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Master Thesis

Report

Unlocking the potential of digital servitization for achieving sustainable industry: A case study of additive manufacturing

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Abstract

Sustainable and digital manufacturing is gaining traction. This shift has increased interest in digital servitization, the strategic transformation process of industrial firms and their ecosystems. Digital servitization integrates business model innovation, ecosystem orchestration, and digital technologies. The process enables firms to integrate digital services into their business models, taking advantage of technologies such as the Internet of Things, artificial intelligence, and cloud computing to drive operational efficiency, resource optimization, and new revenue streams.

Although additive manufacturing is widely recognized for its potential to enhance material efficiency, reduce waste, and enable circular economy principles, its integration with digital servitization remains underexplored. This study investigates how digital servitization contributes to sustainable benefits in the manufacturing industry and how firms can structure its adoption within an additive manufacturing ecosystem.

Using an exploratory single-case study approach, the research examines a laser powder bed fusion additive manufacturing ecosystem orchestrated by a leading original equipment manufacturer. The study draws on 25 in-depth interviews with key stakeholders, including industry executives, supply chain actors, and independent experts. Thematic analysis, following the Gioia methodology, identifies key enablers, barriers, and pathways to the adoption of digital servitization in an industrial ecosystem.

The findings highlight that digital servitization fosters sustainable benefits by enabling business model transformation, ecosystem-wide coordination, and digital technology integration. However, its successful implementation requires a structured, staged approach in which business model innovation precedes ecosystem orchestration and adoption of digital technology. The study proposes a framework that guides firms through this transformation, emphasizing the need for strategic alignment between these three pillars. In addition, it identified key challenges such as the reluctance to share data, difficulties in demonstrating return on investment, and limitations on interoperability.

This research contributes to the theoretical discourse by extending digital servitization research beyond firm-level implementations and providing empirical validation of its role in enabling sustainability in manufacturing ecosystems. It also offers actionable information for industrial firms, policymakers, and technology providers on how to systematically adopt digital servitization strategies to improve economic, environmental, and social sustainability. By bridging the gap between theoretical frameworks and industrial implementation, this study advances the understanding of how digital servitization can be effectively leveraged to drive sustainable industrial transformation.

Contents

1 Introduction

The manufacturing industry is undergoing a profound transformation, driven by increasing pressures to integrate advanced digital technologies while simultaneously adopting sustainable business practices (Schiavone, Leone, Caporuscio, & Lan, 2022). Traditional manufacturing models, often reliant on high material consumption and linear value chains, are increasingly being challenged by demands for efficiency, environmental responsibility, and long-term resilience (Alves & Alves, 2015; Schiavone et al., 2022). To remain competitive, companies are moving from product-centric to service-oriented business models. They leverage digital technologies to improve efficiency, optimize resource use, and enhance value co-creation (Kohtamäki, Parida, Oghazi, Gebauer, & Baines, 2019; Paschou, Rapaccini, Adrodegari, & Saccani, 2020; Rizk, Bergvall-Kåreborn, & Elragal, 2018).

Digital servitization has emerged as a key enabler of this transformation, allowing manufacturers to embed digital services into their offerings through the use of the Internet of Things, big data, artificial intelligence and cloud computing (Adrodegari & Saccani, 2017; Cenamor, Sjödin, & Parida, 2017). Digital servitization enhances traditional products with data-driven services like remote monitoring, predictive maintenance, and pay-per-use models. These additions improve operations, strengthen customer engagement, and create competitive differentiation (Kohtamäki, Rabetino, Parida, Sjödin, & Henneberg, 2022). Beyond economic advantages, digital servitization aligns with the triple bottom line framework, allowing firms to pursue economic, environmental, and social sustainability simultaneously (Elkington, 1998; Sjödin, Parida, Kohtamäki, & Wincent, 2020).

Alongside digital servitization, additive manufacturing, commonly referred to as 3D printing, has gained traction as a disruptive technology that promotes sustainability (Baumers, Dickens, Tuck, & Hague, 2016; Frank, Mendes, Ayala, & Ghezzi, 2019). The layer-by-layer production method of additive manufacturing improves material efficiency, reduces energy consumption, and allows localized production, directly supporting sustainability objectives (Javaid, Haleem, Singh, Suman, & Rab, 2021; Zhang et al., 2024). Although the integration of digital servitization with additive manufacturing provides an opportunity to enhance supply chain agility, enable circular business models, and reduce waste (DebRoy et al., 2018; Mehrpouya, Vosooghnia, Dehghanghadikolaei, & Fotovvati, 2021), in this research, additive manufacturing serves as the technological context within which digital servitization is studied, rather than being the primary focus of transformation itself.

Although digital servitization offers many benefits, companies struggle with its integration. Key challenges include technological complexity, misaligned incentives, and ecosystem fragmentation (Chaney, Gardan, & de Freyman, 2021; Chekurov et al., 2021). The achievement of sustainable outcomes through the adoption of digital services requires a deliberate orchestration of the ecosystem, involving multiple stakeholders, including original equipment manufacturers, software providers, supply chain partners, and customers, who collaborate to drive adoption and implementation (Adner, 2017; Kolagar, 2024). However, a structured framework to guide this transformation remains largely absent in both research and practice.

1.1 Research Problem and Literature Gap

Despite growing interest in digital servitization, its combined impact with sustainability remains underexplored. Research on digital servitization has traditionally focused on firm-level adoption, overlooking the role of ecosystem-wide collaboration in scaling servitized business models

(Gebauer, Paiola, Saccani, & Rapaccini, 2021; Kolagar, Parida, & Sjodin, 2022). Furthermore, while digital servitization is frequently positioned as a sustainability enabler, its tangible impact on waste reduction, circularity, and economic viability remains largely uninformed (Kolagar, 2024; Sjödin, Parida, & Kohtamäki, 2023). Previous studies mainly emphasize successful servitization cases, offering limited information on barriers, failure cases, and the conditions necessary for effective ecosystem orchestration (Birkel & Müller, 2021; Kolagar, 2024).

Key challenges such as governance, trust, and interoperability continue to hinder the adoption of digital servitization in industrial ecosystems (Kolagar, Parida, & Sjodin, 2022). The issues surrounding data security, intellectual property protection, and platform standardization further complicate large-scale adoption (Figueredo, Seed, & Wang, 2020; Kolagar, Reim, Parida, & Sjödin, 2021). Without addressing these challenges, digital servitization risks remaining a fragmented effort rather than a comprehensive transformation strategy.

This study addresses these gaps by investigating the role of digital servitization in achieving sustainable benefits, using additive manufacturing as a contextual medium. Specifically, it explores how companies can leverage digital servitization to drive sustainability through structured ecosystem orchestration and transformation of business models (Elkington, 1998, 2018).

1.2 Research Purpose and Research Questions

The purpose of this study is to investigate the role of digital servitization in fostering sustainable benefits in the manufacturing industry. By examining both theoretical implications and practical applications, this research aims to provide insights into how firms can leverage digital servitization strategies effectively. Specifically, this study seeks to distinguish between the broader academic contributions of digital servitization to sustainability and its practical implementation within an industrial ecosystem, with additive manufacturing serving as the contextual medium.

In line with this purpose, the research is guided by two key research questions.

1. *"How does digital servitization contribute to sustainable benefits in the manufacturing industry, with an additive manufacturing ecosystem serving as the contextual medium through which this connection is examined?"*
2. *"How can firms structure the adoption of digital servitization to achieve sustainable benefits, using additive manufacturing as a case study for implementation strategies?"*

To address these questions, this research employs an exploratory single-case study of a leading laser powder bed fusion additive manufacturing original equipment manufacturer and its ecosystem. The study systematically analyzes 25 in-depth interviews with key informants, including a variety of central orchestrator employees, supply chain actors, customers, and industry experts. Thematic analysis follows the Gioia methodology to systematically identify first-order categories, second-order themes, and aggregate dimensions. (Gehman et al., 2018a; Gioia, Corley, & Hamilton, 2013). The results of this thematic analysis will be used for both the academic implications and the practical applications that this research will produce.

1.3 Theoretical and Practical Contributions

This study makes significant contributions to academic research and industrial practice. From a theoretical perspective, it expands the literature on digital servitization and sustainability by deriving insights from interview data and literature to explain how digital servitization enables sustainable benefits. This contribution focuses on business model transformation, ecosystem orchestration, and the role of digital technologies in the adoption of servitization (Kolagar, Parida, & Sjodin, 2022; Parida, Burström, Visnjic, & Wincent, 2019).

From a practical perspective, this research develops a framework based on empirical findings that serves as a structured road map for firms seeking to adopt digital servitization. Unlike theoretical insights, this framework is designed purely as a practical guide, helping companies navigate adoption barriers, align business models, and integrate digital technologies for sustainability outcomes. The framework consists of three key stages:

1. Innovation in business models: Defining value propositions and economic feasibility.
2. Ecosystem Optimization: Collaborating with ecosystem partners to overcome adoption barriers.
3. Digital Technology Integration: Using artificial intelligence, the Internet of Things, and predictive analytics for efficiency and traceability.

By structuring the adoption of digital servitization as a sequential process, this framework ensures that firms can systematically implement digital servitization strategies, reinforcing its role as a practical tool, not just a theoretical contribution.

1.4 Structure of the Thesis

The remainder of this thesis is structured as follows. Chapter 2 reviews the relevant literature on digital servitization, ecosystem orchestration, and sustainability in (additive) manufacturing. Chapter 3 describes the research methodology, including the design of the case study, data collection, and analysis approach. Chapter 4 presents the results and the discussion, structured according to the four aggregate dimensions identified through thematic analysis. Chapter 5 introduces the proposed framework, detailing its role as a practical guide for companies. Chapter 6 provides conclusions, theoretical contributions, and managerial implications. Chapter 7 offers recommendations for future research and practical implementation strategies.

By separating theoretical contributions from the practical framework, this study ensures clarity in its academic and industrial impact, providing both empirical insights and actionable strategies for the adoption of digital servitization.

2 | Theoretical Background

This section establishes the theoretical foundations of digital servitization, exploring its role in industrial transformation and its broader relationship with sustainability within the framework of the Triple Bottom Line (Elkington, 1998). Although additive manufacturing serves as a contextual medium - a representative industry setting that provides real-world context to examine how digital servitization contributes to sustainability - the findings of this study are designed to extend beyond this domain, ensuring broader applicability in industrial ecosystems.

To differentiate between theoretical contributions and practical applications, this study positions additive manufacturing as a contextual example in theory, while in practice, it serves as a case study demonstrating how firms can structure the adoption of digital servitization to achieve sustainable benefits. This dual perspective enables a more comprehensive understanding of the impact of digital servitization on sustainability, balancing conceptual insights with industry-specific implementation considerations.

Before identifying the broader contextual relationships between digital servitization, additive manufacturing, and sustainable benefits, it is essential to establish a clear conceptual foundation for each element individually. This ensures a structured understanding of how digital servitization and additive manufacturing interact within industrial ecosystems and how they contribute to sustainability objectives.

To achieve a structured theoretical foundation, the section is organized as follows:

- Subsections dedicated to each core concept, providing definitions, discussions of relevant terminology, and an overview of key literature.
- A dedicated section examining how digital servitization, additive manufacturing, and sustainable benefits interconnect, emphasizing their combined role in shaping sustainable industrial transformations.
- A concluding discussion that highlights the limitations in existing studies, emphasizing the need for further research, and establishing the relevance of this study.

Among these key concepts, digital servitization serves as the central theoretical foundation, first examined to establish its strategic role in enabling sustainability-driven transformations before contextualizing its relationship with additive manufacturing. In this study, additive manufacturing serves as a contextual medium that facilitates within the theoretical discourse, providing a structured case to explore how digital servitization connects to sustainable benefits. However, within the practical domain, additive manufacturing takes on a more focal role, offering direct insights into how firms can structure the adoption of digital servitization within this ecosystem.

2.1 Digital Servitization: Transforming Industrial Business Models

Digital servitization, as the name suggests, is a combination of the terms servitization and digitalization (Kohtamäki, Parida, Patel, & Gebauer, 2020). Servitization refers to the strategic transformation of businesses from a product-centric approach to a service-oriented model, where firms integrate a combination of goods, services, support, self-service, and knowledge to create greater value for customers. This shift, driven by increasing customer demands and competitive pressures, blurs the traditional distinction between manufacturing and service industries, fostering deeper customer relationships and new business opportunities (Vandermerwe & Rada, 1988). Although first introduced in the 1980s, critical analists suggest that despite the tremendous interest and output of research, indicating that the field is well established, the research domain was in a theoretical and methodological nascent stage in 2017 (Kowalkowski, Gebauer, & Oliva, 2017).

The concept of digitalization is described by Pellicelli (2023) as follows:

"'Digitalization' uses digitized information to simplify how we work and make it more efficient, such as using digital technology to transform reporting processing and data collection and analysis. Digitalization does not change how we do business or create new types of business. Rather, it deals with making our work faster and better. It is a transformation that goes beyond digitization. While digitization is a conversion of data and processes, digitalization is a transformation" (Pellicelli, 2023).

Since digitization is an integral part of digitalization, it is essential to distinguish between the two concepts. Pellicelli (2023) defines digitization as:

"The process of converting information from analog to digital. When we convert a paper report to a digital file, such as a PDF, the data itself is not changed but simply encoded in a digital format. Digitization can reap efficiency benefits, but does not seek to optimize processes or data."(Pellicelli, 2023).

Thus, while digitization serves as the foundation for digitalization, digitalization represents a strategic transformation that extends beyond data conversion to redefine business operations, decision making, and efficiency. This distinction is crucial because it underscores the role of digitalization in enabling automation, real-time analytics, and improved decision making, which are essential for organizations navigating modern digital transformation.

Although digitalization and servitization can be implemented as separate business strategies (Vendrell-Herrero, Bustinza, Parry, & Georgantzis, 2017), substantial evidence suggests that they are deeply interdependent (Frank et al., 2019; Gebauer et al., 2021). This interdependency has led to the emergence of the term "digital servitization" (Kohtamäki et al., 2019), which captures the synergistic integration of digital technologies with servitization strategies in manufacturing and industrial business models.

A systematic review conducted by Paschou (2020), analyzing publications from 2009 to 2018, highlights the evolution of the digital service as a theoretical construct (Paschou et al., 2020). Over time, the concept has been interpreted in various ways, reflecting its multidimensional nature. Due to its novelty and inherent complexity, reaching a universally accepted definition remains a challenge (Kohtamäki et al., 2019).

The absence of a universally accepted definition poses challenges for both academia and industry, as varying interpretations impact the development of frameworks and implementation strategies (Mphale, Gorejena, & Nojila, 2024). To illustrate the evolution of this concept, a selection of key definitions from the literature is presented chronologically.

- **2019:** *"The transition toward smart product-service-software systems that enable value creation and capture through monitoring, control, optimization, and autonomous function."* (Kohtamäki et al., 2019)
- **2020:** *"The transformation in processes, capabilities, and offerings within industrial firms and their associate ecosystems to progressively create, deliver, and capture increased service value arising from a broad range of enabling digital technologies."* (Sjödin et al.,

2020)

- **2020:** *"The development of new services and/or the improvement of existing ones through the use of digital technologies. These can be exploited to enable new (digital) business models, to find novel ways of (co-)creating value, as well as to generate knowledge from data, improve the firm's operational and environmental performance, and gain a competitive advantage."* (Paschou et al., 2020)

- **2024:** *"Digital servitization represents the integration of enabling technologies from Industry 4.0 into the servitization process, generating additional benefits and creating value for the customer."* (Minaya, Avella, & Trespalacios, 2024)

Despite the absence of a universally accepted definition, recent research has increasingly aligned with the definitions proposed by Paschou et al. (2020) and Sjödin et al. (2020) (Kolagar, 2024; Lamperti, Cavallo, & Sassanelli, 2024; Minaya et al., 2024), reflecting a growing consensus on its core elements. These studies conceptualize digital servitization as a strategic transformation that integrates innovation of business models, orchestration of the ecosystem, and digital technologies to create and capture new value.

Building on these foundational definitions, this research defines digital servitization as:

"The strategic transformation of industrial firms and their ecosystems through the integration of business model innovation, ecosystem orchestration, and digital technologies."

Although digital servitization has been recognized as a key driver of industrial transformation, its potential to enable sustainable benefits remains underexplored in the literature. Existing research suggests that servitization can improve the resilience of the business model, resource efficiency, and value co-creation (Kolagar, Parida, & Sjodin, 2022; Sjödin et al., 2023; Zhang et al., 2024). However, the specific mechanisms through which digital servitization contributes to environmental, social, and economic sustainability remain unclear, particularly in manufacturing ecosystems where firms face operational, technological, and strategic complexities (Kohtamäki et al., 2022; Schiavone et al., 2022).

Emerging research indicates that the synergistic integration of business model innovation, ecosystem orchestration, and digital technologies could serve as a foundation for sustainable industrial transformation (Kolagar, Parida, & Sjodin, 2022; Sjödin et al., 2023; Zhang et al., 2024). These elements are increasingly seen as mutually strengthening, collectively enabling circular business models, optimized resource allocation, and reduced environmental impact. However, their interaction and cumulative impact on sustainability remain ambiguous, particularly in complex industrial ecosystems where multiple stakeholders must align strategies, share data, and coordinate value creation processes.

To address this gap, this research examines three interconnected pillars that are hypothesized to enable and shape the sustainable transformation of digital servitization:

- **Business Model Innovation:** The transition from product-oriented revenue models to service-based models is expected to improve sustainability-driven business models, including pay-per-use, product-as-a-service (PaaS) and circular business strategies. These models enable resource efficiency, extension of the life cycle, and waste reduction, aligning with sustainability objectives (Kohtamäki et al., 2022; Paiola & Gebauer, 2020; Zhang et al., 2024).

- **Ecosystem Orchestration:** The integration of digital service ecosystems fosters multi-actor collaboration, allowing firms to optimize supply chains, enable data-driven decision making, and implement circular economy principles. By strengthening inter-firm coordination, digital servitization facilitates resource efficiency and long-term sustainability improvements (Kolagar, Parida, & Sjodin, 2022; Schiavone et al., 2022).

- **Digital Technologies:** Emerging technologies such as AI, IoT, and cloud computing act as key enablers of digital service delivery by improving operational efficiency, enabling predictive maintenance, and optimizing real-time resource allocation. These capabilities directly contribute to energy reduction, waste minimization, and environmental sustainability (Kohtamäki et al., 2022; Sjödin et al., 2023).

By examining how these three pillars interact, this research aims to assess and conceptualize their role in enabling sustainable transformation in the manufacturing industry. As digital servitization evolves, it is hypothesized that the interplay of business model innovation, ecosystem orchestration, and digital technologies will be crucial in facilitating the shift towards service-oriented, digitally enhanced, and sustainable industrial ecosystems (Kohtamäki et al., 2022; Kolagar, Parida, & Sjodin, 2022; Paiola & Gebauer, 2020; Schiavone et al., 2022; Sjödin et al., 2023).

2.2 Additive Manufacturing: Shaping Modern Manufacturing

Additive manufacturing, commonly known as 3D printing, is a layer-by-layer fabrication process that enables the direct production of complex geometries from digital models (Gibson et al., 2021). Unlike traditional subtractive manufacturing, which removes material from a solid block, additive manufacturing adds material only where necessary, improving material efficiency, reducing waste, and enabling design flexibility (Mehrpouya et al., 2021). Additive manufacturing technologies have gained prominence in various industries, including aerospace, automotive, healthcare and industrial manufacturing, due to their ability to reduce lead time, improve prototyping quality, enable complex geometries, and reduce the number of required production steps (Negi, Dhiman, & Sharma, 2013; Salmi, 2021; Tepylo, Huang, & Patnaik, 2019; Vafadar, Guzzomi, Rassau, & Hayward, 2021; Vasco, 2021).

The origins of Additive Manufacturing date back to the 1980s, when stereolithography was first introduced as a method to cure layer-by-layer liquid photopolymer resins (Hull, 1984). Over time, various additive manufacturing techniques have emerged, including:

- **Fused Deposition Modeling (FDM):** Uses thermoplastic filaments extruded through a heated nozzle to form layers (Crump, 1992).
- **Selective Laser Sintering (SLS):** Uses a high-power laser to sinter powdered material into solid structures (Deckard, 1991).
- **Binder Jetting:** Deposits a liquid binding agent onto a powder bed to create parts without the need for high temperatures (Sachs et al., 1993).
- **Laser Powder Bed Fusion (LPBF):** One of the most advanced metal additive technologies, Laser Powder Bed Fusion uses a high-power laser to selectively melt and fuse metal powder layer by layer, allowing the production of high-precision, high-strength components (DebRoy et al., 2018; Thijs, Verhaeghe, Craeghs, Van Humbeeck, & Kruth, 2010).

Among these, laser powder bed fusion has been particularly effective in high-performance applications, such as aerospace, biomedical implants, and tooling industries, due to its ability to produce intricate and lightweight structures with excellent mechanical properties (Gibson et al., 2021).

Additive Manufacturing as a Contextual Medium

Additive manufacturing serves as a suitable contextual medium and case study to explore digital servitization due to its digital nature, integration within industrial ecosystems, and evolving business models (Piller, Weller, & Kleer, 2015). As a production method that relies on computer-aided design, automated process control, and data-driven optimization, additive manufacturing provides an environment where firms explore and adopt digital innovation (Gibson et al., 2021; Mehrpouya et al., 2021). The ability to customize production, enable remote monitoring, and improve resource efficiency aligns with key aspects of digital servitization, making it a relevant industry to study how manufacturers transition from product-based value creation to service-based (Kohtamäki et al., 2020; Parida et al., 2019).

Beyond its technological attributes, additive manufacturing operates within multi-actor industrial ecosystems, involving equipment manufacturers, material suppliers, software developers, and service providers (Heising, Pidun, Krüger, Küpper, & Schüssler, 2022). This interconnected structure presents an opportunity to examine how firms coordinate activities, develop service-based business models, and integrate digital tools to improve operational efficiency (Cenamor et al., 2017; Sjödin et al., 2020). The need for collaboration between different actors highlights the role of servitization in facilitating efficiency, reliability, and long-term value generation (Kolagar, Parida, & Sjodin, 2022).

Although additive manufacturing business models are traditionally product-centric, an increasing number of firms are experimenting with service-oriented strategies, such as pay-per-use models, on-demand manufacturing, and digitally enabled service contracts (Kohtamäki et al., 2019; Piller et al., 2015). These developments indicate that additive manufacturing is a suitable case for examining how digital servitization principles can be structured and implemented in industrial contexts, making it an ideal environment for studying the broader implications of digital servitization beyond additive manufacturing alone.

By positioning additive manufacturing as both a contextual medium and a case study, this research examines how servitization principles manifest themselves in an advanced manufacturing environment. The findings contribute to a deeper understanding of the role of digital servitization in industrial transformation and its potential to support structured adoption strategies that enable sustainability-oriented business models.

2.3 Sustainable Benefits: the Triple Bottom Line Framework

Sustainability has become a key driver of industrial transformation, prompting companies to rethink traditional manufacturing and service models (Vacchi et al., 2021). The Triple Bottom Line framework, introduced by Elkington (1998), originally framed sustainability as the integration of economic, environmental, and social dimensions (Elkington, 1998). However, in his 2018 reassessment, Elkington acknowledges that, while corporations have adopted sustainability rhetoric, the economic dimension continues to overshadow social and environmental concerns (Elkington, 2018).

Elkington requests a "recall" of the Triple Bottom Line framework, arguing that current sustainability efforts lack the urgency and systemic change required to address planetary boundaries and social inequality (Elkington, 2018). The following subsections explore the updated understanding of economic, environmental and social sustainability in light of Elkington's reflections.

Economic Sustainability

Economic sustainability refers to the ability of a company to generate long-term profitability while ensuring responsible economic practices that contribute to the general well-being of society (Elkington, 1998). Building on Elkington's original framework (1998) and subsequent reflections (2018), economic sustainability can be understood through the following key principles (Elkington, 2018):

- **Systemic Profitability:** Businesses must focus on long-term resilience, shifting away from short-term financial targets that encourage resource depletion.
- **Stakeholder-Centered Value Creation:** Financial success must align with social benefits, ensuring that economic activities generate fair results for all stakeholders.
- **Circular Economy and Resource Efficiency:** Sustainable business models should maximize material efficiency, reducing waste and environmental impact.
- **Adaptability and Innovation:** Firms must anticipate global changes, including climate policies, digitalization, and regulatory changes, ensuring sustainable economic performance.

This section relies heavily on the foundational research conducted by Elkington (1998; 2018), but this reliance is substantiated by broad academic adoption and continued relevance in sustainability discourse. The Triple Bottom Line framework has been widely incorporated into corporate sustainability strategies, governance models, and academic research across disciplines, including finance, management, and environmental sciences (Arowoshegbe, Emmanuel, & Gina, 2016; Coşkun Arslan & KISACIK, 2017; Kolagar, 2024).

The widespread adoption of Triple Bottom Line in academia is reflected in the development of sustainability metrics, reporting standards, and regulatory frameworks, such as the Global Reporting Initiative and the Dow Jones Sustainability Index, which align corporate performance with economic, environmental, and social criteria (Loviscek, 2020). Despite critiques that businesses often adopt the rhetoric of Triple Bottom Line without implementing substantive change (A. K. Srivastava, Dixit, & Srivastava, 2022), its influence remains significant, and studies continue to explore its applicability and effectiveness in driving systemic sustainability transformation (Birkel & Müller, 2021; Filgueiras & Melo, 2024; Khan, Ahmad, & Majava, 2021).

By situating this research within the extensive academic dialogue surrounding Triple Bottom Line, this section acknowledges both its foundational status and the critical evaluations that continue to shape its development.

Environmental Sustainability

Environmental sustainability involves minimizing the ecological impact, ensuring that industrial activities operate within planetary limits (Elkington, 1998). Elkington (2018) warns that corporate sustainability initiatives have failed to prevent environmental overshoot, arguing that sustainability efforts must move beyond incremental improvements to transformative change (Elkington, 2018). He suggests that environmental sustainability must be achieved at a system level rather than through isolated corporate efforts, as despite decades of corporate sustainability initiatives, environmental degradation continues to escalate due to:

- **Greenwashing and Misaligned Incentives:** Many companies claim eco-friendly practices while maintaining unsustainable production models, 'firms talk, suppliers walk' (Pizzetti, Gatti, & Seele, 2021).
- **Lack of Systemic Change:** Industries remain locked into resource-intensive supply chains, making real environmental progress difficult.
- **Insufficient Circular Economy Adoption:** Sustainable business models should maximize material efficiency, reduce waste, and environmental impact.

Social Sustainability

Social sustainability refers to the ensurement of fair labor conditions, the development of the workforce, and inclusive access to goods and services (Elkington, 1998). Elkington (2018) criticizes the failure of the corporate world to balance economic gains with social well-being, noting that global inequality remains a persistent challenge despite sustainability commitments (Elkington, 2018), of which major concerns are:

- **Workforce Displacement:** Automation and digitalization have led to job displacement, without sufficient investment in reskilling initiatives.
- **Inequality in Access to Sustainable Technologies:** Low-income communities have limited access to sustainability innovations, reinforcing economic divides.
- **Lack of Ethical Accountability:** Companies often outsource labor to low-cost regions, where worker protections are weaker.

Elkington's 2018 triple bottom line reassessment challenges businesses to rethink sustainability at a systemic level, recognizing that economic, environmental, and social dimensions are deeply interconnected.

2.4 Synergy of Digital Servitization, Additive Manufacturing, and Sustainable Benefits

This section explores the theoretical synergies between digital servitization and sustainable benefits, positioning additive manufacturing as a contextual example. Figure 2.1 visually represents the relationship between the core concepts in this study.

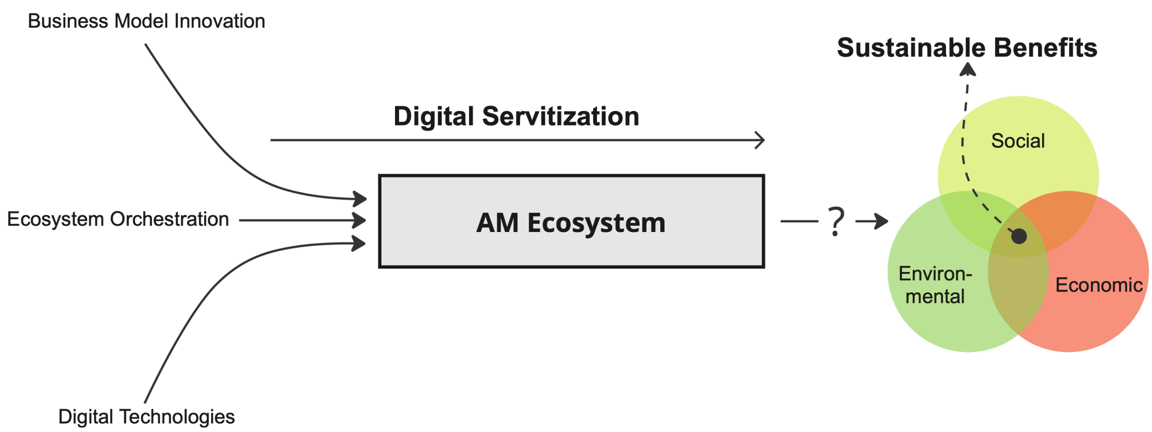

Figure 2.1: An illustration of the relationship between core concepts

As illustrated, business model innovation, ecosystem orchestration, and digital technologies are key components of digital servitization. These elements are applied within an additive manufacturing ecosystem that serves as a contextual medium to examine the servitization process. The relationship between this transformation driven by servitization and sustainable benefits, which spans economic, environmental, and social dimensions, remains an open question to be explored in this study.

To systematically explore this relationship, the following subsections review existing literature on how business model innovation, ecosystem orchestration, and digital technologies contribute to sustainability. By positioning additive manufacturing as a contextual medium, this study provides an industry-specific lens on how these mechanisms influence long-term sustainable value creation.

Business Model Innovation and Economic Sustainability

Economic sustainability, as outlined in the Triple Bottom Line framework (Elkington, 1998, 2018), emphasizes systemic profitability, stakeholder-centered value creation, circular economy principles and adaptability (Elkington, 2018). Innovation in digital servitization business models aligns with these principles, as it facilitates pay-per-use, product-as-a-service, and circular business strategies to enhance resource efficiency, extend product lifecycles, and minimize waste (Kohtamäki et al., 2022; Paiola & Gebauer, 2020; Zhang et al., 2024).

Additive manufacturing serves its purpose as a contextual example, as high initial investment costs remain a major barrier to adoption (Baumers, Dickens, et al., 2016; Herzog, Seyda, Wycisk, & Emmelmann, 2016). However, the implementation of digital servitization-driven business models in manufacturing industries still faces challenges such as cost uncertainty and market acceptance. These challenges will be discussed in a later section, focusing on practical applications and adoption barriers.

Ecosystem Orchestration and Economic Sustainability

Economic sustainability also depends on the efficiency, collaboration, and adaptability of the supply chain, all of which are supported by the orchestration of ecosystems enabled by digital servitization (Kolagar, Parida, & Sjodin, 2022; Schiavone et al., 2022). By integrating multi-actor collaborations and data-driven decision making, digital servitization allows for optimized resource allocation, enhances supply chain resilience, and facilitates industrial symbiosis between manufacturers, suppliers, and service providers.

Within additive manufactuirng ecosystems, supply chain challenges include uncertainty in material availability, inconsistencies in powder quality, and high post-processing costs (Demiralay, Sgarbossa, & Razavi, 2024; Frazier, 2014).

Digital Technologies and Environmental Sustainability

Environmental sustainability emphasizes minimizing industrial ecological impact, transitioning from incremental improvements to systemic change, and ensuring long-term environmental responsibility (Elkington, 1998, 2018). Digital technologies, such as AI, IoT and cloud computing, play a key role in digital servitization-enabled sustainability initiatives by improving operational efficiency, enabling predictive maintenance, and optimizing resource utilization (Kohtamäki et al., 2022; Sjödin et al., 2023).

Additive manufacturing serves as a case study in which digital technologies can contribute to environmental benefits. The monitoring of processes powered by AI enhances the precision of material usage, reducing scrap rates and excess resource consumption (M. Srivastava & Rathee, 2022).

Ecosystem Orchestration and Social Sustainability

Social sustainability emphasizes fair labor conditions, workforce development, and inclusive access to technology (Elkington, 1998, 2018). Digital servitization fosters ecosystem orchestration, strengthening collaborative knowledge sharing, upskilling initiatives, and inclusive industrial participation (Kolagar, Parida, & Sjodin, 2022; Schiavone et al., 2022).

Additive manufacturing, despite its potential, faces workforce challenges, including a lack of skilled labor in design, process monitoring, and post-processing (Felice, Lamperti, & Piscitello, 2022).

These high-level synergies provide a theoretical framework for understanding how digital servitization supports sustainable industrial transformation (Kolagar et al., 2021). The next sections will further explore practical applications and industry-specific challenges related to these sustainability strategies.

2.5 Research Gap

Theoretical Gaps

Despite growing interest in digital servitization, sustainability, and industrial ecosystems, their interconnections have not been adequately explored. Although research has recognized digital servitization as a key enabler of business model innovation, ecosystem orchestration, and digital transformation, its potential to enhance sustainability in industrial ecosystems lacks empirical validation.

Previous studies suggest that digital servitization can improve business resilience, resource efficiency, and value co-creation (Kolagar, Parida, & Sjodin, 2022; Sjödin et al., 2023; Zhang et al., 2024), but its specific contributions to environmental, social, and economic sustainability require further study. Furthermore, most of the research focuses on implementations at the firm level, neglecting multiactor coordination in industrial networks where digital servitization could enable sustainability transitions throughout the system (Gebauer et al., 2021; Schiavone et al., 2022).

Furthermore, while the innovation of business models through servitization has been widely studied, the role of pay-per-use models, circular economy strategies, and service-based value creation in sustainability-driven industries remains underexplored (Kohtamäki et al., 2022; Paiola & Gebauer, 2020; Zhang et al., 2024). Similarly, the role of digital technologies, such as AI-driven optimization, predictive maintenance, and real-time resource allocation, requires further empirical investigation to assess its sustainability potential (Kohtamäki et al., 2022; Sjödin et al., 2023).

Although these theoretical gaps highlight the need for more conceptual clarity, the practical implementation of digital servitization introduces additional challenges that influence its adoption and sustainability impact in industrial settings.

Practical Implementation Challenges

Although digital servitization has been recognized as a sustainability enabler (Kolagar, 2024; Sjödin et al., 2023), its impact in the real world remains highly dependent on the industry context. Practical challenges, including data ownership, cybersecurity risks, and interoperability barriers, continue to hinder its widespread adoption in manufacturing ecosystems (Filgueiras & Melo, 2024; Kolagar, Reim, Parida, & Sjödin, 2022).

Furthermore, existing research primarily examines successful servitization initiatives, providing limited insight into barriers and failure cases (Kolagar, 2024). A clearer understanding of why some servitization implementations succeed, while others fail is essential to develop robust sustainability strategies (Birkel & Müller, 2021).

Finally, governance and trust remain the main challenges in servitization ecosystems. The integration of multiple stakeholders on digital platforms introduces issues related to data-sharing agreements, intellectual property concerns, and regulatory alignment, which have not yet been adequately addressed in empirical studies (Kolagar, Reim, et al., 2022).

Contribution of This Study

By addressing these gaps, this study extends research on digital servitization beyond the perspective of the firm, providing empirical insights into its role in the transformation of digital services geared toward sustainability. This study identifies theoretical mechanisms that link servitization to sustainability while also exploring practical adoption barriers and industry-specific implementation challenges. These insights will contribute to both academic discourse and practical strategies for firms seeking to leverage digital servitization for long-term competitiveness and sustainability.

3 | Methodology

This section outlines the research design, data collection methods, and analytical approach used to examine the role of digital servitization in enabling sustainability-driven transformation within an additive manufacturing ecosystem. Given the complexity of this phenomenon and its multiactor dynamics, a qualitative research design was chosen to gain in-depth insights into how digital servitization strategies influence business model innovation, ecosystem orchestration, and digital technology adoption within industrial contexts (Köhler, 2024; Mihas, 2023).(Köhler, 2024; Mihas, 2023).

A single case study approach (Eisenhardt & Graebner, 2007; Yin, 2018) was used to investigate an additive manufacturing ecosystem, where digital servitization plays a crucial role in technology adoption and sustainability transformation (Kolagar, Parida, & Sjodin, 2022). The selected case is an orchestrated ecosystem led by an original equipment manufacturer specializing in laser powder bed fusion technology. This original equipment manufacturer has introduced highly automated modular additive manufacturing systems, but adoption remains challenging due to high initial investment costs, post-processing complexities, and uncertainties regarding return on investment (Baumers, Holweg, & Rowley, 2016; Herzog et al., 2016; Sæterbø & Solvang, 2024).

To capture diverse stakeholder perspectives, semi-structured interviews were conducted with industry professionals operating across different segments of the ecosystem. A visual representation of the ecosystem is included to contextualize the interactions between key actors and the role of digital servitization in mitigating barriers to technology adoption. The research follows a systematic thematic analysis, structured according to the Gioia methodology, which facilitates the identification of first-order categories, second-order themes, and aggregate dimensions (Gioia et al., 2013). The analysis focuses on the three theoretical pillars identified in the literature:

1. Business model innovation
2. Ecosystem orchestration
3. Digital technology integration

This chapter is structured as follows: first, the research approach and rationale for case selection are discussed, the data collection process is detailed, and finally the data analysis process is outlined.

3.1 Research Approach and Case Selection

This study employs an exploratory single-case study approach to examine the relationship between digital servitization and sustainable benefits within an additive manufacturing ecosystem (Nickels, Fischer-Baum, & Best, 2022; Yin, 2018). The selection of the case follows a purpose sampling strategy that ensures theoretical relevance and analytical depth. The orchestrating company was chosen based on its strategic emphasis on the development of highly automated and modular additive manufacturing systems designed for industrial applications. Despite these innovations, the market continues to face significant adoption challenges, particularly related to the high initial investment costs, complexities associated with post-processing, and uncertainty about the return on investment (Baumers, Holweg, & Rowley, 2016; Herzog et al., 2016; Sæterbø & Solvang, 2024). These barriers present an ideal setting for investigating how digital servitization can address adoption challenges while fostering economic, environmental, and social sustainability.

The rationale for selecting this case aligns with research recommendations that emphasize the need for comparative analyzes between successful and struggling implementations of digital service delivery (Kolagar, 2024). Although the selected ecosystem is not inherently unsuccessful, it operates in a highly uncertain market where many potential adopters remain hesitant due to financial and technological risks. Investigating how digital servitization strategies mitigate these adoption barriers provides valuable insight into their role in enabling sustainability-driven industrial transformation.

To ensure that the study captures meaningful insights, the selection process prioritizes cases where digital servitization strategies have been introduced but are not yet fully integrated in the ecosystem. The selected ecosystem is in an early stage of the implementation of service-based models, providing an opportunity to explore their scalability and long-term sustainability potential. The study also examines multiactor collaboration within the additive manufacturing ecosystem, focusing on interactions between manufacturers, suppliers, customers, distributors, technology enablers, and regulatory bodies. This approach provides a holistic perspective on how digital servitization evolves within an interconnected industrial environment and contributes to overcoming challenges in technology adoption. Furthermore, this aligns with the importance of ecosystem orchestration within digital servitization, as outlined in the theoretical background chapter, emphasizing the need for coordinated efforts across stakeholders to drive sustainable industrial transformation.

The ecosystem under study demonstrates an increasing commitment to sustainability objectives, with efforts to align with circular economy principles, optimize resource efficiency, and reduce environmental impact through emerging digital service strategies. By analyzing early-stage adoption and the potential evolution of digital servitization, this research explores how its further integration could contribute to long-term sustainability and industrial transformation within the additive manufacturing sector.

By selecting an ecosystem that continues to navigate adoption challenges, this study offers a unique opportunity to assess the role of digital servitization in fostering business model innovation, enhancing collaboration across industrial networks, and integrating digital technologies for improved sustainability. Although previous research has largely focused on firm-level implementations of digital servitization, this study expands the scope to an ecosystem-wide perspective, emphasizing how multiple stakeholders coordinate their efforts to shape industrial transformation (Gebauer et al., 2021).

A visual representation of the ecosystem studied is provided in 3.1, illustrating key stakeholders and their interactions. In the center, the original equipment manufacturer serves as the orchestrator, coordinating relationships with suppliers, customers, distributors, investors, and regulatory bodies. The figure highlights the interdependent nature of the ecosystem, where supply chain actors provide critical components and materials, while technology enablers and regulatory bodies influence standardization, compliance, and technological advancements. Customers and distributors play an important role in shaping future service offerings, driving technological improvements, and influencing adoption strategies.

By examining an ecosystem that faces both opportunities and challenges in the adoption of digital services, this study provides a nuanced perspective on how digital services can help overcome adoption barriers, improve coordination between industrial networks, and contribute to sustainable industrial transformation. This approach improves both theoretical and practical understanding, offering empirical insights for companies looking to implement digital serviti-

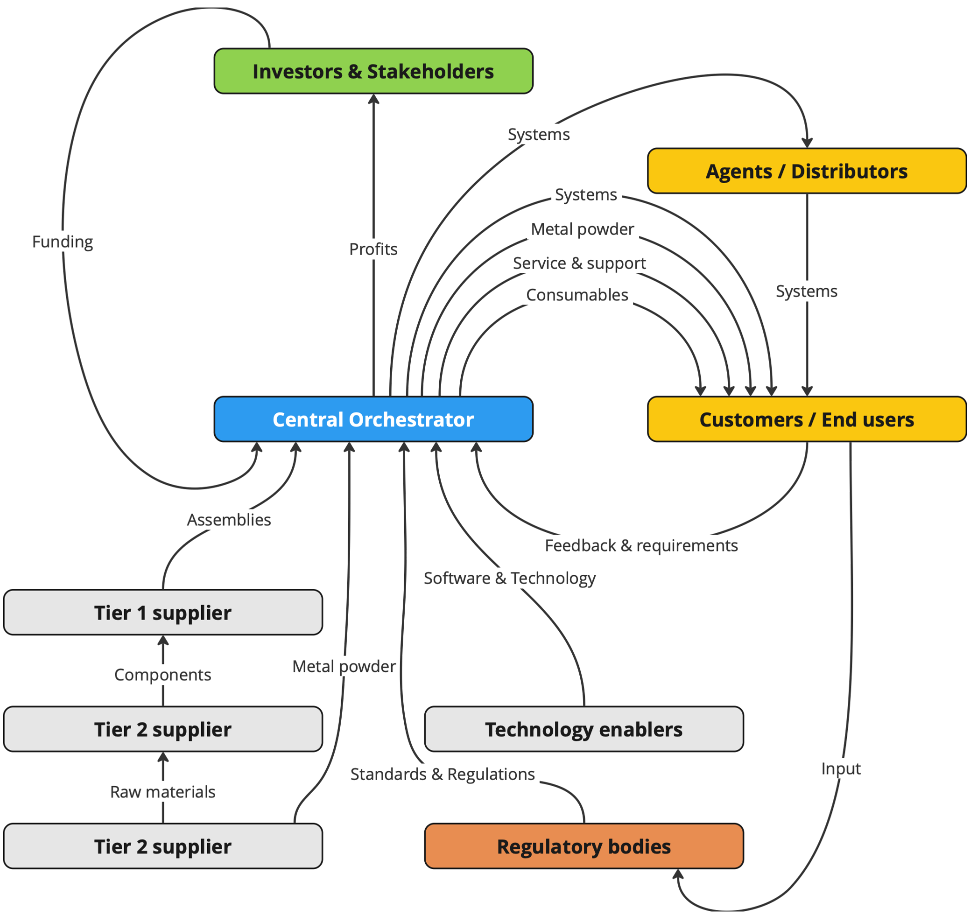

Figure 3.1: Illustration of the studied ecosystem

zation strategies in the additive manufacturing industry to enhance competitiveness and sustainability.

3.2 Data Collection

This study follows a qualitative research design, collecting empirical data through 25 semi-structured in-depth interviews with key stakeholders within the additive manufacturing ecosystem under investigation. These interviews lasted between 40 and 70 minutes and were conducted in 10 different companies, each playing a distinct role in the broader industrial network led by the central orchestrator. The research aimed to capture diverse perspectives on digital servitization, barriers to technology adoption, and sustainability considerations within the ecosystem. This qualitative approach aligns with previous studies on digital servitization, which emphasize the need for rich and detailed insights to understand the transformation of industrial ecosystems (Kolagar, 2024; Kolagar, Reim, et al., 2022; Paiola & Gebauer, 2020).

The data collection process was structured in two stages to ensure analytical depth and methodological triangulation. The first stage involved interviews with key decision makers in the orchestrating company. This was based on the premise that the orchestrator has the most comprehensive understanding of the ecosystem, its stakeholder interactions, and the implementation of digital servitization strategies. The interviews followed a structured protocol designed to explore how the company develops digital service-based business models, facilitates ecosystem-wide collaboration, and addresses sustainability challenges. This approach is consistent with previous research on industrial services, where insights from orchestrators provide a foundation for analyzing broader ecosystem transformations (Gebauer et al., 2021; Kolagar, 2024).

In the second stage, additional interviews were conducted with representatives of other key stakeholders within the ecosystem, including customers, supply chain partners, and technology providers. These interviews were guided by custom protocols that reflected the specific role of each stakeholder group. Customer interviews focused on technology adoption experiences, perceived benefits, and expectations for the development of digital services. These discussions also explored how digital servitization aligns with economic, environmental, and social priorities, structured within the Triple Bottom Line framework (Elkington, 1998, 2018). Interviews with supply chain partners focused on inter-firm collaboration, the adoption of digital servitization strategies in supplier networks, and the challenges of implementing sustainability practices within the ecosystem (Kolagar, Parida, & Sjodin, 2022).

To minimize bias and ensure the inclusion of diverse perspectives, a snowball sampling technique was used, in accordance with best practices in case study research (Eisenhardt & Graebner, 2007; Yin, 2018). The interviews began at the management level of the central orchestrating company A and based on their referrals, the snowball sampling technique was used to identify subsequent interviewees. Initially, the interviews were concentrated within the central orchestrating company to test and refine the interview protocol while ensuring a structured approach to data collection. Once a saturation level was reached, providing a clear overview for generating the concept, the interviews expanded to include external stakeholders throughout the ecosystem. This sequencing was also necessary due to accessibility constraints: While the central orchestrating company was readily available, interviews with other actors in the ecosystem required careful planning to maximize their value. The semi-structured format provided flexibility, allowing interviewees to elaborate on key themes while allowing the researcher to investigate deeper emerging insights, an approach widely validated in servitization research (Kohtamäki et al., 2022).

All interviews were conducted remotely using Microsoft Teams, ensuring a consistent and high-quality recording process (Corporation, 2024). The audio recordings were automatically transcribed using built-in transcription services, offering an efficient and reliable means of capturing data (Eftekhari, 2024). To maintain ethical integrity, all participants signed informed consent forms and a data management plan was implemented to ensure secure storage and handling of sensitive information, according to established ethical guidelines for qualitative research (Arifin, 2018; Pietilä, Nurmi, Halkoaho, & Kyngäs, 2020).

To further enhance validity, two industry experts outside the ecosystem studied were interviewed. Their perspectives provided external validation of the findings, ensuring that interpretations were not solely shaped by internal ecosystem dynamics. Incorporating these external viewpoints strengthens the methodological rigor of the study, reducing potential biases such as retrospective sense making or impression management (Carter, 2014; Denzin, 1978). This triangulation with the participation of external experts helped mitigate issues such as retrospective sense making and impression management, improving the reliability of the findings (Eisenhardt & Graebner, 2007).

The data collection process was conducted iteratively, with continuous refinement of the interview protocol based on emerging insights, leading to the creation of dedicated protocols depending on the ecosystem position of the interviewee. This iterative approach aligns with thematic analysis principles (Gioia et al., 2013), allowing progressive identification and refinement of key themes. By the 25th interview, data saturation was reached, meaning that additional interviews were unlikely to produce new information, a concept well documented in qualitative research (Fusch Ph D & Ness, 2015). This iterative approach ensured a comprehensive understanding of how digital servitization is developing within the additive manufacturing ecosystem, along with its potential to address adoption barriers and sustainability objectives.

To provide an overview of the interview dataset, Table 3.1 presents anonymized details of the companies and interviewees included in the study.

Company	Description	Ecosystem position	Interviewees
A	An additive manufacturing original equipment manufacturer specialized in manufacturing high end, modular, and automated laser powder bed fusion systems.	Central orchestrator	Director Sales and Applications, Director Business Operations, Supply Chain Manager, CEO, Director Global Services, Head of Applications, Business Development Manager, Team Lead Services, Senior Sales Manager (2), Product Marketing Manager, Product Manager, Director Technology, Strategic Marketing Manager, Quality Manager, Program Manager
B	Manufacturer of precision systems and modules	Customer	Production Manager
C	Confidential	Potential customer	Project Manager
D	Supplier of poultry processing solutions	Customer	Industrial Engineer, Cam Programmer
E	Supplier of metal powders	Supplier	Sales Engineer
F	Additive manufacturing consultant	Industry expert	Partner and CCO
G	Supplier of metal powders	Supplier	Product Manager
H	Supplier of equipment for process monitoring	Technology enabler	Business Development
I	Additive manufacturing consultant	Industry expert	Managing Director
J	Manufacturer of precision systems and modules	(Tier 1) Supplier	Business Manager

Table 3.1: Overview of interviewed companies and ecosystem roles

The data collected form the basis for the thematic analysis, where first-order concepts are identified, categorized into second-order themes, and further condensed into aggregate dimensions, following the Gioia methodology (Gioia et al., 2013). This structured analytical approach ensures a rigorous and well-founded exploration of how digital servitization, additive manufacturing, and sustainability interact within the studied ecosystem.

3.3 Data Analysis

To ensure a close alignment between empirical data and theoretical insights, this study adopted an iterative, inductive approach to data analysis, following established thematic analysis techniques (Braun & Clarke, 2006; Gioia et al., 2013). Thematic analysis was chosen due to its suitability for qualitative research exploring complex multi-actor ecosystems, particularly in the context of digital servitization and sustainability transformations (Eisenhardt & Graebner, 2007; Gehman et al., 2018b).

The analysis began with a systematic manual review and coding process, in which all raw data, including interview transcripts and recorded interviews, were carefully examined. This in-depth engagement with the data ensured a nuanced understanding of informants' perspectives, minimizing the risk of overlooking key insights. The initial coding phase involved systematically identifying meaningful excerpts from the interviews, yielding more than 250 sections that contained potential first-order categories. These sections represented recurring themes, unique observations, and key insights into the role of digital servitization within the additive manufacturing ecosystem studied.

To enhance analytical rigor, a prioritization step was taken in which potential first-order categories were assessed based on frequency and consistency among interviewees. Categories that appeared repeatedly, verbatim, or in closely related forms were given higher analytical weight. This process ensured that findings reflected the collective experiences of multiple actors within the ecosystem rather than isolated viewpoints, aligning with best practices in qualitative research(Langley, 1999; Miles, 1994).

Following the initial coding phase, a collaborative review session was conducted with a digital servitization expert, the research supervisor, to validate and refine the coding framework before proceeding to the construction of first-order categories. This session allowed expert input to distinguish between semantically similar, yet theoretically distinct concepts, thus improving the clarity and validity of the coding structure (Corley & Gioia, 2004).

In the next stage, the refined first-order categories were clustered into second-order themes, representing theoretically relevant concepts derived from the synthesis of multiple first-order categories. This process involved recognizing patterns, relationships, and conceptual overlaps within the data, ensuring that emergent themes reflected the broader digital servitization landscape while maintaining their grounding in empirical findings (Strauss & Corbin, 1998). Through this iterative process, the analysis resulted in a set of theoretically significant second-order themes, each encapsulating a distinct, yet interrelated, aspect of digital servitization in the additive manufacturing ecosystem.

These second-order themes were further refined and consolidated into aggregate dimensions, which represent the highest level of abstraction in the coding process. These dimensions synthesize key strategic, operational, and sustainability-related insights derived from the study and serve as a foundation for understanding how digital servitization manifests itself within additive manufacturing ecosystems. The process of moving from first-order categories to second-order themes and ultimately to aggregate dimensions followed the methodological rigor advocated (Gioia et al., 2013), ensuring transparency, traceability, and theoretical robustness.

To improve the reliability of the findings, an additional verification step was undertaken, in which the identified themes and dimensions were compared against insights from existing literature and secondary data sources, including industry reports and technical documentation from ecosystem actors. This cross-validation process helped ensure consistency between empirical observations and established theoretical constructs, strengthening the study's contribution to ongoing discussions on digital servitization and sustainable business transformation (Kumar, Stern, & Anderson, 1993).

Through this structured and iterative analytical process, the study provides a grounded, empirically driven understanding of how digital servitization strategies interact with adoption challenges and sustainability objectives in the additive manufacturing industry. The final coding structure, including the visualization of the coding tree, will be presented in the next chapter to illustrate the analytical pathway from raw data to aggregated insights derived from the research.

4 | Results and Discussion

This chapter presents the key findings derived from the thematic analysis of interviews, structured according to the aggregate dimensions identified in the data analysis process. The analysis revealed four aggregate dimensions: business model innovation, ecosystem orchestration, digital technologies, and sustainable benefits that emerged through iterative code. These dimensions encapsulate the most salient themes related to digital servitization and its potential to drive sustainable benefits within the additive manufacturing ecosystem studied. In addition, they highlight how servitization strategies could play a role in mitigating adoption barriers, facilitating the broader acceptance and integration of additive manufacturing technologies.

Given that the ecosystem exhibits only early signs of digital servitization, as indicated by multiple interviewees, this chapter not only examines existing implementations, but also explores the untapped potential for further servitization strategies. As the thematic analysis progressed, it became evident that, beyond theoretical links between digital servitization and sustainability, the empirical data also provided practical insights into how servitization could be effectively adopted within this specific ecosystem. These insights contributed to the development of a framework that outlines the barriers, enablers, and potential pathways through which digital servitization can foster sustainable benefits in additive manufacturing. Although the framework will be formally introduced in the following chapter, its conceptual underpinnings are interwoven throughout the discussion, as the findings directly informed its construction.

Each section in this chapter follows a structured approach. First, it presents empirical findings, illustrating key patterns and trends that emerged from the interviews. These findings are then examined in relation to existing literature, allowing for a comparison between observed dynamics and theoretical perspectives on digital servitization and sustainable benefits. By situating the findings within a broader academic discourse, this chapter seeks to contribute to the theoretical understanding of digital servitization while offering practical implications for firms operating within additive manufacturing ecosystems.

4.1 Business Model Innovation

Business model innovation plays a central role in the digital servitization of additive manufacturing, offering new pathways to create value, engage customers and adopt technology. Within the ecosystem studied, digital servitization remains in its early stages, with firms exploring service-based models while still relying on traditional hardware sales. Thematic analysis of the interview data revealed key challenges and opportunities associated with the transformation of the business model.

As illustrated in Figure 4.1, the analysis identifies multiple first-order categories, which were grouped into second-order themes and subsequently condensed into the aggregate dimension of business model innovation.

This section presents empirical findings related to business model innovation, contextualizing them within existing literature, and discussing their implications for digital servitization in additive manufacturing.

The analysis highlights several interrelated themes that influence the adoption and implementation of business model innovation in additive manufacturing. A key insight from the interviews is that while some firms recognize the strategic importance of transitioning from product sales

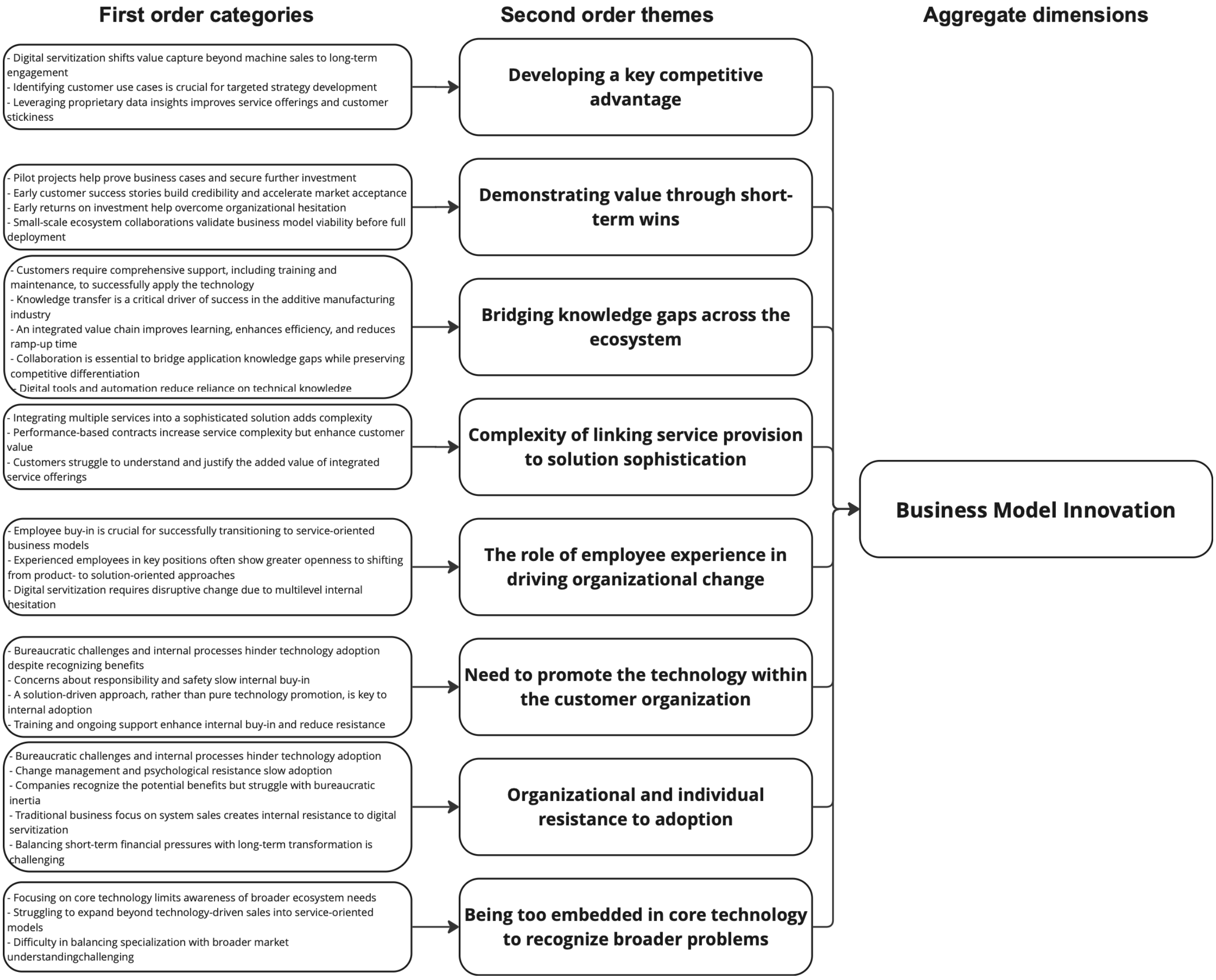

Figure 4.1: Data structure of the first aggregate dimension; Business Model Innovation

to long-term service-driven engagements, others remain hesitant due to financial constraints, internal resistance, and limited understanding of service-based value propositions.

To illustrate how interview data inform the development of first-order categories, figure 4.2 presents a specific case where interview excerpts were coded into the first-order category "Digital servitization shifts value capture beyond machine sales to long-term engagement." Figure 4.2 highlights how qualitative data from industry experts directly support conceptual development.

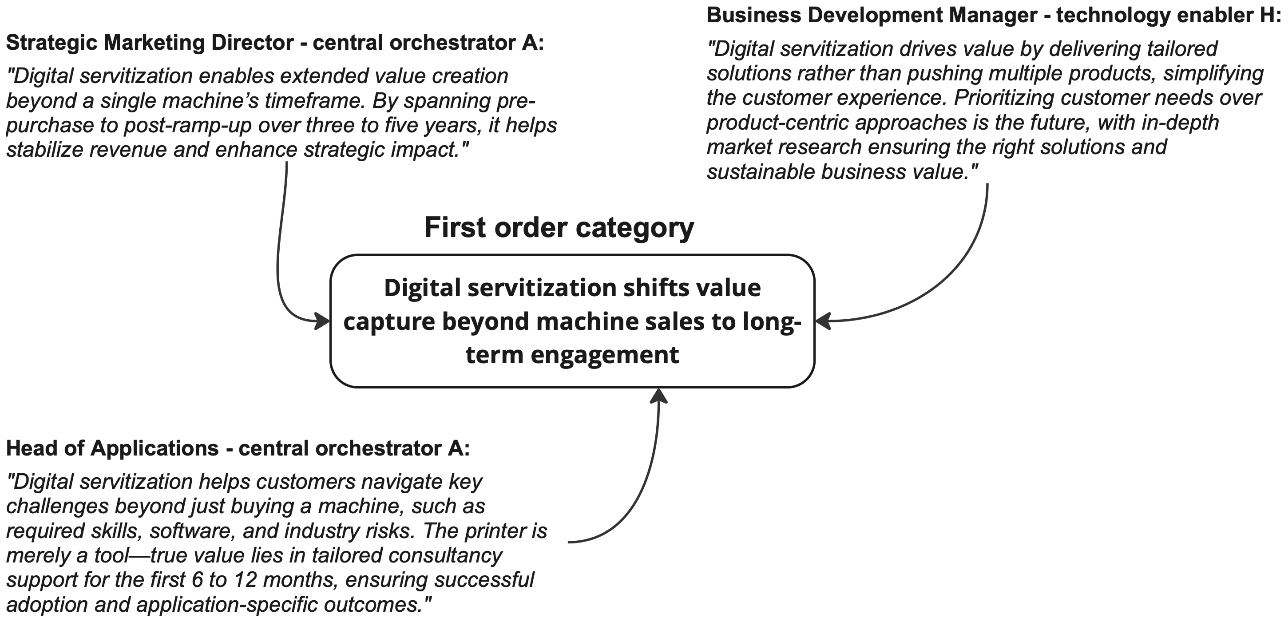

Figure 4.2: Data analysis example

Developing a Key Competitive Advantage

Digital servitization shifts value creation from one-time product transactions to ongoing service-driven revenue streams, allowing firms to foster deeper customer relationships and improve customer retention. However, several interviewees emphasized that identifying relevant use cases of services remains a challenge. A business development manager from the central orchestrator, company A, stated:

"We see digital services as a way to differentiate ourselves, but convincing customers of the long-term benefits remains difficult. They often evaluate investments based solely on hardware." (Interview 7)

Using proprietary data insights and integrating performance-based contracts, firms can enhance their service offerings, reinforcing service provision as a competitive advantage. However, the effectiveness of these strategies depends on the awareness of customers and the willingness to embrace service-based engagements.

Demonstrating Value Through Short-Term Wins

Pilot projects and small-scale collaborations have emerged as crucial mechanisms for demonstrating the feasibility of digital servitization models. Several interviewees pointed out that early customer success stories accelerate technology acceptance and help overcome organizational resistance. A Sales and Applications Director from the central orchestrator, company A, noted:

"A pilot project, in which a more comprehensive approach is taken for the implementation of the technology, could be a way to showcase the potential benefits of more innovative business models and convince the shareholders to free up additional resources." (Interview 1)

This suggests that short-term wins not only help firms validate their business model but also play a role in building trust and credibility within the ecosystem.

Bridging Knowledge Gaps Across the Ecosystem

Successful business model transformation in additive manufacturing requires extensive knowledge transfer and training support. Customers often lack the technical expertise to fully leverage digital service offerings, making education a key enabler of adoption. A Strategic Marketing Director from the central orchestrator, company A, emphasized the following:

"Most of the time, customers do not initially realize the gap between where they are and where they need to be. Only after they start using the technology do they see the need for consulting to unlock its full value." (Interview 15)

Collaboration within the supply chain also plays a role in bridging these knowledge gaps, as suppliers and service providers must align to ensure the seamless integration of digital solutions.

Complexity of Linking Service Provision to Solution Sophistication

Integrating multiple service elements into a cohesive digital offering adds complexity, particularly in performance-based contracts where service delivery is tied to predefined metrics. The interviewees noted that while these models create recurring revenue opportunities, customers struggle to quantify the added value. An employee from company D, a customer in the ecosystem, stated:

"It's difficult to quantify benefits in advance, and it's not something that you can easily test or demonstrate in advance. If that were possible, everything would be solved. But when we see upgrade costs, at some point, it simply becomes unprofitable and we drop out. We would like to proceed in principle, but right now, we just can't justify it." (Interview 17)

Ensuring clarity in service agreements and aligning incentives between suppliers and customers is therefore crucial for the scalability of digital servitization models.

Organizational and Individual Resistance to Adoption

Several interviewees highlighted that transitioning to service-driven business models requires internal support from employees at multiple levels. Perceived barriers, concerns about job security, and traditional performance evaluation metrics hinder adoption. The CEO from the central orchestrator, company A, explained:

"A shift in mindset and culture is necessary. Right now, the company operates with a very transactional approach, but for digital servitization to succeed, we need to move beyond that and embrace a more service-oriented way of thinking." (Interview 4)

In addition, bureaucratic challenges and rigid internal processes further slow down the transformation. Firms that successfully navigate these challenges tend to have leadership teams that actively promote digital servitization initiatives and provide the necessary training programs to support employees in this transition.

Discussion and Theoretical Context

The findings align with existing literature on digital servitization and innovation of business models. Scholars highlight that servitization represents a fundamental shift in industrial firms, which requires changes in value propositions, revenue models, and customer engagement strategies (Kohtamäki et al., 2022; Paiola & Gebauer, 2020). The importance of short-term wins, as identified in this study, is also emphasized in previous research as a mechanism to overcome initial resistance and validate new service models (Sjödin et al., 2023).

However, the empirical findings extend beyond these theoretical perspectives by providing a granular view of the specific challenges faced within additive manufacturing ecosystems. In particular, the complexity of linking service provision with solution sophistication reflects the unique nature of additive manufacturing, where digital services often require deep integration with production processes. This observation suggests that firms in this sector must carefully design their service offerings to align with customer expectations and operational realities.

Moreover, the study highlights that while business model innovation offers a pathway to overcome adoption barriers in additive manufacturing, it requires ecosystem-wide coordination. Resistance to digital servitization is not only an organizational issue, but also an ecosystem-level challenge, as multiple stakeholders must align their incentives and capabilities to enable a seamless transition (Kolagar, Parida, & Sjodin, 2022).

4.2 Ecosystem Orchestration

Ecosystem orchestration plays a pivotal role in enabling digital servitization in additive manufacturing by fostering collaboration among key stakeholders, aligning strategic priorities and ensuring efficient integration of the value chain (Adner, 2017; Kolagar, 2024). Thematic analysis of the interview data highlights that while firms recognize the importance of an orchestrated ecosystem, structural and operational barriers continue to impede seamless coordination. Among the key challenges identified are the misalignment between value perception and adoption, data sharing limitations, and the difficulty of defining responsibilities across the ecosystem. In contrast, leveraging external expertise and fostering standardization emerge as critical enablers of ecosystem-wide service.

As illustrated in Figure 4.3, the analysis identifies multiple first-order categories related to ecosystem orchestration. These were grouped into second-order themes and condensed into the aggregate dimension of ecosystem orchestration. This section presents the key empirical findings, contextualizing them within existing literature and discussing their implications for digital servitization in additive manufacturing.

Leveraging External Expertise and Industry Connections

Collaboration with external partners is a key strategy to overcome knowledge gaps and accelerate the adoption of services. By engaging with technology enablers, established industry experts, and specialized solution providers, companies can access cutting-edge expertise that might not be available in-house. Several interviewees emphasized that external collaborations can mitigate risks associated with immaturity of technology, regulatory constraints, and lack of internal capabilities. A Product Manager from the central orchestrator, company A, said:

"Bringing in experienced partners allows us to integrate specialized capabilities without needing to develop them internally from scratch." (Interview 11)

Research on servitization in manufacturing ecosystems confirms that leveraging external expertise can enhance innovation capabilities and reduce adoption friction by ensuring that firms can offer comprehensive, value-driven solutions rather than isolated product offerings (Baines et al., 2017; Frank et al., 2019). However, to fully capitalize on external expertise, firms must establish long-term strategic partnerships rather than rely solely on short-term transactional engagements.

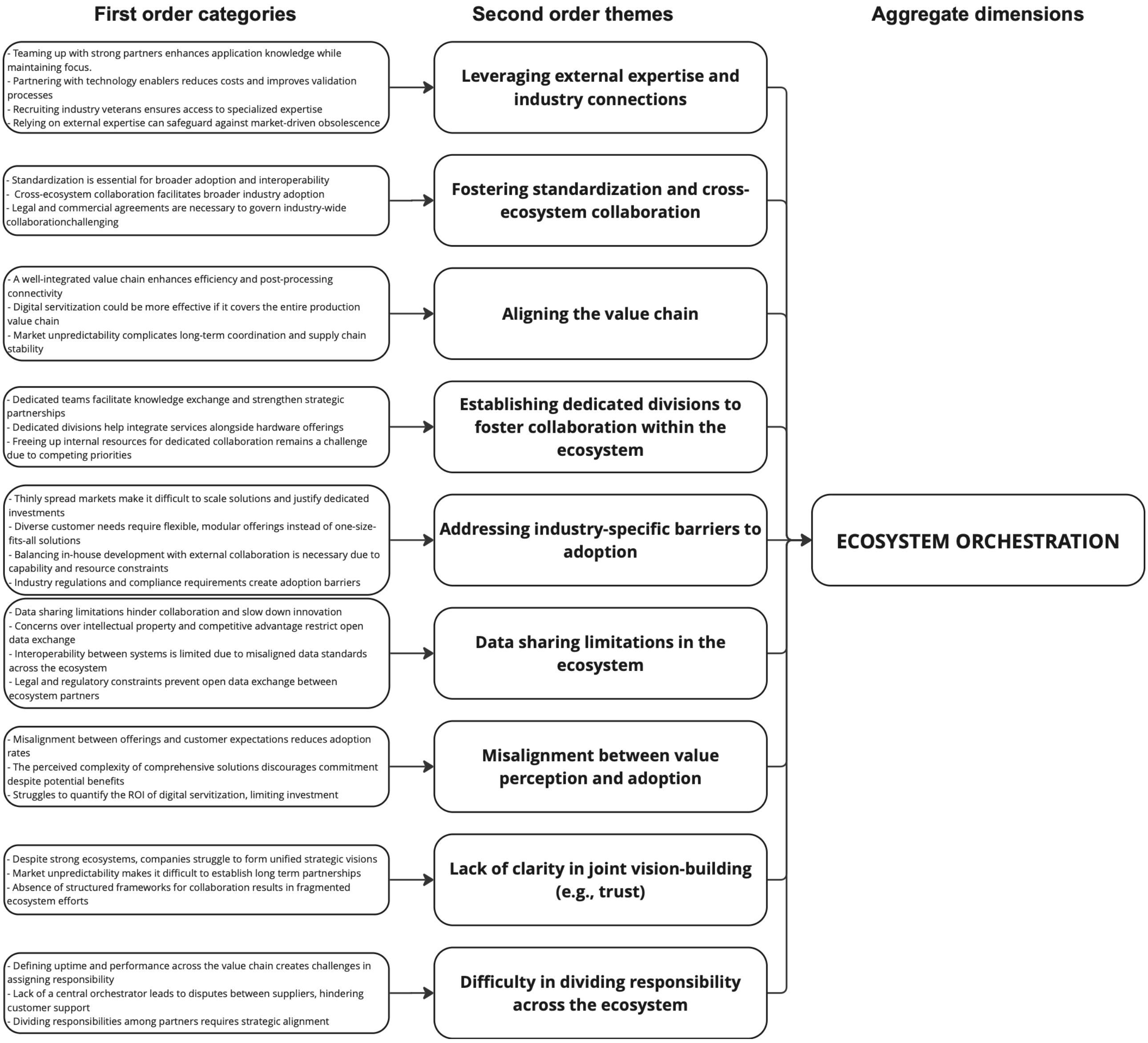

Figure 4.3: Data structure of the second aggregate dimension; Ecosystem Orchestration

Fostering Standardization and Cross-Ecosystem Collaboration

A recurring challenge in the study was the fragmentation of digital service models due to a lack of standardization throughout the ecosystem. Without interoperability frameworks and common digital architectures, it becomes increasingly difficult to integrate servitized offerings across different stakeholders. A Director from the central orchestrator, company A, stated:

"If every company develops its own proprietary approach, then we are just creating more silos instead of enabling real ecosystem-wide solutions." (Interview 6)

Standardization is crucial not only for technical integration but also for streamlining legal and commercial agreements, which can often act as a bottleneck in multi-stakeholder collaborations. Previous research underscores that industry-wide standardization initiatives can accelerate the adoption of services by reducing compatibility concerns and reducing operational complexity (Figueredo et al., 2020). Empirical data suggest that cross-ecosystem collaboration efforts must be institutionalized through shared governance mechanisms to ensure sustained interoperability and strategic alignment.

Misalignment Between Value Perception and Adoption

Data is a fundamental enabler of servitization, but the unwillingness to share operational, process, and performance-related data among ecosystem participants remains a critical challenge. Many firms fear that sharing proprietary data could lead to competitive disadvantages, loss of intellectual property, or dependency on external actors. A Sales Manager from the central orchestrator, company A, stated:

"Companies hesitate to share data, even when it would clearly improve service efficiency. There's always concern over who controls the data and how it will be used." (Interview 9)

The service literature highlights that clear governance structures, contractual agreements, and trust-building mechanisms are required to facilitate secure and beneficial data-sharing arrangements (Smania, Ayala, Coreynen, & Mendes, 2024). The findings suggest that firms that successfully navigate data-sharing concerns are those that implement clear data governance frameworks—ensuring transparent rules on ownership, security, and usage rights.

Misalignment Between Value Perception and Adoption

One of the most significant barriers to the adoption of ecosystem-wide servitization is the misalignment between the perceived value of digital services and the willingness of firms to invest in them. Many customers hesitate to transition to servitized models due to difficulties in quantifying benefits, justifying recurring costs, and integrating digital services within existing workflows. A Product Manager from the central orchestrator, company A, mentioned:

"Many customers do not immediately see the ROI of digital servitization. The benefits are long-term, but they evaluate investments based on short-term gains." (Interview 11)

This hesitation is further compounded by the complexity of integrating multiple service elements into cohesive, performance-driven offerings. Research suggests that companies must improve the way they communicate value to customers by providing clear business cases, pilot demonstrations, and quantifiable success metrics to bridge this perception gap (Cenamor et al., 2017). The study indicates that firms that actively educate customers about the tangible long-term benefits of servitization tend to experience higher adoption rates.

Difficulty in Dividing Responsibility Across the Ecosystem

Defining roles and responsibilities within an ecosystem-wide servitization model is particularly challenging, as multiple stakeholders contribute to the value proposition. The study highlights that unclear accountability structures can lead to inefficiencies, disputes, and delays in service execution. A Quality Manager from the central orchestrator, company A, highlighted:

"There were always discussions with the powder supplier like, oh, was it your part and it was bad or was it our machine? So I think it will lead up to more discussions than it will help the customers." (Interview 16)

This ambiguity not only slows down the resolution of issues, but also creates barriers to long-term customer trust and satisfaction. Previous research suggests that ecosystem governance models must clearly define roles, responsibilities, and escalation pathways to prevent fragmentation and ensure seamless service delivery (Sjödin, Parida, & Kohtamäki, 2019). The findings indicate that firms must establish structured collaboration agreements that define responsibility allocation, service-level expectations, and performance tracking mechanisms.

Discussion and Theoretical Context

The findings reinforce the critical role of ecosystem orchestration in enabling digital servitization. The existing literature highlights that multistakeholder coordination, trust-based collaboration, and standardized interoperability frameworks are essential for service success (Sjödin et al., 2019). The study extends prior research by identifying specific ecosystem barriers within additive manufacturing, such as:

Value perception misalignment: Customers require clear justification of ROI and structured transition pathways.

Data-sharing reluctance: Firms must implement secure data governance frameworks to facilitate trust-based data exchanges.

Fragmented responsibilities: Structured role allocation agreements are necessary to enhance accountability and service coordination.

These findings suggest that servitization in additive manufacturing is highly dependent on ecosystem-wide alignment and shared strategic vision. Future research should explore best practices for structuring collaborative governance models that enable trust, efficiency, and long-term engagement in servitization ecosystems.

4.3 Digital Technologies

Digital technologies serve as the foundation for enabling servitization in additive manufacturing, offering new avenues for automation, traceability, and predictive maintenance. However, the integration of digital technologies into manufacturing ecosystems is not without challenges. Thematic analysis of the interview data reveals that AI-driven optimization, value chain traceability, and overcoming technological barriers are key focus areas, while concerns surrounding data security, regulatory constraints, and technological maturity pose significant obstacles to adoption.

As illustrated in Figure 4.4, the analysis identifies multiple first-order categories related to digital technologies. These were grouped into second-order themes and subsequently condensed into the aggregate dimension of digital technologies. This section presents the key empirical findings, contextualizing them within existing literature, and discussing their implications for digital servitization in additive manufacturing.

Unlocking New Value Through AI and Automation in Digital Servitization

The growing integration of AI-driven optimization and automation is changing how serviceization is implemented in additive manufacturing. AI-powered solutions enable predictive maintenance, process optimization, and improved efficiency, reducing the reliance on manual interventions, and improving cost-effectiveness. The Head of Applications from central orchestrating company A mentioned:

"Automated workflows and AI-driven insights allow us to streamline production, minimizing downtime, and improving efficiency." (Interview 6)

Previous research highlights that predictive analytics and AI-powered automation reduce maintenance costs and improve machine uptime, driving the economic feasibility of servitized business models (Raddats, Naik, & Bigdeli, 2022)]. However, the study also finds that long-term lifecycle management remains a challenge, as AI-driven models require continuous calibration and adaptation to evolving production needs.

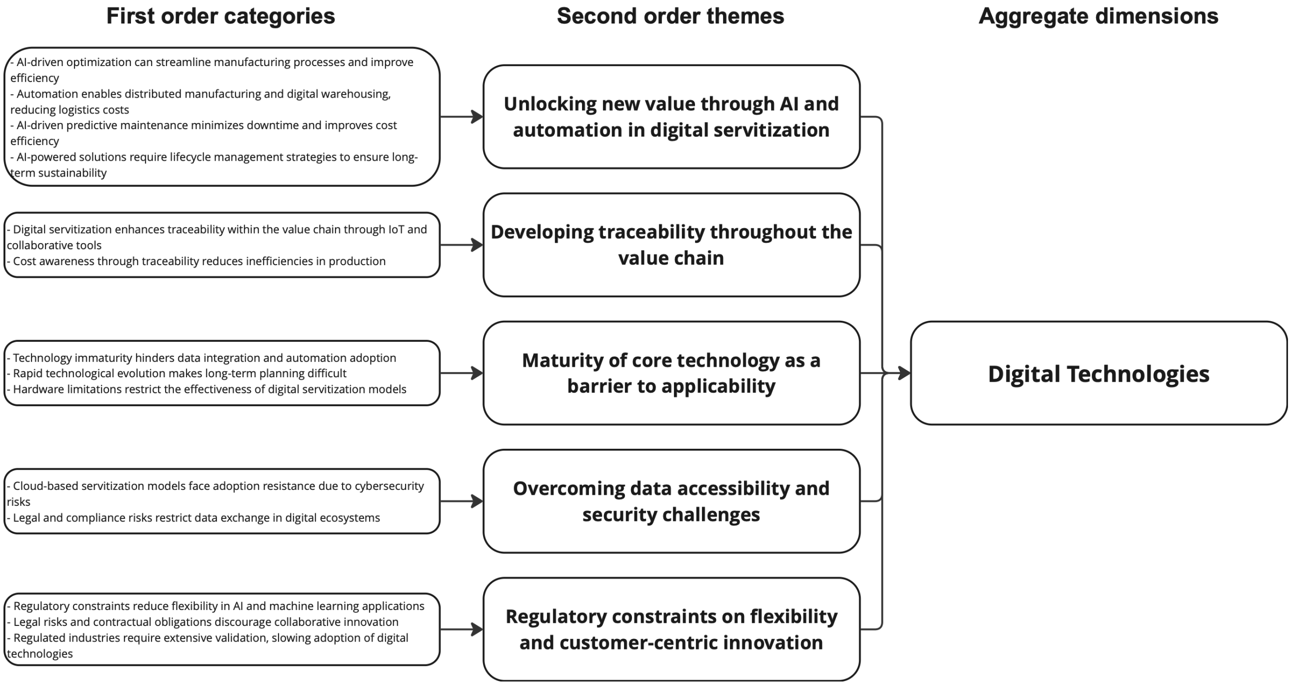

Figure 4.4: Data structure of the third aggregate dimension; Digital Technologies

Maturity of Core Technology as a Barrier to Applicability

Despite the growing potential of digital servitization, the immaturity of core additive manufacturing technologies continues to limit its widespread applicability. The interviewees reported that hardware and software limitations hinder automation adoption, making it difficult for firms to fully transition to service-driven business models. The CEO of central orchestrating company A said:

"The technology itself is not completely mature. While progress has been made, integration between hardware, software, and processes remains a major barrier to automation and mass production." (Interview 4)

Previous research aligns with this observation, suggesting that technological advances in automation, material science, and process reliability must evolve before servitization can achieve full-scale adoption (Kolagar, Reim, et al., 2022). The study indicates that companies investing in parallel advancements, such as software-driven process improvements and hybrid production models, tend to experience greater success in serving implementation.

Overcoming Data Accessibility and Security Challenges

While digital servitization is heavily dependent on real-time data exchange and cloud-based solutions, cybersecurity concerns and access restrictions present major hurdles to adoption. Many interviewees cited concerns about data ownership, IP protection issues, and industry regulations as factors that discourage open data sharing. A Sales Manager from central orchestrating company A noted that:

"There's always hesitation when it comes to sharing data. Companies worry about losing control over their IP and the risks associated with regulatory compliance." (Interview 9)

Research on servitization security frameworks emphasizes the need for secure data governance models that balance openness with confidentiality (Smania et al., 2024). The findings suggest that firms that successfully adopt digital servitization prioritize cybersecurity investments and establish clear data sharing protocols with ecosystem partners.

Discussion and Theoretical Context

The findings emphasize that AI-driven automation, technological maturity, and data security concerns shape the trajectory of servitization in additive manufacturing. The existing literature recognizes these factors as both enablers and barriers to digital servitization (Kolagar, Reim, et al., 2022; Schiavone et al., 2022).

Key takeaways include

- AI-driven automation improves operational efficiency and predictive maintenance, but requires significant upfront investment in infrastructure and expertise.
- Technological immaturity remains a major barrier, slowing the scalability of digital services and limiting ecosystem-wide adoption.
- Data security and regulatory compliance concerns hinder cloud-based servitization, necessitating secure, trust-based data governance models.

These findings extend existing research by providing a granular view of digital technology challenges within the additive manufacturing industry, emphasizing the need for strategic ecosystem-wide collaboration to unlock the full potential of servitization.

4.4 Sustainable Benefits

Sustainability is a core consideration in the adoption of digital servitization within additive manufacturing. Thematic analysis of interview data highlights three primary ways in which servitization contributes to sustainability: economic benefits, environmental benefits, and social benefits. These dimensions illustrate how digital servitization supports not only business model transformation, but also long-term industry resilience, ecological efficiency, and social well-being.

As illustrated in Figure 4.5, the analysis categorizes key findings into first-order categories, second-order themes, and the overarching aggregate dimension of sustainable benefits. This section presents the empirical findings, situating them within the existing literature, and discussing their implications for additive manufacturing.

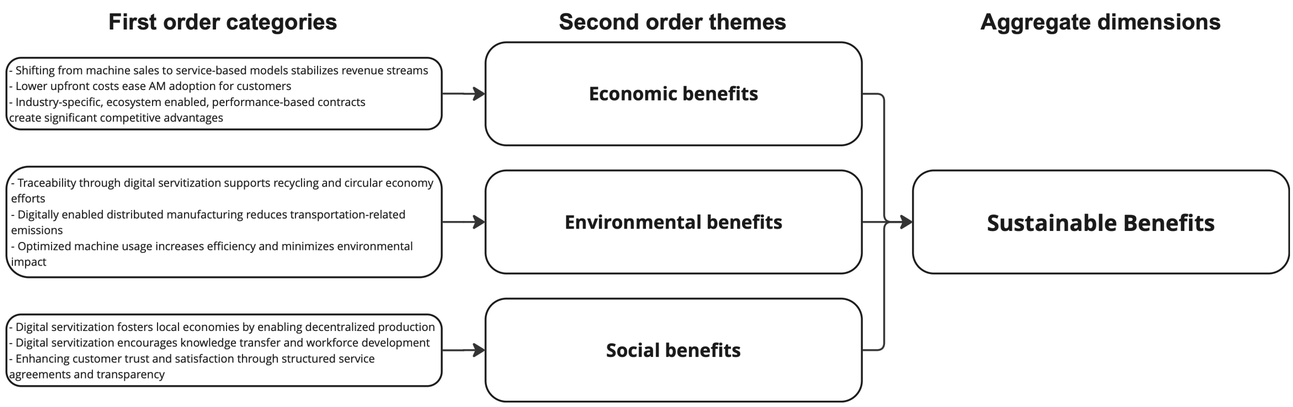

Figure 4.5: Data structure of the fourth aggregate dimension; Sustainable Benefits

Economic Benefits

Shifting from hardware-based sales to service-based models creates economic resilience by enabling recurring revenue streams, reducing upfront costs, and increasing competitiveness. Several interviewees noted that subscription-based services and performance-based contracts help lower financial barriers to the adoption of additive manufacturing. A Sales Manager from central orchestrating company A explained:

"There's always hesitation when it comes to sharing data. Companies worry about losing control over their IP and the risks associated with regulatory compliance." (Interview 12)

This aligns with research indicating that servitization stabilizes revenue by shifting from one-time capital expenditures to predictable long-term operational costs (Frank et al., 2019). In addition, industry-specific ecosystem-enabled service contracts create distinct competitive advantages, allowing firms to tailor their offerings based on customer needs.

However, the findings also highlight challenges related to cost justification and return on investment, particularly for firms accustomed to traditional sales models. To fully leverage economic benefits, firms must demonstrate clear value propositions and ensure financial feasibility across customer segments.

Environmental Benefits

Digital servitization enhances environmental sustainability by optimizing machine usage, reducing waste, and enabling circular economy models. A key enabler is traceability, which ensures more efficient resource utilization across the value chain. A Quality Manager from central orchestrating company A said:

"Digital servitization enhances environmental sustainability by fostering local production, reducing transportation, and promoting the use of recycled materials, thus contributing to circularity and traceability in manufacturing processes." (Interview 16)

Previous research confirms that digitally enabled traceability supports recycling efforts, minimizes excess material use, and promotes sustainable manufacturing practices (Chen et al., 2015). Furthermore, distributed digital manufacturing reduces transportation-related emissions by enabling localized on-demand production instead of centralized mass manufacturing.

Despite these benefits, achieving full environmental impact requires ecosystem-wide adoption, as fragmented implementation limits systemic efficiency improvements. The study suggests that collaboration between manufacturers, suppliers, and technology enablers is essential for maximizing sustainability gains.

Social Benefits

Beyond economic and environmental impacts, servitization promotes positive social outcomes, including the development of the workforce, the transfer of knowledge and the improvement of ecosystem trust. By shifting from product ownership to service-based collaboration, servitization promotes long-term partnerships that prioritize shared value creation over transactional sales. A Quality Manager from central orchestrating company A mentioned:

"Digital servitization fosters a collaborative ecosystem, connecting industry and education to develop a skilled workforce and drive long-term societal change in manufacturing." (Interview 16)

This aligns with literature suggesting that servitization fosters stronger industry ties by shifting from isolated transactions to continuous engagement through service agreements (Spadafora & Rapaccini, 2024). Additionally, decentralized production models enable localized economic growth, creating job opportunities, and reducing dependence on global supply chains.

However, the study also highlights organizational resistance to new service models, as firms accustomed to traditional hardware sales struggle to adapt to long-term relational dynamics. Overcoming these challenges requires cultural changes and proactive engagement strategies to ensure stakeholder participation.

4.4.1 Discussion and Theoretical Context

The findings emphasize that sustainability in servitization extends beyond economic gains, incorporating environmental and social dimensions. Although existing research highlights these benefits, the study contributes a granular perspective on how servitization impacts additive manufacturing specifically. However, certain limitations should be acknowledged, particularly in the scope and representativeness of the data. Given the reliance on interviews, findings can reflect the perspectives of engaged stakeholders while potentially underrepresenting the viewpoints of companies that have yet to adopt servitization. Furthermore, while the study captures early-stage implementations, long-term effects remain uncertain, requiring further validation over time.

To enhance credibility, preliminary validation was conducted by cross-checking the findings with selected interviewees. Their feedback indicated a strong alignment between the insights extracted and real-world industry experiences, strengthening the robustness of the conclusions. However, future research should expand validation efforts to include broader industry perspectives and longitudinal studies.

Key takeaways include

- Economic benefits: Servitization stabilizes revenue and reduces adoption barriers, but requires a clear value demonstration.
- Environmental benefits: Traceability and distributed manufacturing reduce waste, but widespread adoption is needed for full impact.
- Social benefits: Servitization fosters long-term relationships and local economic growth, but requires organizational adaptation.

These insights suggest that successful servitization strategies must integrate sustainability considerations at multiple levels, such as economic viability, environmental responsibility, and social collaboration. At the same time, the challenges associated with adoption, scalability, and long-term impact highlight the need for ongoing research and ecosystem-wide engagement.

5 | A staged framework for structuring digital servitization

Building on the thematic analysis conducted in the previous chapter, this framework provides a structured approach to the adoption of digital servitization in additive manufacturing. Although prior research has linked digital servitization to sustainable benefits, this study reveals a clear sequential process necessary for its effective implementation. The framework is structured around three key stages, Business Model Innovation, Ecosystem Orchestration, and Digital Technologies, each of which has specific barriers, enablers (attractors) and pathways leading to sustainable benefits.

A core insight from the interview data was that digital servitization is often too broad and abstract for firms to adopt directly. Instead of an arbitrary push towards adopting digital technologies, interviewees expressed a clear need for structured reasoning behind servitization. Specifically, they questioned:

- *"Why should we integrate digital technologies?"*
- *"Why should we collaborate with ecosystem partners?"*
- *"What is the business rationale behind servitization?"*

The framework emerged as a response to these concerns, establishing a logical sequence in which firms first innovate their business models, then orchestrate their ecosystem, and finally implement digital technologies. This sequential structure aligns with the practical challenges faced by firms, as well as with the existing literature on industrial servitization and digital transformation (Frank et al., 2019; Kohtamäki et al., 2019; Sjödin, Parida, & Visnjic, 2022).

5.1 Rationale for the Framework Design

The framework suggests that the adoption of digital servitization follows a progressive path, beginning with business model innovation, moving to ecosystem orchestration, and culminating in digital technology integration. This is not an arbitrary sequence, but one strongly supported by both interview data and academic literature.

Business Model Innovation as the Starting Point

Interview data consistently revealed that the first challenge in servitization is not technological, but strategic. Firms struggle to justify the business case for servitization, overcome financial constraints linked to service-driven models, and transition from short-term product sales to long-term value creation. An interviewee from central orchestrating company A summarized this challenge:

"Scaling up in-house development for digital servitization solutions, such as predictive maintenance, is financially challenging without sufficient company size and resources. " (Interview 16)

This aligns with the literature that emphasizes that transformation of business models is a prerequisite for success in servitization (Sjödin et al., 2022). Without a clear value proposition, companies have no incentive to invest in ecosystem collaboration or digital tools.

Ecosystem Orchestration to Address Servitization Barriers

Once firms establish a business model rationale for servitization, they encounter operational barriers that require collaboration across the ecosystem. Interviewees identified several challenges at this stage, like; interoperability and standardization issues between stakeholders, and regulatory complexities in shared service models. An interviewee from company D, a customer in the ecosystem, said:

"Ecosystem orchestration can improve alignment in additive manufacturing, especially in post-processing stages like depowdering, by collaborating with specialized equipment suppliers to improve efficiency and quality." (Interview 17)

The orchestration of the ecosystem serves as a bridge between the viability of the business model and the technological feasibility. Previous research highlights that the success of servitization depends on strong ecosystem coordination (Adner, 2017; Kolagar, Parida, & Sjodin, 2022).

Digital Technologies as the Final Enabler

Only after establishing a business case (business model innovation) and an operational structure (ecosystem orchestration) does digital technology become a necessary enabler. The interviewees indicated that digital technologies help resolve key barriers within the ecosystem, particularly; data standardization and interoperability challenges, the need for traceability and supply chain transparency, and efficiency optimization through AI and automation. An interviewee from company E, a supplier in the ecosystem, said:

"Predictive maintenance and IoT play a key role, but collaboration tools with machine manufacturers for traceability and tracking are just as crucial for effective digital servitization." (Interview 19)

This aligns with research suggesting that digital transformation must be demand-driven, rather than technology-driven (Majda & Imane, 2024; Molenaar, 2022).

5.2 Structure of the Framework

The framework (Figure 5.1) visually represents this staged approach, illustrating the three key phases of digital servitization: business model innovation, ecosystem orchestration and digital technologies, and how they contribute to the achievement of sustainable benefits.

The three concentric layers in the figure represent the sequential nature of servitization, where firms must progress through each stage to fully capture economic, environmental, and social benefits. Each layer contains:

- **Barriers:** Challenges at each stage preventing progress towards sustainable benefits.
- **Attractors:** Factors that enable firms to overcome these barriers.

The Role of Pathways in the Framework

The arrows in the figure convey a dual meaning, highlighting two key principles in the implementation of digital servitization.

- **Multiple pathways exist toward sustainable benefits:** Firms may take different routes based on their industry, size, and strategic priorities. There is no single universal strategy, as each firm's context shapes its approach.

- **A structured sequence must be followed:** While implementation pathways vary, firms must still progress through the three stages in a fixed order:
  - **Business Model Innovation** lays the foundation for servitization by defining the economic rationale.
  - **Ecosystem Orchestration** ensures effective collaboration, addressing the challenges of interoperability and market alignment.
  - **Digital Technologies** act as an executional enabler, enhancing the efficiency and scalability of the services offered.

This staged approach ensures that companies do not prematurely invest in digital technologies without first establishing a viable business case and an ecosystem that supports servitization.

5.3 Strategic Implications for Firms

The framework provides a structured roadmap for anticipating and overcoming barriers, ensuring that servitization efforts are strategic rather than experimental.

By recognizing servitization as a structured process rather than a one-time decision, the framework helps firms align business, operational, and technological considerations to maximize economic, environmental, and social benefits.

Rather than treating servitization as a vague ambition, this framework positions it as a structured and strategically managed transformation, equipping firms in the additive manufacturing ecosystem with a clear evidence-based approach to drive sustainable success.

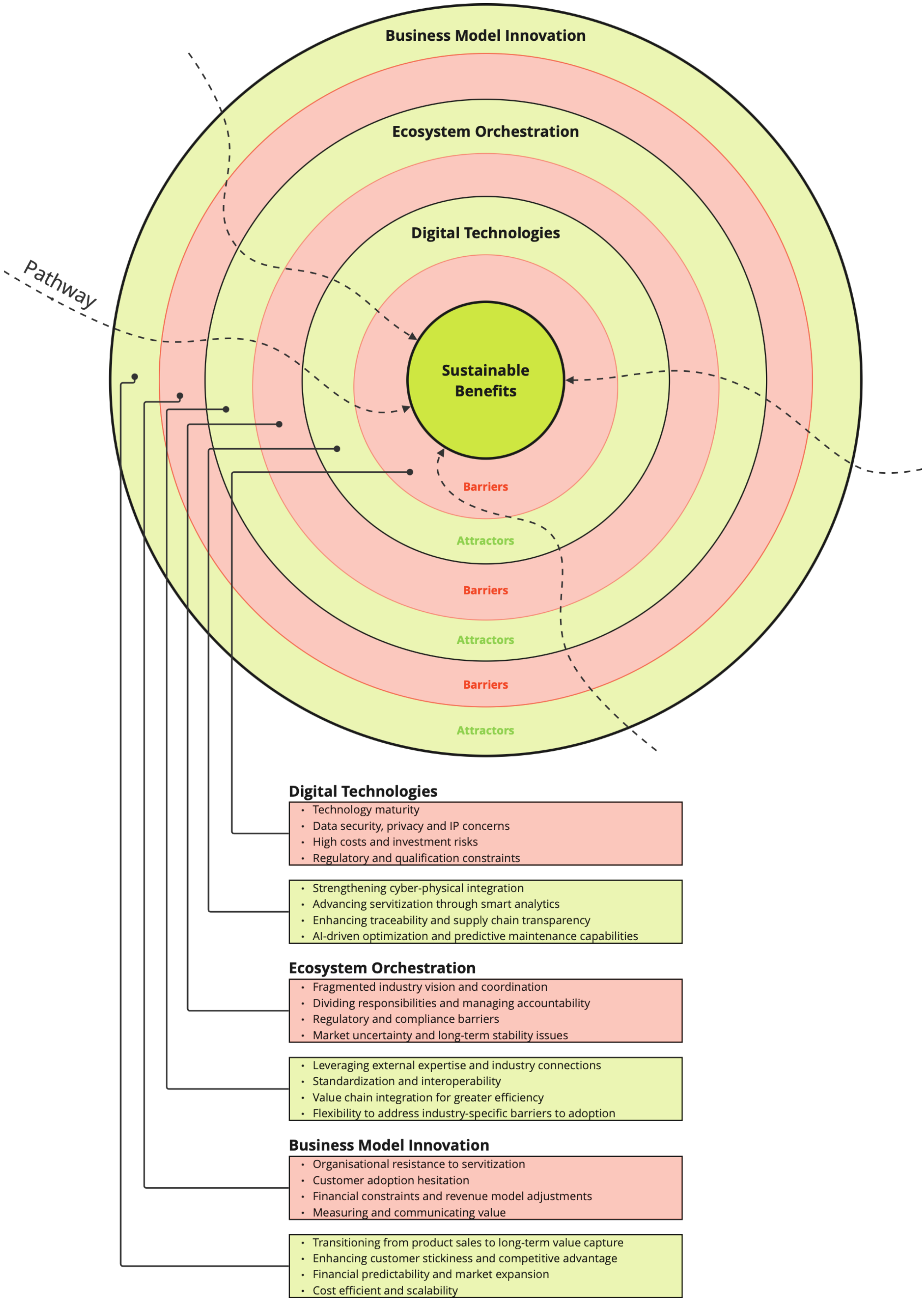

Figure 5.1: A staged framework for structuring digital servitization

6 Conclusion

This study aimed to investigate the role of digital servitization in fostering sustainable benefits in the manufacturing industry and to develop a structured approach for its adoption within an additive manufacturing ecosystem. The research was guided by the following research questions:

1. *"How does digital servitization contribute to sustainable benefits in the manufacturing industry?"*
2. *"How can firms structure digital servitization adoption to achieve sustainable benefits, with additive manufacturing as a case study?"*

Through an in-depth thematic analysis of expert interviews, the study demonstrated that digital servitization contributes to sustainability by transforming business models, orchestrating industrial ecosystems, and leveraging digital technologies. However, for companies to successfully adopt digital servitization and achieve sustainable benefits, a structured process is necessary. This study developed a framework that describes this transformation as a sequential process, beginning with business model innovation, followed by ecosystem orchestration, and culminating in digital technology implementation.

RQ1; How does digital servitization contribute to sustainable benefits in the manufacturing industry, with an additive manufacturing ecosystem serving as the contextual medium through which this connection is examined?

The findings reveal that digital servitization drives sustainability in three key dimensions: economic, environmental, and social.

Economic Benefits

Digital servitization enables firms to move from transactional product sales to service-based revenue models, fostering long-term financial stability. By introducing pay-per-use, subscription-based, or outcome-based pricing structures, companies reduce upfront costs for customers while securing predictable revenue streams. This transformation aligns incentives between providers and customers, ensuring that value delivery is tied to measurable performance improvements. However, the study highlights that firms struggle to justify servitization investments unless a clear business case is first established. Without a well-defined economic rationale, servitization risks being perceived as an experimental initiative rather than a sustainable transformation strategy.

Environmental Benefits

Digital servitization improves sustainability by improving resource efficiency, reducing waste, and enabling circular business models. Through AI-driven monitoring and predictive maintenance, companies can optimize machine usage, extend product lifecycles, and minimize material waste. In addition, servitization enables localized production and digital supply chains, reducing transportation-related emissions and improving overall sustainability. However, achieving significant environmental benefits requires ecosystem-wide alignment, as isolated servitization efforts are unlikely to drive systemic sustainability improvements.

Social Benefits

Beyond financial and environmental advantages, digital servitization contributes to social sustainability by fostering the development of the workforce, knowledge transfer, and trust-based collaboration. By shifting from one-time transactions to continuous service engagements, firms strengthen long-term partnerships with customers, suppliers, and ecosystem actors. The study also highlights that servitization improves accessibility to advanced manufacturing technologies by lowering financial entry barriers, allowing a wider range of firms to participate in digitalized production networks. However, perceived barriers to adoption within organizations and misalignment between stakeholders can slow adoption, emphasizing the need for proactive engagement and education efforts.

The second research question focuses on structuring digital servitization adoption. This study presents a staged framework that outlines a structured approach to digital service delivery, consisting of three key phases: business model innovation, ecosystem orchestration, and integration of digital technology. Firms must first define a viable servitization business model that aligns with customer needs and economic feasibility. Subsequently, they must foster ecosystem collaboration to overcome interoperability and regulatory challenges. Finally, digital technologies, including artificial intelligence, predictive maintenance, and Internet of Things-enabled monitoring, serve as enablers of servitization. The findings indicate that servitization is not a standalone decision, but a strategic transformation process that must be carefully managed to achieve sustainable benefits.

RQ2; How can firms structure the adoption of digital servitization to achieve sustainable ben- efits, using additive manufacturing as a case study for implementation strategies?

Although digital servitization offers clear sustainability advantages, firms require a structured approach to overcome adoption barriers and ensure successful implementation. This study develops a multilevel framework outlining a staged transformation process, ensuring that servitization is implemented as a strategic, rather than experimental, initiative.

Business Model Innovation as the Starting Point

Successful servitization begins with business model transformation, ensuring that firms establish a clear value proposition, economic feasibility, and customer alignment before investing in technology or ecosystem collaboration.

Many interviewees expressed skepticism about digital servitization, perceiving it as too abstract or difficult to justify without a tangible business case. This highlights the need to first define measurable customer benefits before committing to broader service offerings. Without a well-defined business model, digital servitization risks being seen as an unstructured technological experiment rather than a strategic transformation.

Ecosystem Orchestration as a Critical Enabler

Once a servitized business model is established, companies must engage in ecosystem orchestration to address internal resource constraints and create an enabling environment for servitization success.

Challenges such as standardization gaps, lack of trust, and unclear value alignment can significantly stall servitization efforts if not actively managed. Firms must collaborate with industry partners, regulatory bodies, and complementary service providers to reduce risk, improve interoperability, and accelerate adoption. By fostering cross-industry collaboration and regulatory alignment, firms can establish a foundation for scalable servitization initiatives rather than struggling with fragmented, disconnected efforts.

Digital Technologies as the Executional Component

Only after the business model and ecosystem factors are addressed can firms successfully integrate digital technologies in a way that maximizes value.

Technologies such as artificial intelligence, Internet of Things, and predictive analytics enhance automation, efficiency, and traceability, but their impact is significantly reduced when deployed in the absence of a structured servitization framework. The empirical findings revealed that randomly adopting digital technologies without a clear strategic foundation often leads to fragmented and unsustainable initiatives.

This structured approach aligns with both practical challenges faced by firms and theoretical perspectives on industrial servitization, reinforcing the notion that digital servitization must follow a phased, strategically managed transition rather than an ad hoc implementation. By adopting this framework, firms can effectively navigate the complexities of servitization, mitigate risks, and systematically unlock the sustainable benefits of additive manufacturing-based digital services.

6.1 Contributions to Digital Servitization Research

This study contributes to the digital servitization literature by expanding its scope beyond the implementations at the firm level to an ecosystem-wide perspective. Although prior research has emphasized how servitization improves resource efficiency and enables circular business models (Kohtamäki et al., 2022; Paiola & Gebauer, 2020), its integration within additive manufacturing ecosystems has remained largely underexplored. By empirically investigating how digital servitization fosters economic, environmental, and social sustainability across an interconnected industrial network, this study addresses a key gap in understanding how servitization can drive sustainability beyond individual firms.

A significant theoretical contribution of this research lies in its demonstration that digital servitization is not merely a technological or business shift but a structured transformation process. The findings show that successful servitization requires firms to first establish a viable business model, then engage in ecosystem orchestration, and only then implement digital technologies. This multi-stage approach clarifies the complex interplay between servitization, sustainability, and advanced manufacturing, expanding existing theoretical perspectives on digital transformation.

Furthermore, this study empirically validates key sustainability benefits attributed to digital servitization, such as waste reduction through predictive maintenance, improved material efficiency, and enhanced supply chain traceability, within an additive manufacturing ecosystem. Although prior research has suggested that servitization can lead to environmental improvements (Kolagar, 2024; Sjödin et al., 2023), real-world implementations have remained underexamined. By providing qualitative insights into successful and unsuccessful servitization efforts, this research identifies key adoption drivers, including firm size, digital maturity, and industry-specific challenges.

Furthermore, this study advances our understanding of the governance, trust and interoperability barriers that affect the adoption of servitization in industrial ecosystems. Although issues such as data security, intellectual property protection, and platform standardization are widely recognized as obstacles to large-scale adoption (Filgueiras & Melo, 2024; Kolagar, Parida, & Sjodin, 2022), few studies have provided empirical insight into how firms navigate these complexities. By analyzing ecosystem coordination strategies, this research highlights the importance of trust-building mechanisms, data governance frameworks, and standardization efforts to enable scalable and sustainable servitization adoption.

By addressing these gaps, this study extends digital servitization research beyond firm-centric perspectives, integrates empirical evidence on additive manufacturing-enabled sustainability, and identifies both the enablers and barriers shaping servitization adoption within complex industrial ecosystems. These insights contribute to the broader discourse on sustainability-driven digital transformation and provide a foundation for future research exploring servitization in other advanced manufacturing domains.

6.2 Practical Implications for Additive Manufacturing Firms

For firms operating within additive manufacturing ecosystems, this study provides actionable insights into how digital servitization can be effectively implemented to achieve sustainable benefits. The findings emphasize that servitization is not a one-size-fits-all solution, but rather a structured transformation that requires strategic alignment between business models, ecosystem coordination, and technology adoption.

A key insight from this research is the necessity of anchoring servitization efforts in business model innovation. Many firms struggle with servitization adoption because they attempt to implement digital services without first defining a clear value proposition and economic feasibility. The study demonstrates that before committing to servitization initiatives, firms must ensure that they have a scalable, customer-centric service model, a measurable business case that justifies servitization investments, and internal alignment on transitioning from hardware-based to service-driven engagements. Without this foundation, firms risk implementing servitization in an ad hoc manner, leading to unclear value realization and difficulties in adoption.

The study also underscores the critical role of ecosystem orchestration in enabling servitization adoption. In the additive manufacturing industry, where multiple stakeholders—including software providers, material suppliers, and service integrators—must collaborate to deliver value, isolated servitization efforts are unlikely to succeed. Firms must actively engage in cross-industry collaboration, establish clear governance structures, and develop trust-based partnerships to overcome standardization gaps and ensure interoperability. The findings suggest that regulatory alignment, contractual clarity, and co-investment strategies are essential to reduce servitization risks and improve ecosystem-wide adoption.

Another key practical takeaway is that the adoption of digital technology should be the final stage of the implementation of servitization, not the starting point. Many firms prematurely invest in artificial intelligence, the Internet of Things, and predictive analytics without first establishing the necessary business and ecosystem conditions, leading to fragmented implementations and underutilized data. This research highlights that to maximize value creation, digital technologies must be implemented only after a structured servitization strategy is defined, used to improve operational efficiency and enable predictive maintenance, and integrated with clear data governance frameworks to ensure security and trust. By treating digital technologies as an execution tool rather than a primary driver of service, companies can ensure that their investments contribute to long-term sustainability objectives.

To guide firms through this transformation, this study develops a multistage framework that structures the adoption of digital servitization in additive manufacturing. The framework, derived from empirical findings, outlines three sequential steps: (1) business model innovation, in which firms establish a clear business rationale for servitization and ensure that service-based revenue models are financially viable; (2) ecosystem orchestration, where firms coordinate with supply chain partners, technology providers, and regulatory bodies to establish trust, standardization, and collaborative governance structures; and (3) digital technology integration, where firms implement digital tools, such as predictive analytics, Internet of Things-enabled monitoring, and artificial intelligence-driven process optimization to improve servitization efficiency and sustainability outcomes. By following this structured approach, firms can systematically transition toward servitization, ensuring financial viability, ecosystem collaboration, and technology-enabled sustainability benefits.

Beyond outlining a structured framework, this study provides practical guidance on navigating key challenges that hinder servitization adoption. Perceived barriers to adoption remain a major obstacle, as firms accustomed to transactional business models may hesitate to embrace long-term service-oriented engagements. This reluctance may stem from perceived risks or uncertainty about the added value, rather than a simple preference for existing models, highlighting the need for a value-driven approach rather than a technology push approach. The findings highlight the need for cultural transformation, in which companies invest in internal training and change management initiatives to shift their organizational mindset toward servitization. Financial constraints also present a challenge, as servitization often requires upfront investments in digital infrastructure. The study suggests that firms can mitigate financial risk by launching pilot programs and phased service offerings to demonstrate value before scaling up investments. Cybersecurity concerns further complicate the adoption of servitization, as companies remain reluctant to share operational data due to intellectual property risks and regulatory uncertainties. To address this issue, firms must develop secure data governance models that clearly define ownership, access rights, and compliance measures.

By adopting the structured approach outlined in this study, companies can systematically overcome adoption barriers, accelerate the transition to servitization, and unlock sustainable economic, environmental, and social benefits. This research thus serves as both a theoretical and practical roadmap for firms seeking to leverage digital servitization as a competitive advantage in industrial ecosystems.

7 | Future Research Recommendations

While this study provides critical information on the role of digital servitization in achieving sustainable benefits within additive manufacturing, several avenues remain for future research. These recommendations focus on addressing the limitations of the study, expanding its theoretical and empirical contributions, and further refining the proposed framework.

Broadening the Empirical Scope Across Industries and Ecosystems

This study focused on a single case analysis within an additive manufacturing ecosystem orchestrated by a leading original equipment manufacturer. Although this approach provided in-depth insights, future research should expand beyond the additive manufacturing sector to examine the adoption of digital servitization in different industrial contexts. Sectors such as aerospace, medical devices, and heavy manufacturing can exhibit distinct challenges, adoption patterns, and sustainability outcomes. Comparative studies across multiple ecosystems could provide a more generalizable understanding of the interplay between servitization, ecosystem orchestration, and sustainability.

Furthermore, future studies should explore servitization models in which the central orchestrator is not an original equipment manufacturer, but a software provider, platform operator, or specialized service provider. This would clarify how different ecosystem roles influence servitization strategies and sustainability outcomes, contributing to a broader conceptualization of servitization beyond hardware-driven industries.

Exploring the Long-Term Evolution and Maturity of Servitization

Digital servitization is an evolutionary process and its benefits can take years to materialize. Although this study captured insights at a particular moment in time, future research should adopt a longitudinal approach to assess how firms progress through different phases of business model innovation, ecosystem orchestration, and technology adoption over time. Investigating the transition points between early experimentation and fully integrated service-driven business models would provide a deeper understanding of the enablers and barriers at each stage of maturity.

Furthermore, developing and applying servitization maturity models could help identify critical success factors and assess how firms navigate technological, financial, and organizational hurdles. This would offer valuable guidance for companies seeking to structure their digital servitization journey in a strategic and phased manner.

Addressing the Economic and Organizational Challenges of Servitization

This study highlights the economic challenges associated with transitioning from hardware-based sales to service-based models, including difficulties in demonstrating return on investment, managing large upfront investments, and overcoming resistance to organizational change. Future research could explore financial models that facilitate the adoption of servitization, such as risk-sharing agreements, performance-based contracts, and public-private funding mechanisms. Empirical approaches such as comparative case studies, policy analysis, and financial modeling could provide deeper insights into the economic viability of servitization strategies.

In addition, research should examine the organizational challenges linked to servitization, such as cultural resistance, workforce skill gaps, and the need for new performance metrics. Investigating best practices for change management in servitization transformations, particularly within traditional manufacturing firms, would help firms successfully navigate the transition and ensure internal alignment with service-based business models.

Investigating Digital Trust, Data Sharing, and Governance in Servitization Ecosystems

A key challenge identified in this study is the reluctance of firms to share data due to concerns about ownership, intellectual property protection, and regulatory restrictions. Future research should explore governance mechanisms that facilitate secure and equitable data sharing in servitization ecosystems. This could include smart contracts, secure multiparty computation, regulatory frameworks for data transparency, and standardized agreements for digital service transactions.

In addition, research should examine how firms build trust within servitization ecosystems to foster open collaboration. Understanding the role of ecosystem orchestrators in establishing governance structures that balance competitive concerns with mutual benefits will be critical to scaling servitization adoption. Empirical studies could assess the effectiveness of different trust-building mechanisms and data governance models in enhancing servitization viability across various industries.

Assessing the Socio-Environmental Impact of Digital Servitization at Scale

While this study confirms that digital servitization has the potential to generate economic, environmental, and social benefits, more empirical validation is required to quantify these impacts at scale. Future research could employ quantitative methods such as life cycle assessments, econometric modeling, and sustainability impact assessments to measure how servitization influences material efficiency, carbon footprints, and employment dynamics across industries.

Furthermore, research should explore how servitization contributes to broader sustainability objectives, such as circular economy transitions and workforce upskilling. Examining the social implications of servitization, including changes in job roles, skill development, and regional economic impacts, would provide a more holistic understanding of its long-term effects on industrial transformation and workforce evolution.

Validating and Enhancing the Proposed Framework

This study introduces a structured framework for the implementation of digital servitization in additive manufacturing, emphasizing a sequential transition from business model innovation to ecosystem orchestration and adoption of digital technologies. Future research should empirically test and refine this framework in different industrial settings to assess its robustness and adaptability.

Studies could explore whether firms in diverse sectors follow the same structured pathway or if alternative sequences exist. In addition, experimental research could investigate interventions that accelerate servitization adoption, such as targeted policy incentives, ecosystem coordination strategies, and digital upskilling programs. By systematically testing and refining the framework, future research can enhance its applicability and provide practical guidance for firms seeking to leverage digital servitization as a tool for sustainable industrial transformation.

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A | Interview Protocols

A.1 Interview Protocol for Employees from the Central Orchestrator

Section 1: Understanding the Current Business Model

Business Model Overview

- Can you describe your company's current business model? What are the primary products or services you offer, and how do you differentiate yourself in the market?
- What are the main elements that drive your business success today?

Value Creation

- How does your company create value for your customers? What are the key factors that contribute to your value proposition?
- Are there any unique resources or capabilities that are critical to delivering this value?

Value Delivery

- What processes or operations are in place to ensure that value is effectively delivered to your customers?
- What role do your supply chain, partnerships, or internal teams play in delivering this value?

Value Capture

- How does your company generate revenue from your products or services? What are your primary revenue models?
- Do you encounter any challenges with your current revenue models, and how do you address them?

Operational Structure

- How is your company structured to support your current business model? Are there any departments or divisions that are especially critical?
- Do you find any inefficiencies or areas for improvement in the way your company is organized?

Section 2: Digital Innovation

Introduction to Digital Servitization

In digital servitization, we aim to transition beyond traditional services like maintenance to more advanced digitally enabled solutions. For example, selling mobility instead of just a vehicle or selling the hole instead of the drill.

Understanding and Relevance

- Can you describe what digital innovation means to you in the context of your industry?
- What is your view on the transition process from a product-oriented to a service and solution-oriented business model?

Steps Taken Towards Transition

- What specific steps or initiatives have you taken to transition toward a service-oriented model?
- *If yes:* Are these initiatives part of a formal strategy, or are they evolving based on market demands?
- *If no:* Do you have any specific plans for moving towards providing more advanced services to your customers, instead of just the product?

Degree of Service Integration

- How integrated are digital services within your core business operations?
- What percentage of your revenue comes from services compared to traditional products?

Technologies Used

- What digital technologies are you currently employing or developing to support these servitization efforts? (e.g., AI, ML, Cloud computing, etc.)
- How does each technology contribute to this transition?
- How do you obtain the digital technologies used for servitization (e.g., partnerships, vendors, in-house development)?
- Any challenges in this process?

Organizational Adaptations

- What internal changes (e.g., operations, procedures) have you had to implement to facilitate this shift?
- Are external factors like new regulations impacting your approach?

Successful Projects

- Can you share a successful project where product, service, and software integration were key?
- What were the critical factors (human, structural, organizational, network-related) that contributed to its success?

Section 3: Business Model Innovation

Value Creation Challenges

- What are the main challenges in creating value for your customers when developing new, advanced digitally enabled services?

Value Delivery Challenges

- What challenges do you face in delivering value to your customers through service-based business models?

Value Capture Adaptations

- What challenges do you encounter when trying to capture value from your digital services?
- Do you need to make any adaptations in your cost structure or revenue models?

- Have you moved towards outcome-based or performance-based contracts, or adjusted your pricing models?

Section 4: Ecosystem Orchestration

Key Partners and Selection

- Who are your key partners in delivering digital services, and how do you select them?
- What criteria are most important—technological capabilities, trust, sustainability?

Building Trust

- How do you build and maintain trust over time with your partners?
- What formal or informal mechanisms do you use to strengthen these partnerships?

Business Model Alignment

- How do you align your business model with those of your partners?
- What challenges have you encountered in achieving alignment, particularly regarding sustainability goals?

Informal Coordination

- What informal methods do you use to orchestrate different activities, partners, and business models? (e.g., meetings, gatherings, workshops, face-to-face interactions)
- Can you share any examples where informal coordination was critical for success?

Section 5: Triple Bottom Line Framework

The triple bottom line framework considers the economic, environmental, and social impacts of business practices. I'd like to understand how your company's shift toward digital servitization aligns with these three aspects.

Economic Benefits

- What economic benefits can digital solutions bring to your customers?

Environmental Benefits

- What environmental benefits have you observed?

Social Benefits

- What social benefits have resulted from your digital servitization efforts?

Section 6: Closing Questions

Future Outlook

- What do you see as the future of digital services and solutions in your industry? Do you think that manufacturing businesses are trying to move towards this direction?
- Are there any emerging trends that could accelerate or hinder the transition to service-oriented models?
- How do you see the role of humans in facilitating this transition?

Additional Insights

- Is there anything we haven't covered that you think is important for understanding the impact of digital servitization and the shift to service-oriented models, particularly in terms of sustainability?

A.2 Interview Protocol for Customers in the Ecosystem

Section 1: Current Technology Usage

Experience with Current Technology

- Could you describe how you currently use the technology provided by "company A"?
- What are the primary benefits you've experienced from using this technology?

Performance and Challenges

- Are there any challenges or limitations you face with the current technology?
- Are there specific features or functionalities that you believe could be improved or added?

Integration into Operations

- How well does this technology integrate with your existing systems or workflows?
- Have you encountered any barriers to effective integration?

Support and Training

- How would you rate the support and training provided by "company A"?
- Are there any additional resources or support services you think would be helpful?

Section 2: Requirements for Future Improvements

Desired Features and Capabilities

- What additional features or capabilities would make the technology more valuable for your operations?
- Are there any specific pain points you'd like future improvements to address?

Sustainability and Efficiency

- Do you have any expectations for how this technology could contribute to sustainability goals (e.g., reducing waste, energy efficiency)?
- What improvements would help you operate more efficiently or reduce costs?

Ease of Use

- How important is ease of use in your adoption of new technology?
- Are there areas where you feel training, documentation, or support could be enhanced?

Section 3: Introduction to Digital Servitization

Digital servitization involves a shift from traditional product offerings to advanced service-based models, often enabled by digital technologies. Examples include predictive maintenance, outcome-based contracts, and real-time monitoring. Instead of just selling a product, it focuses on delivering value-added services and solutions, such as selling mobility instead of just a vehicle.

Understanding and Perspectives

- What does digital servitization mean to you?
- How do you perceive this shift? Is it relevant to your business operations?

Value of Digital Services

- Have you utilized any digital services offered by "company A"? If so, what was your experience?
- What digital services would you find most valuable (e.g., real-time monitoring, data-driven insights, lifecycle management, predictive maintenance, augmented support)?

Adoption Drivers

- Which factors are most important to you when considering adopting digital services (e.g., economic value, sustainability goals)?
- Can you share an example of a driver that influenced your decision to adopt a new technology or service?

Adoption Challenges

- Do you foresee any challenges in adopting digital services as part of your operations?
- What would make you more likely to adopt these services (e.g., cost incentives, proven ROI, training)?

Section 4: Triple Bottom Line Framework

The triple bottom line is a framework that evaluates business success across three dimensions:

1. **Economic:** Financial gains and cost efficiencies.
2. **Environmental:** Reducing waste, emissions, and energy usage.
3. **Social:** Positive impacts on employees, customers, and communities.

Economic Benefits

- How important are economic benefits in your decision to adopt new technologies or services?
- What specific economic outcomes would you expect from enhanced digital services?

Environmental Benefits

- How significant are environmental benefits (e.g., waste reduction, lower energy consumption) in your decision-making process?
- Does your organization have specific sustainability goals that this technology or service could help address?

Social Benefits

- How relevant are social benefits (e.g., employee satisfaction, community impact) in your adoption of new technologies?
- Can you think of any ways that "company A"' technology could help achieve social benefits for your organization?

Balance of Priorities

- Of the three dimensions—economic, environmental, and social—which do you prioritize most highly? Why?
- How do you balance these priorities when making decisions about adopting new technologies or services?

Section 5: Closing Questions

Future Trends and Needs

- What do you see as the future of digital services and solutions in your industry?
- Are there any emerging trends or needs you believe "company A" should focus on?

Feedback for "company A"

- Is there anything you'd like to share about your experience with "company A"' technology, services, or customer engagement?

Open Floor

- Is there anything else you'd like to add or discuss that we haven't covered?

A.3 Interview Protocol for the Ecosystem's Supply Side

Section 1: Role and Collaboration in the Ecosystem

Role in the Ecosystem

- Can you describe your role in the additive manufacturing ecosystem?
- What specific products, materials, or services do you supply to "company A"?

Collaborative Relationship

- How would you describe your working relationship with "company A"?
- Are there any key areas where you collaborate closely?

Challenges in Collaboration

- Have you encountered any challenges in collaborating with "company A" or other ecosystem stakeholders?
- What steps could be taken to improve collaboration within the ecosystem?

Supply Chain Dynamics

- How do you perceive your position in the ecosystem? Is it well-integrated, or are there bottlenecks or inefficiencies that could be addressed?

Section 2: Digital Servitization in the Supply Chain

Digital servitization involves a shift from traditional product offerings to advanced service-based models, often enabled by digital technologies. Examples include predictive maintenance, outcome-based contracts, and real-time monitoring. Instead of just selling a product, it focuses on delivering value-added services and solutions, such as selling mobility instead of just a vehicle.

Understanding Digital Servitization

- How does digital servitization relate to your role in the ecosystem?

Adoption of Digital Technologies

- Are you currently leveraging digital technologies to improve your processes or offerings? If so, how?
- How could these digital advancements enhance your collaboration with "company A" or other stakeholders?

Impact on the Ecosystem

- What impact do you think digital servitization has on the broader ecosystem? For example, does it create new challenges or opportunities?

Section 3: Sustainability and the Triple Bottom Line

The triple bottom line is a framework that evaluates business success across three dimensions:

1. **Economic:** Financial gains and cost efficiencies.
2. **Environmental:** Reducing waste, emissions, and energy usage.
3. **Social:** Positive impacts on employees, customers, and communities.

Sustainability Practices

- Does your organization have specific sustainability goals, and how do these align with the demands of the additive manufacturing ecosystem?
- How do you see sustainability considerations influencing your relationship with "company A"?

Prioritization of Benefits

- Of the triple bottom line dimensions—economic, environmental, and social—which do you prioritize most highly in your operations? Why?
- How do you think these priorities align with "company A"' expectations or goals?

Sustainability Challenges

- Are there specific challenges you face in meeting sustainability goals within the ecosystem?
- How could "company A" or other stakeholders support you in overcoming these challenges?

Section 4: Innovation and Future Outlook

Innovative Collaboration

- What opportunities do you see for innovation through your collaboration with "company A"?
- Are there any co-development initiatives or joint projects that could benefit the ecosystem?

Trends and Future Needs

- What emerging trends in additive manufacturing or digital technologies do you think will shape the supply chain in the next five years?
- How do you see your role evolving in response to these trends?

Barriers to Innovation

- What are the key barriers to innovation in the supply chain, and how do you think these could be addressed collectively?

Section 5: Closing Questions

Feedback for "company A"

- What feedback would you give "company A" about their role as an orchestrator within the ecosystem?
- Are there specific areas where they could improve collaboration or support with supply chain partners?

Open Floor

- Is there anything else you'd like to add or discuss that we haven't covered?