**	**5**
NP2	Our industry expects all firms to be environmentally and socially responsible.	**1**	**2**	**3**	**4**	**5**
NP3	Being environmentally and socially responsible is a requirement for firms to be part of this industry.	**1**	**2**	**3**	**4**	**5**
NP4	Emerging environmental education programs in schools and universities in your country are increasing people's interest in the value of nature	**1**	**2**	**3**	**4**	**5**
Mimetic Pressure (MP)						
MP1	The market leader in our industry sets an example for environmentally and socially responsible conduct.	**1**	**2**	**3**	**4**	**5**
MP2	The market leaders in our industry are known for their practices that promote environmental preservation and care for people's needs.	**1**	**2**	**3**	**4**	**5**
MP3	The market leader in our industry has worked on ways to reduce their	**1**	**2**	**3**	**4**	**5**

	environmental impact.					

Part G

The following items are used to determine top management support for circular supply chain capability. Please provide your rate from the following scale: 1. Strongly disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly agree.

Top Management Commitment (TMC)						
TMC 1	Top management supports the adoption and implementation of circular practices	**1**	**2**	**3**	**4**	**5**
TMC2	Top management provides sufficient funds to procure, adopt, and implement tools and techniques for circular supply chain practices.	**1**	**2**	**3**	**4**	**5**
TMC3	Top management creates a culture where people in the organisation are open to adopting new methods for sustainable management and circular economy.	**1**	**2**	**3**	**4**	**5**
TMC4	Top management provides sufficient training to the employees of the organisation to implement a circular economy.	**1**	**2**	**3**	**4**	**5**
TMC5	Top management facilitates the coordination with suppliers for joint projects/coordination to maintain circular practices	**1**	**2**	**3**	**4**	**5**

Part H

The following items are used to describe the circular supply chain capability. Please provide your rate from the following scale: 1. Strongly disagree; 2. Disagree; 3. Neutral; 4. Agree; 5. Strongly agree.

Circular Supply Chain Practices						
CSCM1	The company's managerial processes support the reuse, remanufacturing, and recycling of materials	**1**	**2**	**3**	**4**	**5**
CSCM2	The company has digital/information systems to manage its ability to monitor circular supply chain activities	**1**	**2**	**3**	**4**	**5**
CSCM3	The company's supplier selection and management processes support reuse, remanufacturing, and recycling of materials	**1**	**2**	**3**	**4**	**5**
CSCM4	The company's human resource management processes support reuse, remanufacturing, and recycling of materials	**1**	**2**	**3**	**4**	**5**

Part I

In part E, there are four constructs and associated items used for identifying sustainable business performance. It would be helpful if you put a tick based on your company performance in the following items: 1 – Strongly disagree, 2 – Disagree, 3– Neutral, 4 – agree, 5 – Strongly agree.

Economic Performance						
EcoP1	In our company, we have improved our turnover in recent years	**1**	**2**	**3**	**4**	**5**
EcoP2	In our company, we have reduced our operation costs in recent years	**1**	**2**	**3**	**4**	**5**
EcoP3	Our business has experienced growth in recent years	**1**	**2**	**3**	**4**	**5**
EcoP4	Our level of customer loyalty has increased in recent years	**1**	**2**	**3**	**4**	**5**
Environmental Performance						
EnvP1	In our company, we have reduced waste across our processes	**1**	**2**	**3**	**4**	**5**
EnvP2	In our company, we have achieved resource efficiency across our processes	**1**	**2**	**3**	**4**	**5**
EnvP3	In our company, we have improved compliance with environmental standards	**1**	**2**	**3**	**4**	**5**
Social Performance						
ScoP1	In our company, we have improved work safety in recent years	**1**	**2**	**3**	**4**	**5**
ScoP2	In our company, we have improved the work environment in recent years	**1**	**2**	**3**	**4**	**5**
ScoP3	In our company, we have improved our relationship with the community and/or stakeholders in recent years	**1**	**2**	**3**	**4**	**5**
ScoP4	In our company, we have improved the living quality of the surrounding community in recent years	**1**	**2**	**3**	**4**	**5**

Appendix 4: Qualitative Questionnaire

Dear Sir or Madam,

Your responses to this questionnaire will be used only in research about "Circular Supply Chain Management for Sustainability: Evidence from a Developing Country". The questionnaires will not include you and your firm's addresses, names, and other information. I appreciate your cooperation. For each of the following statements and/or questions, please read each one and give your comments that you feel are most appropriate in describing you or your firm.

Part A:

A. Gender	**B. Education**	**C. Age**	**D. Industry**
I. Male	I. SSC	I. 18-25	I. Food/Beverage
II. Female	II. HSC	II. 26-33	II. Steel Manufacturing
	III. Bachelor	III. 34-41	III. Pharmaceuticals
	IV. Masters	IV. 42-49	IV. FMCG
	V. PhD	V. 50 and above.	V. Garments
	VI. Others		VI. Textile
			VII. Plastics
			VIII. Paints
			IX. Others
E. Position	I. Entry-Level	II. Mid-Level	. III. Top Level
F. Experiences	I. 1-5 years of Experience	II.6-12 years of experience)	III. More than 12 years of experience)
G. Company Size	I. Small Size Company (10-49 employees)	II. Medium Size Company (50-249 employees)	III. Large Size Company (More than 250 employees
H. Age of Company	I.1-5 Years	II.5-10 Years	III. 10 and more

Part B:

S.L	**Items**
1	To maintain sustainability, what are your company's current practices?
2	Have you heard of the circular economy?
3	During the material selection, what criteria do you consider?
4	Do you consider reuse, repair, remanufacturing, refurbishing, reducing, recovery, and repurposing during material selection?
5	In the case of using recycled raw materials, what factors are most important to you and why? Probe: - Quality - Energy saving
6	How do you deal with environmentally sensitive raw materials?
8	How much your product can easily be assembled and disassembled? Probe: What aspects do you find easy or difficult?
9	How do you improve recycling rates for raw materials?
10	Do you use 3D/AM software tools in the design process? Can you describe how these tools have impacted your design process? Probe: - less material consumption

	- decentralization of production facilities - flexibility in operations - lower inventory -
11	Tell me about your experiences designing or working with products that have standardized components. - What are the advantages and disadvantages of disassembling/separating these components easily? - How do these standardized components make repairing, modifying, or upgrading the product easier?
12	Do your new products support recycling, reusing, reducing, reproducing, remanufacturing, refurbishing, and other sustainable attributes? How?
13	What about your opinion regarding the circular/new product regarding revenue growth, company sales/profit, and customer satisfaction?
14	Do you have any institutional pressures to change your existing manufacturing practices? - Regulations - industry standards - Customer pressures - social/environmental pressures - competitors
15	Do you think there is a relationship between institutional pressures and adopting circular supply chain capabilities?
16	What do you think top management support/commitment affects the adoption of circular economy practices?
17	How do regulators and policymakers affect the adoption of circular supply chain practices?
18	How do different bodies like the Ministry of Commerce FBCCI/Chamber of Commerce/BGMEA BKMEA affect environmentally and socially responsible practices?
19	How do you know the awareness of environmentally and socially responsible practices?
20	How do market leaders affect environmentally and socially responsible practices?
21	How far do companies' managerial processes support product recycling, reuse, and remanufacturing? - Information Systems - Product Design - Supplier Selection - Human Resources
22	How far have you noticed any financial (increased sales/profits) and competitive advantages due to circular supply chain practices?

Appendix 5: List of Review Articles

1. Oliveira, B. G., Liboni, L. B., Cezarino, L. O., Stefanelli, N. O., & Miura, I. K. (2020). Industry 4.0 in systems thinking: From a narrow to a broad spectrum. *Systems Research and Behavioral Science*, *37*(4), 593-606.
2. Akturk, B., & Cakmak, P. I. (2024). An in-depth investigation of digital construction technologies from a building economics perspective. *Construction Economics and Building*, *24*(3), 40-75.
3. Luoma, P., Penttinen, E., Tapio, P., & Toppinen, A. (2022). Future images of data in circular economy for textiles. *Technological forecasting and social change*, *182*, 121859.
4. Zhao, Q., Ni, D., & Fang, X. (2026). How do 3D printing suppliers facilitate manufacturers' product differentiation via component provision? A scope economies perspective. *International Journal of Production Research*, *64*(10), 3963-3982.
5. Fadeyi, J. A., & Monplaisir, L. (2022). Instilling lifecycle costs into modular product development for improved remanufacturing-product service system enterprise. *International Journal of Production Economics*, *246*, 108404.
6. Massari, G. F., Nacchiero, R., & Giannoccaro, I. (2024). Circular supply chains as complex adaptive ecosystems: A simulation-based approach. *Journal of Cleaner Production*, *475*, 143517.
7. Jarrar, Q., Belkadi, F., Blanc, R., Kestaneci, K., & Bernard, A. (2023). Knowledge reuse for decision aid in additive manufacturing: application on cost quotation support. *International Journal of Production Research*, *61*(20), 7027-7047.
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9. Almahamid, S. M., Almurbati, N., Al-Alawi, A. I., & Fataih, M. A. (2023). What determines 3D printing adoption in the GCC region?. *Journal of Science and Technology Policy Management*, *14*(5), 912-940.
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12. Alexopoulos, K., Anagiannis, I., Nikolakis, N., & Chryssolouris, G. (2022). A quantitative approach to resilience in manufacturing systems. *International Journal of Production Research*, *60*(24), 7178-7193.

13. Bofylatos, S. (2022). Upcycling systems design, developing a methodology through design. *Sustainability*, *14*(2), 600.
14. Jasiulewicz-Kaczmarek, M., Legutko, S., & Kluk, P. (2020). Maintenance 4.0 technologies–new opportunities for sustainability driven maintenance. *Management and production engineering review*, *11*.
15. Arian, N. H., Pooya, A., Rahimnia, F., & Sibevei, A. (2021). Assessment the effect of rapid prototyping implementation on supply chain sustainability: a system dynamics approach. *Operations Management Research*, *14*(3), 467-493.
16. O'Grady, T., Minunno, R., Chong, H. Y., & Morrison, G. M. (2021). Design for disassembly, deconstruction and resilience: A circular economy index for the built environment. *Resources, Conservation and Recycling*, *175*, 105847.
17. Chiarini, A. (2021). Industry 4.0 technologies in the manufacturing sector: are we sure they are all relevant for environmental performance? *Business Strategy and the Environment*, *30*(7), 3194-3207.
18. van Oudheusden, A., Bolaños Arriola, J., Faludi, J., Flipsen, B., & Balkenende, R. (2023). 3D printing for repair: An approach for enhancing repair. *Sustainability*, *15*(6), 5168.
19. Upadhyay, A., Mukhuty, S., Kumar, V., & Kazancoglu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of cleaner production*, *293*, 126130.
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33. Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S. J., Garmulewicz, A., ... & Rowley, J. (2017). Unlocking value for a circular economy through 3D printing: A research agenda. *Technological Forecasting and Social Change*, *115*, 75-84.

34. Liu, C., Le Roux, L., Körner, C., Tabaste, O., Lacan, F., & Bigot, S. (2022). Digital twin-enabled collaborative data management for metal additive manufacturing systems. *Journal of Manufacturing Systems*, *62*, 857-874.

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41. Liu, C., Law, A. C. C., Roberson, D., & Kong, Z. J. (2019). Image analysis-based closed loop quality control for additive manufacturing with fused filament fabrication. *Journal of Manufacturing Systems*, *51*, 75-86.

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43. Petrulaityte, A., Ceschin, F., Pei, E., & Harrison, D. (2020). Applying distributed manufacturing to product-service system design: a set of near-future scenarios and a design tool. *Sustainability*, *12*(12), 4918.

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45. Elsacker, E., Peeters, E., & De Laet, L. (2022). Large-scale robotic extrusion-based additive manufacturing with living mycelium materials. *Sustainable Futures*, *4*, 100085.

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Appendix 6: Data Coding Circular Value propositions

Additive Manufacturing Role for Circular Value propositions		
Additive manufacturing supports value creation for the CE by enabling customised parts and producing products with complex geometry, dealing with more customers by localised production, and ensuring overall quality of the products, thereby extending product lifetimes and reducing waste.		
Evidence	**References**	
Mass Customisation	Oh et al., (2020); Moussa & ElMaraghy (2021); Mellor et al., (2014); Attaran (2017); Klemenčić et al., (2023); Di Lorenzo et al., (2024); Shen et al., (2023); Rahman et al., (2024); Massari et al., (2024); Mitic et al., (2025)	
Complex Geometry	Elsacker et al., (2022); Oliveira et al., (2022); Luoma et al. (2022) ; Massari et al., (2024); Jarrar et al., (2022);Jasiulewicz-Kaczmarek et al., (2021); van Oudheusden et al., (2023); Tian et al., (2021); Jin and Gao (2023);Zhong & Pearce (2018); Moussa & ElMaraghy (2021); Stavropoulos et al., (2021); Liu et al., (2019); Le et al., (2017); Gouveia et al., (2022); Chen et al., (2021); Zhang & Zhao (2022); Ratnayake (2019); Zheng et al., (2020); Paz et al., (2016); Rayna and west (2023); Cui et al., (2023); Di Lorenzo et al., (2024); Xu et al., (2029); Veiga et al., (2023)	
Customer Participation	Naeem & Di Maria (2021); Aljuaid et al. (2024); Chowdhury et al. (2019); Zhang & Zhao (2022); Attaran (2017); Salwin and Kraslawski (2024); Romero et al., (2021); Rodriguez-Conde & Campos (2020)	
Quality Focused	Sun et al., (2020); Liu et al., (2022); Sun et al., (2020); Shen et al., (2023)	
Mechanisms		
Implement different R's Strategies within the design by ensuring circularity	Reuse	Jarrar et al., (2022); Friesike et al., (2018); Le et al., (2017)
	Reduce	Luoma et al., (2022); Ahmed et al., (2022); Jasiulewicz-Kaczmarek et al., (2021); O'Grady et al., (2021); Upadhyay et al., (2021); Navas et al., (2020); Liu et al., (2018); Moussa & ElMaraghy (2022); Liu et al., (2019); Le et al., (2017); Wang et al., (2025)
	Remanufacturing	Fadeyi and Monplaisir (2022); Kenger et al., (2021); Geng et al., (2020); Zheng et al., (2020)
	Recycle	O'Grady et al., (2021); Sun et al., (2020); Zhong & Pearce (2018); Top et al., (2022); Gardan (2016); Kenger et al., (2021); Reyes et al., (2025)
	Recover	Sun et al., (2020); Sauerwein et al., (2020); O'Grady et al., (2021); Sun et al., (2020); Wurst et al., (2023)
	Redesign	Sinclair et al., (2018); Westerweel et al., (2018); Borgue et al., (2019); Gebre et al., (2025)
	Resell	Sinclair et al., (2018); Alexopoulos et al., (2021); Luoma et al., (2022); Wang et al., (2019)
	Remove	Moussa & ElMaraghy (2021); Chowdhury et al., (2019)
	Repair	Ratnayake (2019); Wagner & Walton (2016); Hu et al., (2022); Zheng et al., (2020)
	Refurbish	Wurst et al., (2023); Chowdhury et al., (2019); Dong et al., (2022); Chiarini (2021); Bauwens et al., (2020); Reyes et al., (2025)
	Reproduce	Salwin et al., (2024); Chowdhury et al., (2019); Rose & Bharadwaj (2023); Maiyar et al., (2019)
Decision		
Decisions to increase	van Oudheusden et al., (2023); Bauwens et al., (2020); Wurst et al., (2023);	

the circularity through reparability and durability	Sinclair et al., (2018); Despeisse et al., (2017); Stavropoulos et al., (2017); Gouveia et al., (2022); Knofius et al., (2019); Ratnayake (2019); Wagner and Walton (2016); Hu et al., (2022); Zheng et al., (2020); Xu et al., (2019)

Appendix 7: Data Coding Circular Value Creation and Delivery

Additive Manufacturing for Circular Value Creation and Delivery	
Additive manufacturing supports circular value creation and delivery by enabling product lifetime extensions, industrial symbiosis, modular design and durability, closed-loop supply chain, life cycle assessment, and reverse engineering by ensuring resource mobilisation and decentralized production, thereby ensuring sustainable supply chain practices.	
Evidence	**References**
Product Lifetime extensions	Sauerwein et a., (2020); Sinclair et al., (2028); Kadel et al., (2022); Romagnoli et al., (2023); Liu et al., (2022); Romero et al., (2021)
Industrial Symbios	Urbinati et al., (2024); Oliveira et al., (2020); Alexopoulos et al., (2021)
Modular Design and Durability	Fadeyi & Monplaisir (2022); Despeisse et al., (2017); Moussa & ElMaraghy (2021); Borgue et al., (2019)
Closed-loop supply chain	Sun et al., (2020); Liu et al., (2022); Karkaria et al., (2024)
Life Cycle Assessment	Cakmak & Akturk (2024); Luoma et al. (2022); Sauerwein et al., 2020); Bofylatos (2022); Navas et al., (2020); Wurst et al., (2023); Sinclair et al., (2028); Liu et al., (2022); Le et al., (2017); Top et al., (2022); Gouveia et al., (2022); Raoufi et al., (2022); Nagarajan et al., (2018); Ratnayake (2019); Ribeiro et al., (2020)
Reverse Engineering	Salles & Gyi (2013); Top et al., (2022); Geng et al., (2013); Rayna & West (2023)
Mechanisms	
AM enabled CLSC and LCA for ensuring sustainable supply chain practices	Rogers et al., (2025); Bhatti et al., (2023); Romagnoli et al., (2023); Wurst et al., (2023); Liu et al., (2022); Elsacker et al., (2022); Gouveia et al., (2022); Jin et al., (2017); Rose and Bharadwaj (2023); Nagengast et al., (2023); Rogers et al., (2025)
Decision	
Ensuring resource mobilisation from centralised to decentralized and implementing reverse logistics	Liu et al., (2024); Roozkhosh et al., (2024); Sinclair et al., (2018); Sauerwein et al., (2020); Salles & Gyi (2013); Top et al., (2022); Geng et al., (2013); Geng et al., (2022); Rayna and West (2023); Dai & Lu (2025)

Appendix 8: Data Coding for Circular Value Capture

Additive Manufacturing for Circular Value Capture	
Additive manufacturing supports circular value creation and delivery by enhancing material circularity and scalability through varying pricing strategies and industrial symbiosis, thereby ensuring better customer satisfaction.	
Evidence	**References**
Material circularity for enhancing scalability	Sauerwein et al., (2020); Bofylatos (2022); Jasiulewicz-Kaczmarek et al., (2021); Sun et al., (2020); Bauwens et al., (2020); Zhong & Pearce (2018); Borgue et al., (2019); Wang et al., (2019); Chowdhury et al., (2019); Elsacker et al., (2022); Kunovjanek & Reiner (2020); Salles & Gyi (2013); Le et al., (2017); Kamble et al., (2024); Top et al., (2022); Mellor et al., (2014); Chen et al., (2021); Gardan et al., (2016); Zhang et al., (2022); Knofius et al., (2019); Raoufi et al., (2022); Nagarajan & Haapala (2018); Jin et al., (2017); Ratnayake (2019);Fuchs et al., (2021); Paz et al., (2016); Ribeiro et al., (2020); Klemenčić et al., (2023); Khoshsepehr et al., (2023); Rayna and West (2023); Rose & Bharadwaj (2023); Roozkhosh et al., (2024); Karkaria et al., (2024); Romagnoli et al., (2023); Jagtap et al., (2023); Minguella-Canela et al., (2018); Markstedt et al., (2017); Romero et al., (2021); Mishra et al., (2023); Kladovasilakis et al., (2023); Gu et al., (2021); Moreno Nieto et al., (2021); Xu et al., (2019); Kumar et al., (2020); Tay et al., (2023); Nagengast et al., (2023); Dasan et al., (2021); Veiga et al., (2023); Navas et al., (2020); Luoma et al., (2022); Massari et al., (2024); O'Grady et al., (2021); Wurst et al., (2023); Wang et al., (2025)
Mechanisms	
Capturing value through pricing strategies and industrial symbiosis	Sun et al., (2020); Chen et al., (2021); Urbinati et al., (2024); Oliveira et al., (2020); Alexopoulos et al., (2021); Wurst et al., (2023); Sinclair et al., (2018); Stavropoulos et al., (2018); Li et al., (2024); Gu et al., (2021); Xu et al., (2019); Peron et al., (2025)
Decision	
Decisions for digital rights investment for customer co-created designs	Urbinati et al., (2024); Oliveira et al., (2020); Alexopoulos et al., (2021); Rogers et al., (2025)

Appendix 9: Data Coding for External and Internal Factors for CPD

External and Internal Factors for implementing Additive Manufacturing for Circular Product Design		
Using AM for circular product design is not straightforward. Both the external and internal factors needed to be accommodated for the proper execution of AM for CPD.		
Antecedents	**References**	
External	Scarcity of natural resources	Elsacker et al., (2022); Zhu et al., (2024); Klemenčić et al., (2023)
	Climate change/global	Rahman et al. (2024); Nagarajan & Haapala (2018)

	warming	
	Degradation of biodiversity	Moreno Nieto et al., (2021); Xu et al., (2019); Nagengast et al., (2023); Gebre et al., (2025)
	Demand for quick delivery	Chowdhury et al., (2019); Cui, et al., (2023); Müller et al., (2024); Jagtap et al., (2021); Hedenstierna et al., (2018)
	Growing awareness of sustainable products	Cakmak and Akturk (2024); Bauwens et al., (2020); Kunkel and Matthess (2020); Moreno Nieto et al., (2021); Alwashah et al., (2025)
Internal	Organisational values and culture	Nagengast et al., (2023); Lupton (2017); Khoshsepehr et al., (2023); Zhao et al., (2024); Aljuaid et al., (2024); Maiyar et al., (2019); Rodriguez-Conde & Campos (2020); Zhao et al., (2024); Sucuoglu et al., (2025)
	Top management commitment	Luoma et al., (2022); Jasiulewicz-Kaczmarek et al., (2020); Rogers et al., (2024); Gardan (2016); Lupton (2027); Rayna & West (2023); Zhao et al., (2023); Lim et al., (2024); Di Lorenzo et al., (2024); Minguella-Canela et al., (2018); Kladovasilakis et al., (2020); Moreno Nieto et al., (2021); Rodriguez-Conde & Campos (2020); Veiga et al., (2023); Lee et al., (2025)
	Adoption of digital technologies i.e., AM	Oliveira et al., (2020); Cakmak et al., (2024); Luoma et al., (2022); Almahamid et al., (2022); Jasiulewicz-Kaczmarek et al., (2020); Tian et al., (2021); Navas et al., (2020); Ul Haq & Franceschini (2020); Liu et al., (2022); Knofius et al., (2019); Salwin and Kraslawski (2024); Hu et al., (2022); Rayna and West (2023); Rose and Bharadwaj (2023); Kunkel & Matthess (2019); Kadel et al., (2022); Karkaria et al., (2024); Romagnoli et al., (2023); Müller et al., (2024); Luthra et al., (2019); Bonnard et al., (2019); Dai & Lu (2025); Rogers et al., (2025); Martinsuo (2025); Lee et al., (2025)

Appendix 10: Data Coding for Boundary Conditions for CPD

Boundary conditions for implementing Additive Manufacturing for Circular Product Design		
Many challenges need to be resolved for operationalising circular product design. Both the contextual and organisations specific boundary conditions needed to be accommodated for the proper execution of AM for CPD.		
Boundary Conditions	**References**	
Contextual boundary conditions	Regulations	Romagnoli et al., (2023); Almahamid et al., (2022); Khoshsepehr et al., (2023); Kadel et al., (2022); Verma et al., (2023); Kamble et al., (2024); Attaran (2017)
	Socio-cultural	Jasiulewicz-Kaczmarek et al., (2020); Kamble et al., (2024)
	Environmental	Jasiulewicz-Kaczmarek et al., (2020); Kamble et al., (2024)
	Technical	Tian et al., (2021); Moussa and ElMaraghy (2021); Elsacker et al., (2022); Kamble et al., (2024); Mellor et al., (2014); Ratnayake (2019); Attaran (2017); Flores Lara et al., (2025)
Organisations' specific boundary conditions	Corporate Governance	Ahmed et al., (2022); Bauwens et al., (2020); Sinclair et al., (2018); Kenger et al., (2021); Salwin & Kraslawski (2024); Cui et al., (2023); Romero et al., (2021); Luthra et al., (2019); Flores Lara et al., (2025)

	Top Management Support	Jasiulewicz-Kaczmarek et al., (2020); Rogers et al., (2024); Gardan (2016); Lupton (2027); Rayna & West (2023); Zhao et al., (2023); Lim et al., (2024); Di Lorenzo et al., (2024); Minguella-Canela et al., (2018); Kladovasilakis et al., (2020); Moreno Nieto et al., (2021); Rodriguez-Conde & Campos (2020); Veiga et al., (2023); Guerrero et al., (2025)
	Application of digital strategy	Almahamid et al., (2022); Dong et al., (2022); Oberg & Shams (2019); Jin et al., (2017); Jafari-Marandi et al., (2019); Romero et al., (2021); Luthra et al., (2019); Flores Lara et al., (2025)

Appendix 11: Data Coding for Outcomes of CPD

Outcomes of Circular Product Design		
Circular Product Design facilitate for operational outcomes in the forms of sustainable, operational and strategic level outcomes		
Outcomes	**References**	
Sustainable Outcomes	Environmental	Luoma et al., (2022); Aljuaid et al., (2024); Bofylatos (2022); Jasiulewicz-Kaczmarek et al., (2021); Le et al., (2017); Top et al., (2022); Gouveia et al., (2022); Zhong and Pearce (2018); Petrulaityte et al., (2020); Chiarini (2021); Navas et al., (2020); Sun et al., (2020); Bauwens et al., (2020); Akkad et al., (2022); Wurst et al., (2023); Jin & Gao (2023); Sinclair et al., (2018); Stavropoulos et al., (2021); Elsacker et al., (2022); Barrulas & Corvo (2023); Raoufi et al., (2022); Nagarajan and Haapala (2018);Bhatti et al., (2023); Müller et al., (2024); Alcaide-Marzal, & Diego-Mas (2025)
	Economic	Aljuaid et al., (2024); Bofylatos (2022); Jasiulewicz-Kaczmarek et al., (2021); Upadhyay et al., (2021); Bauwens et al., (2020); Ul Haq & Franceschini (2020); Zhong and Pearce (2018); Petrulaityte et al., (2020); Top et al., (2022); Mellor et al., (2014); Bhatti et al., (2023); Müller et al., (2024); Peron et al., (2025)
	Social	Luoma et al., (2022); Aljuaid et al., (2024); Bofylatos (2022); Petrulaityte et al., (2020); Jasiulewicz-Kaczmarek et al., (2021); Upadhyay et al., (2021); Navas et al., (2020); Bauwens et al., (2020); Despeisse et al., (2017); Beltagui et al., (2020); Chatzoglou & Michailidou (2019); Ribeiro et al., (2020); Bhatti et al., (2023); Kadel et al., (2022); Chatterjee et al., (2023); Müller et al., (2024); Massari et al., (2025)
Operational Outcomes	Operational efficiency	Dong et al., (2022); Sun et al., (2020); Naeem and Di Maria (2021); Liu et al., (2022); Top et al., (2022)
	Energy/resource efficiency	Nagarajan & Haapala (2018); Kunkel & Matthess (2020); Rahman et al., (2025)
	Inventory management	Moussa & ElMaraghy (2022); Kunovjanek & Reiner (2020)
	Waste management	Jasiulewicz-Kaczmarek et al., (2021); Khoshsepehr et al., (2023); Mishra et al. (2023); Salesa et al., (2025)
	Shorter lead time	Westerweel et al., (2018); Maiyar et al., (2019); Knofius

		et al., (2019); Jin et al., (2017); Attaran (2017)
	Increase quality and flexibility	Liu et al., (2019); Dong et al., (2022); Le et al., (2017); Kamble et al., (2024); Canciglieri et al., (2019); Aboutaleb et al., (2017); Sun et al., (2020); Zheng et al., (2020); Geng & Bidanda (2022); Klemenčić et al., (2023); Kadel et al., (2022); Verma et al., (2023); Chatterjee et al., (2023); Zhu et al., (2024); Shen et al., (2023); Jagtap et al., (2021); Romero et al., (2021); Mishra et al., (2023); Kumar et al., (2020); Gomes et al., (2025)
	Continuous process improvement	Friesike et al., (2018); Guerrero et al., (2025)
	Minimising transportation cost	Fadeyi & Monplaisir (2022); Ahmed et al., (2022); Kamble et al., (2024); Luthra et al., (2019); Bade et al., (2025)
Strategic Outcomes	Sustainable product design	Chowdhury et al. (2019); Rose and Bharadwaj (2023); Srivastava et al., (2025)
	Dynamic planning	Oh et al., (2020); Cakmak & Akturk (2024); Massari et al., (2024); Kunovjanek & Reiner (2024); Beltagui et al., (2024); Bilbao-Ubillos et al., (2025)
	Resilience in manufacturing	Alexopoulos et al., (2021); Jasiulewicz-Kaczmarek et al., (2021); O'Grady et al., (2021)
	Innovation Economy	Stavropoulos et al., (2021); Bauwens et al., (2020); Naeem & Di Maria (2021); Chatzoglou & Michailidou (2019); Rayna & West (2023); Rose & Bharadwaj (2023); Bhatti et al., (2023); Verma et al., (2023); Chatterjee et al., (2023); Rose & Bharadwaj (2023); Christina Öberg (2022); Bade et al., (2025); Jimo et al., (2025)

Appendix 12a: Non-Response Bias Test

Construct / item	Early mean	Early SD	Late mean	Late SD	Levene's F	Levene p
MS						
MS5	4.020	0.915	3.608	0.666	0.267	0.607
MS4	4.320	0.868	3.765	0.473	16.093	0.000
MS3	4.000	0.728	3.549	0.673	1.366	0.245
MS2	4.440	0.760	3.961	0.528	9.892	0.002
DfAD						
DAD5	4.100	0.814	3.608	0.635	0.302	0.584
DAD4	4.180	0.774	3.686	0.547	0.948	0.333
DAD3	3.960	0.903	3.353	0.594	1.065	0.305
DfM						
DM5	4.120	0.961	3.706	0.610	2.695	0.104
DM4	4.060	1.058	3.490	0.612	1.836	0.178
DM3	3.820	0.774	3.294	0.610	0.064	0.800
DfR						
DR3	3.980	0.795	3.961	0.720	0.009	0.925
DR2	4.140	0.904	4.157	0.579	3.597	0.061
DR1	4.240	0.797	4.196	0.401	12.558	0.001
CPD						
CPD6	4.180	0.850	3.137	0.491	10.768	0.001
CPD8	4.360	0.776	3.647	0.522	3.580	0.061
CPD9	4.180	0.691	3.843	0.464	3.039	0.084
CPD10	4.280	0.784	3.863	0.491	10.237	0.002
CPD5	4.060	0.818	3.235	0.513	3.892	0.051
CPD4	4.240	0.822	3.471	0.578	1.206	0.275
CPD3	4.100	0.678	3.784	0.577	0.091	0.764
CPD2	4.360	0.802	4.020	0.374	34.982	0.000
AM						
AM3	4.020	0.685	4.157	0.857	5.877	0.017
AM2	4.340	0.895	4.098	0.781	0.132	0.717
AM4	4.420	0.835	4.039	0.824	0.117	0.733
AM5	4.180	0.523	4.176	0.793	13.594	0.000
NPP						
NPP1	4.340	0.593	4.235	0.737	1.659	0.201
NPP2	4.280	0.573	4.275	0.802	10.353	0.002
NPP3	4.360	0.598	4.235	0.764	2.227	0.139
NPP4	4.320	0.587	4.176	0.767	2.877	0.093

Appendix 12b: Heterotrait-Monotrait Ratio (HTMT)

	MSS	DfAD	DfM	DfR	CPDD	AMM
DfAD	0.735					
DfM	0.469	0.752				
DfR	0.508	0.669	0.616			
CPDD	0.604	0.815	0.707	0.730		
AMM	0.578	0.572	0.546	0.648	0.602	
NPPP	0.461	0.508	0.457	0.473	0.485	0.498

Appendix 12c: Standardised Loadings with and without the Common Latent Factor

Construct	Item	No CLF	Constrained: trait	Constrained: CLF	Unconstrained: trait	Unconstrained: CLF	Δ constrained	Δ unconstrained
MS	MS5	0.768	0.550	0.517	0.613	0.460	0.218	0.155
MS	MS4	0.805	0.575	0.544	0.630	0.490	0.231	0.175
MS	MS3	0.691	0.511	0.516	0.639	0.332	0.180	0.052
MS	MS2	0.642	0.364	0.533	0.462	0.443	0.278	0.180
DfAD	DAD5	0.759	0.567	0.518	0.351	0.641	0.193	0.408
DfAD	DAD4	0.810	0.605	0.545	0.475	0.650	0.206	0.335
DfAD	DAD3	0.628	0.360	0.527	0.490	0.467	0.268	0.139
DfM	DM5	0.731	0.362	0.535	0.312	0.612	0.369	0.419
DfM	DM4	0.687	0.530	0.492	0.803	0.403	0.157	-0.117
DfM	DM3	0.688	0.645	0.500	0.438	0.490	0.044	0.250
DfR	DR3	0.733	0.512	0.544	0.438	0.573	0.221	0.295
DfR	DR2	0.832	0.574	0.599	0.592	0.591	0.258	0.239
DfR	DR1	0.753	0.495	0.581	0.549	0.530	0.258	0.204
CPDD	CPD6	0.774	0.655	0.504	0.230	0.744	0.119	0.544
CPDD	CPD8	0.738	0.401	0.577	-0.127	0.758	0.337	0.864
CPDD	CPD9	0.612	0.132	0.647	-0.326	0.654	0.480	0.938
CPDD	CPD10	0.694	0.207	0.643	-0.373	0.760	0.487	1.066
CPDD	CPD5	0.770	0.566	0.553	0.162	0.752	0.204	0.608
CPDD	CPD4	0.750	0.559	0.532	0.242	0.726	0.191	0.508
CPDD	CPD3	0.715	0.484	0.519	0.345	0.695	0.231	0.370
CPDD	CPD2	0.706	0.400	0.558	0.242	0.694	0.306	0.464
AM	AM3	0.801	0.524	0.618	0.639	0.480	0.277	0.162
AM	AM2	0.827	0.572	0.592	0.657	0.501	0.255	0.170
AM	AM4	0.721	0.398	0.557	0.528	0.483	0.323	0.193
AM	AM5	0.760	0.514	0.590	0.658	0.410	0.245	0.101
NPP	NPP1	0.900	0.661	0.604	0.778	0.448	0.239	0.122
NPP	NPP2	0.891	0.716	0.588	0.827	0.367	0.175	0.064
NPP	NPP3	0.833	0.580	0.620	0.699	0.451	0.253	0.134
NPP	NPP4	0.811	0.558	0.602	0.679	0.439	0.252	0.132

Appendix 13a: Non-Response Bias Test

Construct / item	Early mean	Early SD	Late mean	Late SD	Levene's F	Levene p
CP						
CP4	4.160	0.912	4.137	0.980	2.103	0.150
CP3	3.980	0.915	4.235	0.862	2.759	0.100
CP2	4.120	0.940	4.020	0.990	0.910	0.342
CP1	4.200	0.926	4.353	0.716	0.210	0.647
NP						
NP4	4.360	0.693	4.373	0.747	0.269	0.605
NP3	4.020	0.820	4.451	0.642	0.460	0.499
NP2	4.220	0.790	4.412	0.669	0.143	0.706
NP1	4.200	0.881	4.333	0.712	0.082	0.776
MP						
MP3	4.020	0.820	3.667	1.033	6.805	0.010
MP2	4.220	0.737	4.020	0.927	1.417	0.237
MP1	4.100	0.863	3.882	1.089	5.242	0.024
TMC						
TM4	4.100	0.974	4.059	0.835	0.048	0.828
TM3	3.960	0.755	4.157	0.784	5.346	0.023
TM2	4.320	0.794	4.098	0.806	0.005	0.945
TM1	4.220	0.708	4.255	0.771	3.116	0.081
TM5	4.240	0.797	3.824	0.793	0.557	0.457
CSCM						
CSCC4	4.240	0.822	4.216	0.783	0.593	0.443
CSCC3	4.080	0.665	4.255	0.796	8.758	0.004
CSCC2	4.300	0.909	4.216	0.808	0.009	0.924
CSCC1	4.160	0.710	4.235	0.681	0.980	0.325
ENP						
EnP3	4.340	0.593	3.922	0.796	1.535	0.218
EnP2	4.300	0.544	4.157	0.784	4.147	0.044
EnP1	4.220	0.507	4.118	0.864	17.835	0.000
SOCP						
ScoP4	4.340	0.593	4.196	0.749	1.659	0.201
ScoP3	4.260	0.527	4.392	0.695	5.069	0.027
ScoP2	4.360	0.598	4.118	0.791	1.091	0.299
SocP1	4.360	0.563	4.078	0.688	0.007	0.934
ECOP						
EcoP3	4.200	0.535	4.118	0.621	0.565	0.454
EcoP2	4.440	0.611	4.353	0.688	0.131	0.718
EcoP1	4.280	0.607	4.216	0.503	2.322	0.131
EcoP4	4.420	0.575	4.373	0.631	0.086	0.770

Appendix 13b: Heterotrait-Monotrait Ratio (HTMT)

	CP	NP	MP	TMC	CSCM	ENP	SOCP
NP	0.735						
MP	0.502	0.496					
TMC	0.656	0.657	0.583				
CSCM	0.511	0.553	0.427	0.501			
ENVP	0.474	0.548	0.463	0.589	0.609		
SOCP	0.570	0.592	0.508	0.638	0.543	0.711	
ECOP	0.471	0.483	0.474	0.566	0.538	0.687	0.636

Appendix 13c: Standardised Loadings with and without the Common Latent Factor

Construct	Item	No CLF	Constrained: trait	Constrained: CLF	Unconstrained: trait	Unconstrained: CLF	Δ constrained	Δ unconstrained
CP	CP4	0.878	0.797	0.379	0.857	-0.17	0.08	0.02
CP	CP3	0.872	0.799	0.386	0.861	-0.222	0.073	0.011
CP	CP2	0.766	0.669	0.381	0.763	-0.04	0.097	0.003
CP	CP1	0.713	0.583	0.431	0.772	0.276	0.13	-0.058
NP	NP4	0.795	0.696	0.402	0.797	0.011	0.099	-0.001
NP	NP3	0.846	0.772	0.392	0.845	-0.144	0.074	0
NP	NP2	0.882	0.781	0.412	0.876	-0.059	0.1	0.006
NP	NP1	0.71	0.574	0.449	0.733	0.232	0.136	-0.022
MP	MP3	0.812	0.718	0.382	0.816	0.017	0.094	-0.003
MP	MP2	0.904	0.807	0.418	0.896	0.074	0.097	0.007
MP	MP1	0.839	0.732	0.387	0.832	0.191	0.107	0.008
TMC	TM4	0.866	0.768	0.397	0.865	-0.003	0.099	0.001
TMC	TM3	0.875	0.793	0.393	0.876	-0.088	0.082	-0.001
TMC	TM2	0.862	0.752	0.407	0.864	0.055	0.111	-0.002
TMC	TM1	0.701	0.542	0.466	0.708	0.19	0.158	-0.007
TMC	TM5	0.837	0.738	0.406	0.836	-0.109	0.099	0
CSCM	CSCC4	0.902	0.84	0.378	0.902	-0.134	0.062	0
CSCM	CSCC3	0.878	0.786	0.407	0.872	-0.071	0.093	0.006
CSCM	CSCC2	0.754	0.656	0.391	0.751	-0.015	0.098	0.002
CSCM	CSCC1	0.808	0.703	0.421	0.824	0.142	0.105	-0.017
ENVP	EnP3	0.76	0.622	0.443	0.759	0.021	0.138	0.001

ENVP	EnP2	0.837	0.687	0.49	0.836	0.069	0.15	0.001
ENVP	EnP1	0.819	0.647	0.498	0.819	0.015	0.172	0
SOCP	ScoP4	0.787	0.678	0.442	0.785	-0.066	0.109	0.002
SOCP	ScoP3	0.804	0.731	0.43	0.803	-0.118	0.074	0.001
SOCP	ScoP2	0.755	0.6	0.445	0.756	0.013	0.155	-0.001
SOCP	SocP1	0.753	0.562	0.468	0.758	0.076	0.191	-0.005
ECOP	EcoP3	0.741	0.568	0.508	0.741	0.022	0.174	0
ECOP	EcoP2	0.676	0.448	0.511	0.675	0.018	0.228	0
ECOP	EcoP1	0.605	0.253	0.597	0.602	0.209	0.352	0.003
ECOP	EcoP4	0.749	0.559	0.513	0.748	0.003	0.19	0