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Estêvão Passuello Ruffoni

EXPLORING THE DIGITAL SERVITIZATION CAPABILITIES OF THE FIRM

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ABSTRACT

Digital servitization is a transition process through which manufacturing firms move from offering products to offering integrated solutions between products, services, and digital technologies. Digital servitization consists of one of the main paradigm changes that manufacturing firms are facing in the current rise of the fourth industrial revolution (Industry 4.0). In this regard, many studies are exploring the capabilities that firms must develop to successfully carry out this transition. However, important research gaps remain, among which stand out: I) How firms can create value through their digital servitization capabilities; II) Which digitial servitization capabilities are required for the offering of smart services and; III) How firms can use their digital servitization capabilities to create value in the different trajectories of the digital servitization paradigm. To cover these gaps, this thesis is organized into three articles. ***Article I*** proposes a theoretical framework of four core digital servitization capabilities (Integration, Provision, Orchestration, and Manufacturing), conducts a multiple case study, and applies the fuzzy-set Qualitative Comparative Analysis (fsQCA) to identify configurations of these capabilities for value creation. ***Article II*** uses this same framework to identify how firms build digital servitization capabilities for the successful offering of smart services. This is done by applying a mixed-method approach, combining the emerging quantitative technique Necessary Conditions Analysis (NCA) with a qualitative multiple case study. ***Article III*** uses the framework to explore how firms following different digital servitization trajectories can configure their capabilities to create value. To do so, a cluster analysis is applied, followed by the fsQCA. Together, the results of the three articles demonstrate that integration and manufacturing capabilities, as well as their interaction, is the basis of value creation through digital servitization. Provision and orchestration capabilities are only secondary in this regard, but they have multiple interchangeable elements that confer different options for firms to configure them in order to create value.

Keywords: Digital Servitization, Core Capabilities, Value Creation, Smart Services, Digitalization, Servitization, Industry 4.0, Mixed-method

RESUMO EXPANDIDO

A servitização digital consiste em um processo de transição, através do qual firmas de setores industriais transitam da oferta de produtos para a oferta de soluções integradas entre produtos, serviços e tecnologias digitais. O fenômeno da servitização digital está altamente associado à atual quarta revolução industrial (Indústria 4.0), iniciada a partir do advento de tecnologias digitais diruptivas, como a Internet das Coisas, Computação em Nuvem, Análise de Big Data, Aprendizado de Máquina e Inteligência Artificial. Tais tecnologias têm imposto novas formas de produção e de criação de valor às firmas industriais, dentre as quais a servitização digital se destaca como uma das principais mudanças de paradigma enfrentadas. Por esta razão, muitos estudos tem explorado as capacidades (conjuntos de conhecimentos, recursos, rotinas e habilidades) que as firmas precisam desenvolver para transitarem com sucesso para servitização digital. Porém, importantes lacunas de pesquisa permanecem, dentre as quais se destacam: I) Como as capacidades de servitização digital criam valor para firma; II) Quais capacidades de servitização digital são necessárias para a oferta de serviços inteligentes e; III) Como as firmas usam suas capacidades de servitização digital para criarem valor nas diferentes trajetórias do paradigma da servitização digital. Com o objetivo de preencher estas lacunas, a presente tese propõe-se a responder à seguinte pergunta de pesquisa: ***Como as firmas utilizam suas capacidades de servitização digital para criarem valor?*** Para tanto, a tese foi estruturada em três artigos. O ***Artigo I – Explorando Configurações de Capacidades de Servitização Digital para Criação de Valor***, propõe um modelo teórico de quatro capacidades centrais de servitização digital da firma (Integração, Provisão, Orquestração e Manufatura), conduz um estudo de múltiplos casos, e aplica a Análise Comparativa Qualitativa de Conjuntos Fuzzy (do inglês: *Fuzzy-Set Qualitative Comparative Analysis*, fsQCA) para identificar configurações dessas capacidades que criam valor. Os resultados mostram que as firmas podem criar valor através de duas configurações de capacidades: integração, provisão e manufatura (CI*CP*CM), ou integração, orquestração e manufatura (CI*CO*CM). O ***Artigo II – Construindo Capacidades de Servitização Digital para a Oferta de Serviços Inteligentes***, utiliza o mesmo modelo de capacidades proposto no Artigo I, e aplica o método misto, combinando a técnica quantitativa emergente Análise de Condições Necessárias (do inglês: *Necessary Conditions Analysis*, NCA) com um estudo qualitativo de múltiplos casos. Os resultados identificam que empresas de setores industriais seguem três etapas na construção de capacidades de servitização digital visando a oferta de serviços inteligentes: Implementação, Otimização e Customização. O ***Artigo III – Configurando as Capacidades de Servitização Digital da Firma para Criação de Valor em Diferentes Trajetórias***, também utiliza o modelo de capacidades desenvolvido no Artigo I, conduz uma análise de cluster para identificar as trajetórias de servitização digital das firmas, e aplica o fsQCA para identificar as configurações de capacidades que resultam em criação de valor em cada trajetória. Os resultados demonstram que as firmas seguem quatro trajetórias de servitização digital (Tradicional, Digitalização, Servitização e Convergência), e que, em cada trajetória, diferentes configurações de capacidades são utilizadas para criação de valor. Juntos, os três artigos da tese demonstram que as capacidades de integração e de manufatura, bem como a interação entre elas, é a base da criação de valor através da servitização digital. As capacidades de provisão e de orquestração possuem apenas um papel secundário neste sentido, porém, a intercambialidade entre seus elementos confere diferentes opções para as firmas configurá-las a fim de criarem valor.

Palavras-chave: Servitização Digital, Capacidades Centrais, Criação de Valor, Serviços Inteligentes, Digitalização, Servitização, Indústria 4.0, Método Misto

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SUMMARY

1. INTEGRATED INTRODUCTION

Digital servitization consists of a transition process, through which manufacturing firms move from the offering of products to the offering of integrated solutions between products, services, and digital technologies (Favoretto *et al.*, 2022; Kohtamäki *et al.*, 2021). In other words, digital servitization refers to the merge between servitization, the addition of services to products, and digitalization, the adoption of digital technologies (Bortolluzi *et al.*, 2022; Shen *et al.*, 2023). Although servitization is not a new phenomenon (see Vandermerwe and Rada, 1988), it gained strength recently, due to its interplay with the adoption of disruptive digital technologies, brought by the fourth industrial revolution (Industry 4.0): the Internet of Things, Cloud Computing, and Big Data Analytics (Frank *et al.*, 2019; Paiola *et al.*, 2021). This interplay led to the redefinition of servitization as digital servitization.

Digital servitization is one of the main paradigm changes that manufacturing firms are facing in the rise of Industry 4.0 (Culot *et al.*, 2020; Weking *et al.*, 2019), and already can be taken as a matter of necessity for their survival, rather than as a matter of option. This has led studies to explore the capabilities that firms must build to succeed in digital servitization. In this thesis, capabilities are understood as sets of knowledges, resources, routines and skills accumulated overtime by firms for the execution of its activities (Dosi, 2000; Lall, 1992; Reichert *et al.*, 2016; Zawislak *et al.*, 2012).

Regarding digital servitization capabilities, the literature highlights that manufacturing firms need to develop capabilities related to servitization and digitalization. Servitization capabilities include knowledge, resources, routines and skills to design services (Adrodegari and Sacanni, 2020; Beltagui, 2018; Wallin *et al.*, 2015), to deliver services to customers directly, through internal processes (Sjödin *et al.*, 2016; Storbacka, 2011; Ulaga and Reinartz, 2011), or indirectly, through partnerships with service companies (Lütjen *et al.*, 2019; Marcon *et al.*, 2022; Story *et al.*, 2017). In turn, digitalization capabilities encompass knowledge, resources, routines and skills for the search, selection, absorption, and operation of digital technologies in order to support service offerings (Hasselblat *et al.*, 2018; Kimita *et al.*, 2022; Lenka *et al.*, 2017).

Furthermore, some studies suggest that manufacturing capabilities, through which firms develop and fabricate products, must be adapted to enable the offer of digital services (Sousa and Silveira, 2017). Specially for the offering of services that rely on knowledge related to the performance of products and of their production, such as maintenance services (Manresa *et al.*, 2021) and spare parts services (Matthyssens *et al.*, 2009), but mainly, for product customization services (Qi *et al.*, 2020; Sousa and Silveira, 2019).

However, important research gaps remain. ***First***, although the literature suggests a positive relationship between the firm's transition to digital servitization and its financial performance (Martin-Peña *et al.*, 2020; Kharlamov and Parry, 2020; Kohtamäki *et al*., 2020), the role of digital servitization capabilities is not explained in this regard (Kohtamäki *et al.*, 2019), remaining unclear how these capabilities create value for the firm. Notwithstanding, firms must know how they can thrive in digital servitization, given the substantial risks involved in the transition process, once high investments are required in infrastructure to develop and deliver services (Neely, 2009), as well as to adopt and use advanced digital technologies (Kohtamäki *et al.*, 2020).

Second, studies are still more focused on the servitization elements of the capabilities, with a further analysis of the digitalization elements being necessary, especially on how both elements can be merged to build digital servitization capabilities (Munch *et al.*, 2022). ***Third***, the literature generally does not interpret digital servitization capabilities through the lens of maturity models, which could contribute to understanding how firms develop and evolve these capabilities overtime (Khanra *et al.*, 2021). ***Fourth***, manufacturing capabilities are rarely addressed in digital servitization research. However, the interaction between digital servitization and Industry 4.0 (Frank *et al.*, 2019; Paiola *et al.*, 2021) suggests that exploring manufacturing capabilities can bring valuable insights to better understand both phenomena.

Fifth, one of the ultimate goals of manufacturing firms that entered the digital servitization process is the successful offering of smart services (Kohtamäki *et al.*, 2022). Smart services consist of proactive services supported by advanced digital technologies to monitor, analyze, improve, and predict the performance of products (Allmendiger and Lombreglia, 2005; Shen *et al.*, 2023; Töytäri *et al.*, 2018). Although smart services have a great potential to result in value creation, only a few studies address the digital servitization capabilities required for their offering (e.g., Huikkola *et al.*, 2022), making necessary a better examination in this regard (Kohtamäki *et al.*, 2022).

Sixth, digital servitization represents a paradigm change for manufacturing firms. A paradigm is defined as a pattern, an ideal model to be followed (Dosi, 1982; Von Tunzelman *et al.*, 2008). While the current established paradigms drive manufacturing firms to focus on the development and fabrication of standardized products, the emerging digital servitization paradigm drives them to the offering of integrated customized solutions between products, services, and digital technologies (Kohtamäki *et al.*, 2021). Considering that firms can achieve the same paradigm through multiple trajectories (Christensen, 1995), there are multiple trajectories towards the digital servitization paradigm (Abou-Foul *et al.*, 2021; Coreynem *et al.*, 2017; Kharlamov and Parry, 2020; Martin-Peña *et al.*, 2020; Frank *et al.*, 2019). However, the literature does not cross this trajectory approach with the capabilities approach, remaining unknown how firms use their digital servitization capabilities to create value in different trajectories.

Therefore, to contribute to the advancement of research on digital servitization capabilities, this thesis aims to cover the research gaps presented above by answering the question: ***How do the digital servitization capabilities of the firm create value?*** In this regard, this thesis concentrates on the core capabilities of the firm. Core capabilities are few high-order capabilities that systematize multiple minor capabilities in order to generate competitive advantages and create value (Leonard-Barton, 1992). Core capabilities are also referenced in the literature as core competencies (Prahalad and Hammel, 1990), or dynamic capabilities (Teece, 2007; 2018).

To answer the research question, the thesis is structured into three articles. Following the suggestion of Da Costa *et al.* (2019) for theses developed as a set of articles, Table 1 presents a methodological matrix, detailing how the articles differentiate from each other, and how they are combined to achieve the general objective of the thesis.

Table 1 – Methodological Matrix

General Objective of the Thesis:	**To identify how the digital servitization capabilities of the firm create value**						
Article Order and Title	Specific Objectives	Research Gaps Addressed	Theoretical Background	Method	Data Collection	Data Analysis	Publication Status
I) Exploring Configurations of Digital Servitization Capabilities for Value Creation	• To develop a theoretical framework of the firm's core digital servitization capabilities; • To identify configurations of core digital servitization capabilities through which firms create value.	I, II, III and IV	• Digital Servitization; • Digital Servitization Capabilities.	• Multiple case study.	• Semi-structured interviews.	• Content analysis; • fsQCA.	Submitted to Industrial Marketing Management. Awaiting feedback on the third round of revisions, in which minor changes were requested.
II) Building Digital Servitization Capabilities for the Successful Offering of Smart Services	• To identify how firms build core digital servitization capabilities to successfully offer smart services.	I, III, IV and V	• Digital Servitization; • Digital Servitization Capabilities; • Smart Services.	• Mixed-method (quantitative study and multiple case study).	• Survey; • Semi-structured interviews.	• EFA; • NCA; • Content analysis.	Not submitted. Awaiting the publication of Article I.
III) Configuring the Firm's Digital Servitization Capabilities for Value Creation in Different Trajectories	• To identify configurations of core digital servitization capabilities through which firms create value in different trajectories.	I, IV and VI	• Digital Servitization; • Digital Servitization Capabilities; • Technological Paradigms.	• Quantitative study.	• Survey.	• Cluster analysis; • EFA; • Nonparametric tests; • fsQCA.	Not submitted. Awaiting the publication of Article I.

Article I – Exploring Configurations of Digital Servitization Capabilities for Value Creation, conducts an extensive literature review to develop a theoretical framework of the core digital servitization capabilities of the firm. The framework is composed of four core capabilities: Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability, each of which is conceptualized as having three levels of development: Basic, Intermediate, and Advanced. To identify configurations of these capabilities for value creation, a multiple case study was carried out with 24 manufacturing firms, and the fuzzy-set Qualitative Comparative Analysis (fsQCA) was applied.

Article II – Building Digital Servitization Capabilities for the Successful Offering of Smart Services, expands Article I by addressing how firms build the four core digital servitization capabilities proposed in the theoretical framework, specifically for the offering of smart services. To do so, a mixed-method approach was applied. First, the qualitative data of the 24 cases explored in Article I were utilized to develop a survey instrument for a quantitative study, which resulted in a sample with 411 companies. Then, an Exploratory Factor Analysis (EFA) was applied to certify the validity and reliability of the core digital servitization capabilities proposed. After this, the emerging quantitative technique, Necessary Conditions Analysis (NCA) (Dul, 2016a), was carried out to measure the degree to which digital servitization capabilities are necessary for different levels of a successful offering of smart services. At last, to characterize the digital servitization capabilities, qualitative data from 13 well-succeed offerors of smart services, present in both studies, were further analyzed. With this, it was possible to examine how firms build core digital servitization capabilities for the offering of smart services.

Article III – Configuring the Firm's Digital Servitization Capabilities for Value Creation in Different Trajectories, also expands Article I by addressing how firms configure their core digital servitization capabilities to create value in different trajectories towards the digital servitization paradigm. Using the quantitative data with 411 companies, obtained in Article II, a cluster analysis was performed based on variables related to levels of digitalization and servitization to identify the digital servitization trajectories followed by firms. Then, based on the theoretical framework proposed in Article I, the fsQCA was applied to each cluster (trajectory) to identify the configurations of core digital servitization capabilities through which firms create value.

The three articles contribute to covering how digital servitization capabilities create value (first gap), and the role of manufacturing capabilities in digital servitization (fourth gap). Articles I and II jointly contribute to explain how digital servitization capabilities mature (third gap). While Article I does it theoretically, through the proposition of the theoretical framework, Article II does it empirically, by applying the NCA technique. Moreover, Article I focuses on addressing how digitalization and servitization elements can be merged into digital servitization capabilities (second gap), Article II concentrates on exploring the capabilities required for the offering of smart services (fifth gap), and Article III centers on examining how firms use their capabilities to create value in different digital servitization trajectories (sixth gap).

The three articles also contribute to the literature by addressing digital servitization in emerging economies, once studies generally only explore the phenomenon in companies in developed economies (Paschou *et al.*, 2020). Since emerging economies are known to be technological laggards, digital servitization could have different characteristics in this context, especially with respect to the adoption of digital technologies. Furthermore, as the research field on digital servitization capabilities is majorly composed of purely exploratory case studies (Paschou *et al.*, 2020), Articles II and III also support the advancement of the literature by applying normative and confirmatory approaches.

Besides this Integrated Introduction, the thesis has four more sections. Sections 2, 3, and 4 present, respectively, Articles I, II, and III. Then, Section 5 brings the Integrated Conclusion of the thesis.

2. **ARTICLE I –** Exploring Configurations of Digital Servitization Capabilities for Value Creation

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Status: Submitted to Industrial Marketing Management. Awaiting feedback on the third round of revisions, in which minor changes were requested (already included in this version).

Abstract

Digital servitization is the process by which firms transition from offering products to offering integrated solutions of products, services, and digital technologies. Although studies have explored the capabilities that a firm must build to transition to digital servitization, important gaps remain in the literature. Stand out a better understanding of how digitalization and servitization elements are merged into digital servitization capabilities, the role of manufacturing capabilities in digital servitization, and how digital servitization capabilities mature. Notwithstanding, the main research gap lies in how digital servitization capabilities can be configured to create value. To address these gaps, a theoretical framework of four digital servitization capabilities was developed: Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability. To identify the configurations of these capabilities for value creation, a multiple case study was conducted with 24 Brazilian manufacturing firms, and the fuzzy-set Qualitative Comparative Analysis (fsQCA) was applied. The results indicate that firms can create value through two configurations of digital servitization capabilities: Integration, Provision, and Manufacturing or; Integration, Orchestration, and Manufacturing.

Keywords: Digital Servitization, Firm Capabilities, Core Capabilities, Value Creation, fsQCA

1. Introduction

The concept of servitization refers to manufacturing firms transition from offering products to offering integrated solutions of products and services (Baines *et al*., 2020).

Servitization has always been associated with the embedding of digital technologies into products and processes (Kohtamäki *et al*., 2019), which has been intensified by the fourth industrial revolution, the so-called Industry 4.0, through the advent of disruptive new digital technologies, such as the Internet of Things, Cloud Computing and Big Data Analytics (Frank *et al.*, 2019; Paiola *et al.*, 2021). This is redefining the concept of servitization as digital servitization, referring to the firm's transition from offering products to offering integrated solutions of products, services, and digital technologies (Favoretto *et al.*, 2022).

Many studies explore the capabilities – sets of knowledge, resources, routines and skills through which a firm executes its activities (Dosi, 2000) – that must be developed for firms to transit to digital servitization. The literature highlights that firms need capabilities to develop services (Adrodegari and Sacanni, 2020; Beltagui, 2018; Wallin *et al.*, 2015), and to deliver services to consumers directly (Sjödin *et al.*, 2016; Storbacka, 2011; Ulaga and Reinartz, 2011) or indirectly, through partnerships with service companies (Marcon *et al.*, 2022; Story *et al.*, 2017). Manufacturing capabilities (Manresa *et al.*, 2021) and digitalization capabilities (Lenka *et al.*, 2017) are also considered relevant for this transition.

However, important research gaps remain. First, the literature is still more focused on servitization capabilities rather than digital servitization capabilities, being required a further examination of digitalization elements, especially to understand how they can be merged with servitization elements into capabilities (Munch *et al.*, 2022). Second, the literature generally does not interpret digital servitization capabilities through the lens of maturity models, which could contribute to understanding how firms develop and evolve these capabilities overtime (Khanra *et al.*, 2021). Third, manufacturing capabilities are rarely mentioned in digital servitization research, although there is a clear interaction between digital servitization and Industry 4.0 (Frank et al., 2019; Paiola et al., 2021), to which a better exploration of the role of manufacturing capabilities in service offerings could bring valuable new insights.

Notwithstanding, the main research gap lies in how digital servitization capabilities can create value for the firm. Although some studies suggest a positive relationship between the firm's transition to digital servitization and its financial performance (Martin-Peña, 2020; Kharlamov and Parry, 2020; Kohtamäki *et al*., 2020), the literature does not explain the role of digital servitization capabilities to do so

(Kohtamäki *et al.*, 2019). However, given the financial risks involved in digital servitization, such as the servitization paradox (Neely, 2009), and the digitalization paradox (Kohtamäki *et al.*, 2020), it is fundamental for companies to know how they can thrive through digital servitization.

Therefore, this article aims to answer the following question: ***Through which configurations of digital servitization capabilities do firms create value?*** In this regard, the present study concentrates on the core capabilities of the firm. Core capabilities are defined as few high-order capabilities that systematize minor capabilities in order to generate competitive advantages and create value (Leonard-Barton, 1992; Prahalad and Hammel, 1990; Teece, 2018).

To answer this question and cover the research gaps presented, this study develops a theoretical framework of the firm's digital servitization capabilities, conducts a multiple case study with 24 Brazilian manufacturing companies, and applies the fuzzy-set Qualitative Comparative Analyses (fsQCA) to identify configurations of the capabilities for value creation. With this, the present article also contributes to the literature by exploring digital servitization in companies from emerging economies, which has received little attention so far (Paschou *et al.*, 2020).

The theoretical framework was developed through an extensive literature review, and is composed of four core digital servitization capabilities of the firm, all of which merge servitization and digitalization elements. **Integration Capability** develops services, incorporates digital technologies to support them, and integrates both with products. **Provision Capability** creates, executes, and digitalizes processes to directly deliver services to consumers. **Orchestration Capability** builds, coordinates, and digitalizes a network of partners to indirectly deliver services to consumers. **Manufacturing Capability** improves products, their production, and digitalizes manufacturing processes in order to support service offerings. Each of these core capabilities has three levels of development: **Basic**, **Intermediate**, and **Advanced**, which represents their maturity level.

The results indicate that firms create value through two configurations of digital servitization capabilities: integration, provision, and manufacturing (IC*PC*MC) or; integration, orchestration, and manufacturing (IC*OC*MC). By deepening in the cases, it was possible to describe how these capabilities interact with each other to create value.

While integration and manufacturing capabilities play a key role in this regard, provision and orchestration capabilities only have supporting functions.

2. Digital Servitization Capabilities

The concept of digital servitization refers to the firm's transition from offering products to offering integrated solutions of products, services, and digital technologies, also known as Digital-Product-Service Systems (DPSSs) (Favoretto *et al.*, 2022; Kohtamäki *et al.*; 2019; Paiola *et al.*, 2021). According to Frank *et al.* (2019), firms' transition toward digital servitization consists of increasing the complexity of the DPSSs offered in terms of servitization and digitalization. Regarding servitization, this transition goes from the offering of services that only complement the products (e.g., technical assistance, insurance, financing), to the offering of services that substitute the products (e.g., renting, pay-per-use). Regarding digitalization, this transition goes from services delivered without digital technologies, to services delivered with advanced digital technologies (e.g., Internet of Things, Cloud Computing, and Big Data Analytics) (Frank *et al.*, 2019).

The firm's capabilities consist of sets of knowledge, resources, routines and skills through which a firm performs its activities (Dosi *et al.*, 2000; Lall, 1992; Reichert *et al.*, 2016). Therefore, firms have multiple capabilities, but to generate competitive advantages and create value, they must be grouped and systematized into a few high-order core capabilities (Leonard-Barton, 1992). Core capabilities are also known as core competencies (Prahalad and Hammel, 1990), or dynamic capabilities (Teece, 2018).

Regarding digital servitization, while some studies explore the multiple minor capabilities that firms must develop to transit in this regard (e.g., Adrodegari and Sacanni, 2020; Gebauer, 2011; Marcon *et al.*, 2022; Munch *et al.*, 2022; Storbacka, 2011), other studies concentrate on the few core capabilities (e.g., Huikkola and Kohtamäki, 2017; Jovanovic *et al.*, 2019; Parida *et al.*, 2015; Sjödin *et al.*, 2016; Ulaga and Reinartz, 2011). This article takes into account capabilities of both levels, but since its aim is to identify how digital servitization capabilities create value, its focus is on the systematization of minor capabilities into core capabilities. In this sense, summarizing both approaches, the literature overall identifies that firms need five types of capabilities to successfully transition to digital servitization: service development capabilities, service delivery capabilities, partnership building capabilities, manufacturing capabilities, and digitalization capabilities.

Service development and service delivery capabilities are the most addressed types in research. While service development capabilities refer to activities to develop services (Adrodegari and Sacanni, 2020; Rajala *et al.*, 2019; Wallin *et al*., 2015), service delivery capabilities refer to activities to directly deliver services to consumers, through the creation of internal processes to do so (Sjödin *et al.*, 2016; Storbacka, 2011; Valtakoski and Wittel, 2018). On the other hand, partnership building capabilities refer to activities to indirectly deliver services to customers, through the building of partnerships with service suppliers (e.g., dealers, franchises, technical assistance, and so on) (Huikkola and Kohtamäki, 2017; Lütjen *et al.*, 2019; Story *et al*., 2017).

In turn, manufacturing capabilities refer to activities to design and fabricate products, supporting services offerings that rely on expertise in this regard (Manresa *et al.*, 2021). For example, maintenance services depend on technical knowledge about products (Sousa and Silveira, 2017), spare parts services on skills to plan the production (Matthyssens *et al.*, 2009), and customization services on abilities to design and fabricate customized products (Sousa and Silveira, 2019). Manufacturing capabilities are very little addressed in the context of digital servitization, being required a further understanding of their role in the offering of DPSSs.

At last, digitalization capabilities refer to activities to select, incorporate, and operate digital technologies in order to support service offerings by collecting and analyzing data (Ardolino *et al.*, 2018; Hasselblat *et al.*, 2018; Lenka *et al.*, 2017). Studies tend to concentrate digitalization elements into capabilities dissociated from those with servitization elements (e.g., Herterich *et al.*, 2016; Sjödin *et al.*, 2016; Ulaga and Reinartz, 2011), taking the adoption of digital technologies as a phenomenon that occurs separately from the addition of services to products. However, since digital servitization is a merge between servitization and digitalization (Favoretto *et al.*, 2022; Paiola *et al.*, 2021), it requires capabilities that amalgamate elements related to both processes. Therefore, it is necessary to better understand how digitalization and servitization elements can be merged into capabilities (Munch *et al.*, 2022; Paschou *et al*., 2020).

Another reason to further explore manufacturing and digitalization capabilities is because they might be essential for the offering of factory-integrated services, which are the most complex type of DPSS (Frank *et al.*, 2019). Factory-integrated services combine service offerings with advanced digital technologies to collect and analyze data related to product performance, in order to improve products and their production processes. With this, factory-integrated services have a high potential to create value, combining the value generated from the addition of services to products (for example, by increasing product differentiation, customer satisfaction, and customer loyalty), with the value obtained from improvements in products and production (for example, by enhancing product quality, and reducing operational costs) (Frank *et al.*, 2019).

Besides these research gaps, the literature generally does not approach digital servitization capabilities from the perspective of maturity models, which could contribute by detailing how firms develop and evolve these capabilities overtime (Khanra *et al.*, 2021). Heirteirich *et al.* (2016), one of the few studies that adopts a perspective in this sense, proposes a theoretical framework in which development levels are attributed to the firm's digital servitization capabilities. These levels represent the complexity of the DPSSs that the firm is able to offer (Herteirich *et al.*, 2016), that is, represents the firm's level of digital servitization (Frank *et al.*, 2019).

Furthermore, although the research field attests a positive relationship between the firm's transition to digital servitization and its financial performance (Martin-Peña, 2020; Kharlamov and Parry, 2020; Kohtamäki *et al.*, 2020), it is not clearly explained how firms articulate their digital servitization capabilities to create value (Kohtamäki *et al.*, 2019). Notwithstanding, more than ever, this topic needs to be clarified. Firms' transition to digital servitization is becoming frequent, and when this transition is not well handled, it can result in significant financial losses due to ineffective investments in service development and delivery (Gebauer, 2005; Kastalli and Van Loy, 2013; Neely, 2009), as well as in digital technologies (Kohtamäki *et al.*, 2020). In an effort to cover the research gaps described here, the next section proposes a theoretical framework of the firm's core digital servitization capabilities.

3. Building a Framework of the Firm's Digital Servitization Capabilities

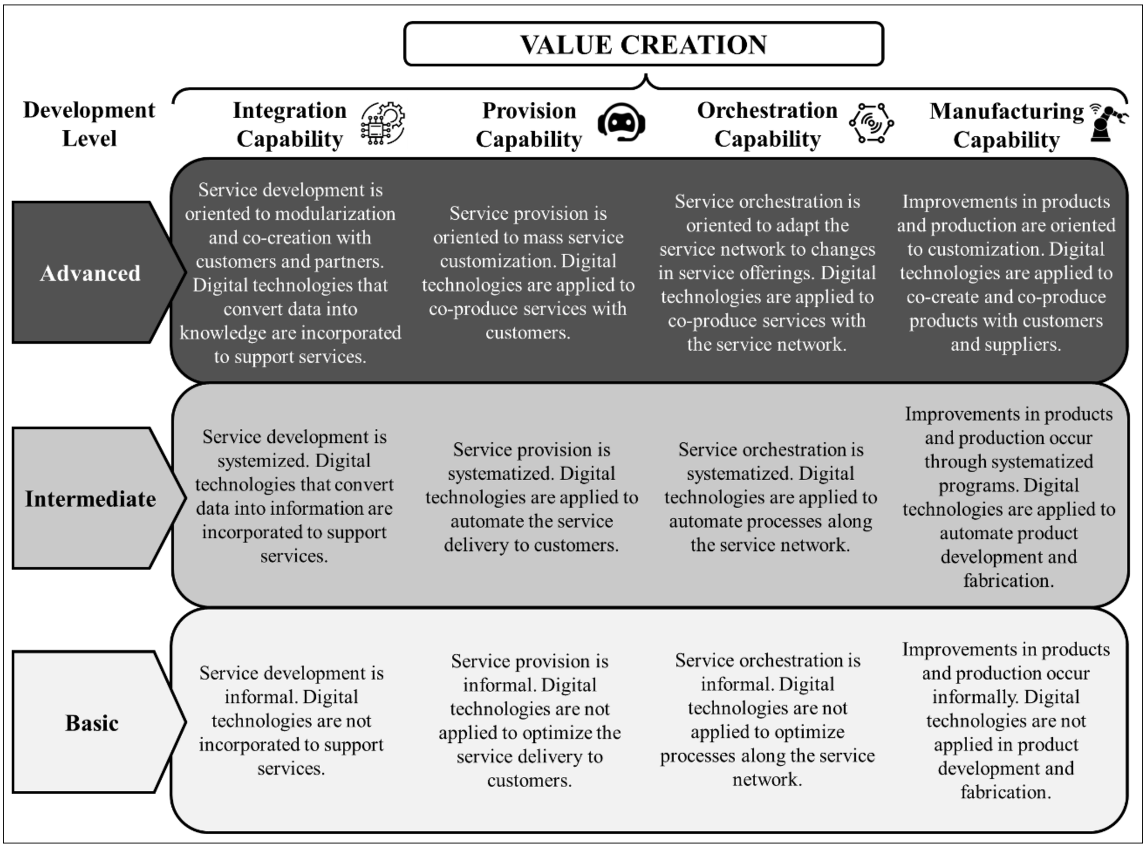
The proposed theoretical framework resumes the five types of capabilities described in the previous section into four core digital servitization capabilities. Following Kohtamäki *et al.* (2020) suggestion, digitalization elements were considered as fundamental resources for the building of the four capabilities, and thus, are spread among them, rather than being concentrated into a single capability. In this sense, the four core capabilities merge elements of servitization and digitalization, relating to both processes (Favoretto *et al.*, 2022; Munch *et al.*, 2022; Paschou *et al.*, 2020).

Integration Capability develops services, as well as searches, selects, and incorporates digital technologies to support them, integrating both with products (Ardolino *et al.*, 2018; Wallin *et al.*, 2015). **Provision Capability** creates and executes processes to directly deliver services to customers, and applies digital technologies to optimize those processes (Sjödin *et al.*, 2016; Storbacka, 2011). **Orchestration Capability** builds and coordinates a network of partners to indirectly deliver services to customers, and applies digital technologies to optimize processes along this service network (Lütjen *et al.*, 2019; Marcon *et al.*, 2022). **Manufacturing Capability** improves products and production, and applies digital technologies to optimize manufacturing processes, in order to support services offerings (Manresa *et al.*, 2021; Sousa and Silveira, 2017).

Following Khanra *et al.* (2021) suggestion, a maturity model perspective was adopted to detail how firms develop these four core digital servitization capabilities. Using an approach similar to that of Heirterich *et al.* (2016), each capability is considered to have levels of development, which represent the complexity of the DPSSs that a given firm can offer. Lall (1992), one of the first authors to propose that the firm's capabilities have maturity levels, suggested three levels of development, considering that the more developed the capabilities, the greater the firm's potential to create value (Figueiredo *et al.*, 2020). Similarly, the framework considers that each digital servitization capability has a **Basic**, **Intermediate**, and **Advanced** level of development.

In sum, the more developed the firm's core digital servitization capabilities, the greater the firm's potential to offer complex DPSSs (Herteirich *et al.*, 2016), as well as to create value (Martin-Peña, 2020; Kharlamov and Parry, 2020; Kohtamäki *et al.*, 2020). Since practically all companies incorporate some type of service into their products (Manresa *et al.*, 2021; Parida *et al.*, 2014), all firms have these four core capabilities at least at basic levels. Figure 1 illustrates the theoretical framework.

Figure 1 – Theoretical Framework of the Firm's Core Digital Servitization Capabilities



The following subsections detail each core capability, and their respective development levels. Then, Section 4 presents the methodological procedures adopted to explore how digital servitization capabilities can be configured to create value.

3.1 Integration Capability

This core capability represents the systematized set of minor capabilities by which the firm develops services, as well as searches, selects, and incorporates digital technologies to support them, integrating both with products. At **the basic level**, the integration capability consists of an informal service development process, which only allows the firm to react to market needs in this regard (Beltagui, 2018; Rapaccini *et al.*, 2013). Furthermore, the development of services involves little interaction with customers and partners (Kindström and Kowalkowski, 2014). At this level, this capability does not incorporate digital technologies and does not integrate them into products, or into their delivery process, in order to support service offerings (Chen *et al.*, 2021).

At **the intermediate level**, this capability is characterized by a more systematized service development process, with formalized stages of market research, prototyping, testing, and implementation (Adrodegari and Sacanni, 2020; Janssen *et al*., 2015; Solem *et al*., 2022). Equally, consumers and partners are more involved in the service development, participating in its improvement (Raddats *et al*., 2017). In addition, processes to search, select, and incorporate digital technologies are refined (Munch *et al.*, 2022). This results in the embedding of sensors, software and Cloud Computing platforms into products to support service offerings by collecting, transmitting, storing, analyzing and converting data related to product usage and customers preferences into information (Hasseblat *et al*., 2018; Ritter and Pedersen, 2019).

At **the advanced level**, the integration capability involves a highly systematized service development process (Huikkola *et al*., 2021; Wallin *et al*., 2015), oriented to create modular services, easily tailored to consumer needs (Rajala *et al*., 2019). The involvement of customers and partners in the service development is intensified, characterizing the co-creation of services with both actors (Sun and Zhang, 2022). In parallel, processes to incorporate digital technologies are even better developed (Huikkola *et al.*, 2022). This results in the embeddedness of Big Data Analytics technologies into products, such as machine learning and artificial intelligence which support service offerings through an automated and efficient transformation of data about products and consumers, not only into information, but also into knowledge (Ardolino *et al*., 2018; Lenka *et al*., 2017).

3.2 Provision Capability

This core capability relates to the systematized set of minor capabilities by which a firm creates and executes processes to directly deliver services to customers, and applies digital technologies to optimize those processes. At **the basic level**, the provision capability is characterized by an informal service delivery process (Oliva and Kalenberg, 2003). As there are no specific departments, personnel or management systems to provide services, they are informally executed and managed by the sales staff (Jovanovic *et al*., 2019). Furthermore, digital technologies are not applied to optimize the service delivery to clients (Leoni and Chirumalla, 2021).

At **the intermediate level**, this capability involves a more systematized service delivery process, which allows services scalability (Kanninen *et al*., 2017). There are dedicated service provision teams (Raddats *et al*., 2015), with established procedures to plan, control, and schedule the necessary resources for the service delivery (Valtakoski and Wittel, 2018), as well as to monitor quality (Baines *et al*., 2009), to cost, to price, and to sell services (Coreynem *et al*., 2017; Ulaga and Reinartz, 2011). At this level, digital technologies, such as software (Storbacka, 2011), online platforms, and apps, are used to automate the service delivery to consumers (Raddats *et al.*, 2021).

At **the advanced level**, the provision capability consists in a highly systematized service delivery process, achieving high levels of efficiency and flexibility that enable mass service customization. With this, services can be quickly adapted to customer needs without incurring increased costs or loss of quality (Alghisi and Sacanni, 2015; Sjödin *et al*., 2016). Besides dedicated teams and formalized procedures, specific departments focused on providing services are established (Huikkola *et al.*, 2016), with their own management system and performance goals (Gebauer, 2011). Digital technologies are applied not only to automate the service delivery, but also to support the service co-production with customers, enabling exchanges of data, information and knowledge with them (Kamalaldin *et al*., 2020).

3.3 Orchestration Capability

This core capability represents the systematized set of minor capabilities by which a firm builds and coordinates a network of partners to indirectly deliver services to customers, and applies digital technologies to optimize processes throughout this service network. The service network, also known as service ecosystem, includes not only the building and coordination of partnerships with service suppliers (e.g., dealers, franchises, technical assistance, and so on), but also with software suppliers (Marcon *et al.*, 2022), and even with other manufacturing firms (Momeni, 2021), that somehow can be involved in the service delivery to customers. At **the basic level**, the orchestration capability involves a limited ability to seek, select, hire, evaluate, and coordinate partnerships to deliver services (Kindström *et al*., 2013; Paiola *et al.*, 2013). Furthermore, digital technologies are not applied to optimize processes along the service network (Parida *et al*., 2015).

At **the intermediate level**, this capability consists in a more systematized process for establishing partnerships to deliver services (Gebauer *et al*., 2017; Story *et al*., 2017), with procedures in this regard being better defined (Ayala *et al*., 2019; 2021). However, the orchestration capability is still not fully able to coordinate these partnerships, and even less to play a central role in the service network (Huikkola and Kohtamäki, 2017; Huikkola *et al*., 2020). Digital technologies, such as software, online platforms, and apps, are used to automate processes along the service network (Annarelli *et al*., 2021; Li *et al.*, 2022).

At **the advanced level**, this capability is characterized by a highly systematized process for building partnerships to deliver services (Parida *et al*., 2014). The orchestration capability assumes a leading role in the service network, determining which services will be offered to consumers and how, being able to adapt partners to any changes in the service offerings (Lütjen *et al*., 2019). At this level, digital technologies are applied to support the service co-production with the service network, enabling the exchange of data, information, and knowledge with partners (Marcon *et al*., 2022; Skylar *et al*., 2019).

3.4 Manufacturing Capability

This core capability relates to the systematized set of minor capabilities by which a firm improves its products and production, and applies digital technologies to optimize manufacturing processes, in order to support services offerings. At **the basic level**, the manufacturing capability conducts little efforts in this regard, working only to maintain minimal levels of product quality, production efficiency, and production flexibility (Sousa and Silveira, 2017). Moreover, the fabrication technologies employed are outdated, and digital technologies are not applied to improve products and production (Manresa *et al.*, 2021).

At **the intermediate level**, the manufacturing capability is characterized by systematized programs to continuously improve products and production, working to achieve competitive advantages through high levels of quality, efficiency, and flexibility (Matthyssens *et al.*, 2009). To do so, this capability applies methods that promote operational excellence, such as Lean Manufacturing, Six Sigma, and Total Quality Management, and employs updated fabrication technologies (Qi *et al.*, 2020). In parallel, digital technologies, such as software, online platforms, and apps, are used to optimize the design of products as well as the planning, control, and execution of their production (Meindl *et al.*, 2021).

At **the advanced level,** this capability focuses the systematized programs for continuous improvement toward product customization (Sousa and Silveira, 2019). With this, the manufacturing capability applies principles of mass product customization, such as product modularity (Duray *et al.*, 2000), process integration with customers and suppliers (Fogliatto *et al*., 2012), and multifunctional shopfloor workers (Salvador *et al.*, 2020). Additionally, emerging fabrication technologies, such as advanced robotics and additive manufacturing (3D printers), are employed to make unitary production economically viable by reducing costs related to labor, materials waste, and setup (Kapetaniou *et al.*, 2018; Zheng *et al.*, 2020). Digital technologies are applied to support the co-creation and co-production of products with customers and suppliers, enabling the exchange of data, information, and knowledge with both (Wang *et al.*, 2017; Zhong *et al.*, 2017).

4. Method

To identify configurations of core digital servitization capabilities through which firms create value, a qualitative multiple case study was conducted. A multiple case study consists of an empirical investigation of real-life scenarios, and aims to deeply understand a given phenomenon (Eisenhardt, 1989; Yin, 2013). To analyze the data obtained, the fuzzy-set Qualitative Comparative Analysis (fsQCA) was applied. The fsQCA converts qualitative deep case knowledge into robust quantitative data to identify configurations of conditions for a given outcome (Ragin, 2008), and thus, is adequate for the objectives of this research. The following subsections describe the methodological procedures adopted.

4.1 Data Collection

In multiple case studies, the selection of cases must follow criteria that allow the observation of the desired phenomenon (Miles and Huberman, 1994). In this regard, only companies that offer Digital-Product-Service-Systems (DPSSs), that is, companies that complement their products by offering services through apps, software, or online platforms, were selected for this study. The case selection was based on specialized magazines, lists of participants of fairs about Industry 4.0, news, companies' websites, and products' catalogs.

After a careful case selection, in-depth interviews were conducted, using a semi-structured questionnaire (Appendix) based on the theoretical framework proposed (Fig. 1). For each case, managers of areas such as after-sales services, information technology (IT), or operations, were interviewed, once a person in these positions has the necessary knowledge to answer the questions. The interviews were conducted between April and September 2022, and all were recorded and transcribed. Data collection continued until theoretical saturation was reached, that is, when incremental knowledge became minimal (Glaser and Strauss, 1967).

The data obtained from the interviews were triangulated with visits to factories, corporate reports, and product catalogs in order to guarantee its validity and reliability (Denzin, 1989). Table 2 describes the 24 selected cases.

Table 2 – Cases Selected

No	Case	Size	Main Products	Main Digital-Product-Service- Systems (Apps, software or online platforms to...)	Interviewed	Duration (Hours)	Pages Transcript
1	Alpha	Large	Elevators	Monitor elevator performance; Schedule maintenance services.	Service Manager	1:04:39	15
2	Beta	Large	Automobiles	Monitor vehicle performance; Schedule maintenance services; Manage insurance; Customize vehicles.	Quality Manager	1:27:31	21
3	Gamma	Medium	Asphalt plants	Monitor equipment performance; Manage equipment utilization; Conduct remote maintenance services (Virtual Reality).	Sales Manager	2:43:08	49
4	Delta	Large	Cranes	Monitor crane performance.	Sales Manager	1:03:18	28
5	Epsilon	Large	Agricultural Machinery	Monitor equipment performance; Manage equipment utilization; Schedule maintenance services; Conduct remote maintenance services (Virtual Reality).	IT Manager	1:34:07	35
6	Zeta	Large	Automobiles	Rent and share vehicles; Customize vehicles.	After Sales Manager	1:33:41	26
7	Eta	Large	Construction Machinery	Monitor equipment performance; Manage equipment utilization; Schedule maintenance services; Conduct remote maintenance services (Virtual Reality).	After Sales Manager	1:20:39	25
8	Theta	Medium	Grain dryers	Monitor equipment performance.	After Sales Manager	1:07:32	19
9	Iota	Large	Personal computers	Configure pay-per-use services; Monitor computer performance; Schedule and conduct remote maintenance services.	Service Manager	1:18:01	23
10	Kappa	Large	Belt conveyors	Monitor equipment performance.	Product Manager	1:07:12	19
11	Lambda	Large	Power generators	Monitor equipment performance.	After Sales Manager	1:01:03	13
12	Mu	Medium	Machining tools	Monitor tools performance; Manage tools inventories and logistics.	Service Manager	1:31:55	24
13	Nu	Large	Agricultural Machinery	Monitor equipment performance; Manage equipment utilization; Schedule maintenance services; Conduct remote maintenance services (Virtual Reality).	Marketing Manager	1:35:43	29

No	Case	Size	Main Products	Main Digital-Product-Service- Systems (Apps, software or online platforms to...)	Interviewed	Duration (Hours)	Pages Transcript
14	Xi	Large	Furniture	Customize furniture; Monitor furniture delivery; Schedule maintenance services.	Innovation Manager	0:58:07	18
15	Omicron	Large	Pesticides	Monitor pesticides performance; Manages pesticides application.	Digital Solutions Manager	1:22:35	19
16	Pi	Large	Instant sauces and meals	Support customer operation (management of small restaurants).	Sales Manager	1:02:19	19
17	Rho	Medium	Asphalt plants	Monitor equipment performance.	After Sales Manager	2:06:47	37
18	Sigma	Large	Agricultural Machinery	Monitor equipment performance; Manage equipment utilization; Schedule maintenance services; Conduct remote maintenance services (Virtual Reality).	Digital Solutions Manager	1:03:10	21
19	Tau	Large	Cattle, poultry and pork meat	Support product usage (recipes suggestions); Purchase products; Monitor product delivery; Track product origin.	New Business Manager	1:18:25	19
20	Upsilon	Large	T-shirts and footwear	Customize T-shirts and footwear; Support customer operation (management of T-shirts stores).	Digital Products Manager	0:59:51	18
21	Phi	Medium	Electrical wheelchairs	Monitor equipment performance.	Technology Manager	1:41:23	33
22	Chi	Large	Silos	Monitor equipment performance; Manage equipment utilization.	Service Manager	1:12:16	17
23	Psi	Medium	Marble cutting machines	Support customer operation (management of marble factories).	CEO	0:52:01	18
24	Omega	Large	Tires	Monitor tires performance; Manage tires utilization.	Service Manager	1:14:35	23
					Total	**32:19:58**	**568**

16 cases are machinery and equipment manufacturers, and eight cases (Iota, Mu, Xi, Omicron, Pi, Tau, Upsilon, and Omega) are in other industries, such as chemicals, furniture, food, and textiles. Although digital servitization is mostly observable in the machinery and equipment industry (Paschou *et al.*, 2021), it also occurs in other sectors (Chen *et al.*, 2021; Kanninen *et al.*, 2017; Sousa and Silveira, 2017). By including companies from other industries in the study, it was possible to test the broadness of the proposed theoretical framework.

All companies are located in Brazil. The company size (Table 2, column 3) is based on the classification of the BNDES (Banco Nacional de Desenvolvimento – Bank of National Development), which classifies firms according to their annual revenue: large company (annual revenue greater than or equal to BR$ 300 million), medium company (annual revenue greater than or equal to BR$ 4.8 million, but less than BR$ 300 million) and small company (annual revenue less than BR$ 4.8 million). Thus, 18 cases are large companies, and six cases are medium companies.

4.2 Data Analysis

The fsQCA follows a set-theoretic approach to identify configurations of conditions for a given outcome (Fiss, 2011; Pappas and Woodside, 2021; Ragin, 2008). In this study, considering the proposed theoretical framework (Fig. 1), each firm's core digital servitization capability corresponds to a set of conditions, while the value created by the firm corresponds to the set of the outcome.

To work with the fsQCA, qualitative data must be converted into membership scores (or fuzzy scales) with values varying between 0.05 and 0.95, a process called calibration (Ragin, 2008). To do so, the transcribed interviews were codified with the Nvivo software. When working with the fsQCA, a deductive code must be carried out, in order to standardize the conditions and outcomes for all cases (Tóth *et al.*, 2017). Therefore, empirical evidences related to core digital servitization capabilities were calibrated by using thresholds that represent the development levels suggested in the theoretical framework: Basic level = 0.05 (non-membership); Intermediate level = 0.50 (partial membership) and; Advanced level = 0.95 (full membership) (Pappas and Woodside, 2021). For each core digital servitization capability, three minor capabilities were used as codes, and for each minor capability, two empirical evidences were used as calibration criteria (Table 3).

Table 3 – Calibration Criteria for Conditions (Core Digital Servitization Capabilities)

Core Capability (Condition)	Minor Capability (Code)	Empirical Evidences (Calibration Criteria)
Integration Capability	Service Development	Systematized service development process
		Services are offered in customizable packages (modularity)
	Service Co-creation	Involvement of customers in the service creation
		Involvement of partners in the service creation
	Merge of Products, Services, and Digital Technologies	Embeddedness of digital technologies into products, or into their delivery processes
		Data obtained through services are analyzed with advanced digital technologies (Big Data Analytics)
Provision Capability	Service Delivery Building	Has its own service personnel
		Dedicated department to deliver services to customers
	Service Delivery Management	Systematized service delivery process
		Service performance is measured through KPIs (Key Process Indicators)
	Service Delivery Digitalization	Service delivery is optimized through software, online platforms, or apps
		Use of CRM (Customer Relationship Management) software
Orchestration Capability	Service Network Building	Establishes formal partnerships to deliver services
		Dedicated department to establish partnerships to deliver services
	Service Network Coordination	Systematized process to establish partnerships to deliver services
		The performance of services delivered by partners is measured through KPIs
	Service Network Digitalization	Processes along the service network are optimized through software, online platforms, or apps
		Implements standard CRM software along the service network
Manufacturing Capability	Manufacturing Improvement	Has systematized programs for the continuous improvement of products and production
		Improvements in products and production are oriented to product customization
	Manufacturing Technology	Highly automated production processes (e.g., advanced robotics and additive manufacturing)
		There are practically no production stages with human interference
	Manufacturing Digitalization	Use of software, online platforms, or apps for product development or production management
		Use of data collected through services to improve products and production

For each case, if both empirical evidences for a minor capability are absent, the minor capability was considered at the basic level of development (membership score = 0.05). If at least one empirical evidence is present, the minor capability was considered at the intermediate level (membership score = 0.50). And if both empirical evidences were present, the minor capability was considered at the advanced level (membership score =

0.95). Then, the membership score for each core digital servitization capability was obtained by calculating the mean of the membership scores attributed to their respective minor capabilities, as indicated in Table 3.

The outcome, value creation, was accessed by measuring three items identified by Schumpeter (2008) as indicatives of the firm's performance: net profit, revenue, and market share. Following Reichert *et al.* (2016), these items were measured with five-point Likert scales, varying from decreased too much in the last three years (1), to increased too much in the last three years (5). The mean of these items was taken as a representation of the value created by the firm (Reichert *et al.*, 2016). Following studies that applied the fsQCA with data in Likert scales, the outcome was calibrated to membership scores using a direct correspondence criterion: 1 = 0.05; 3 = 0.50; 5 = 0.95 (Peters *et al.*, 2022). To calibrate the outcome and identify the configurations of conditions, the software fsQCA 4.0 was used. The following section presents the results.

5. Results

The results of the fsQCA are generated in two steps: necessity analysis and sufficiency analysis (Ragin, 2008). While the necessity analysis indicates individual conditions that must be present for the outcome to occur, the sufficiency analysis indicates configurations of individual conditions that generate the outcome. Both analyses are evaluated through measurements of consistency and coverage, which vary from 0 (low) to 1 (high). **Consistency** measures the degree in which an individual condition/ configuration results in a desired outcome, while **Coverage** evaluates the percentage of cases that use an individual condition/ configuration to do so (Fiss, 2011; Pappas and Woodside, 2021). Table 4 presents the necessity analysis.

Table 4 – Necessity Analysis

Outcome:	Value Creation	
Condition	Consistency	Coverage
Integration Capability [IC]	0.899	0.925
~Integration Capability [~IC]	0.290	0.928
Provision Capability [PC]	0.672	0.919
~Provision Capability [~PC]	0.526	0.949
Orchestration Capability [OC]	0.672	0.881
~Orchestration Capability [~OC]	0.445	0.852
Manufacturing Capability [MC]	0.765	0.972
~Manufacturing Capability [~MC]	0.457	0.918

A condition is considered "necessary" or "almost always necessary" for a given outcome when its consistency is greater than 0.900 or 0.800, respectively (Ragin, 2000; Santos and Gonçalves, 2019). Once the integration capability has a consistency equal to 0.899, it can be considered an "almost always necessary condition", or practically a "necessary condition", for value creation.

However, that does not mean that the integration capability alone is sufficient for value creation. To identify this, the sufficiency analysis must be carried out, which consists in the generation and reduction of a truth table (Ragin, 2008). The truth table lists all possible configurations of conditions for a given outcome, indicates the number of cases that belong to each configuration (frequency), and the degree in which they belong to these configurations (raw consistency) (Tóth *et al.*, 2017). Applying the recommendations of Pappas and Woodside (2021), configurations with the following characteristics were removed from the truth table: those with a frequency smaller than two cases (the recommended for small samples) and; those with a raw consistency smaller than the natural breakpoint observed (0.98), when this natural breakpoint is greater than the minimal threshold of 0.80 (Pappas and Woodside, 2021).

After the reduction of the truth table, the fsQCA generates three solutions: complex, intermediate, and parsimonious, with the difference between them residing in the inclusion of counterfactuals (Fiss, 2011). Following several studies (e.g., Jovanovic and Morschet, 2022; Santos and Gonçalves, 2019), the recommendation of Ragin (2008), to consider only the intermediate solution, was applied. According to Ragin (2008), the intermediate solution is the most realistic, since it includes only plausible counterfactuals. Furthermore, following Pappas and Woodside (2021), intermediate and parsimonious solutions were compared to identify peripheral conditions, which are present only in intermediate solutions (Peters *et al.*, 2022). Since the results of both solutions are the same, no peripheral conditions were identified. Table 5 presents the sufficiency analysis.

Table 5 – Sufficiency Analysis

Outcome:	Value Creation	
Condition	Configuration 1	Configuration 2
Integration Capability [IC]	●	●
Provision Capability [PC]	●	
Orchestration Capability [OC]		●
Manufacturing Capability [MC]	●	●
Configuration Consistency	1.000	0.965
Raw Coverage	0.594	0.550
Unique Coverage	0.200	0.156
Solution Consistency	0.974	
Solution Coverage	0.751	

● = Condition must be present; ○ = Condition must be absent; Blank = Condition is indifferent | Frequency threshold < 2; Raw consistency threshold < 0.98

The solution identified by the fsQCA for the obtention of a given outcome can contain multiple configurations of conditions (equifinality) (Ragin, 2008). Table 5 demonstrates that the solution is valid: its consistency (0.974) and the consistency of each configuration in the solution (1.000 and 0.965) easily exceed the threshold of 0.750 (Jovanovic and Morschet, 2022; Pappas and Woodside, 2021). Although the literature has not yet established thresholds for coverage scores, it is understood that the higher they are, the higher the explanatory power of the solution (Pappas and Woodside, 2021). While the solution coverage (0.751) measures the explanatory power of the entire solution, the raw coverage measures it for each configuration (0.594 and 0.550). The unique coverage (0.200 and 0.156), in turn, excludes from the raw coverage the cases that are explained by more than one configuration (Peters *et al.*, 2022; Tóth *et al.*, 2017).

Therefore, the results indicate that none of the core digital servitization capabilities is able to create value alone. To do so, firms must combine the integration capability and manufacturing capability with the provision capability (IC*PC*MC), or with the orchestration capability (IC*OC*MC). The following section further discusses the results obtained.

6. Discussions

The integration capability can be considered the most important core capability for value creation, since besides being present in both configurations, it is the only capability that is a necessary condition. In parallel, the presence of the manufacturing capability in both configurations indicates that its combination with the integration capability plays a key role in value creation. The difference between the configurations resides in the tactic chosen by firms to deliver services to customers: directly, by creating and executing internal service delivery processes with the provision capability (IC*PC*MC), or indirectly, by building and coordinating a network of partners with the orchestration capability (IC*OC*MC).

To further explore these configurations, the analysis of the well-succeed cases was deepened. In this regard, cases with a membership score greater than 0.50 to at least one of the configurations were considered as well-succeed (Ragin, 2008). With this, 17 cases can be considered as well-succeed: five cases using the IC*PC*MC configuration (Alpha, Iota, Kappa, Mu, and Tau), nine cases using the IC*OC*MC configuration (Beta, Gamma, Epsilon, Zeta, Eta, Nu, Pi, Sigma, and Chi), and three cases using both configurations (Omicron, Upsilon, and Omega). Seven cases do not use any of the configurations and, hence, are not able to create value through digital servitization (Delta, Theta, Lambda, Xi, Rho, Phi, and Psi). Then, the minor capabilities utilized to determine the development level of each core digital servitization capability (specified in Table 3) were further examined in the 17 well-succeed cases. Table 6 presents the analysis.

Table 6 – Development Level of the Core Digital Servitization Capabilities in Well-Succeed Cases

Config.	Cases	Core Capab.:	Integration Capability [IC]			Provision Capability [PC]			Orchestration Capability [OC]			Manufacturing Capability [MC]		
		Minor Capab.:	Service Development	Service Co-creation	Merge of Products, Serv., and Dig. Tech.	Service Delivery Building	Service Delivery Management	Service Delivery Digitalization	Service Network Building	Service Network Coordination	Service Network Digitalization	Manufacturing Improvement	Manufacturing Technology	Manufacturing Digitalization
IC*PC*MC	Alpha		A	A	A	A	A	A	A	I	B	I	I	A
	Iota		A	A	A	A	A	A	B	B	B	I	A	A
	Kappa		I	A	A	A	A	I	B	B	B	A	I	I
	Mu		A	A	A	A	A	A	B	B	B	A	I	A
	Tau		I	A	A	A	A	A	B	B	B	I	A	A
IC*PC*MC IC*OC*MC	Omicron		A	A	I	A	A	A	A	A	B	I	A	A
	Upsilon		A	A	A	A	A	A	A	A	A	A	I	A
	Omega		A	A	I	A	A	A	A	I	I	I	I	A
IC*OC*MC	Beta		A	A	A	B	B	A	A	A	A	I	A	A
	Gamma		A	A	A	B	B	A	A	A	A	I	I	A
	Epsilon		A	A	A	B	B	A	A	A	A	I	I	A
	Zeta		A	A	A	B	B	A	A	A	A	I	A	A
	Eta		A	A	A	B	B	A	A	A	A	I	I	A
	Nu		A	I	A	B	B	A	A	A	A	I	I	A
	Pi		A	A	I	B	B	A	A	A	A	I	A	A
	Sigma		A	A	A	B	B	A	A	A	A	I	I	A
	Chi		A	I	A	B	B	A	A	A	A	I	I	A

A (Dark Gray) = Minor capability at advanced level; I (Gray) = Minor capability at intermediate Level; B (Light Gray) = Minor capability at basic level

Overall, the integration capability is homogeneous between the well-succeed cases, with practically all of them having its minor capabilities at the advanced level. The service development is systematized (Huikkola *et al*., 2021) and oriented to service modularization (Rajala *et al*., 2019), resulting in the offering of customizable services packages. Services are co-created with customers, by involving them in market research and to test service prototypes. In parallel, services are also co-created with partners, mainly with software companies, to develop digital technologies that support services (Sun and Zhang, 2022). These digital technologies are embedded into products or into their delivery processes to collect and analyze data related to product performance with Big Data Analytics technologies, such as artificial intelligence and machine learning (Lenka *et al.*, 2017).

The manufacturing capability also is homogeneous between the well-succeed cases, but is not so well developed, with the majority of the cases having its minor capabilities at the intermediate level. Improvements in products and production occur through formalized programs (Qi *et al.*, 2020), but only three cases focus these programs on product customization (Kappa, Mu, and Upsilon). Although production technology includes emerging technologies, such as advanced robotics and additive manufacturing (Zheng *et al.*, 2020), automation tends to be limited, maintaining considerable human interference in the process. Notwithstanding, the digitalization of product development and production is advanced in practically all well-succeed cases, including from the use of software to develop products and manage the production (e.g., CAD/CAM, MRP, SCADA), to the use of data obtained from services to improve products and processes (Zhong *et al.*, 2017).

It is at this point that integration and manufacturing capabilities are linked to create value in both configurations. While the integration capability adds services and digital technologies to products, enabling the collection and conversion of data into knowledge, the manufacturing capability uses this knowledge to improve products and production. Therefore, the combination of these two core capabilities represents the offering of factory-integrated services. Factory-integrated services are one of the most complex types of DPSSs, but also have the highest potential to create value, since they combine the value created through the addition of services and digital technologies to products (e.g., at increasing product differentiation), with the value created through improvements in products and production (e.g., at enhancing product quality, or reducing operational costs) (Frank *et al.*, 2019). Table 7 presents citations from interviews that demonstrate this.

Table 7 – Focus of Digital Servitization in Well-Succeed Cases

Configuration	Case	Citations
IC*PC*MC	Alpha	*"The consequence of this* (digital servitization)*, is that now we are working predictively" (...) "The elevators generate a lot of data that we can use to improve them."*
	Iota	*"A benefit from these services is that they gave us a lot of insight about the quality of our products, and what we have to do to improve them."*
	Kappa	*"Our goal with these digital services is to improve our products. We are still working to achieve this. Today, we have few people to analyze the data that we get, but we are structuring this."*
	Mu	*"... the services generate data about the performance of our tools. This is useful for our customers and for us too, because we can use this data to improve our products and processes."*
IC*PC*MC IC*OC*MC	Omicron	*"We use a lot of the data obtained through our services to improve the actual products, and to develop new ones too."*
	Omega	*"Independently of the service that we are providing, our focus is to collect data about the product performance to improve it."*
IC*OC*MC	Beta	*"Our goal always was to use the data generated by our vehicles to improve them. To enhance their design and their production processes."*
	Gamma	*"Our aim with these services is to improve our products. The most important for us is to have data about the product performance. With this, we can enhance their design and production processes."*
	Epsilon	*"We use a lot of IA and machine learning to analyze the data obtained through the services" (...) "We have dedicated teams within our engineering that only work with these data. To improve products and processes."*
	Zeta	*"We have the data base of all vehicles, of all our clients" (...) "We constantly use it* (data) *to improve the development of future automobiles."*
	Eta	*"All the data that we collect through our services is analyzed to identify flaws, and improve our equipment."*
	Nu	*"We are on this path. Now, with a more robust telemetry in our equipment, we are focusing on using these data to improve the development and production of our equipment."*

Therefore, well-succeed cases take digital servitization as a strategy to obtain data capable of supporting the improvement of products and production. Although these firms focus on offering services, they are still manufacturing firms, driven by the development and fabrication of tangible goods. In this scenario, the function of provision and orchestration capabilities is to operationalize a service delivery focused on collecting data related to product performance, supporting the interaction between integration and manufacturing capabilities. Since provision and orchestration capabilities are not homogenous among well-succeed cases, they assume different roles in each configuration to do so.

In the IC*PC*MC configuration, the provision capability is responsible for delivering services to customers. Cases that use IC*PC*MC practically have all the minor capabilities related to the provision capability at the advanced level. They have exclusive service personnel and departments, as well as systematized processes to plan, execute, and control the service delivery to customers (Gebauer, 2011). Digital technologies, such as software, online platforms, or apps, are applied to automate the service delivery (Raddats *et al.*, 2021), together with the use of CRM software to improve customer relationship management (Storbacka, 2011). The advanced level of these minor capabilities enables the provision capability to: Support the interaction between integration and manufacturing capabilities by collecting data related to products performance; Co-produce services with customers through an intensive exchange of data with them and; Assist the integration capability in the service co-creation with customers (Kamalaldin *et al*., 2020).

The orchestration capability is not totally absent from the IC*PC*MC configuration. Although cases that use IC*PC*MC have an orchestration capability at the basic level, they use this capability to establish informal partnerships with service suppliers, such as technical assistance, which work as backups for internal service delivery processes when it is necessary.

On the other hand, in the IC*OC*MC configuration, the orchestration capability plays the main role in the service delivery to customers. Cases that use IC*OC*MC have all minor capabilities related to the orchestration capability at the advanced level. They have well-established partnerships to deliver services (Story *et al*., 2017), dedicated departments to coordinate them, as well as systematized processes to select, manage, and evaluate these partners (Lütjen *et al.*, 2019). Digital technologies are applied to optimize processes along the service network (Li *et al.*, 2022; Parida *et al.*, 2015), making available to service suppliers: Online platforms for the purchase of products and spare parts; Standard software to manage service orders and; Standard CRM software to manage their relationship with their customers.

The provision capability is also not totally absent from the IC*OC*MC configuration. Cases that use IC*OC*MC have the majority of the minor capabilities associated with the provision capability at the basic level, except the service delivery digitalization. This is reflected in the use of digital technologies to deliver services to customers, and in the establishment of internal departments to analyze customer data, obtained through the CRM software utilized by service suppliers. This occurs because the digitalization of the service network does not enable a proper collection of data related to product performance and customers preferences. Therefore, in IC*OC*MC, the provision capability supplies the interaction between integration and manufacturing capabilities, while also complementing the orchestration capability to: Co-produce services with service suppliers and; Assist the integration capability in the service co-creation with service suppliers (Marcon *et al.*, 2022).

At last, cases that use both configurations have the advantage of being able to easily alternate the roles of the provision and orchestration capabilities to deliver services. However, Omicron and Omega seem to prefer to use the IC*PC*MC configuration, since they struggle with some minor capabilities related to the orchestration capability, especially with regard to the service network digitalization. Figure 2 resumes the results.

Figure 2 – Configurations of Core Digital Servitization Capabilities for Value Creation

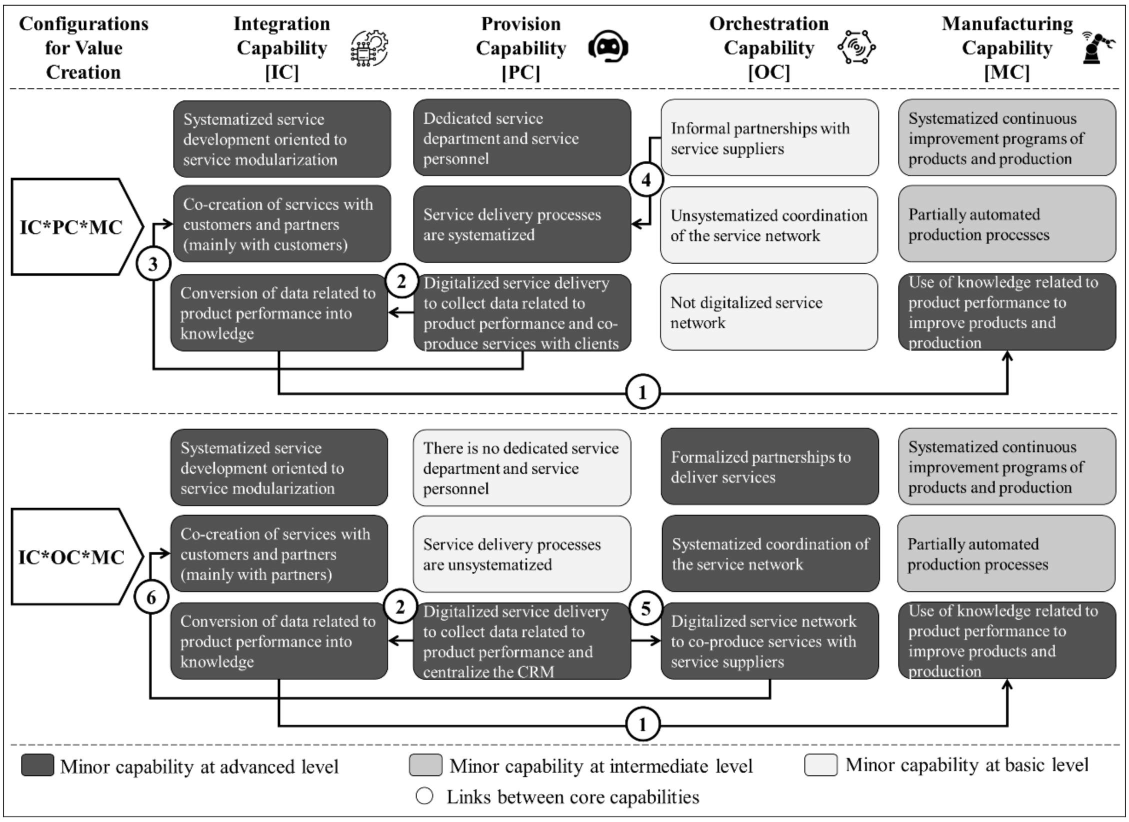


Figure 2 illustrates the two configurations of core capabilities, the development level of each minor capability that composes them, and the links through which the core capabilities are connected to create value. In both configurations, the main connection occurs between integration and manufacturing capabilities (Link 1). While the integration capability converts data related to product performance into knowledge, the manufacturing capability uses this knowledge to continuously improve products and production processes. For this link to work properly, the integration capability must receive data related to the product performance, which, in both configurations, is collected by the provision capability through the digitalization of the service delivery (Link 2). However, the execution of the service delivery occurs differently in each configuration.

In IC*PC*MC, the provision capability not only digitalizes, but also executes the service delivery, co-produces services with customers, and assists the integration capability in the service co-creation with them (Link 3). The orchestration capability supports the provision capability in the execution of the service delivery, through informal partnerships with service suppliers (Link 4). In IC*OC*MC the service delivery is mainly executed by the orchestration capability, but is digitalized by the provision capability, which supports the orchestration capability in the co-production of services with the service network (Link 5). With this, the orchestration capability also became able to assist the integration capability in the service co-creation with service suppliers (Link 6). At co-creating services, the integration capability continuously improves the DPSSs, refining the conversion of data related to product performance into knowledge, and then, stablishing a virtuous cycle of value creation.

7. Conclusions

The article achieved its objective of identifying the configurations of core digital servitization capabilities through which firms create value. Based on an extensive literature review, a theoretical framework of four core digital servitization capabilities was proposed: Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability. The configurations of these capabilities for value creation were identified by applying the fsQCA on data obtained through a multiple case study with 24 Brazilian manufacturing firms. The results indicate that firms create value through two configurations of core capabilities: integration, provision, and manufacturing (IC*PC*MC) or; integration, orchestration, and manufacturing (IC*OC*MC).

In other words, firms thrive through digital servitization when they link the offering of services with improvements in products and production. This occurs because the value created by the addition of services to products (e.g., at promoting product differentiation, or customer loyalty) is increased by the value created through improvements in products and production (e.g., at enhancing product quality, or reducing operational costs). In this regard, the integration capability must design services capable of collecting and converting data related to product performance into knowledge. In parallel, the manufacturing capability needs to apply the knowledge generated by the integration capability to continuous improvement programs.

In this context, the main function of provision and orchestration capabilities is to support the interaction between integration and manufacturing capabilities by operationalizing a service delivery focused on collecting data related to product performance. In IC*PC*MC, this is done by the provision capability, while in IC*OC*MC, this role is taken by the orchestration capability. At operationalizing the service delivery, provision and orchestration capabilities assist the integration capability in the service co-creation, respectively, with customers and partners. And in co-creating services, the integration capability continuously improves DPSSs, establishing a virtuous cycle of value creation.

This study provides academic and managerial contributions. Regarding academic contributions, the study promotes advances in the literature on the firm's digital servitization capabilities by demonstrating: How digitalization and servitization elements can be merged into core digital servitization capabilities; How core digital servitization capabilities can mature; The role of manufacturing capabilities in digital servitization, and the most important of all; How core digital servitization capabilities can be configured to create value. In addition, the study also contributes to the research field by exploring the characteristics of digital servitization in companies in emerging economies.

In terms of managerial contributions, the theoretical framework (Fig. 1) would be useful for companies to plan their transition toward digital servitization and to Industry 4.0, given the interplay between these two phenomena. Managers can use the framework to analyze the level of the digital servitization capabilities of their companies, identify the strengths and weaknesses of these capabilities, and plan their development. The results obtained (Fig. 2) can guide companies in this transition, working as a reference point. Moreover, public managers can use the theoretical framework to assess the level of digital servitization in different industries and regions, in order to elaborate public policy that aids their development in this regard.

A limitation of this research lies in the generalization of the results, once multiple case studies are restricted in this regard, due to the use of small samples. Another limitation is that the firm's capabilities approach restricts the creation of value to internal competencies of companies, ignoring external aspects, such as the influence of institutions and public policy. Moreover, only companies from Brazil were addressed. Although the identified characteristics of firms' digital servitization capabilities were similar to the findings of the present literature, focused on firms in developed economies, some caution should be taken when applying the results. Especially with respect to the sufficiency of a manufacturing capability not so well-developed for value creation, since emerging economies tend to be late adopters of new technologies.

These limitations can be overcome by future studies. The theoretical framework can be applied with a quantitative approach, using large samples to obtain more generalizable results. Likewise, the theoretical framework can be utilized to assess the impact of factors that are external to the firm on the development of its digital servitization capabilities, or to compare the capabilities of firms from emerging and developed economies. Future studies can also employ the framework to explore topics that commonly appear in the literature, such as which capabilities are necessary for the offering of specific types of DPSSs. In this regard, the offering of smart services, given its great potential to create value, has been taken as the ultimate goal of digital servitization. However, the capabilities required for their offering have received little attention in the literature.

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Appendix: Semi-Structured Questionnaire

Overall Questions

1. Briefly describe the main products offered by your company.
2. Briefly describe the services offered to complement these products. Such services could be offered directly by the company, or through partnerships (e.g., dealers, franchises, …).
3. Which digital technologies are involved in the services offered to customers (e.g., apps, Cloud Computing, Machine Learning, …)?

Integration Capability

4. How does the service development occur?
5. How do customers participate in service development?
6. How do partners participate in service development (e.g., service companies, software developers, …)?
7. How data obtained through services are analyzed?

Provision Capability

8. Describe the company's organizational structure to provide services to its customers.
9. How does the service provision occur (e.g., norms, procedures, ...)?
10. How does the company manage the service provision (e.g., trainings, indicators, …)?
11. How do digital technologies support service provision?

Orchestration Capability

12. How the company establish partnerships to deliver services to its customers (e.g., search, selection, hiring …)?
13. How do these partners participate of the service delivery to customers?
14. How the company monitor the performance of these service partners (e.g., training, indicators, …)?
15. How digital technologies are applied to interact with these service partners?

Manufacturing Capability

16. What drives the product development (e.g., product standardization, product modularization, product customization, …)?
17. Briefly describe the main characteristics of the company's production process (e.g., job-shop, mass production, production technology, automation, …).
18. How the company improve its products and production (e.g., informally, formalized programs, …)?

19. How digital technologies are applied in product development and production (e.g., design software, production management software, use of data collected through services)?

Financial Performance

20. Describe the company's financial performance in the last three years (2019, 2020, and 2022).
21. Regarding the company's financial performance in the last three years (2019, 2020, and 2022), please evaluate the following items on a scale from 1 (decreased too much) to 5 (increased too much).
    a) Net profit:
    b) Revenue:
    c) Market share:

3. **ARTICLE II –** Building Digital Servitization Capabilities for the Successful Offering of Smart Services

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Status: Not submitted. Awaiting the publication of Article I.

Abstract

Smart services are highly digitalized services with great potential to result in value creation. This leads their offer to be the ultimate goal of manufacturing firms that have entered the digital servitization process – the transition from the offer of products to the offer of integrated solutions between products, services, and digital technologies. Although studies had approached the capabilities required for firms to transition to digital servitization, the capabilities specifically necessary for offering smart services had received little attention. To cover these gaps, the present study explores how firms can build four core digital servitization capabilities (Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability) to successfully offer smart services. Using a mixed-method approach, a quantitative study was carried out, applying the emergent Necessary Conditions Analysis (NCA) technique to measure the degree to which these four core capabilities are necessary for different levels of a successful offering of smart services. By combining the NCA with a qualitative multiple case study of well-succeed cases, it was possible to examine how firms build digital servitization capabilities for the offering of smart services.

Keywords: Smart Services, Digital Servitization, Core Capabilities, Capability Building, Necessary Conditions Analysis

1. Introduction

Smart services are proactive services that monitor, analyze, improve, and predict the performance and supply of products, based on knowledge and intelligence generated by digital technologies (Allmendiger and Lombreglia, 2005; Shen *et al.*, 2023; Töytäri *et al.*, 2018). Given its potential to create value, the offer of smart services is the ultimate goal of manufacturing firms that entered the process of digital servitization (Kohtamäki *et al.*, 2022).

Digital servitization refers to the transition of manufacturing firms from the offering of products to the offering of integrated solutions between products, services, and digital technologies (Favoretto *et al.*, 2022). This transition is becoming fundamental, once digital servitization consists of one of the most prominent business models for the current fourth industrial revolution (Industry 4.0) (Frank *et al.*, 2019; Paiola *et al.*, 2021). As a result of digital servitization, smart services create value for the firm that offers them in two ways: Increasing the aggregated value of products, at complementing them (Santamaría *et al.*, 2011) or; Providing insights for decision making, through the digital technologies incorporated into products or into their delivery processes (Neirotti *et al.*, 2018).

A robust literature explores the firm's digital servitization capabilities, through which firms make their transition to digital servitization. The firm's capabilities are defined as sets of knowledge, resources, and routines for a given end (Winter, 2003). In the case of digital servitization, studies highlight the importance of capabilities to develop services (Adrodegari and Saccani, 2019), to deliver services (Ulaga and Reinartz, 2011), to coordinate a network of service partners (Story *et al.*, 2017), to adapt product development and production processes for service offerings (Sousa and Silveira, 2017), as well as capabilities to incorporate and operate digital technologies (Kimita *et al.*, 2022).

However, only a few studies address the digital servitization capabilities necessary for the offering of smart services (e.g., Huikkola *et al.*, 2022). To cover this gap, the present study aims to answer the following question: ***How do firms build digital servitization capabilities for the successful offering of smart services?***

To answer this question, the theoretical framework of the firm's digital servitization capabilities suggested by Ruffoni and Reichert (2023) was considered. The framework encompasses four core capabilities of the firm: few high-order capabilities that systematize minor capabilities to generate competitive advantages and create value (Leonard-Barton, 1992; Prahalad and Hammel, 1990; Teece, 2007). The ***Integration Capability*** develops services, incorporates digital technologies to them, and integrates both with products into a single solution. The ***Provision Capability*** creates, manages, and digitalizes processes to directly deliver services to customers. The ***Orchestration Capability*** builds, coordinates, and digitalizes a service network to indirectly deliver services to customers. The ***Manufacturing Capability*** improves products and production processes, as well as incorporates digital technologies in manufacturing to support service offerings (Ruffoni and Reichert, 2023).

Based on this framework, a mixed-method approach was adopted. First, a quantitative study with 411 Brazilian manufacturing firms was carried out, applying the Necessary Conditions Analysis (NCA). The NCA is an emerging quantitative technique put forward by Dul (2016a), which has been gaining relevant attention in management studies (e.g., Bokhorst *et al.*, 2022; Frommeyer *et al.*, 2022; Yang and Hurmelinna-Laukkanen, 2022). The NCA measures the degree to which a condition is necessary for different degrees of an outcome (Dul, 2016a; Richter *et al.*, 2020), assessing to what extent a condition enables an outcome to occur. To complement the NCA, a qualitative multiple case study was conducted with 13 manufacturing firms to characterize the digital servitization capabilities of well-succeed smart services offerors. By combining both methods, it was possible to examine how firms build digital servitization capabilities for a successful offering of smart services.

With this, the article also brings methodological contributions. By applying the emerging NCA, a confirmatory approach, the present research advances the literature on digital servitization capabilities, since it is mainly composed of purely exploratory case studies (Paschou *et al.*, 2020).

The results of the mixed-method approach indicate a three-stage path of capability building for the successful offering of smart services. In the ***Implementation Stage***, firms must focus on building integration and manufacturing capabilities, to properly design the offering of smart services. In the ***Optimization Stage***, besides further developing integration and manufacturing capabilities, firms should also develop the provision capability, to digitalize the direct service delivery to customers. At last, in the ***Customization Stage***, firms must focus on better building provision and orchestration capabilities, to operationalize the delivery of customized smart services.

2. Theoretical Background

2.1 Digital Servitization

The concept of digital servitization is an evolution of the concept of servitization, which refers to the addition of services into products (Vandermerve and Rada, 1988).

Servitization was always related to digitalization, that is, to the incorporation of digital technologies into products and processes, but the emergence of the fourth industrial revolution (Industry 4.0) led this interaction to a new level (Frank *et al.*, 2019; Müller *et al.*, 2018). The merge between servitization and digitalization resulted in the phenomenon of digital servitization: the transition process through which manufacturing firms move from the offering of products to the offering of integrated solutions between products, services, and digital technologies (Favoretto *et al.*, 2022; Kohtamäki *et al.*, 2019; Paiola *et al.*, 2021).

Manufacturing firms can add different types of service to their products. These services are generally typified as: basic services (e.g., warranties, financing, spare parts), which only support the product; intermediate services (e.g., retrofit, product customization), which adapt and add functionalities to the product according to customer preferences and; advanced services (e.g., pay-per-use; operate the customer process), which can substitute the consumer's need to purchase the product (Baines and Lightfoot, 2013; Cusumano *et al.*, 2015; Tukker, 2004). In parallel, firms can also incorporate different types of digital technologies into their products and processes. Digital technologies are generally classified in two levels: those that only optimize processes (e.g., software) (Verhoef *et al.*, 2019), and those that can generate knowledge and intelligence (e.g., artificial intelligence and machine learning) (Ardolino *et al.*, 2018; Shen *et al.*, 2023).

Considering these levels, digital servitization can result in the addition of manual, digital, and smart services to products (Kohtamäki *et al.*, 2022). Manual services consist of any service that is not supported by digital technologies (Park *et al.*, 2012; Raddats *et al.*, 2019). On the other hand, digital services are optimized through digital technologies, being services with higher quality, faster delivery, and less input of resources (Lerch and Goestch, 2015). Examples of digital services include maintenance services scheduled with apps, or pay-per-use services contracted and configured through online platforms (Frank *et al.*, 2019).

Smart services go beyond digital services, being not only optimized through digital technologies, but also based on the knowledge and intelligence generated by them (Ardolino *et al.*, 2018; Geum *et al.*, 2016). An example of smart service is an online platform that complements a given product by offering customers an analysis of the product performance in real time, as well as suggestions of predictive maintenance schedules, purchases of spare parts, or a more efficient way to use the given product (Chen *et al.*, 2021; Grubic and Peppard, 2016). Another example of smart service is an app that complements products by offering customers an analysis of product consumption in real time, as well as demand forecasts (Kamp *et al.*, 2022; Koldwey *et al.*, 2021).

Smart services are defined as proactive services that monitor, analyze, improve, and predict product performance and supply (Allmendiger and Lombreglia 2005; Klein *et al.*, 2018; Töytari *et al.*, 2018). The dynamics of smart service offerings is based on the functionalities of three disruptive digital technologies, which represent the emergence of Industry 4.0: the Internet of Things, Cloud Computing, and Big Data Analytics (Frank *et al.*, 2019; Paiola *et al.*, 2021). The Internet of Things enables the collection and transmission of data related to products (e.g., operational performance, sales history, customer preferences), while Cloud Computing platforms permit the remote access and storage of these data. With this, Big Data Analytics technologies, such as machine learning and artificial intelligence, allow for the quick conversion of these data sets into information, and then, into knowledge and intelligence (Ardolino *et al.*, 2018; Boldosova *et al.*, 2019).

The offer of smart services is the ultimate goal of manufacturing firms that entered the digital servitization process, given the potential of smart services to result in value creation (Kohtamäki et al., 2022; Xing *et al.*, 2023). There are basically two ways through which smart services create value for the firm that offers them.

First, smart services increase the aggregated value of products by complementing them. The pure addition of services differentiates products in the market, increases customer loyalty, and facilitates the introduction of new products (Santamaría *et al.*, 2011; Vandermerwe and Rada, 1988). Second, the offering of smart services involves the incorporation of digital technologies into products or into their delivery processes (Ardolino *et al.*, 2018; Lerch and Goestch, 2015). This results in value creation by generating knowledge and intelligence for decision making (Khin and Ho, 2019; Neirotti *et al.*, 2018; Shen *et al.*, 2023). An example in this regard is the use of knowledge and intelligence obtained through smart services to improve products and production processes (Frank *et al.*, 2019; Wei *et al.*, 2022; Zambetti *et al.*, 2021).

However, for firms to achieve a successful offering of smart services, they need to develop capabilities in this regard. The following section presents a brief review of the literature on the firm's digital servitization capabilities, detailing the theoretical framework utilized in this study.

2.2 Digital Servitization Capabilities

The firm's capabilities are defined as sets of knowledge, resources, routines and skills for the execution of activities (Dosi, 2000; Winter, 2003). The literature highlights that, in order to successfully transit to digital servitization, manufacturing firms need to build capabilities to develop services (Adrodegari and Saccani, 2019; Huikkola *et al.*, 2022), to deliver services to customers directly, through internal processes (Jovanovic *et al.*, 2019; Storbacka, 2011), or indirectly, through partnerships with service companies (Lütjen *et al.*, 2019; Story *et al.*, 2017).

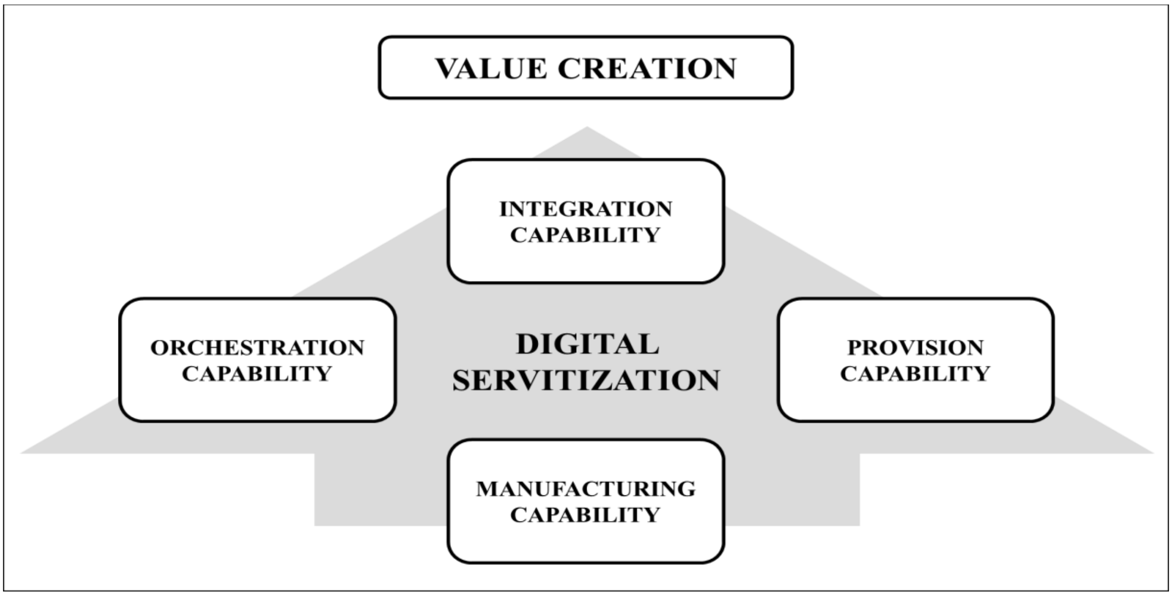
Some studies also suggest that manufacturing capabilities, through which firms develop and fabricate products, need to be adapted for digital servitization, especially for the offer of services that rely on knowledge in this regard, such as maintenance, spare parts, and product customization services (Manresa *et al.*, 2021; Qi *et al.*, 2020; Sousa and Silveira, 2017). Moreover, since digital servitization merges digitalization and servitization, digitalization capabilities are also necessary. Digitalization capabilities encompass activities through which firms implement and use digital technologies to support service offerings (Hasselblat *et al.*, 2018; Lenka *et al.*, 2017; Kimita *et al.*, 2022). In this sense, the literature has been highlighting the importance of capabilities to establish partnerships also with IT (information technology) companies, to assist in the development and delivery of digital and smart services (Momeni, 2023).

Many studies systematize the firm's digital servitization capabilities into theoretical frameworks of core capabilities: few high-order capabilities that organize minor capabilities in order to create competitive advantages (Leonard-Barton, 1992; Prahalad and Hammel, 1990; Teece, 2007). Ulaga and Reinartz (2011) suggested one of the first propositions in this regard, addressing core capabilities related to the development, delivery, and digitalization of services. Later, other studies proposed frameworks more focused on core capabilities to establish and coordinate partnerships with service companies (Huikkola and Kohtamäki, 2017; Huikkola *et al.*, 2022; Sjödin *et al.*, 2016), or on core manufacturing capabilities (Manresa *et al.*, 2021; Sousa and Silveira, 2017). Overall, the frameworks tend to focus on specific types of core digital servitization capabilities. Although this enables a deeper understanding of certain aspects, it does not allow a broad perception of the phenomenon.

Furthermore, since the theoretical frameworks generally concentrate elements of digitalization into core capabilities dissociated from those with servitization elements (e.g., Manresa *et al.*, 2021; Sjödin *et al.*, 2016; Ulaga and Reinartz, 2011), they tend to approach digitalization as a process that occurs separately from the process of servitization, rather than an integral part of it. Notwithstanding, digital servitization is the combination of services and digital technologies and, thus, requires capabilities that fully amalgamate both elements (Munch *et al.*, 2022; Paschou *et al.*, 2020).

In this regard, the present study adopts the theoretical framework put forward by Ruffoni and Reichert (2023) for two reasons. First, it aims a broad understanding of the phenomenon of digital servitization, enabling the analysis of the multiple dimensions involved in the process. Second, all the core capabilities included in the framework merge elements of digitalization and servitization, properly representing digital servitization capabilities, rather than solely servitization or digitalization capabilities. According to Ruffoni and Reichert (2023), firms need four core capabilities to succeed in digital servitization: ***Integration Capability***, ***Provision Capability***, ***Orchestration Capability***, and ***Manufacturing Capability***. Figure 3 illustrates the theoretical framework.

Figure 3 – Theoretical Framework of the Firm's Core Digital Servitization Capabilities



Adapted from Ruffoni and Reichert (2023)

The ***Integration Capability*** refers to a systematized set of minor capabilities to develop services, incorporate digital technologies, and combine both with products into single solutions (Ruffoni and Reichert, 2023). This core capability encompasses minor capabilities to monitor market needs related to services, to design services (Adrodegari and Saccani, 2019; Huikkola *et al.*, 2021; Rajala *et al.*, 2019), as well as to co-create services with customers and partners, such as service companies and IT companies (Chirumalla *et al.*, 2023; Huikkola and Kohtamäki, 2017; Raddats *et al.*, 2017). The integration capability also includes minor capabilities to search, select, incorporate, and operate digital technologies, such as the Internet of Things, Cloud Computing, and Big Data Analytics, focusing on collecting and converting data into knowledge and intelligence to support service offerings (Hasseblat *et al.*, 2018; Huikkola *et al.*, 2022; Lenka *et al.*, 2017).

The ***Provision Capability*** refers to a systematized set of minor capabilities to directly deliver services to customers, as well as to digitalize this service delivery (Ruffoni and Reichert, 2023). This core capability encompasses minor capabilities to select and manage service personnel (Gebauer, 2011; Munch *et al.*, 2022), to organize, plan, control, and execute the service delivery (Jovanovic *et al.*, 2019; Sjödin *et al.*, 2016), as well as to sell services (Storbacka, 2011; Ulaga and Reinartz, 2011). Furthermore, the provision capability applies digital technologies, such as software, apps, and online platforms, to automate and optimize the direct service delivery to customers (Kimita *et al.*, 2022).

The ***Orchestration Capability*** refers to a systematized set of minor capabilities to indirectly deliver services to customers, as well as to digitalize this indirect service delivery (Ruffoni and Reichert, 2023). To do so, the orchestration capability establishes partnerships with other companies to build a service network, which includes: service suppliers, to operationalize the service delivery; software suppliers, to support the service delivery through specialized data analysis (Dalenogare *et al.*, 2023; Marcon *et al.*, 2022) and; goods suppliers, that somehow can be involved in the indirect service delivery to customers (Momeni *et al.*, 2023). Therefore, this core capability encompasses minor capabilities to search, select, hire, train, and coordinate all actors of the service network (Story *et al.*, 2017; Lütjen *et al.*, 2019). The orchestration capability also applies digital technologies, such as software, apps, and online platforms, to automate and optimize processes along the service network (Parida *et al.*, 2015; Skylar e*t al.*, 2019).

The ***Manufacturing Capability*** refers to a systematized set of minor capabilities to improve products and production processes, as well as to digitalize the product development and fabrication, in order to support service offerings (Ruffoni and Reichert, 2023). This core capability encompasses minor capabilities to continuously improve products and production toward modular designs and lean production (Qi *et al.*, 2020; Salvador *et al.*, 2020), balancing efficiency and flexibility in manufacturing (Sousa and Silveira, 2017; 2019). Moreover, the manufacturing capability applies digital technologies to automate and optimize product development and production planning, control, and execution (Manresa *et al.*, 2021). These digital technologies include from software, apps, and online platforms, to updated production technologies, such as additive manufacturing (a.k.a. digital layered manufacturing) and advanced robotics (Savastano *et al.*, 2021).

Based on this framework, it is possible to explore how firms build digital servitization capabilities for a successful offering of smart services. The next section presents the methodological procedures adopted to do so.

3. Method

This study adopts a mixed-method approach, combining qualitative and quantitative methods. The main advantage in using mixed-methods is the extraction of substantive inferences from data, which is allowed by the combination of depth (qualitative methods) and breadth (quantitative methods) of knowledge on a phenomenon (Venkatesh *et al.*, 2013). Following Greene (1989), this study has three purposes in combining different methods: to use the results of one method to develop the other, to identify convergences between the results of each method, and to exemplify the results of one method with the other.

First, a qualitative multiple case study was conducted with 24 Brazilian manufacturing firms to collect empirical evidence and develop a survey instrument for the quantitative study. This was done because most of the literature on digital servitization capabilities consists of purely exploratory case studies (Paschou *et al.*, 2020). Therefore, there is a lack of questionnaire models to collect quantitative data. Especially models that reflect the reality of companies in emerging economies, since studies concentrate on companies in developed economies (Paschou *et al.*, 2020).

The quantitative study resulted in a sample with 411 Brazilian manufacturing firms. With these data, the Necessary Conditions Analysis (NCA) (Dul, 2016a) was applied to measure the degree to which digital servitization capabilities are necessary for different levels of a successful offering of smart services. To complement the NCA, the qualitative data of 13 cases, present in both studies, were further analyzed to characterize the capabilities of well-succeed smart services offerors. The results of both methods were crossed to examine how firms build digital servitization capabilities to offer smart services.

3.1 Qualitative Study

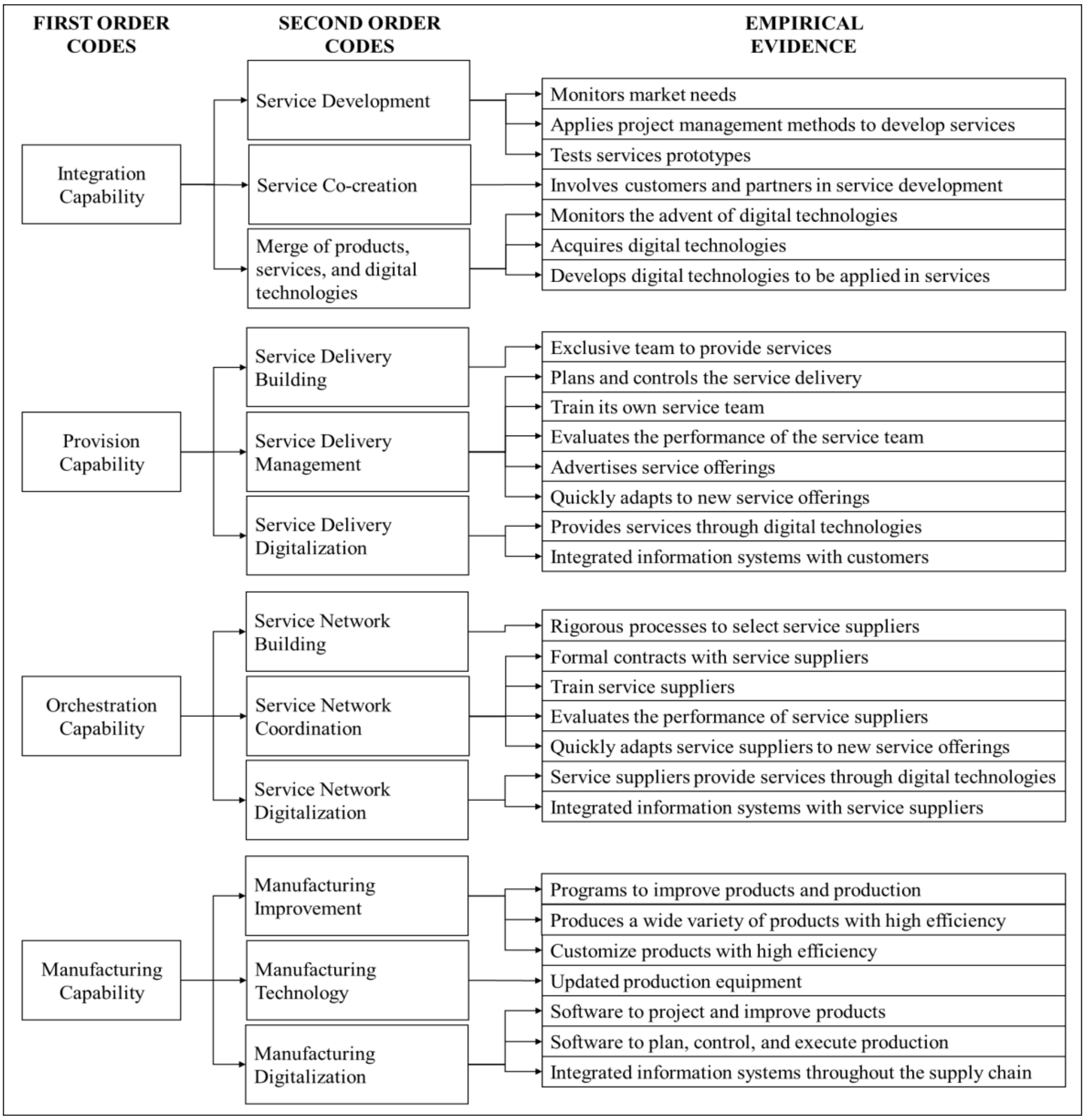
For the qualitative multiple case study, a semi-structured questionnaire was developed based on the theoretical framework proposed by Ruffoni and Reichert (2023) (Appendix 1). Since multiple case studies should only include cases that allow the observation of the desired phenomenon (Eisenhardt, 1989; Yin, 2013), only manufacturing firms offering smart services were selected. Therefore, the criterion for a case to be selected for the study was to be a manufacturing firm that offers services based on the three digital technologies that build the basis for the offering of smart services: Internet of Things, Cloud Computing, and Big Data Analytics (Ardolino *et al.*, 2018; Boldosova *et al.*, 2019). The selection of cases was based on news in specialized magazines about Industry 4.0, lists of participants in trade fairs related to Industry 4.0, news websites, company websites, and product catalogs.

All cases selected for the study are companies located in Brazil, and are from different manufacturing industries, such as machinery and equipment, metallurgical, textile, and chemical. Although digital servitization is more evident in the machinery and equipment industry, it also occurs in other sectors, as was also perceived in previous research (e.g., Blichfeldt and Faullant, 2021; Manresa *et al.*, 2021; Sousa and Silveira, 2017).

After this careful case selection, in-depth interviews were conducted between April and September 2022. Managers from service, sales, after-sales, marketing, product development, innovation, and IT areas were interviewed, as a person in these positions has the knowledge necessary to answer the questionnaire. Following Denzin (1989), the data obtained from the interviews were triangulated with visits to factories, as well as reviews of corporate reports and product catalogs, to guarantee its validity and reliability. Data collection continued until theoretical saturation was reached, that is, when incremental knowledge became minimal (Eisenhardt, 1989).

The multiple case study resulted in interviews with managers from 24 manufacturing firms (one representative per company). All interviews were recorded and transcribed, obtaining more than 30 hours and 500 pages of empirical evidence. The transcribed interviews were codified using the N-Vivo software. An inductive approach was applied in the codification, based on the concepts of the four core digital servitization capabilities (first order codes), and on the minor capabilities that compose them (second order codes). Figure 4 presents the empirical evidence identified through the codification process.

Figure 4 – Codification Process and Empirical Evidence Identified



Then, the empirical evidence identified for each core digital servitization capability, and for their corresponding minor capabilities, was used to support the development of the survey instrument for the quantitative study.

3.2 Quantitative Study

3.2.1 Survey Instrument, Data Collection and Principal Component Analysis

Each empirical evidence was converted into a question (resulting in 29 questions) with answers measured with five-point Likert scales, ranging from completely disagree (1) to completely agree (5). The survey instrument also includes three questions related to value creation (also measured with five-point Likert scales), addressing the three elements identified by Schumpeter (2008) as representatives in this regard: constant increases in profits, revenue, and market share (Reichert *et al.*, 2016). Moreover, the survey instrument encompasses questions related to the types of services offered and to the types of digital technologies incorporated, both with dichotomous answers (Yes or No).

Data collection was carried out among Brazilian manufacturing firms between November 2022 and January 2023. The same approach used in the qualitative study was replicated: firms from different industries were considered, and managers from service, sales, after-sales, marketing, product development, innovation, and IT areas were interviewed. To contact companies, a database with more than 3,700 companies provided by the South Brazilian Manufacturing Association (FIERGS) was used. Data collection occurred by phone, and was performed by trained applicators. Data collection stopped when 411 companies (11% of the database) were obtained.

To evaluate the impact of the measurement method on variance, the Harman single factor test (Podsakoff *et al.*, 2003) was applied using the Social Package for Social Sciences (SPSS) software. To do so, the 32 questions related to digital servitization capabilities and value creation were grouped into a single factor. This single factor covered only 28% of the total variance, indicating the adequacy of the model, since there is no single factor that accounts for most of the variance. Then, the Exploratory Factor Analysis (EFA) was carried out to reduce these 32 items in five latent factors (the four core digital servitization capabilities and firm’s value creation), and evaluate their validity as constructs. Table 8 presents the final factors.

Table 8 – Exploratory Factor Analysis

Item: Does your firm...	Orchestration Capability	Provision Capability	Integration Capability	Manufacturing Capability	Value Creation
Have a rigorous process to select service partners	0.953				
Stablishes formal contracts with service partners	0.940				
Train service partners	0.908				
Makes digital technologies (apps, software, online platforms, ...) available for partners to provide services	0.797				
Have information systems integrated with service partners	0.925				
Periodically evaluate the performance of service partners	0.939				
Have an exclusive internal team to provide services		0.841			
Plan and control the necessary resources for the service offering		0.774			
Train its own service team		0.870			
Provide services through digital technologies (apps, software, online platforms, ...)		0.568			
Periodically evaluates the performance of the service team		0.866			
Advertises the service offerings		0.821			
Monitor the advent of digital technologies that can be applied to services			0.575		
Develop digital technologies to be applied in services			0.776		
Apply project management methods to develop services			0.744		
Involve customers and partners in the development of services			0.670		
Test services before making them available to customers			0.572		
Have programs to continuously improve products and production				0.642	
Produce a wide variety of products without compromise the efficiency of production				0.735	
The machinery and equipment utilized are on the technological frontier of the industry				0.621	
Use specific software to project and improve products (CAD-CAM)				0.509	
Use specific software to plan, control, and execute production (MRP, MES, SCADA)				0.597	
Have increased its profit in the last four years					0.905
Have increased its revenue in the last four years					0.911
Have increased its market share in the last four years					0.713
Cronbach's Alpha	0.970	0.885	0.801	0.734	0.817

Five factors fixed with varimax rotation based in kaiser normalization. Rotation converged in six interactions.

Following Hair *et al.* (2009) recommendations, only factor loadings above 0.500 were considered relevant, leading to the removal of seven items from the original 32 (Appendix 2). The suitability of the data for the EFA is ensured by the Kayser-Meyer-Olkin (KMO) test equal to 0.894 and by the significance of the Barlett sphericity test (p = 0.000), while the discriminant validity of the factors is guaranteed by their Cronbach's Alpha greater than 0.700 (Hair *et al.*, 2009). In addition, the five factors explained 68.95% of the variance, which is a considerable part of it.

3.2.2 Data Calibration and Necessary Conditions Analysis

The outcome examined in this study, the successful offering of smart services, can be represented by the value created through the offering of services based on knowledge and intelligence generated by digital technologies. Therefore, the successful offering of smart services can be understood as the combination of three variables: value creation, service offerings, and the generation of knowledge and intelligence through digital technologies incorporated into services.

To build a variable that represents the successful offering of smart services, the fuzzy-set Qualitative Comparative Analysis (fsQCA) was applied, using the fsQCA 4.0 software. The fsQCA is based on a set-theoretic approach, addressing each variable as a set, which allows the combination of variables through logical operators (Ragin, 2008). To do so, data must first be calibrated in membership scores (or fuzzy scales), ranging between 0 and 1, to represent the degree to which observations "belong" to variables (sets) (Pappas and Woodside, 2021). Following previous studies that calibrate variables measured in five-point Likert scales, the minimum, median, and maximum values of each variable were used as thresholds, respectively corresponding to 0.05 (non-membership), 0.50 (partial membership), and 0.95 (full membership) (Chen and Tian, 2021; Du and Kim, 2020; Fiss, 2011; Reichert *et al.*, 2016).

Then, the logical operator "fuzzy and" was used to combine the value creation variable, identified in the EFA (Table 8), with a variable related to service offerings, which corresponds to the sum of several dichotomous variables related to types of services added to products (detailed in Appendix 3), and two variables related to the obtention of knowledge and intelligence through digital technologies. Table 9 details the procedures carried out.

Table 9 – Calibration Parameters and the Built of a Variable for the Successful Offering of Smart Services

Variable	Description	Scale	Calibration Parameters		
			Min.	**Median**	**Max.**
Value Creation	The mean of the variables that compose it (Table 8)	1 to 5	2.00	4.00	5.00
Service Offerings	The sum of twelve dichotomous variables related to types of services added to products (Appendix 3)	0 to 12	0.00	7.00	12.00
Our services generate a great amount of data	Related to the obtention of knowledge and intelligence through digital technologies incorporated into services	1 to 5	1.00	4.00	5.00
We use advanced digital technologies to analyze service data (Big Data Analytics, Machine Learning, Artificial Intelligence, …)	Related to the obtention of knowledge and intelligence through digital technologies incorporated into services	0 or 1	No need to be calibrated		
Successful Offering of Smart Services	The combination (fuzzy and) of Value Creation; Service Offerings; Our services generate a great amount of data, and; We use advanced digital technologies to analyze service data	-	-	-	-
Integration Capability	The mean of the variables that compose it (Table 8)	1 to 5	1.20	3.80	5.00
Provision Capability	The mean of the variables that compose it (Table 8)	1 to 5	1.00	4.33	5.00
Orchestration Capability	The mean of the variables that compose it (Table 8)	1 to 5	1.00	3.00	5.00
Manufacturing Capability	The mean of the variables that compose it (Table 8)	1 to 5	1.60	4.20	5.00

At last, the Necessary Conditions Analysis (NCA) was applied, using the NCA package of the RStudio software (Dul, 2023). The NCA is an emerging quantitative technique put forward by Dul (2016a), and has been gaining relevant attention in management research (e.g., Bokhorst *et al.*, 2022; Frommeyer *et al.*, 2022; Yang and Hurmelinna-Laukkanen, 2022) for proposing a new approach.

According to Dul (2016b), traditional quantitative techniques, such as multiple regression, measure whether a condition produces an outcome, however, they do not evaluate the necessity of the condition for the outcome to occur. The fact that X produces Y does not mean that X is necessary for Y (Dul, 2016b). A necessary condition is a critical and irreplaceable condition for an outcome to occur (Dul, 2016a; Richter *et al.*, 2020). The NCA was developed to identify necessary conditions, and the degree to which they are necessary for different degrees of an outcome (Dul, 2016a).

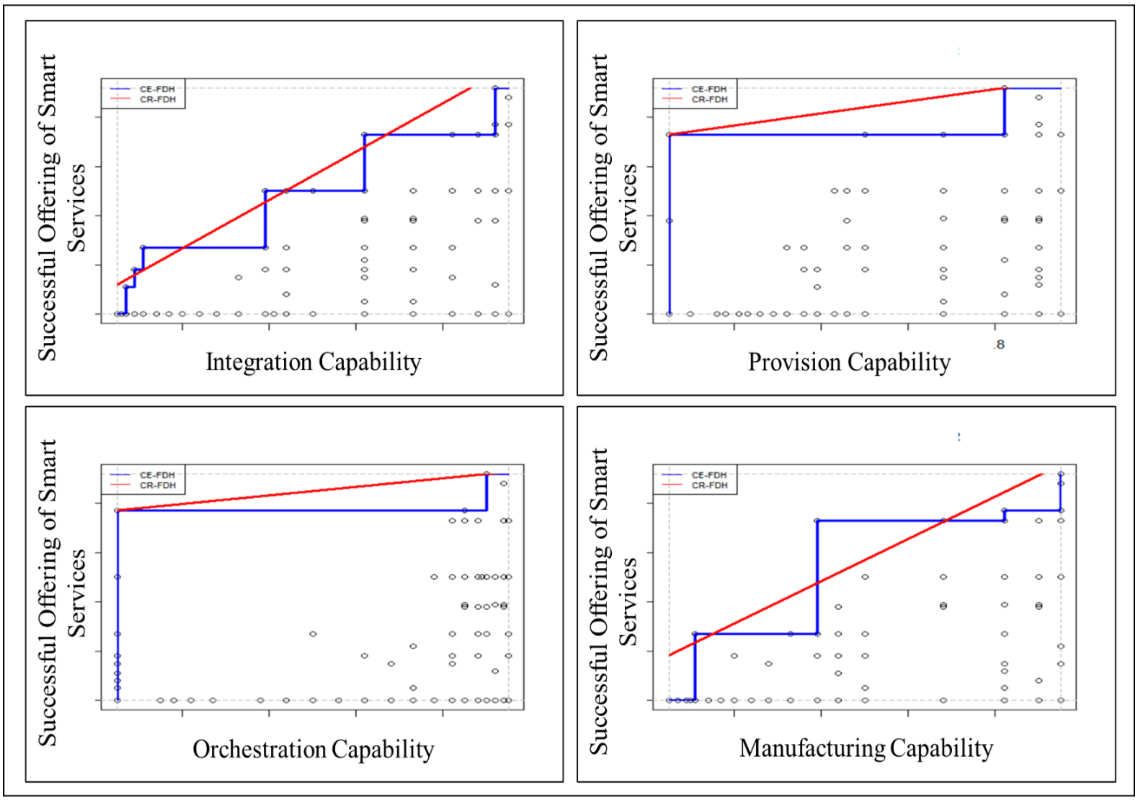
Therefore, the combination of the NCA with a qualitative multiple case study allows the examination of how firms build digital servitization capabilities for the successful offering of smart services. The following section presents the results obtained, and the discussions that they imply.

4. Results

4.1 Necessity of Digital Servitization Capabilities for the Successful Offering of Smart Services

In short, the NCA is based on area calculations. First, a scatterplot is built between a condition (X) and the outcome of interest (Y) to calculate the area that can contain observations (scope area) (Dul, 2016a). Then, using a ceiling technique, the NCA draws a line to isolate and calculate the area without cases in the upper left corner of the scatterplot (ceiling area) (Richter *et al.*, 2020). Figure 5 shows the scatterplots between each core digital servitization capability (X_n) and the successful offering of smart services (Y), as well as the ceiling lines drawn. By default, the NCA package includes two ceiling techniques: Ceiling Envelopment Free Disposal Hull (CE-FDH, the blue lines in Figure 5), and Ceiling Regression Free Disposal Hull (CR-FDH, the red lines in Figure 5) (Dul, 2021).

Figure 5 – Scatterplots between Core Digital Servitization Capabilities and the Successful Offering of Smart Services



According to Dul (2016a), the necessity of a condition for an outcome is determined by the ratio between the ceiling area and the scope area. This ratio represents the effect size: the size of the constraint imposed by the absence of the condition for the obtention of the outcome (Dul, 2016a). Therefore, the effect size depends on the ceiling technique utilized. Since there are no hard criteria for the choice of a ceiling technique in detriment of the other, it is recommended to identify the necessary conditions with both techniques, and compare their results for robustness check (Dul, 2021). In addition, the NCA performs a statistical significance test to measure the p-value of the effect size (Dul *et al.*, 2020). Table 10 presents the results.

Table 10 – Necessary Conditions Analysis (NCA)

Outcome (Y):	Successful Offering of Smart Services			
Ceiling Technique:	CE-FDH		CR-FDH	
Conditions (X_n)	Effect Size	p-value	Effect Size	p-value
Integration Capability	0.465***	0.000	0.393***	0.000
Provision Capability	0.177	0.234	0.088	0.472
Orchestration Capability	0.154*	0.090	0.077	0.154
Manufacturing Capability	0.409***	0.000	0.382***	0.000

*** = Significant at 1%; ** = Significant at 5%; * = Significant at 10%

The effect size varies from 0 to 1, and can be small ($0<d<0.1$), medium ($0.1\leq d<0.3$), large ($0.3\leq d<0.5$), or very large ($d\geq 0.5$) (Dul, 2016b; Richter *et al.*, 2020). According to Dul (2016a), circa 90% of the studies identify small and medium effect sizes. With both ceiling techniques, integration and manufacturing capabilities have large effects (which is rarely found in studies), statistically significant at 1%. With CE-FDH, provision and orchestration capabilities have medium effects, but only the orchestration capability is significant, and only at 10%. With CR-FDH, provision and orchestration capabilities have small effects, and both capabilities are not significant.

Hence: Integration and manufacturing capabilities are necessary conditions for a successful offering of smart services; Orchestration capability is also necessary, but to a lower degree, and; Provision capability is not necessary. To further examine the results, the NCA provides the bottleneck table (Table 11), which represents the ceiling lines in tabular form, demonstrating the degree to which the conditions are necessary for different degrees of the outcome (Dul, 2016a; Richter *et al.*, 2020).

Table 11 – Bottleneck Table

Ceiling Technique	Successful Offering of Smart Services (Y)	Integration Capability (X_1)	Provision Capability (X_2)	Orchestration Capability (X_3)	Manufacturing Capability (X_4)
CE-FDH	0%	NN	NN	NN	NN
	10%	2.2%	NN	NN	6.7%
	20%	6.7%	NN	NN	6.7%
	30%	37.8%	NN	NN	37.8%
	40%	37.8%	NN	NN	37.8%
	50%	37.8%	NN	NN	37.8%
	60%	63.3%	NN	NN	37.8%
	70%	63.3%	NN	NN	37.8%
	80%	96.7%	85.6%	NN	85.6%
	90%	96.7%	85.6%	94.4%	100%
	100%	96.7%	85.6%	94.4%	100%
CR-FDH	0%	NN	NN	NN	NN
	10%	NN	NN	NN	NN
	20%	7.2%	NN	NN	0.2%
	30%	17.6%	NN	NN	12.1%
	40%	28.0%	NN	NN	24.0%
	50%	38.4%	NN	NN	35.9%
	60%	48.8%	NN	NN	47.8%
	70%	59.2%	NN	NN	59.7%
	80%	69.5%	2.7%	NN	71.6%
	90%	79.9%	44.1%	36.5%	83.5%
	100%	90.3%	85.6%	94.4%	95.4%

NN = Non necessary condition

Considering both ceiling techniques, the bottleneck table demonstrates that little developed integration and manufacturing capabilities allow between 10% and 40% of a successful offering of smart services. Better developed integration and manufacturing capabilities, together with the provision capability, enable between 50% and 80% of a successful offering. And the combination of highly developed integration, manufacturing, provision, and orchestration capabilities enable between 90% and 100% of it. Therefore, although integration and manufacturing capabilities are more necessary than provision and orchestration capabilities for a successful offering of smart services, all four digital servitization capabilities are necessary to achieve high levels of this outcome.

To better understand the lower necessity of provision and orchestration capabilities, Table 12 presents descriptive statistics of the four core digital servitization capabilities, across groups of firms that use different service delivery strategies.

Table 12 – Descriptive Statistics of Core Digital Servitization Capabilities in Different Service Delivery Strategies

Service Delivery Strategy	Descriptive Statistic	Integration Capability	Provision Capability	Orchestration Capability	Manufacturing Capability
Mainly through service suppliers (n = 35)	Mean	3.89	2.03	4.45	4.21
	SD	0.99	1.60	0.55	0.72
	VC	26%	79%	12%	17%
Balanced between service suppliers and the firm (n = 82)	Mean	3.86	4.34	4.08	4.28
	SD	0.69	0.51	0.66	0.53
	VC	18%	12%	16%	13%
Mainly by the firm (n = 294)	Mean	3.57	4.25	2.15	4.01
	SD	0.90	0.52	1.52	0.70
	VC	25%	12%	71%	17%
Overall (n = 411)	Mean	3.66	4.08	2.73	4.08
	SD	0.88	0.92	1.62	0.68
	VC	24%	23%	59%	17%

SD = Standard Deviation; VC = Variation Coefficient

Table 12 shows that integration and manufacturing capabilities follow the same pattern across different service delivery strategies. The mean of integration and manufacturing capabilities is always, respectively, between 3.5 and 4.0, and between 4.0 and 4.3. On the other hand, the mean of provision and orchestration capabilities presents a relevant variation across the groups. In firms that mainly deliver services through service suppliers (e.g., dealers, technical assistance, distributors) (n = 35) the mean of the orchestration capability is 4.45, and of the provision is 2.03. In parallel, in firms that mainly deliver services by themselves (n = 294), the contrary occurs, the mean of the provision capability is 4.25, and of the orchestration capability is 2.15. Firms that balance both strategies (n = 82) have well-developed provision and orchestration capabilities, with means of 4.34 and 4.08, respectively.

Since most firms choose to deliver services either through service suppliers or through an internal operation (n = 35 + 294 = 329, which corresponds to 80% of the sample), then most firms tend to choose to use one capability to the detriment of the other, rather than combine them. This suggests that provision and orchestration capabilities have an interchangeable nature, being substitutable by each other. As replaceability is a characteristic of non-necessity (Dul, 2016a), this explains why provision and orchestration capabilities are less necessary for a successful offering of smart services than integration and manufacturing capabilities. To characterize the digital servitization capabilities, the next subsection further analyzes the results of the qualitative multiple case study.

4.2 Characteristics of Digital Servitization Capabilities for the Successful Offering of Smart Services

Through the scatterplots between core digital servitization capabilities and the successful offering of smart services (Figure 5), it was possible to identify 13 cases, from the 24 cases addressed in the multiple case study, among the observations in the upper right corner. That is, among observations that have highly developed capabilities and simultaneously create value by offering smart services. To characterize the digital servitization capabilities for the successful offering of smart services, qualitative data from these 13 cases were further analyzed. Table 13 describes them.

Table 13 – Well-Succeed Cases

ID	Main Product	Main Smart Service (Apps, Software, Online platforms to/ for...)	Interviewed	Duration (Hours)	Pages Transcript
Alpha	Elevators	Manage elevators performance	Service Manager	1:04:39	15
Beta	Automobiles	Manage vehicles performance; Customize vehicles	Quality Manager	1:27:31	21
Gamma	Mobile asphalt plants	Manage equipment performance; Remote maintenance services	Sales Manager	2:43:08	49
Delta	Agricultural tractors	Manage equipment performance; Remote maintenance services	IT Manager	1:34:07	35
Epsilon	Construction tractors	Manage equipment performance; Remote maintenance services	After Sales Manager	1:20:39	25
Zeta	Personal computers	Manage computers performance; Customize pay-per-use services	Service Manager	1:18:01	23
Eta	Belt conveyors	Manage equipment performance	Product Manager	1:07:12	19
Theta	Machining tools	Manage tools performance; Inventory management	Service Manager	1:31:55	24
Iota	Agricultural planters	Manage equipment performance; Remote maintenance services	Marketing Manager	1:35:43	29
Kappa	Pesticides	Manage pesticides performance	Innovation Manager	1:22:35	19
Lambda	T-shirts and footwear	Customize t-shirts and footwear	Product Manager	0:59:51	18
Mu	Silos	Manage equipment performance	Service Manager	1:12:16	17
Nu	Tires	Manage tires performance	Service Manager	1:14:35	23
			TOTAL	18:32:12	317

Regarding integration capability, the 13 cases present well-established processes to develop smart services: they monitor customers' needs, design services to meet these needs, and incorporate Big Data Analytics technologies into services. Service design is oriented to modularity, resulting in modular service packages. Alpha comments: "*Our maintenance contracts are customizable. We offer five standard contracts, each with different features. Consumers can add or remove these features to adapt the contract to their needs.".* The 13 cases establish partnerships with software companies, or even acquired them, to develop smart services. They also maintain partnerships with customers to test smart services prototypes, before making them available to the market. Iota states: "*We have customers who are our partners in the development of services, testing the services before we launch them. (...) They are the main users, and always give a lot of ideas on how to improve our services!*".

In terms of provision capability, seven cases have departments focused on the direct delivery of services to customers, counting on systematized internal service delivery processes that are simultaneously efficient and flexible, which enable quick adaptation to consumer needs without increase costs. Zeta comments: "*Our services follow standard scripts. Of course, each case has its particularities, and we must be flexible to adapt. But we follow a main line of action.*". These seven cases also have formalized service management processes to plan and control the service delivery, using KPIs (Key Process Indicators) to do so (e.g., delivery time, consumer satisfaction, service quality). Moreover, all 13 cases maintain an internal structure to manage their relationship with customers, with processes digitalized through CRM software. Delta highlights: "*Although our services are delivered through our dealers* (service suppliers)*, we maintain a whole structure here to manage the relationship with our customers. We consider it a key activity.*".

Concerning the orchestration capability, the 13 cases maintain some kind of partnership with service suppliers to indirectly deliver services, as well as partnerships with software companies, to support the analysis of data obtained from smart services. Alpha states: "*We count on a company specialized in data science. We cannot be good at everything, so we need partners to analyze the data. (...) In this process, we also have to guarantee data security, as the data belong to our consumers. It is not ours.*". Furthermore, eight cases have departments focused on coordinating the service network, establishing systematized service delivery processes to service suppliers, making them able to quickly adapt to new service offerings. These eight cases also make substantial investments to digitalize their service network. Epsilon comments: "*All our dealers use the same software to provide services to customers. This helps to standardize the service delivery across our network.*".

For the manufacturing capability, the 13 cases have well-established programs for the continuous improvement of products and production processes, such as total quality management and just-in-time. They also use data related to product performance (e.g., operational performance, sales history, consumer preferences), collected through smart services, as input for these programs. Gamma highlights: "*Our goal with the offering of services was always to use them as a means of collecting data to improve our products and processes.*". All 13 cases apply advanced manufacturing technologies, including the incorporation of software, apps, and online platforms to develop products, manage and execute production, as well as the adoption of updated production technologies, such as additive manufacturing and advanced robotics. In basically all cases, the product design is oriented to modularity, enabling mass product customization. Lambda states: "*Our business model, and consequently our production, is focused on the customization of our products.*".

Table 14 summarizes the characteristics of the digital servitization capabilities in the well-succeed cases. Table 14 indicates in which cases these characteristics are present, highlighting when their presence consists of a pattern among the successful cases.

Table 14 – Characterization of Core Digital Servitization Capabilities in Well-Succeed Cases

Capability	Characteristics	Cases												
		Alpha	Beta	Gamma	Delta	Epsilon	Zeta	Eta	Theta	Iota	Kappa	Lambda	Mu	Nu
Integration Capability	Systematized processes to develop smart services	X	X	X	X	X	X	X	X	X	X	X	X	X
	Service design oriented to modularity	X	X	X	X	X	X	X	X	X	X	X	X	X
	Formalized partnerships with software companies to develop smart services	X	X	X	X	X	X	X	X		X	X		X
	Formalized partnerships with customers to develop smart services	X	X	X	X		X	X		X	X	X	X	X
Provision Capability	Exclusive service department and personnel	X					X	X	X		X	X		X
	Systematizes efficient and flexible internal processes to deliver services	X					X	X	X		X	X		X
	Formalized service management	X					X	X	X		X	X		X
	Digitalized customer relationship management	X	X	X	X	X	X	X	X	X	X	X	X	X
Orchestration Capability	Formalized partnerships with service suppliers to deliver services	X	X	X	X	X	X	X		X	X	X	X	X
	Formalized partnerships with software companies to analyze data obtained through smart services	X	X	X	X	X	X	X	X		X	X		X
	Systematizes efficient, and flexible processes for service suppliers to deliver services		X	X	X	X				X	X	X	X	
	Digitalized service network		X	X	X	X				X		X	X	X
Manufacturing Capability	Systematized continuous improvement programs	X	X	X	X	X	X	X	X	X	X	X	X	X
	Use of data obtained through smart services in continuous improvement programs	X	X	X	X	X	X		X	X	X	X	X	X
	Updated manufacturing technologies	X	X	X	X	X	X	X	X	X	X	X	X	X
	Product design oriented to modularity	X	X	X	X	X	X	X	X	X		X	X	

X = Presence of the characteristic; Gray = The characteristic consists of a pattern among the successful cases

Table 14 shows that basically all the characteristics related to integration and manufacturing capabilities are present in successful cases, consisting of patterns. Successful cases are strongly characterized by the interaction between these two capabilities. While the integration capability develops smart services that enable the collection and conversion of data related to product performance into knowledge and intelligence, the manufacturing capability applies this knowledge and intelligence to continuous improvement programs. Therefore, successful cases create value not only by adding services to products, but also by using the data obtained through smart services to improve product design, quality, and performance, as well as production planning, control, and execution.

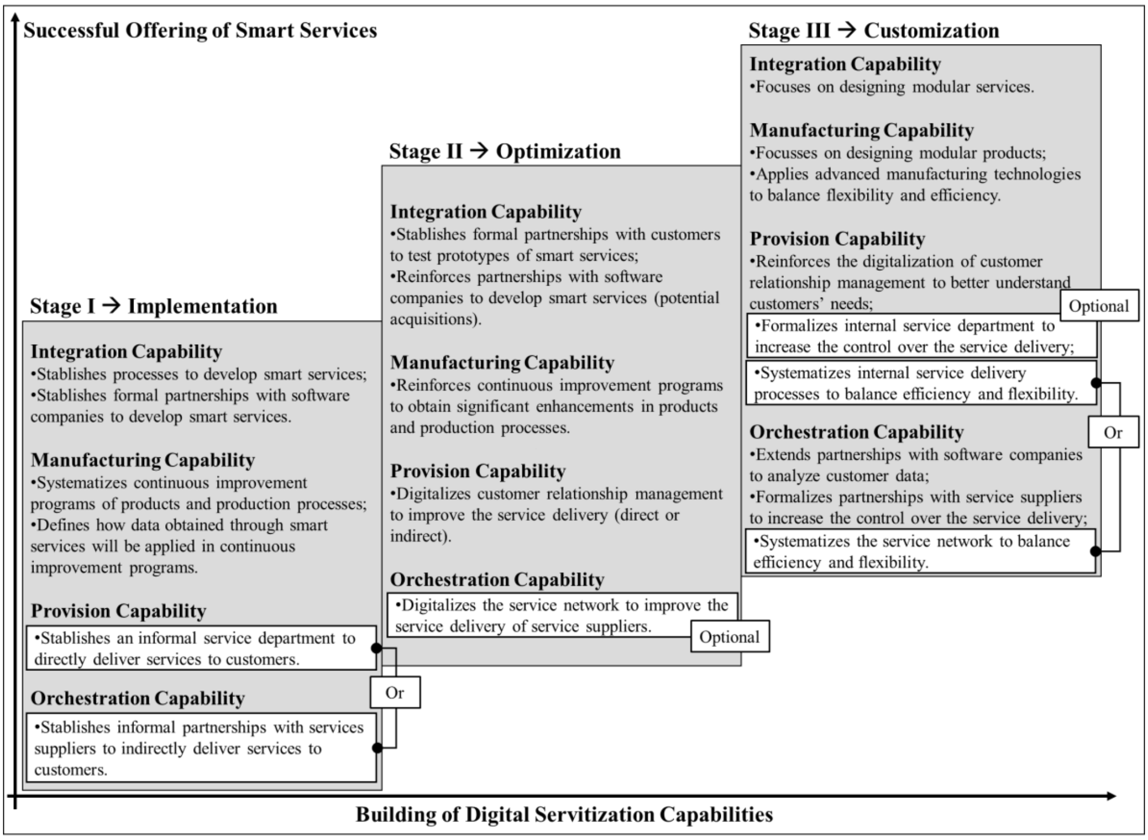
In parallel, Table 14 shows that two characteristics of the orchestration capability and one characteristic of the provision capability consist of patterns in successful cases, while the other characteristics of these capabilities are interchangeable. The central pattern of well-succeed cases is to use the orchestration capability to formalize partnerships with service suppliers and software companies to indirect deliver services to customers, and the provision capability to support it by digitalizing the customer relationship management. Six cases complement this pattern with the interchangeable characteristics of the orchestration capability (Beta, Gamma, Delta, Epsilon, Iota, and Mu), while four cases prefer to use the interchangeable characteristics of the provision capability (Alpha, Zeta, Eta, and Theta), combining the indirect and direct service delivery. Three cases (Kappa, Lambda, and Nu) use the interchangeable characteristics of both capabilities. The following section discusses the results of the qualitative and quantitative studies.

5. Discussion: Building Digital Servitization Capabilities for the Successful Offering of Smart Services

The results of the qualitative study reinforce the results of the quantitative study. The strong interaction between integration and manufacturing capabilities observed in successful cases corroborates the high necessity of these two capabilities for a successful offering of smart services. In parallel, the interchangeability between certain characteristics of the provision and orchestration capabilities is consistent with their low necessity: since these capabilities have characteristics that are replaceable, they cannot be highly necessary conditions (Dul, 2016a). Furthermore, the qualitative analysis complements the quantitative study by characterizing how integration and manufacturing capabilities interact to create value, and by demonstrating which elements of provision and orchestration capabilities are interchangeable, and which are mandatory.

The results of both studies were combined to examine how firms build digital servitization capabilities to reach a successful offering of smart services. To do so, the bottleneck table (Table 11) was divided into three levels of capability development, following the natural breakpoints identified in Section 4.1: from 10% to 40% of a successful offering, from 50% to 80%, and from 90% to 100%. Then, the characteristics of the digital servitization capabilities identified in the well-succeed cases (Table 14) were combined with these three levels. This combination was made taking into account the previous literature, resulting in a three-stage path of capability building: ***Implementation***, ***Optimization***, and ***Customization*** (Figure 6).

Figure 6 – The Building of Core Digital Servitization Capabilities for a Successful Offering of Smart Services



The first stage, ***Implementation***, consists of implementing the offering of smart services, resulting only on low levels of value creation. For the integration capability, firms must build processes to develop smart services (Adrodegari and Saccani, 2019;

Huikkola *et al.*, 2021), and must establish formal partnerships with software companies to support it (Chirumalla *et al.*, 2023). In parallel, for the manufacturing capability, firms must systematize continuous improvement programs (Qi *et al.*, 2020; Sousa and Silveira, 2017), and define how data obtained through smart services will be applied to improve products and production processes.

Since provision and orchestration capabilities are non-necessary conditions for low levels of a successful offering of smart services, firms do not need to develop them in the implementation stage. However, services must be delivered to customers in some way. In this regard, firms can start building the provision capability by setting up an informal service department, generally with current sales personnel (Jovanovic *et al.*, 2019), to directly deliver services to customers. Another option is to start building the orchestration capability by establishing informal partnerships with service suppliers, such as technical assistance, distributors, stores, and so on (Story *et al.*, 2017), to indirectly deliver services.

The second stage, ***Optimization***, consists of optimizing the offering of smart services, resulting in intermediate levels of value creation. For the integration capability, firms must establish formal partnerships with key customers to test service prototypes (Huikkola *et al*., 2017), and reinforce the already consolidated partnerships with software companies. Acquisitions of software companies must be considered in some cases, to ensure the security of data and intellectual property of the smart services developed (Huikkola *et al.*, 2022). Furthermore, for the manufacturing capability, firms must refine the use of data obtained through smart services in continuous improvement programs, aiming to obtain significant enhancements in products and production (Wei *et al.*, 2022).

Independtly of the capability chosen in the implementation stage to deliver smart services, in the optimization stage firms must develop the provision capability, digitalizing the customer relationship management to improve the identification and correction of flaws in service delivery processes (Storbacka, 2011). Firms that use the orchestration capability to indirectly deliver services have the option to improve these processes even more. They can develop the orchestration capability, implementing digital technologies in service suppliers to standardize and automate indirect service delivery processes throughout the service network (Parida *et al.*, 2015).

The third stage, ***Customization***, consists of customizing the offering of smart services, resulting in high levels of value creation. For the integration capability, firms must build processes to design modular services, through which different standard features can be combined to assemble personalized services (Adrodegari and Saccani, 2019; Rajala *et al.*, 2019). This makes service customization feasible, increasing flexibility without losing efficiency. Similarly, for the manufacturing capability, firms must build processes to design modular products, which allows the offering of product customization services (Qi *et al.*, 2020; Sousa and Silveira, 2019). Moreover, to support product customization, firms must also adopt advanced manufacturing technologies that refine the balance between production flexibility and efficiency, the so-called flexible automation equipment, such as additive manufacturing and advanced robotics (Salvador *et al.*, 2020).

To assist in the development of customized services, firms must develop both provision and orchestration capabilities to refine the understanding of customers' needs. For the provision capability, the digitalization of customer relationship management must be reinforced (Kimita *et al.*, 2022), while for the orchestration capability, partnerships with software companies must be extended to enhance the analysis of customer data (Dalenogare *et al.*, 2023; Momeni *et al.*, 2023).

The delivery of customized smart services must occur indirectly, through the orchestration capability, or by combining orchestration and provision capabilities. This probably occurs because service suppliers have more expertise in delivering complex services than manufacturing firms (Marcon *et al.*, 2022). Therefore, for the orchestration capability, partnerships with service suppliers must be formalized, while for the provision capability, the formalization of an internal service department is optional. Consequently, to balance flexibility and efficiency in service delivery, if firms use only the orchestration capability, they must systematize the indirect service delivery processes (Lütjen *et al.*, 2019). However, if firms use orchestration and provision capabilities, they can choose if they will systematize the indirect or direct service delivery (Sjödin *et al.*, 2016).

In sum, integration and manufacturing capabilities are essential for a successful offering of smart services, while provision and orchestration capabilities are only auxiliary. In the three stages of capability building, integration and manufacturing capabilities play the key role in designing (implementation stage), improving (optimization stage), and personalizing (customization stage) smart services. Provision and orchestration capabilities complement them by operationalizing an informal service delivery (implementation stage), a digitalized service delivery (optimization stage), and a service delivery that can balance efficiency and flexibility (customization stage). Although the development of some characteristics of the provision and orchestration capabilities is mandatory, other characteristics are interchangeable, which confers different options for firms to configure the service delivery in each stage. The next section brings some final remarks.

6. Conclusion

The article reached its objective of identifying how manufacturing firms build digital servitization capabilities for a successful offering of smart services. To do so, a theoretical framework of four core digital servitization capabilities (Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability) was considered, and a mixed-method approach was adopted. First, a quantitative study was carried out, applying the NCA to measure the degree to which these four core capabilities are necessary for different levels of a successful offering of smart services. To complement the NCA, a qualitative multiple case study was conducted to characterize these capabilities in well-succeed cases.

The NCA demonstrates that the building of integration and manufacturing capabilities is fundamental for a successful offering of smart services, while the building of provision and orchestration capability is only complementary. The multiple case study characterizes a strong interaction between integration and manufacturing capabilities to develop smart services, defining how data will be collected and applied to improve products and production processes. Moreover, the multiple case study also characterizes an interchangeable nature between elements of provision and orchestration capability. This explains their lower necessity for a successful offering of smart services, once replaceability is a characteristic of non-necessary conditions. On the other hand, this interchangeability allows firms to combine these two capabilities in different forms to deliver smart services.

The combination of these results suggests a three-stage path of capability building for the successful offering of smart services: Implementation, Optimization, and Customization. In the implementation stage, firms must develop basic elements of integration and manufacturing capabilities to establish the offering of smart services. In the optimization stage, firms should further develop integration and manufacturing capabilities, as well as the provision capability, to improve the design and delivery of smart services. And in the customization stage, firms must develop elements of the four core capabilities to offer personalized smart services.

This study brings theoretical contributions by shedding light on how digital servitization capabilities enable the offering of smart services. Moreover, by applying the emerging quantitative technique NCA, this article also makes methodological contributions. The interest in the NCA is increasing, given the observed growth of its use in management studies. The present article supports the consolidation of this new technique, and suggests a novel way to use the NCA, by complementing it with a qualitative multiple case study. The relevance of these methodological contributions is even greater in the context of the literature on digital servitization capabilities, which is mostly composed of purely exploratory case studies.

With regard to practical contributions, this article can assist managers in establishing a successful offering of smart services in their companies. The proposed three-stage path of capability development can work as a guide for managers, helping them to identify the development level of the digital servitization capabilities of their companies, as well as the future steps to develop them towards a well-succeed offering of smart services. In parallel, public decision makers can also benefit from this study. The proposed three-stage path can be utilized to analyze the digital servitization capabilities of manufacturing firms at the sectoral level, supporting public managers to create public policies for their development in this regard.

The present research has two main limitations. First, the capability approach can only capture the role of the firm’s internal competencies in value creation, ignoring the role of external aspects, such as the influence of public policies and institutions. Second, since only Brazilian companies were addressed in the research, some caution should be taken when generalizing the results to companies in developed economies. Emerging economies tend to be laggards in the adoption of new technologies, and thus, the proposed path of capability building may not be sufficient for companies in central economies to achieve a successful offering of smart services.

However, future studies can overcome both limitations. Future studies can explore how external factors to the firm affect the building of digital servitization capabilities towards the offering of smart services, as well as can replicate this research with companies in developed countries, comparing the results and identifying if a different path of capability building is required. Furthermore, the present article explored the capability building towards a trajectory of convergence between servitization and digitalization. An important research gap that remains in the literature is how firms in different digital servitization trajectories use their capabilities to create value.

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Appendix 1: Qualitative Semi-structured Questionnaire

Overall Questions

1. Briefly describe the main products offered by your company.
2. Briefly describe the services offered to complement these products. Such services could be offered directly by the company, or through partnerships (e.g., dealers, franchises, …).
3. Which digital technologies are involved in the services offered to customers (e.g., apps, Cloud Computing, Machine Learning, …)?

Integration Capability

4. How does the service development occur?
5. How do customers participate in service development?
6. How do partners participate in service development (e.g., service companies, software developers, …)?
7. How data obtained through services are analyzed?

Provision Capability

8. Describe the company's organizational structure to provide services to its customers.
9. How does the service provision occur (e.g., norms, procedures, ...)?
10. How does the company manage the service provision (e.g., trainings, indicators, …)?
11. How do digital technologies support service provision?

Orchestration Capability

12. How the company establish partnerships to deliver services to its customers (e.g., search, selection, hiring …)?
13. How do these partners participate of the service delivery to customers?
14. How the company monitor the performance of these service partners (e.g., training, indicators, …)?
15. How digital technologies are applied to interact with these service partners?

Manufacturing Capability

16. What drives the product development (e.g., product standardization, product modularization, product customization, …)?

17. Briefly describe the main characteristics of the company's production process (e.g., job-shop, mass production, production technology, automation, …).
18. How the company improve its products and production (e.g., informally, formalized programs, …)?
19. How digital technologies are applied in product development and production (e.g., design software, production management software, use of data collected through services)?

Appendix 2: Items removed in the Principal Component Analysis (PCA)

Integration Capability

- We monitor market needs related to services
- We acquire digital technologies available in the market

Provision Capability

- We have information systems integrated with our customers to provide services
- We can quickly adapt to new services offerings

Orchestration Capability

- We can quickly adapt our partners to new services offerings

Manufacturing Capability

- We customize our products without compromise our efficiency
- We have integrated information systems with our customers and suppliers to exchange data related to production

Appendix 3: Types of Services Added to Products (Dichotomous Variables)

Does your firm add the following services to its products?

Type of Service	Yes (1)	No (0)
Exchanges and returns		
Technical support		
Spare parts		
Installation and assembly		
Training		
Financing		
Insurances		
Maintenance		
Product update (Retrofit)		
Product personalization		

Type of Service	**Yes (1)**	**No (0)**
Functional services		
Renting or pay-per-use		

4. **ARTICLE III –** Configuring the Firm's Digital Servitization Capabilities for Value Creation in Different Trajectories

Authorship: Estêvão Passuello Ruffoni and Fernanda Maciel Reichert

Status: Not submitted. Awaiting the publication of Article I.

Abstract

Digital servitization is one of the main paradigm changes in the current emergence of Industry 4.0. A paradigm is a pattern, an ideal model to be followed, which can be achieved by firms through different trajectories. The purpose of this study is to identify the trajectories followed by firms towards the digital servitization paradigm, and the configurations of capabilities through which firms create value in each trajectory. To identify the digital servitization trajectories, a cluster analysis was applied to a database of 411 Brazilian manufacturing firms. Then, to each cluster (trajectory), the fsQCA was applied to identify the configurations of capabilities through which firms create value, considering a theoretical framework of four digital servitization capabilities (Integration Capability, Provision Capability, Orchestration Capability, and Manufacturing Capability). The results confirm previous studies, indicating that firms follow four digital servitization trajectories: Traditional, Digitalization, Servitization, and Convergence. In parallel, results also demonstrate that, in each trajectory, firms use specific configurations of digital servitization capabilities to create value. However, firms in convergence trajectories obtain a higher level of value creation than the others.

Keywords: Digital Servitization, Core Capabilities, Servitization, Digitalization, Industry 4.0

1. Introduction

A paradigm can be defined as a pattern, an ideal model to be achieved by firms (Dosi, 1982; Von Tunzelman *et al.*, 2008). In the current emergence of the fourth industrial revolution (Industry 4.0), digital servitization is one of the main paradigm changes that manufacturing firms face (Frank *et al.*, 2019; Paiola *et al.*, 2021), which is moving them from established paradigms, oriented to only develop and fabricate products, to a new paradigm, oriented to the offering of integrated solutions between products, services, and digital technologies (Kohtamäki *et al.*, 2021). In this regard, digital servitization is the amalgamation of two changing processes: digitalization, the incorporation of digital technologies, and servitization, the addition of services to products (Bortolluzi *et al.*, 2022; Shen *et al.*, 2023).

The transition of manufacturing firms to the digital servitization paradigm is a consolidated trend (Culot *et al.*, 2020; Martin-Peña *et al.*, 2018), and already can be taken as a matter of necessity for their survival, rather than as a matter of option. To achieve a paradigm, firms can follow different trajectories towards it (Christensen, 1995; Dosi, 1982). In terms of digital servitization, studies suggest that manufacturing firms follow four major trajectories (Frank *et al.*, 2019). Firms following ***Traditional Trajectories*** only add simple services to products, and incorporate few digital technologies (Lerch and Gotsch, 2015). Firms following ***Servitization Trajectories*** focus on adding services to products, while firms following ***Digitalization Trajectories*** focus on the incorporation of digital technologies (Coreynem *et al.*, 2017). At last, firms following ***Convergence Trajectories*** merge servitization and digitalization, and generally are those that obtain the best results (Frank *et al.*, 2019; Kohtamäki *et al.*, 2020).

In parallel, the firm's capabilities consist of sets of knowledge, resources, routines and skills accumulated overtime for the execution of a given activity (Lall, 1992; Pufal and Zawislak, 2021; Teece, 2007, 2018). Regarding digital servitization, the literature highlights that firms need capabilities related to servitization and digitalization. While through servitization capabilities, firms develop and deliver services (Marcon *et al*., 2022; Ulaga and Reinartz, 2011; Valtakoski and Wittel, 2018), through digitalization capabilities, firms search, select, and incorporate digital technologies (Kimita *et al.*, 2022; Lenka *et al.*, 2017). Furthermore, manufacturing capabilities, through which firms develop and fabricate products, are also considered relevant for digital servitization (Matthyssens *et al.*, 2009; Sousa and Silveira, 2017).

Once every firm incorporates some type of service into its products (Manresa *et al.*, 2021; Parida *et al.*, 2014), all firms have digital servitization capabilities at some level (Ruffoni and Reichert, 2023), even those in traditional trajectories. However, since the literature does not cross the capabilities approach with the trajectory approach, it remains unclear if and how firms can use their digital servitization capabilities to create value in different trajectories. To cover this research gap, the present study aims to answer the following question: ***How can firms configure their capabilities to create value in different digital servitization trajectories?***

To answer the research question, the framework of digital servitization capabilities proposed by Ruffoni and Reichert (2023) was adopted. The framework encompasses four core capabilities: few high-order capabilities that systematize minor capabilities to generate competitive advantages and create value (Leonard-Barton, 1992; Prahalad and Hammel, 1990; Teece, 2007; 2018). The ***Integration Capability*** relates to service development and incorporation of digital technologies. The ***Provision Capability*** relates to the execution and digitalization of the service delivery. The ***Orchestration Capability*** relates to the building and digitalization of a network of service partners. And the ***Manufacturing Capability*** relates to the execution and digitalization of product development and production processes in order to support service offerings (Ruffoni and Reichert, 2023).

Based on this framework, a survey was conducted with 411 Brazilian manufacturing firms. To identify the digital servitization trajectories followed by firms, a cluster analysis was performed, and to identify the configurations of capabilities through which firms create value in each trajectory (in each cluster), the fuzzy-set Qualitative Comparative Analysis (fsQCA) was applied. With large samples, the main advantage of using the fsQCA, to the detriment of traditional statistical methods, is its focus on obtaining multiple solutions for a given outcome (equifinality), which enriches the results obtained. Additionally, nonparametric statistical tests were carried out to compare the digital servitization capabilities between clusters.

The results confirm the literature, indicating that firms follow four trajectories towards the digital servitization paradigm: traditional, digitalization, servitization, and convergence. For each trajectory, there are specific configurations of digital servitization capabilities through which firms can create value. The results also demonstrate that the transition of firms between trajectories requires considerable efforts, but that firms on convergence trajectories obtain a higher level of value creation than the others, being worthwhile for firms to transit in this direction.

2. Theoretical Background

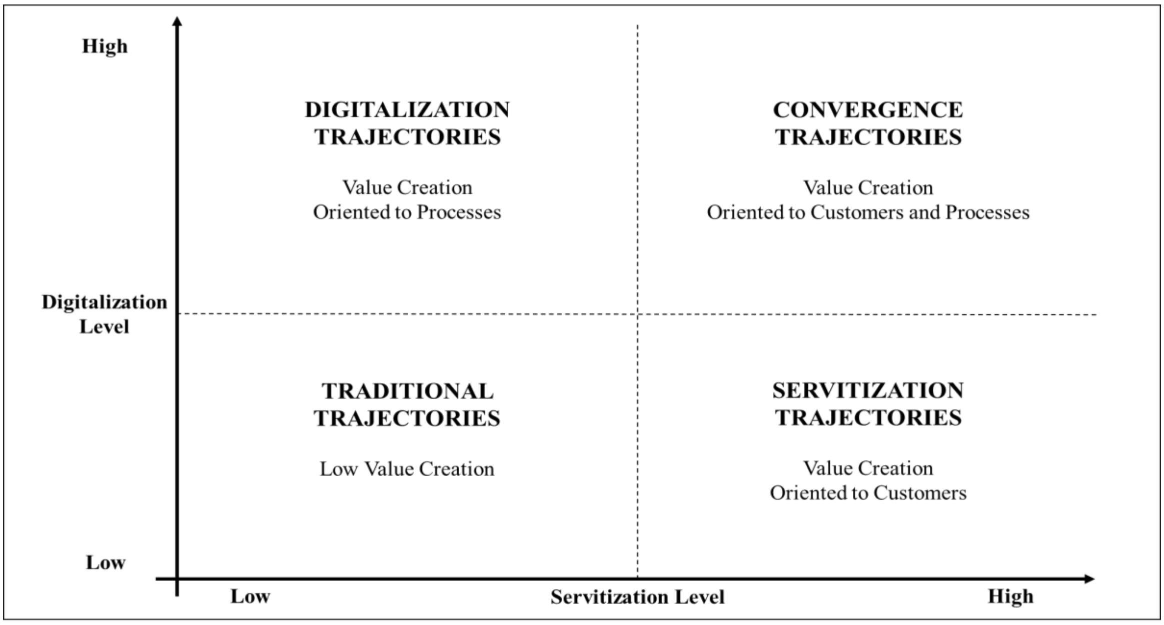
2.1 Digital Servitization Paradigm and Trajectories

According to Dosi (1982), technological and market changes are the drivers of economic growth, shaping the paradigms, that is, the patterns to be followed by firms (Von Tunzelman *et al.*, 2008). The first three industrial revolutions established paradigms in which manufacturing firms should focus on the development and fabrication of standardized products (Liao *et al.*, 2017; Xu *et al.*, 2018). However, the emergence of the fourth industrial revolution (Industry 4.0) is bringing new paradigms, caused by the advent of disruptive digital technologies and market needs for more customized products (Culot *et al.*, 2020; Martin-Peña *et al.*, 2018; Weking *et al.*, 2019).

Digital servitization is one of the main new paradigms, being the amalgamation of two changing processes: digitalization and servitization (Bortoluzzi *et al.*, 2022; Paiola *et al.*, 2021; Shen *et al.*, 2023). Digitalization is a technological change, consisting of the incorporation of digital technologies to add new functionalities to products and optimize processes (Guo *et al.*, 2023; Nasiri *et al.*, 2022; Vial, 2019). Servitization is a market change, consisting of the aggregation of services to products to make them more customized and less commoditized (Baines *et al.*, 2020; Brax, 2005; Vandermerwe and Rada, 1988). With this, digital servitization moves manufacturing firms from the offering of standardized products, to the offering of customized integrated solutions between products, services, and digital technologies (Favoretto *et al.*, 2022; Kohtamäki *et al.*, 2021).

Firms may follow different trajectories towards a paradigm, that is, may follow different directions of advancement (Christensen, 1995; Dosi, 1982). In terms of the digital servitization paradigm, studies suggest that firms follow trajectories more oriented to servitization, or to digitalization, or to the combination of both (Abou-Foul *et al.*, 2021; Coreynem *et al.*, 2017; Kharlamov and Parry, 2020; Kohtamäki *et al.*, 2020; Lerch and Goestch, 2015; Martin-Peña *et al.*, 2020). In this regard, Frank *et al.* (2019) propose that firms can follow four major trajectories in direction to the digital servitization paradigm, which are determined by their level of digitalization and of servitization: ***Traditional Trajectories***, ***Digitalization Trajectories***, ***Servitization Trajectories,*** and ***Convergence Trajectories*** (Figure 7).

Figure 7 – Firms' Trajectories Toward the Digital Servitization Paradigm



Source: Adapted from Frank *et al*. (2019)

The level of digitalization refers to the degree in which firms incorporate digital technologies (Abou-Foul *et al.*, 2021; Martin-Peña *et al.*, 2020). The term digital technology encompasses from established technologies, such as sensors and software, to the most recent novelties of Industry 4.0, such as the Internet of Things (connectivity between devices), Cloud Computing (remote storage and availability of data), and Big Data Analytics (complex analysis of data with machine learning and artificial intelligence) (Cater *et al.*, 2021; Santos and Martinho, 2019; Zangiacomi *et al.*, 2020). Emerging manufacturing technologies are also considered as digital technologies, such as industrial robots (robots that automate heavy repetitive processes), collaborative robots (robots that automate delicate handmade processes by supporting operators), AGVs (Automatic Guided Vehicles), and additive manufacturing equipment (a.k.a. digital layered manufacturing, or 3D printers) (Eyers *et al.*, 2021; Kerin and Pham, 2020; Zheng *et al.*, 2020).

The level of servitization refers to the degree in which firms add services to their products (Kharlamov and Parry, 2020; Kohtamäki *et al.*; 2020). Firms can add simple services, which only support the product (e.g., training, spare parts, financing) (Tukker, 2004), services with an intermediate complexity, which adapt the product to customers' needs (e.g., product customization, product update) (Cusumano *et al.*, 2015), or complex services, which substitute the customers' need to purchase products (e.g., renting, pay-per-use, operating the customer process) (Baines and Lightfoot, 2013; Parida *et al.*, 2014). It is important to note that the level of servitization does not represent the linear move of firms across these complexity levels, but rather the degree in which firms accumulate the offering of different types of services (Cusumano *et al.*, 2015; Kohtamäki *et al.*, 2020).

Regarding the four major trajectories, firms following ***Traditional Trajectories*** are those that resist adapting to the digital servitization paradigm (Frank *et al.*, 2019). Traditional firms add few services to their products and incorporate few digital technologies (Lerch and Goestch, 2015). Considering that paradigms coexist (Freeman and Perez, 1988), traditional firms try to remain in the paradigms established by the previous industrial revolutions, maintaining their focus on developing and fabricating standardized products (Liao *et al.*, 2017; Xu *et al.*, 2018). However, given that manufacturing firms are intensively moving towards digital servitization (Culot *et al.*, 2020; Martin-Peña *et al.*, 2018; Weking *et al.*, 2019), firms in traditional trajectories are taking the risk of losing competitiveness.

Firms following ***Digitalization Trajectories*** are pushed to the digital servitization paradigm by technological advancements (technology-push), creating value by increasing efficiency through the digitalization of processes (Frank *et al.*, 2019). Although digitalized firms incorporate a wide variety of digital technologies, including the most advanced technologies, they add few services to products (Abou-Foul *et al.*, 2021; Martin-Peña *et al.*, 2020). With this, digitalized firms are focused on the back-end digitalization: the digitalization solely oriented to optimize processes (Coreynem *et al.*, 2017).

On the other hand, firms following ***Servitization Trajectories*** are pulled to the digital servitization paradigm by emerging market needs (demand-pull), creating value by increasing product differentiation through the addition of services to them (Frank *et al.*, 2019). Servitized firms add a broad variety of services to products, offering different types of services, however, they incorporate few digital technologies (Kharlamov and Parry, 2020; Kohtamäki *et al.*; 2020).

At last, firms following ***Convergence Trajectories*** are driven towards the digital servitization paradigm simultaneously by digitalization (technology-push) and servitization (demand-pull), achieving the highest level of value creation (Frank *et al.*, 2019). Convergent firms add a broad variety of service types to their products and incorporate a wide range of digital technologies (Kohtamäki *et al.*, 2020; Lerch and Goestch, 2015; Martin-Peña *et al.*, 2020). With this, unlike digitalized firms, convergent firms are not focused only on a back-end digitalization. The combination of the incorporation of digital technologies with the addition of services makes convergent firms also focus on a front-end digitalization: the digitalization oriented to add value to customers, which is manifested in the offering of digital services (Coreynem *et al.*, 2017).

The trajectories followed by firms can be further understood through the lens of firms' capabilities. Capabilities can explain how firms create value in their current digital servitization trajectory, as well as how firms can transit from one trajectory to another. In this regard, the next section explores the literature on the digital servitization capabilities of the firm.

2.2 Digital Servitization Capabilities

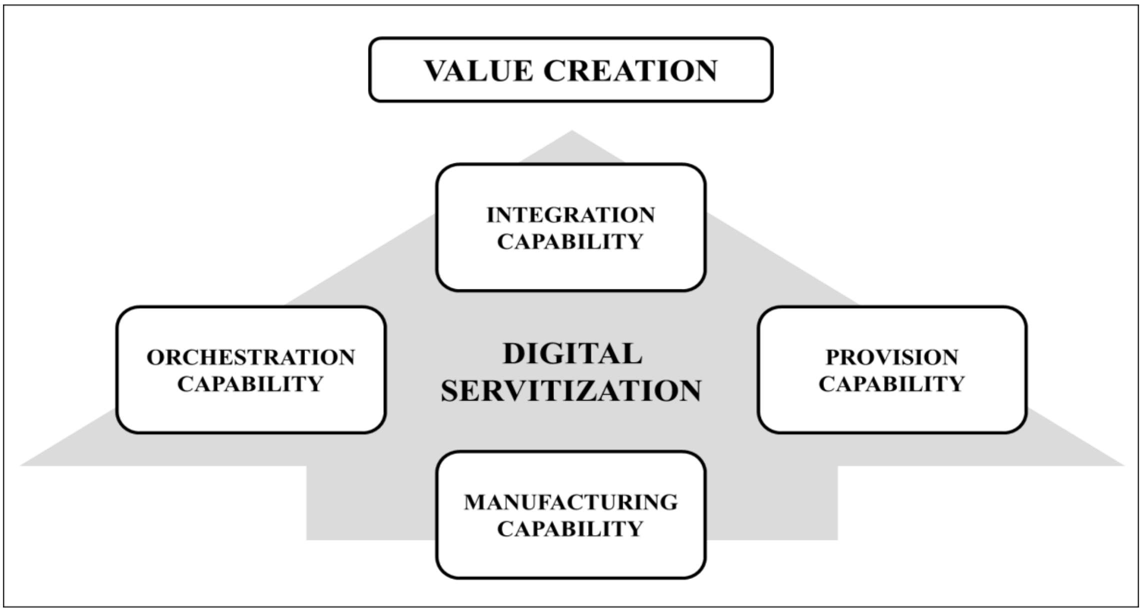
The firm's capabilities can be defined as sets of knowledge, resources, routines and skills accumulated overtime by the firm for the execution of a given activity (Lall, 1992; Pufal and Zawislak, 2021; Teece, 2007, 2018). Regarding digital servitization, the literature highlights the importance of capabilities related with servitization, such as capabilities to develop services (Adrodegari and Sacanni, 2020; Kindström *et al.*, 2013; Wallin *et al.*, 2015), to directly deliver services to consumers, through the creation and management of internal service delivery processes (Gebauer, 2011; Ulaga and Reinartz, 2011; Valtakoski and Wittel, 2018), as well as to indirectly deliver services, through the building and coordination of partnerships with service companies (Lütjen *et al.*, 2019; Marcon *et al*., 2022; Story *et al*., 2017).

Some studies also address the role of manufacturing capabilities in digital servitization, exploring their importance for the offering of different types of services. For example, manufacturing capabilities support the offering of warranties and maintenance services by enhancing product performance (Manresa *et al.*, 2021; Sousa and Silveira, 2017), as well as assist the offering of spare parts services by perfecting production planning, scheduling, and control (Matthyssens *et al.*, 2009). Notwithstanding, the main role of manufacturing capabilities lies in the offering of product customization services, through the adoption of mass product customization practices (Qi *et al.*, 2020; Sousa and Silveira, 2019).

Moreover, capabilities related to digitalization are also necessary. Digitalization capabilities enable a proper selection, incorporation, and use of digital technologies to collect and analyze data related to product usage and customer preferences, in order to support service offerings (Hasselblat *et al.*, 2018; Kimita *et al.*, 2022; Lenka *et al.*, 2017). However, studies still focus more on capabilities related to servitization, putting capabilities related to digitalization in a second level of relevance (Munch *et al.*, 2022).

The present study adopts the theoretical framework of digital servitization capabilities presented by Ruffoni and Reichert (2023) because it considers that servitization and digitalization elements have the same degree of importance for digital servitization to occur. This enables the reading of both changing processes and, thus, the achievement of the research objective. The theoretical framework (Figure 8) consists of four core capabilities: few high-order capabilities that systematize minor capabilities in order to create competitive advantages (Leonard-Barton, 1992; Prahalad and Hammel, 1990; Teece, 2007, 2018).

Figure 8 – Theoretical Framework of the Firm's Core Digital Serivitization Capabilities



Source: Adapted from Ruffoni and Reichert (2023)

The ***Integration Capability*** develops services, incorporates digital technologies to support them, and integrates both with products (Ruffoni and Reichert, 2023). This core capability encompasses minor capabilities to monitor customer needs, design services to meet these needs (Adrodegari and Sacanni, 2020; Beltagui, 2018; Solem *et al.*, 2022), co-create services with customers and partners (Kindström *et al.*, 2013), test prototypes of services, and implement the service offering (Wallin *et al*., 2015). In parallel, the integration capability also involves minor capabilities to search, select, and incorporate digital technologies that can be applied in service offerings (Chirumalla *et al.*, 2023), such as the Internet of Things, Cloud Computing platforms, and Big Data Analytics (Hasseblat *et al.*, 2018; Lenka *et al.*, 2017).

The ***Provision Capability*** creates and manages internal service delivery processes to directly deliver services to customers, as well as digitalizes these processes (Ruffoni and Reichert, 2023). This core capability involves minor capabilities to organize, plan, control, and execute the service delivery (Baines *et al*., 2009; Jovanovic *et al.*, 2019; Valtakoski and Wittel, 2018), as well as to train and manage service personnel (Gebauer, 2011), and to promote and sell services to customers (Gebauer *et al.*, 2017; Huikkola and Kohtamäki, 2017; Ulaga and Reinartz, 2011). The provision capability also includes minor capabilities to apply digital technologies to the service delivery, such as software, online platforms, and apps, in order to optimize and automate it (Kimita *et al.*, 2022; Sjodin *et al.*, 2016).

On the other hand, the ***Orchestration Capability*** builds and coordinates a network of partners to indirectly deliver services to customers, and digitalizes this service network (Ruffoni and Reichert, 2023). This core capability consists of minor capabilities to seek, select, hire, evaluate, and coordinate third parties involved in the indirect service delivery (Johnson *et al.*, 2021; Lütjen *et al.*, 2019; Story *et al.*, 2017), such as service companies (Ayala *et al.*, 2019; 2021), but also software developers, or even other manufacturing enterprises (Momeni *et al.*, 2023). The orchestration capability also involves minor capabilities to apply digital technologies throughout the service network, such as software, online platforms, and apps, aiming to optimize and automate processes along it (Chen *et al.*, 2021; Marcon *et al*., 2022).

The ***Manufacturing Capability*** improves and digitalizes manufacturing processes to support service offerings (Ruffoni and Reichert, 2023). This core capability encompasses minor capabilities to continuously improve products and production processes, involving the adoption of practices such as lean manufacturing, agile manufacturing, and product modularity (Qi *et al.*, 2020) to simultaneously increase efficiency and flexibility (Matthyssens *et al.*, 2009; Sousa and Silveira, 2017), and then enable mass product customization (Sousa and Silveira, 2019). The manufacturing capability also involves minor capabilities to apply digital technologies (e.g., software, online platforms and apps) in product development and in production planning, control and execution, in order to automate and optimize it (Manresa *et al.*, 2021). Furthermore, the application of these digital technologies also encompasses the adoption of advanced production technologies, such as advanced robotics and additive manufacturing (Savastano *et al.*, 2021).

To understand how firms can configure these four core capabilities to create value in different digital servitization trajectories, and how firms can transit from one trajectory to another, the next section details the methodological procedures adopted.

3. Method

This study uses a combination of quantitative techniques to achieve its objectives. The following subsections details the data collection procedures and the three stages of the data analysis: 1) Cluster analysis; 2) Exploratory Factor Analysis (EFA) and; 3) Fuzzy-set Qualitative Comparative Analysis (fsQCA).

3.1 Data Collection

To collect data, a survey was developed with a questionnaire divided into two main blocks. The first block included items related to types of digital technologies (Kerin and Pham, 2020; Zangiacomi *et al.*, 2023; Zheng *et al.*, 2020) and types of services offered by manufacturing firms (Baines and Lightfoot, 2013; Cusumano *et al.*, 2015; Parida *et al.*, 2014; Tukker, 2004). The second block included items related to firms' core digital servitization capabilities and value creation, based in the theoretical framework proposed by Ruffoni and Reichert (2023) (Figure 8).

Data collection was carried out among Brazilian manufacturing firms. To contact companies, a database with more than 3,700 firms was used, which was provided by the South Brazilian Manufacturing Association (FIERGS). Companies in different industries were considered. Although studies generally focus on machinery and equipment manufacturers to explore digital servitization (Paschou *et al.*, 2021), the phenomenon also occurs in different industries, such as metallurgical, textiles, food, paper, chemicals, and so on, as attested by Blichfeldt and Faullant (2021), Manresa *et al.* (2021), and Sousa and Silveira (2017).

Data collection occurred between November 2022 and January 2023. The survey was applied by telephone, interviewing employees in decision making positions, such as service manager, after-sales manager, or sales manager, once a person in these positions has a broad and clear understanding of the subject. Data collection stopped when 411 companies (11% of the database) were obtained.

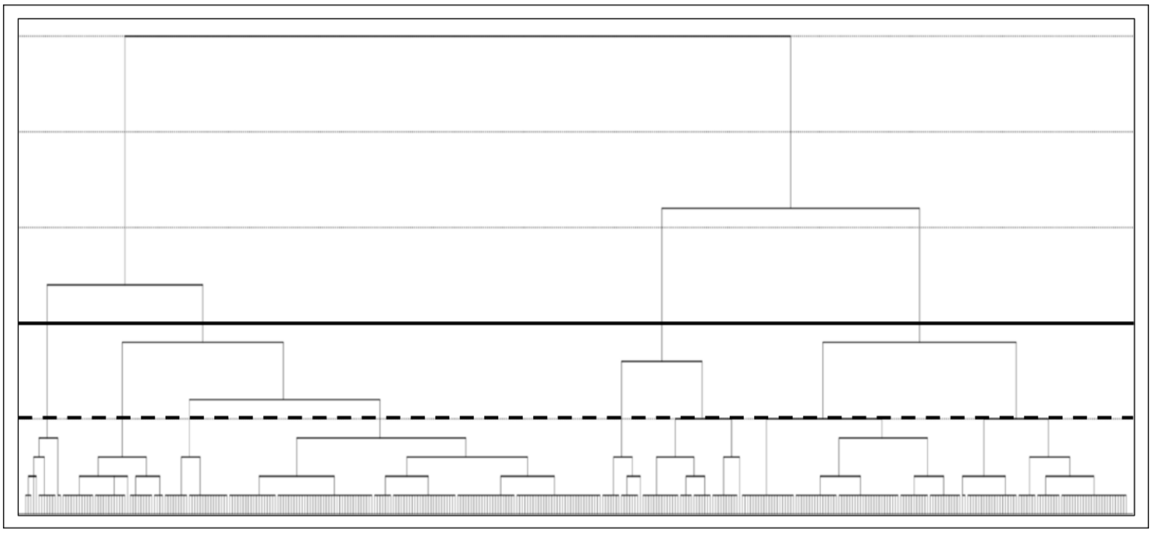
3.2 Data Analyses

3.2.1 Cluster Analysis

The first stage of the data analysis was the cluster analysis, to identify the digital servitization trajectories followed by firms. To do so, two variables were created: digitalization intensity and servitization intensity. Using the same approach as Martin-Peña *et al.* (2020), the variable for digitalization intensity refers to the sum of 10 dichotomous variables related to the incorporation of different types of digital technologies (0 = the firm does not use the technology; 1 = the firm uses the technology). Using an approach similar to that of Kohtamäki *et al.* (2019) and Parida *et al.* (2014), the variable for servitization intensity refers to the sum of 12 dichotomous variables related to the types of services added to products (0 = the firm does not offer the service; 1 = the firm offers the service). The types of digital technologies and services considered are detailed in Table 17, in the Results and Discussion section.

Then, cluster analysis was applied, using the Statistical Package for Social Sciences (SPSS). First, following Hair *et al.* (2009) recommendation, the two variables created for digitalization and servitization intensity were standardized, since they have different scales, respectively, ranging from 0 (low digitalization intensity) to 10 (high digitalization intensity), and from 0 (low servitization intensity) to 12 (high servitization intensity). After this, a two-step cluster analysis was carried out: with Hierarchical Cluster Analysis (HCA), the appropriate number of clusters was identified (using the average linked method) and; with the K-means Cluster Analysis (KCA), the clusters' membership was refined (Hair *et al.*, 2009; Rencher, 2002). Figure 9 presents the dendrogram obtained with the HCA.

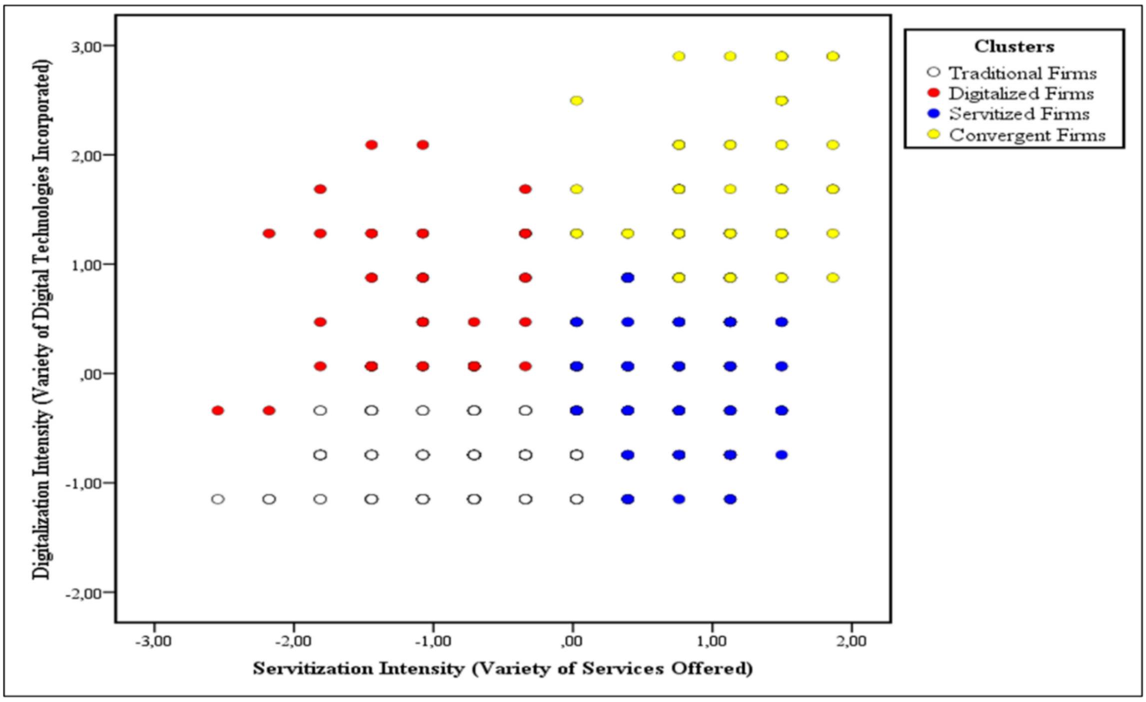
Figure 9 – Dendrogram (HCA)



The dendrogram suggests that three or four clusters would be adequate (continuous bold line), or even eight clusters (dashed bold line). Since a too refined number of clusters implies little representativeness within groups and little heterogeneity between groups (Hair *et al.*, 2009), four clusters were adopted. After this, the clusters' centroids were used as seeds to refine the groupings through the KCA (Hair *et al.*, 2009; Rencher, 2002). The centroids can be checked in Appendix 1.

With the KCA, the four clusters converged in eight interactions. The Anova test confirmed that the four clusters are statistically different in terms of digitalization intensity (F = 394.901, p = 0.000) and servitization intensity (F = 346.550, p = 0.000). However, since the data do not follow a normal distribution (Kolmogorov-Smirnova and Shapiro-Wilk tests indicate a p = 0.000), the Kruskal-Wallis' test, the non-parametric equivalent of Anova, is better suited to examine their differences (Field, 2009; Hair *et al.*, 2009). The Krukal-Wallis' test reinforced the results of Anova, confirming that clusters are statistically different in digitalization intensity (Chi-square = 293.96, p = 0.000) and also in servitization intensity (Chi-square = 312.42, p = 0.000). Figure 10 shows the scatter plot of these two variables, illustrating the clusters' memberships obtained by combining HCA and KCA.

Figure 10 – Scatterplot between Servitization Intensity and Digitalization Intensity (HCA complemented by KCA)



The scatter plot clearly resembles the four major trajectories suggested by Frank *et al.* (2019) (Figure 7). The white cluster (n = 149) represents firms following traditional trajectories (few service offerings and low incorporation of digital technologies). The red cluster (n = 48) consists of firms following digitalization trajectories (high incorporation of digital technologies, but few service offerings), while the blue cluster (n = 144) refers to firms following servitization trajectories (many service offerings, but low incorporation of digital technologies). The yellow cluster (n = 70) represents firms following convergence trajectories (many service offerings and high incorporation of digital technologies).

3.2.2 Exploratory Factor Analysis

The second stage of data analysis was the Exploratory Factor Analysis (EFA), applied to reduce the items used to measure the four core digital servitization capabilities and firms' value creation in five latent factors, as well as to evaluate their validity as constructs. 32 items were utilized in this regard, with 29 items related to the digital servitization capabilities, and three items related to the value created by the firm. The three items utilized to measure firm's value creation represent the three outcomes identified by Schumpeter (2008) as representatives in this regard: net profit growth, revenue growth, and market share growth (Reichert *et al.*, 2016). All these 32 items were measured with five-point Likert scales, ranging from 1 (Completely Disagree) to 5 (Completely Agree).

SPSS was also utilized at this stage. First, to evaluate the impact of the measurement method on variance, the Harman's single factor test was performed, grouping these 32 items into a single factor (Podsakoff *et al.*, 2003). As the single factor encompassed only 28% of the total variance, it can be assumed that there is no single factor that accounts for the majority of the variance in the model. Then, the EFA was carried out using five fixed factors, and the varimax rotation with kaiser normalization. Table 15 presents the final factors and the items that compose each of them.

Table 15 – Exploratory Factor Analysis[1]

Item: Does your firm...	Orchestration Capability	Provision Capability	Integration Capability	Manufacturing Capability	Value Creation
Have a rigorous process to select service partners	0.953				
Stablishes formal contracts with service partners	0.940				
Train service partners	0.908				
Makes digital technologies (apps, software, online platforms, ...) available for partners to provide services	0.797				
Have information systems integrated with service partners	0.925				
Periodically evaluate the performance of service partners	0.939				
Have an exclusive internal team to provide services		0.841			
Plan and control the necessary resources for the service offering		0.774			
Train its own service team		0.870			
Provide services through digital technologies (apps, software, online platforms, ...)		0.568			
Periodically evaluates the performance of the service team		0.866			
Advertises the service offerings		0.821			
Monitor the advent of digital technologies that can be applied to services			0.575		
Develop digital technologies to be applied in services			0.776		
Apply project management methods to develop services			0.744		
Involve customers and partners in the development of services			0.670		
Test services before making them available to customers			0.572		
Have programs to continuously improve products and production				0.642	
Produce a wide variety of products without compromise the efficiency of production				0.735	
The machinery and equipment utilized are on the technological frontier of the industry				0.621	
Use specific software to project and improve products (CAD-CAM)				0.509	
Use specific software to plan, control, and execute production (MRP, MES, SCADA)				0.597	
Have increased its profit in the last four years					0.905
Have increased its revenue in the last four years					0.911
Have increased its market share in the last four years					0.713
Cronbach's Alpha	0.970	0.885	0.801	0.734	0.817

The rotation converged in 6 interactions. By taking factor loadings above 0.500 as significant (Hair *et al.*, 2009; Rencher, 2002), seven of the 32 items had to be removed

[1] This is the same EFA presented in Article II (Table 8).

(detailed in Appendix 2). The five factors have a Cronbach's Alpha above 0.700, confirming their discriminant validity (Hair *et al.*, 2009), and explain 68.95% of the variance, which is a considerable part of it. The Kayser-Meyer-Olkin (KMO) measure of sample adequacy is 0.894, and Barlett's sphericity test is significant (p = 0.000), indicating the suitability of the data for EFA (Field, 2009; Hair *et al.*, 2009).

Subsequently, descriptive statistics, Kruskal-Wallis and Mann-Whitney tests were applied to characterize and identify the differences between firms' core digital servitization capabilities and value creation across the four clusters. Kruskal-Wallis and Mann-Whitney tests are the nonparametric equivalents, respectively, of Anova and the t-test, being more adequate for this study since the data do not follow a normal distribution (Field, 2009; Hair *et al.*, 2009).

3.2.3 Fuzzy-set Qualitative Comparative Analysis

The third and final stage of the data analysis consisted in applying the fuzzy-set Qualitative Comparative Analysis (fsQCA) to each cluster (trajectory), to identify configurations of digital servitization capabilities through which firms create value. The fsQCA is a relatively new technique, put forward by Ragin (2000). The main advantage in using fsQCA is its focus on obtaining multiple solutions for a given outcome (equifinality), differently from traditional statistical methods, which focus on identifying a single optimal solution (Greckhamer *et al.*, 2013; Vis, 2012). Furthermore, the fsQCA is applicable to examine small and large quantitative data sets (from $n \geq 50$ to n = thousands of observations) (Salonen *et al.*, 2021; Pappas and Woodside, 2021), fitting the sizes of the clusters obtained.

In this stage, the fsQCA 4.0 software was utilized. The fsQCA considers a set-theoretic approach to identify configurations of conditions for a given outcome (Ragin, 2008). In this study, each core capability refers to a set of conditions, while the value created by the firm refers to the set of the outcome. Hence, to apply the fsQCA, data must be converted to membership scores (fuzzy scales, varying from 0 to 1), a process called calibration. Following previous studies that utilize Likert scales, the data were calibrated considering three break-points: 1 = 0.05 (non-membership); 3 = 0.50 (partial membership) and; 5 = 0.95 (full-membership) (Leischnig and Kasper-Brauer, 2015; Peters *et al.*, 2022).

With the data calibrated, the fsQCA identifies the individual necessary conditions and the sufficient configurations of conditions for the given outcome. While individual necessary conditions must be present for the outcome to occur, sufficient configurations of conditions cause the outcome (Leischning *et al.*, 2019; Schneider and Wagemann, 2012).

The identification of sufficient configurations starts with the assembly of a truth table. The truth table contains all possible configurations of conditions for a given outcome ($2^{\text{number of conditions}}$), indicates the number of cases that belong to each configuration (frequency), and the degree in which they belong to these configurations (raw consistency) (Ragin, 2008). After this, the truth table should be reduced by removing the configurations with low frequency and low raw consistency. In terms of frequency, Pappas and Woodside (2021) recommend, for small samples ($n \leq 50$), to remove configurations with or less than one or two cases. For larger samples, this cut-off can be higher, since at least 80% of the cases were retained. Regarding raw-consistency, it is suggested to remove configurations below 0.800, but the threshold can be higher (Pappas and Woodside, 2021). Table 16 presents the parameters adopted for the reduction of the truth table in each cluster (trajectory).

Table 16 – Parameters for the Reduction of the Truth Table in each Cluster

Outcome:	Value Creation			
Cluster (Trajectory):	Traditional	Digitalization	Servitization	Convergence
Observations (n)	149	48	144	70
Frequency Cut-off	≤ 9	≤ 1	≤ 9	≤ 1
Percentage of Cases Retained	84%	97%	87%	98%
Raw Consistency Cut-off	0.934	0.929	0.908	0.919

After the reduction of the truth table, the fsQCA generates three solutions, which differentiate from each other in terms of the counterfactuals included: complex solution (do not include counterfactuals), intermediate solution (include only plausible counterfactuals), and parsimonious solution (include all counterfactuals) (Pappas and Woodside, 2021). The present study adopted the intermediate solution to be the most realistic, following Ragin's (2008) recommendation, which is considered in many other studies applying the fsQCA (e.g., Alam *et al.*, 2023; Hao *et al.*, 2022; Wang *et al.*, 2023).

4. Results and Discussions

4.1 Characteristics of Digital Serivitization Trajectories

To explore the characteristics of each digital servitization trajectory, each cluster was detailed in terms of the adoption rate of service offerings (servitization intensity) and digital technologies (digitalization intensity), together with the proportion rate of firms' size (small, medium and large). Table 17 presents the results.

Table 17 – Characteristics of Digital Servitization Trajectories

Cluster (Trajectory):	Traditional		Digitalization		Servitization		Convergence		Kruskal-Wallis	
Observations (n):	149		48		144		70			
Types of Services Offered	Obs	Adop%	Obs	Adop%	Obs	Adop%	Obs	Adop%	Chi-Square	Sig
Exchanges and returns	145	97%	46	96%	141	98%	69	99%	1.02	0.797
Technical support	130	87%	27	56%	136	94%	69	99%	**55.71****	0.000
Spare parts	93	62%	27	56%	138	96%	70	100%	**84.94****	0.000
Installation and assembly	45	30%	13	27%	124	86%	65	93%	**148.01****	0.000
Training	25	17%	9	19%	117	81%	66	94%	**196.14****	0.000
Financing	53	36%	11	23%	106	74%	60	86%	**89.53****	0.000
Insurances	59	40%	9	19%	91	63%	56	80%	**60.62****	0.000
Maintenance	39	26%	15	31%	123	85%	66	94%	**156.27****	0.000
Product update (Retrofit)	61	41%	7	15%	110	76%	63	90%	**106.56****	0.000
Product personalization	50	34%	18	38%	96	67%	51	73%	**48.22****	0.000
Functional services	15	10%	5	10%	56	39%	50	71%	**98.05****	0.000
Renting or pay-per-use	2	1%	0	0%	9	6%	12	17%	**25.55****	0.000
Overall Servitization Intensity									**312.41****	0.00
Types of Digital Technologies Incorporated	Obs	Adop%	Obs	Adop%	Obs	Adop%	Obs	Adop%	Chi-Square	Sig
ERP software	22	15%	36	75%	92	64%	60	86%	**133.01****	0.000
E-commerce platforms	24	16%	28	58%	77	53%	55	79%	**88.96****	0.000
Big Data Analytics (IA, machine learning)	0	0%	10	21%	15	10%	40	57%	**121.13****	0.000
Virtual reality	0	0%	5	10%	3	2%	25	36%	**92.41****	0.000
Industrial robots	6	4%	29	60%	27	19%	47	67%	**131.79****	0.000
Transportation robots (AGVs)	3	2%	24	50%	15	10%	52	74%	**173.38****	0.000
Collaborative robots (Cobots)	0	0%	16	33%	16	11%	46	66%	**148.11****	0.000
Machine-to-machine communication (M2M)	50	34%	34	71%	70	49%	59	84%	**56.86****	0.000
Additive manufacturing for prototyping	11	7%	16	33%	36	25%	55	79%	**119.30****	0.000
Additive manufacturing for mass production	1	1%	9	19%	13	9%	39	56%	**118.58****	0.000
Overall Digitalization Intensity									**293.96****	0.000
Size (Annual Revenue)	Obs	Prop%	Obs	Prop%	Obs	Prop%	Obs	Prop%	Chi-Square	Sig
Small	31	21%	8	17%	44	31%	9	13%	-	-
Medium	101	68%	25	52%	78	54%	43	61%	-	-
Large	17	11%	15	31%	22	15%	18	26%	-	-

Adoption and Proportion Rates (%): Gray gradient (Light Gray = 0%, Gray = 50%; Dark Gray = 100%) | Kruskal-Wallis: ** = Clusters are significantly different at 1%; * = Clusters are significantly different at 5%

The Kruskal-Wallis' test demonstrates that the four clusters are statistically different not only in overall servitization and digitalization intensity, but also in the adoption of specific types of services and digital technologies. The only item in which the adoption is not divergent is product exchange and returns services, which is a very common service type offered by manufacturing firms (Manresa *et al.*, 2021; Parida *et al.*, 2014).

The characteristics of the clusters are consistent with the four digital servitization trajectories suggested by the literature (Coreynem *et al.*, 2017; Frank *et al.*, 2019; Kharlamov and Parry, 2020). Traditional firms (first column) concentrate on offering few and simple service types, such as technical support and spare parts. They also incorporate few digital technologies, focusing on established technologies, such as ERP software and e-commerce platforms. Digitalized firms (second column) also offer few and simple service types, but intensively incorporate digital technologies, including the most recent novelties, such as advanced robotics and additive manufacturing (especially for prototyping).

Servitized firms (third column), in turn, offer a broad variety of service types, encompassing complex services, such as product update, product personalization, and functional services (e.g., operate the customer process). Although servitized firms are not as intensive in the incorporation of digital technologies as digitalized firms, they are more digitalized than traditional firms. At last, convergent firms (fourth column), offer a broader variety of service types than servitized firms, as well as are more intensive in the incorporation of digital technologies than digitalized firms, consisting in the cluster with the most digitalized and servitized firms.

Companies' size (the last three lines of Table 17) is based on the classification of the Brazilian Bank of National Development (BNDES), which considers the annual revenue: small company (annual revenue less than BR$ 4.8 million), medium company (annual revenue greater than or equal to BR$ 4.8 million, but less than BR$ 300 million), and large company (annual revenue greater than or equal to BR$ 300 million). Convergence and digitalization trajectories proportionally concentrate more large companies than traditional and servitization trajectories. This probably occurs due to the high investments required for digitalization (Guo *et al.*, 2023; Kohtamäki *et al.*, 2020). Since small and medium companies generally cannot count on substantive financial resources to make investments, they tend to focus on traditional and servitization trajectories to adapt to the digital servitization paradigm.

4.2 Characteristics of Capabilities in Digital Servitization Trajectories

To better understand the trajectories, this section explores the characteristics of the core digital servitization capabilities in each of them. In this regard, Table 18 presents the mean of each digital servitization capability and the mean of the value created by firms in each cluster.

Table 18 – Characteristics of Firms' Core Digital Servitization Capabilities and Value Creation in each Trajectory

	Cluster (Trajectory)	Integration Capability	Provision Capability	Orchestration Capability	Manufacturing Capability	Value Creation
Mean	Traditional	3.04	3.84	2.46	3.78	3.72
	Digitalization	3.76	3.86	3.41	4.36	3.84
	Servitization	3.89	4.25	2.50	4.08	3.72
	Convergence	4.40	4.38	3.32	4.54	4.04
Kruskal-Wallis Test	Chi-Square	**139.98****	**47.83****	**28.20****	**74.36****	**23.79****
	Sig	0.000	0.000	0.000	0.000	0.000
Mann-Whitney Test	Dig – Trad	**0.72****	**0.02***	**0.95****	**0.59****	0.12
	Sig	0.000	0.034	0.000	0.000	0.164
	Serv – Trad	**0.85****	**0.41****	0.04	**0.31****	0.01
	Sig	0.000	0.000	0.686	0.000	0.984
	Conv – Trad	**1.36****	**0.54****	**0.86****	**0.76****	**0.32****
	Sig	0.000	0.000	0.000	0.000	0.000
	Serv – Dig	0.14	0.38	**-0.91****	**-0.28****	-0.12
	Sig	0.429	0.492	0.001	0.002	0.181
	Conv – Dig	**0.64****	**0.52****	-0.09	0.17	**0.20***
	Sig	0.000	0.004	0.958	0.090	0.019
	Conv – Serv	**0.51****	**0.14****	**0.82****	**0.45****	**0.32****
	Sig	0.000	0.001	0.001	0.000	0.000

** = Clusters are significantly different at 1%; * = Clusters are significantly different at 5%

The non-parametric tests reinforce the differences between the clusters. While the Kruskal-Wallis' test proves that firms' capabilities and value creation are statistically different between clusters, the Mann-Whitney test identifies between which clusters the main differences reside. In terms of digital servitization capabilities, convergent firms have the most developed capabilities. Digitalized firms and servitized firms occupy a middle position in this regard, although digitalized firms have capabilities a little better developed than servitized firms. Traditional firms have the least developed capabilities.

Table 18 demonstrates that it is harder for traditional firms to transit to digitalization trajectories than to transit to servitization trajectories. Traditional firms have four capabilities less developed than digitalized firms (Dig – Trad line), and three capabilities less developed than servitized firms (Serv – Trad line). It is even harder for traditional firms to directly move to convergence trajectories (Conv – Trad line). Furthermore, it is harder for servitized firms to transit to convergence trajectories than it is for digitalized firms. Servitized firms have four capabilities less developed than convergent firms (Conv – Serv line), whereas digitalized firms only have two capabilities less developed (Conv – Dig line). In parallel, servitized firms have two capabilities less developed than digitalized firms (Serv – Dig line).

In sum, it is harder for firms to digitalize, than it is to servitize. Firms have to develop more capabilities to digitalize (to move from traditional to digitalization trajectories, or from servitization to convergence trajectories), than to servitize (to move from traditional to servitization trajectories, or from digitalization to convergence trajectories). Therefore, in addition to the high investments required for digitalization (Guo *et al.*, 2023; Kohtamäki *et al.*, 2020), it is harder for firms to build capabilities to digitalize in comparison to servitize. These are probably the reasons why there are more firms in servitization trajectories (n = 144) than in digitalization trajectories (n = 49), or in convergence trajectories (n = 70).

On the other hand, traditional, digitalized and servitized firms do not statistically differ in terms of value creation. Only convergent firms present a statistically significant higher value creation than the other groups. This confirms previous studies (Abou-Foul *et al.*, 2021; Kharlamov and Parry, 2020; Kohtamäki *et al.*, 2020; Martin-Peña *et al.*, 2020), which identified that firms following convergence trajectories obtain the best results. Hence, the only transition between digital servitization trajectories able to improve the value created is in direction to convergence trajectories.

Notwithstanding, given the emergence of the digital servitization paradigm (Culot *et al.*, 2020; Martin-Peña *et al.*, 2018; Weking *et al.*, 2019) and the difficulty of traditional firms to directly move to convergence trajectories, transitions to digitalization or servitization trajectories could be necessary to ensure the firm's survival. Although these intermediate transitions may not increase the level of value created by the firm, they could be necessary to maintain the current level of value creation. In this regard, the next section explores how firms configure their core capabilities to create value in each digital servitization trajectory.

4.3 Configurations of Capabilities for Value Creation in Digital Servitization Trajectories

To do so, the fsQCA was applied. The fsQCA generate results in two stages: the analysis of individual necessary conditions, and the analysis of sufficient configurations of conditions (Schneider and Wagemann, 2012). Both are validated through consistency and coverage measurements, which vary from 0 (low) to 1 (high). While consistency measures the degree in which a condition/ configuration results in the desired outcome, coverage evaluates the percentage of cases that use a condition/ configuration to obtain the desired outcome (Ragin, 2008; Vis, 2012). Table 19 presents the analysis of the necessary conditions in each trajectory.

Table 19 – Analysis of Necessary Conditions for each Trajectory

Outcome:	Value Creation							
Cluster (Trajectory):	Traditional		Digitalization		Servitization		Convergence	
Condition	Cons.	Cov.	Cons.	Cov.	Cons.	Cov.	Cons.	Cov.
Integration Capability [IC]	0.659	0.936	0.860	0.906	0.897	0.863	**0.974**[ANC]	0.895
~Integration Capability [~IC]	0.609	0.904	0.347	0.945	0.330	0.971	0.154	1.000
Provision Capability [PC]	0.877	0.849	0.830	0.851	**0.959**[ANC]	0.830	**0.939**[ANC]	0.881
~Provision Capability [~PC]	0.322	0.932	0.312	0.913	0.216	0.964	0.166	0.945
Orchestration Capability [OC]	0.491	0.885	0.729	0.883	0.496	0.879	0.685	0.902
~Orchestration Capability [~OC]	0.666	0.808	0.405	0.823	0.642	0.787	0.421	0.873
Manufacturing Capability [MC]	0.870	0.874	**0.970**[ANC]	0.854	**0.950**[ANC]	0.855	**0.988**[ANC]	0.884
~Manufacturing Capability [~MC]	0.368	0.962	0.181	1.000	0.260	0.968	0.124	1.000

[ANC] = Almost Always Necessary Conditions for Value Creation (consistency greater than 0.900)

Generally, a condition is considered necessary, or almost always necessary, when its consistency is greater than 0.900 (Leischning *et al.*, 2019; Sjödin *et al.*, 2016; Peters *et al.*, 2022). Schneider and Wagemann (2012) suggest even higher thresholds, especially when the raw consistency threshold for sufficiency is greater than 0.900, which is the case of the present study (see Table 16). In this regard, conditions with a consistency greater than 0.900 were considered almost always necessary.

Therefore, the necessity of core digital servitization capabilities for value creation increases accordingly with the fit of the trajectories followed by firms to the digital servitization paradigm. For traditional firms, none capability is almost always necessary because they are not fully in the digital servitization paradigm, and thus, also use capabilities driven to the old paradigms to create value. As digitalized and servitized firms are more adapted to the digital servitization paradigm, they already present almost always necessary capabilities for value creation (one and two capabilities, respectively). For convergent firms, which are totally adapted to the digital servitization paradigm, three capabilities are almost always necessary. However, this does not mean that these capabilities are sufficient for value creation. To attest it, the analysis of sufficiency must be carried out (Table 20).

Table 20 – Analysis of Sufficient Conditions for each Trajectory

Outcome:	Value Creation						
Cluster (Trajectory):	Traditional		Digitalization		Servitization	Convergence	
Condition	Config. A	Config. B	Config. C	Config. D	Config. E	Config. D	Config. E
Integration Capability (IC)	○			●	●	●	●
Provision Capability (PC)	●	●	●		●		●
Orchestration Capability (OC)	○		○	●		●	
Manufacturing Capability (MC)		●	●	●	●	●	●
Configuration Consistency	0.952	0.890	0.882	0.933	0.892	0.919	0.907
Raw Coverage	0.491	0.792	0.384	0.533	0.862	0.668	0.922
Unique Coverage	0.038	0.339	0.221	0.697	0.862	0.046	0.300
Solution Consistency	0.885		0.907		0.892	0.908	
Solution Coverage	0.831		0.918		0.862	0.968	

● = Condition must be present | ○ = Condition must be absent | Blank = Condition is indifferent

Since the consistencies of the solutions (Solution Consistency) and the consistencies of the configurations in the solutions (Configuration Consistency) are all greater than 0.750, the results can be considered valid (Schneider and Wagemann, 2012). Furthermore, the coverages of the solutions (Solution Coverage) are all greater than 0.800, indicating that they have considerable explanatory power for the occurrence of the outcome (Greckhamer *et al.*, 2013; Pappas and Woodside, 2021). The Raw Coverage indicates the explanatory power of each configuration in the solution, while the Unique Coverage does the same, but disregarding observations that are explained by more than one configuration (Ragin, 2008; Vis, 2012). Thus, firms can create value through their core digital servitization capabilities independently of the trajectory they are following. However, the more adequate the trajectory to the digital servitization paradigm, the more complex the configurations of capabilities for value creation.

Traditional firms create value by combining the provision capability with either the absence of integration and orchestration capabilities (ic*PC*oc), or with the manufacturing capability (PC*MC). Both configurations represent efficient internal processes to directly deliver services to customers (Ulaga and Reinartz, 2011; Valtakoski and Wittel, 2018). However, while in ic*PC*oc the development of new services and the use of a service network for an indirect delivery do not lead to value creation, in PC*MC such activities are indifferent to do so. In PC*MC, the manufacturing capability is focused on increasing production efficiency, since traditional firms concentrate on offering services whose performance is related to improvements in this regard, such as exchanges, technical support, and spare parts (Table 17) (Matthyssens *et al.*, 2009; Sousa and Silveira, 2017).

Digitalized firms create value by combining provision and manufacturing capabilities, with the absence of orchestration capability (PC*oc*MC), or combining integration, orchestration and manufacturing capabilities (IC*OC*MC). PC*oc*MC is basically a merge of the two configurations utilized by traditional firms, working similarly to PC*MC. On the other hand, IC*OC*MC uses the integration capability to digitalizes existing services (Hasseblat *et al.*, 2018; Lenka *et al.*, 2017), but not to create new services, as the services offered by digitalized firms are similar to those offered by traditional firms (Table 17). Moreover, IC*OC*MC uses the orchestration capability to indirectly deliver services to customers, coordinating a network of service companies, such as dealers and technical assistances (Ayala *et al.*, 2019). Once services are digitalized by the integration capability, the use of the orchestration capability also involves the coordination of software companies to support service delivery through specialized data analysis (Momeni *et al.*, 2023).

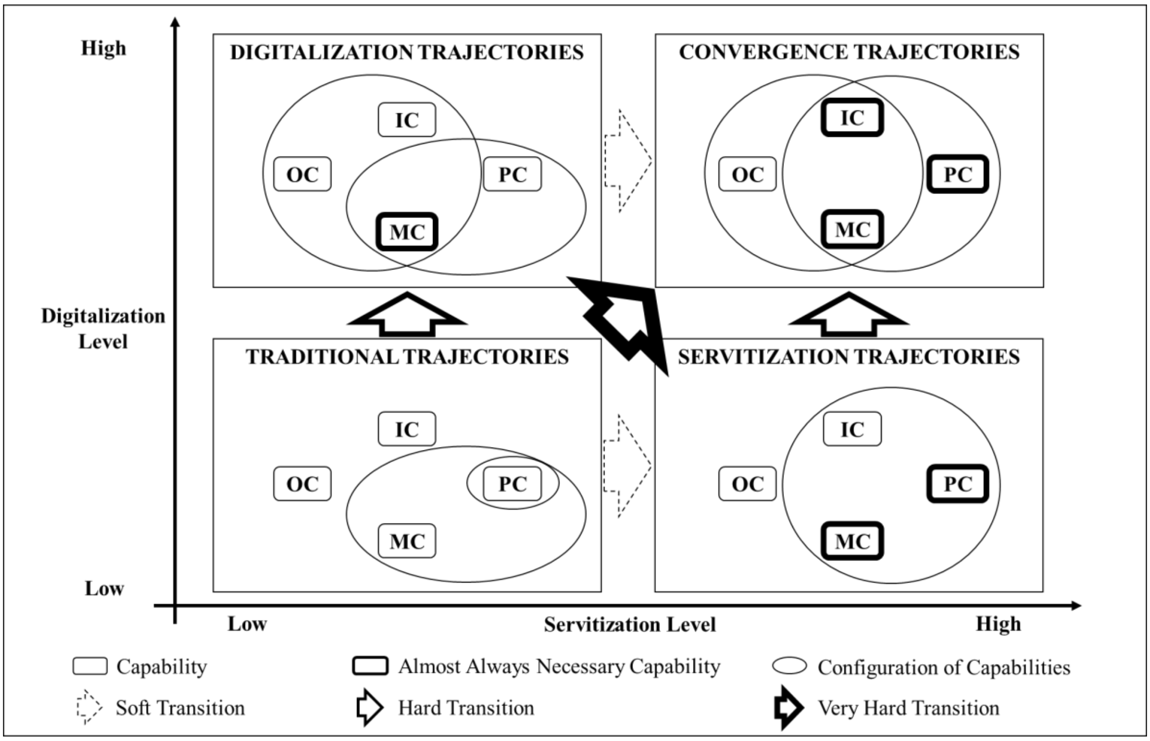
In PC*oc*MC and IC*OC*MC, the manufacturing capability is focused on improving production efficiency in the same way as it does in traditional firms, once service offerings are basically the same in both trajectories. However, the manufacturing capability is more developed in digitalized firms than in traditional firms (Table 18), providing a stronger support to service offerings. In digitalized firms, the manufacturing capability is based on back-end digitalization (Coreynem *et al.*, 2017), incorporating advanced robotics and additive manufacturing technologies into production (Table 17) (Savastano *et al.*, 2021) to promote “high-tech” betterments.

Servitized firms create value by combining integration, provision and manufacturing capabilities (IC*PC*MC). The integration capability has the opposite function of what it has in digitalized firms: it focusses on developing new services (Beltagui, 2018; Wallin *et al.*, 2015), but little on incorporating digital technologies to support them. As a result, service offerings are expanded and complexified, but remain little digitalized (Table 17). Furthermore, IC*PC*MC uses the provision capability to directly deliver to customers, executing internal processes to do so. The provision capability is more useful for servitized firms to deliver services because they focus on offering product customization services (Table 17), which depends on a close relationship with the final customers to be effective (Baines *et al.*, 2009; Sousa and Silveira, 2019).

Hence, in IC*PC*MC, the manufacturing capability simultaneously focuses on improving production efficiency and flexibility to enable mass product customization. Although the manufacturing capability is basically at the same development level in servitized and digitalized firms (Table 18), servitized firms do not rely on back-end digitalization as digitalized firms do. Therefore, servitized firms allow mass product customization through the adoption of practices such as lean manufacturing, agile manufacturing, and product modularity (Qi *et al.*, 2020; Sousa and Silveira, 2019), implementing "low-tech" betterments in production.

Convergent firms create value through two configurations, IC*OC*MC and IC*PC*MC, that is, alternating between the configurations utilized by digitalized and servitized firms, respectively. Notwithstanding, capabilities are more developed in convergent firms than in the other groups (Table 18). With this, the integration capability works at its full potential, developing new services and incorporating digital technologies into them (Adrodegari and Sacanni, 2020; Lenka *et al.*, 2017). This results in the broadest, most complex, and most digitalized service offerings of all trajectories (Table 17). To deliver services, convergent firms alternate between provision and orchestration capabilities. By using these two capabilities, convergent firms complement their expertise with the expertise of partners (Ayala *et al.*, 2021), achieving higher efficiency levels in the service delivery. The manufacturing capability also works to its fullest, applying both "high-tech" and "low-tech" betterments in production. Figure 11 synthesizes the results.

Figure 11 – Configurations of Core Capabilities for Value Creation in Different Digital Servitization Trajectories



In sum, to create value in the digital servitization paradigm, **traditional firms**, offering few, simple and not digitalized services, focus on stablishing efficient internal service delivery processes and on supporting them through marginal improvements in production processes. **Digitalized firms**, offering few, simple and digitalized services, focus on improving existing services through digitalization, establishing partnerships to indirectly deliver services, and on implementing "high-tech" improvements in production. **Servitized firms**, offering many, complex and not digitalized services, focus on developing new services, stablishing efficient internal service delivery processes, and on applying "low-tech" improvements in production. **Convergent firms**, offering many, complex and digitalized services, focus on developing and digitalizing services, combining direct and indirect service delivery to customers, and on implementing "high-tech" and "low-tech" improvements in production.

Although firms can create value in the digital servitization paradigm independently of the trajectory they follow, convergent firms presented a statistically higher value creation than the others. In this regard, it is advised that firms make efforts to transit towards convergence trajectories. This transition is harder for servitized firms than for digitalized firms, since digitalization demands a more intensive capability development than servitization. That is, it is harder to move vertically than to move horizontally in Figure 11. Evidently, the direct transition from traditional trajectories to convergence trajectories is even harder, once it simultaneously involves digitalization and servitization. Therefore, it is recommended that firms conduct this transition gradually, alternating their focus between digitalization and servitization until they reach convergence.

5. Conclusion

The article reached its objective of identifying configurations of capabilities through which manufacturing firms create value in different digital servitization trajectories. First, through cluster analysis, it was identified that firms follow four major trajectories towards the digital servitization paradigm: traditional trajectories, digitalization trajectories, servitization trajectories, and convergence trajectories. Then, based on a framework of four digital servitization capabilities: integration, provision, orchestration, and manufacturing, the fsQCA was applied to identify configurations of these capabilities through which firms create value. The results demonstrate that, in each trajectory, firms create value using specific configurations of digital servitization capabilities. The more adequate the trajectory to the digital servitization paradigm, the more complex the configurations of capabilities for value creation.

This occurs because technological paradigms coexist, or in other words, because different technological and market contexts coexist. Traditional firms are mostly related to the old paradigm, being driven to develop and produce standardized products. In this scenario, the offer of few, simple, and not digitalized services, which involves simple configurations between provision and manufacturing capabilities, is already sufficient for value creation. Digitalized and servitized firms, in turn, are transitioning between the old paradigm and the digital servitization paradigm. They are driven to offer more complex solutions between products, services, and digital technologies, which depend on more complex configurations of capabilities, to create value. At last, convergent firms are totally in the digital servitization paradigm. They are driven to offer products incorporated with very complex digital services, which relies not only on more complex configurations, but also on better developed capabilities, to create value.

Furthermore, the results show that firms transition between trajectories demands considerable efforts, as well as that it is harder for firms to digitalize than to servitize. In addition to involving high investments, digitalization also requires more efforts to develop capabilities in comparison to servitization. However, since firms in convergence trajectories obtain higher levels of value creation, transitions in this regard are worthwhile. To do so, it is suggested that firms conduct a gradual process, alternating between servitization and digitalization until they reach convergence.

Concerning theoretical contributions, the article advances the research field by crossing two streams of the literature on digital servitization: trajectories and capabilities. With this, the present study demonstrated that firms can create value through their digital servitization capabilities independently of the trajectory they follow. This brings a new discussion to the research field: the smoothness and hardness of capability development for firms to transit between digital servitization trajectories.

In terms of managerial contributions, the article offers managers with a roadmap on how firms can create value along their entire transition to digital servitization, not only at the end of it, as the literature generally demonstrates. Figure 11 is a good reference point for practitioners in this regard. Based on this study, managers can identify the digital servitization trajectory followed by their companies, how to configure its capabilities to create value in the current trajectory, and how to plan its transition towards convergence trajectories. Moreover, public managers can also use this road map to plan and implement public policies that aid the development of manufacturing firms in direction to digital servitization.

The present study has three main limitations. The first concerns the firm's capability approach, which limits the creation of value to internal competencies, ignoring external aspects such as the influence of institutions, public policies, and interactions with other firms, as in the case of local clusters. The second limitation is that only Brazilian companies were addressed in the research. Since emerging economies tend to be laggards in the adoption of new technologies, some caution should be taken when generalizing the results to companies in developed economies. The digital servitization trajectories and the configurations of capabilities to create value in each of them may be substantially different in developed economies. The third limitation is related to the scales used to measure firms' level of digitalization and servitization. Although the sum of several dichotomous variables was used in this regard, binary variables, limited to yes or no answers, restrict the range of responses.

These limitations can be overcome in future studies. Future studies can address how external factors to the firm affect the development of digital servitization capabilities in different trajectories, and can replicate this research with companies in developed economies, comparing the results. In parallel, future studies can better examine digital servitization trajectories, using variables with a broader range of variation, as well as looking for more specific trajectories. Additionally, future studies can also deepen the role of manufacturing capabilities in digital servitization, further exploring the relationship between the offer of digital services with the digitalization of manufacturing (smart manufacturing, or "high-tech" improvements), and with the adoption of lean and agile manufacturing practices ("low-tech" improvements).

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Appendix 1: Clusters Centroids

Cluster	Centroids	
	Servitization Intensity (Standardized)	Digitalization Intensity (Standardized)
1	1.29779	1.77153
2	-0.69979	-0.68951
3	0.64341	0.19819
4	-1.3913	1.2809

Appendix 2: Items removed in the Principal Component Analysis (PCA)

Integration Capability

- We monitor market needs related to services
- We acquire digital technologies available in the market

Provision Capability

- We have information systems integrated with our customers to provide services
- We can quickly adapt to new services offerings

Orchestration Capability

- We can quickly adapt our partners to new services offerings

Manufacturing Capability

- We customize our products without compromise our efficiency

- We have integrated information systems with our customers and suppliers to exchange data related to production

5. INTEGRATED CONCLUSION

Through the development of three articles, the thesis achieved its objective of identifying how the digital servitization capabilities of the firm create value. The results of the three studies reinforce each other, leading to a single conclusion.

Article I – Exploring Configurations of Digital Servitization Capabilities for Value Creation developed a theoretical framework of four core digital servitization capabilities of the firm, carried out a multiple case study with 24 manufacturing firms, and applied the fsQCA to identify configurations of these capabilities for value creation. The four core digital servitization capabilities of the firm are ***Integration Capability (IC)***, ***Provision Capability (PC)***, ***Orchestration Capability (OC)***, and ***Manufacturing Capability (MC).*** Results indicate that firms use two configurations of capabilities to create value: ***IC*PC*MC*** or ***IC*OC*MC***. The combination of integration and manufacturing capabilities in both configurations highlights the relevance of their interaction for value creation. While the integration capability develops digital services, the manufacturing capability uses the data obtained through them to improve products and production processes. In parallel, the role of provision and orchestration capabilities is secondary, being only focused on operationalizing the service delivery to customers.

Article II – ***Building Digital Servitization Capabilities for the Successful Offering of Smart Services*** used the theoretical framework developed in Article I to explore how firms build digital servitization capabilities to offer smart services. Through a mixed-method approach, the emerging NCA technique was applied to a sample with 411 companies, measuring the degree to which digital servitization capabilities are necessary for different levels of a successful offering of smart services. Then, a qualitative multiple case study was conducted with 13 well-succeed offerors of smart services to characterize their digital servitization capabilities. This combination of methods enabled the examination of how firms built these capabilities. Results suggested a three-stage path of capability building for the successful offering of smart services: ***Implementation***, ***Optimization***, and ***Customization***. Along this path, firms must first build integration and manufacturing capabilities to design the offering of smart services and define how they will profit from it. Later, firms must build provision and orchestration capabilities to establish efficient processes to deliver smart services to customers.

Article III – Configuring the Firm's Digital Servitization Capabilities for Value Creation in Different Trajectories also used the theoretical framework developed in Article I, but to explore how firms following different digital servitization trajectories can configure their capabilities to create value. Through a sample with 411 companies, a cluster analysis was performed to identify the digital servitization trajectories followed by firms. Then, the fsQCA was applied to each cluster (trajectory), to identify how firms configure their capabilities to create value. At last, nonparametric tests were utilized to complement the analyzes. The results indicated that firms follow four digital servitization trajectories: ***Traditional, Digitalization, Servitization*** and ***Convergence***. For each trajectory, there are specific configurations of digital servitization capabilities through which firms can create value. These configurations are simple in traditional trajectories, but became more complex in convergence trajectories. Furthermore, the results demonstrated that firms on convergence trajectories obtain higher levels of value creation, being recommended that firms transition in this direction.

Gathering the results of the three articles, the general conclusion of the thesis is as follows:

All firms have digital servitization capabilities and do not need to fully develop them, totally transiting to digital servitization, to create value. However, to achieve high levels of value creation through digital servitization, it is fundamental for firms to substantially develop and establish an interaction between integration and manufacturing capabilities. While the integration capability designs digital and smart services, the manufacturing capability uses the data collected through these services to improve products and production. In parallel, provision and orchestration capabilities have only a secondary role in value creation. Their importance is diminished by the interchangeability between their elements, which makes them non-critical conditions for value creation. On the other hand, this interchangeability confers different options for firms to combine the elements of provision and orchestration capabilities in order to build an efficient service delivery to customers.

Following the suggestion of Da Costa *et al.* (2019) for theses developed as a set of articles, Table 21 presents a contribution matrix. This matrix demonstrates how each article contributed to achieve the general objective of the thesis.

Table 21 – Contribution Matrix

General Objective of the Thesis:	**To identify how the digital servitization capabilities of the firm create value**			
Article Order and Title	Specific Conclusion	Main Contributions	Limitations	Suggestions for Future Studies
I) Exploring Configurations of Digital Servitization Capabilities for Value Creation	Firms can create value through two configurations of core digital servitization capabilities: integration, provision, and manufacturing (IC*PC*MC), or integration, orchestration, and manufacturing (IC*OC*MC).	• Theoretical framework of the firm's core digital servitization capabilities; • How core digital servitization capabilities create value; • Roadmap for manufacturing firms to successfully transition to digital servitization.	• The method limits the generalization of the results; • The capability approach limits the perspective of value creation to the internal competencies of the firms; • Only companies in an emerging economy were addressed.	• Apply the theoretical framework using a quantitative approach [**Covered in Articles II and III**]; • Explore how external factors to the firm affect the development of digital servitization capabilities; • Reproduce the study with companies in developed economies; • Explore the capabilities required for the offering of smart services [**Covered in Article II**].
II) Building Digital Servitization Capabilities for the Successful Offering of Smart Services	To achieve a successful offering of smart services, firms must first build integration and manufacturing capabilities, to later build provision and orchestration capabilities.	• How firms build core digital servitization capabilities for the offering of smart services; • Application of the emerging NCA technique; • Roadmap for manufacturing firms to achieve a successful offering of smart services.	• The capability approach limits the perspective of value creation to the internal competencies of the firms; • Only companies in an emerging economy were addressed.	• Explore how external factors to the firm affect the development of digital servitization capabilities; • Reproduce the study with companies in developed economies; • Explore how firms following different digital servitization trajectories use their capabilities to create value [**Covered in Article III**].
III) Configuring the Firm's Digital Servitization Capabilities for Value Creation in Different Trajectories	Firms following different digital servitization trajectories can configure their core capabilities to create value. However, firms on convergence trajectories obtain higher levels of value creation.	• How firms in different digital servitization trajectories can configure their core capabilities to create value; • Roadmap for manufacturing firms to transit between digital servitization trajectories.	• The capability approach limits the perspective of value creation to the internal competencies of the firms; • Only companies in an emerging economy were addressed; • Measurements for the intensities of digitalization and servitization had restricted variability.	• Explore how external factors to the firm affect the development of digital servitization capabilities; • Reproduce the study with companies in developed economies; • Better explore specific digital servitization trajectories; • Further explore the role of manufacturing capabilities in digital servitization.

The thesis brings theoretical, methodological, and managerial contributions. The main theoretical contribution is the framework of four core digital servitization capabilities of the firm (Integration, Provision, Orchestration, and Manufacturing). The framework is a valuable contribution to the literature, since it explains how firms can strategize a transition toward digital servitization that results in value creation. Moreover, since the four core capabilities merge elements of digitalization and servitization, the framework is able to examine how firms can successfully organize for both changes. In parallel, the framework also demonstrates how firms mature these four core digital servitization capabilities.

Furthermore, the thesis also contributes to elucidate topics that have received little attention in studies: The importance of manufacturing capabilities in adapting the product development and production for the offering of services; The role of digital servitization capabilities in the offering of smart services; How firms create value in different digital servitization trajectories and; The characteristics of digital servitization in companies in emerging economies.

In terms of methodological contributions, the present study brings relevant advances by applying normative and confirmatory approaches, once the literature on digital servitization capabilities is mostly composed of purely exploratory case studies. In this regard, the application of the emerging quantitative technique, NCA, is highlighted. The interest in the NCA is increasing, given the observed growth of its use in studies published in important management journals. The thesis supports the consolidation of this new technique, and also suggests a novel way to use it: complementing with a qualitative multiple case study.

With regard to practical contributions, this thesis provides multiple roadmaps on how firms can progress toward digital servitization. These roadmaps can be applied by managers in planning the conversion of their companies toward digital servitization, or by public decision makers in developing public policies that support manufacturing industries in this regard. While Article I offers a more generic roadmap, Article II proposes a specific path for the offering of smart services, and Article III suggests different routes through which firms can transit between different digital servitization trajectories.

However, three limitations remain. The first refers to the restrictions of the capability approach to capture the creation of value from factors external to the firm, such as the influence of public policies, institutions, and interactions with other companies. Second, since only Brazilian companies were addressed in the research, some caution should be taken when generalizing the results to companies in developed economies, given differences in market contexts. In this regard, emerging economies tend to be laggards in the adoption of new technologies, such as the disruptive digital technologies associated with digital servitization. Third, the variables used to measure firms' level of digitalization and servitization in Article III have limited variability, since they were built through the sum of several dichotomous variables.

Future studies can overcome these limitations by exploring how external factors to the firm affect the development of digital servitization capabilities, and by reproducing the research in companies in developed economies. In parallel, future studies can develop other scales to measure firms' level of digitalization and servitization, better exploring digital servitization trajectories. Moreover, future research can also further investigate issues raised in this thesis, such as: How exactly do integration and manufacturing capabilities interact to develop services and improve products and production? What is the relationship between digitalization of manufacturing (smart manufacturing), lean manufacturing, and digital servitization? By answering these questions, future studies will promote further advancements in the literature on digital servitization.

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