JÖNKÖPING UNIVERSITY
School of Engineering

Doctoral Thesis

A Solution Space Perspective on Customization

Nikolas Käkelä

Jönköping University
School of Engineering
Dissertation Series No. 068 • 2022

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Abstract

Customization is an important feature in today's manufacturing industry. Although this sector is typically associated with standardization and mass production, the increase in global competition, technological development and demand for product variety has driven many manufacturers, starting from the end of the last century, to offer customized products and services. There are various approaches to customization, ranging from situations where standard components are assembled according to customers specifications to situations where one-off solutions are developed from first principles to customer specific needs.

The point of departure of this doctoral thesis is an inquiry into the concept of solution spaces and how it can be used to explain different practical applications of customization. The thesis comprises a total of four papers, two of which are conceptual and address the broad spectrum of customization approaches, providing a comparative outlook on customization. The empirical body of the thesis specifically focuses on what is commonly known as engineer-to-order (ETO) environments, comprising two papers in which the managerial challenges associated with customization, such as learning in organizations, evaluation of tendering invitations and the elicitation of customer needs, are empirically investigated.

This work makes several notable contributions to the literature. Three types of solution spaces are proposed, representing distinct customization approaches. By synthesizing the solution spaces according to a comprehensive and multidisciplinary frame of reference, this thesis attempts to advance customization research and render it a coherent research field, consolidating key customization concepts within, for instance, operations and supply chain management, product development management, organizational learning and marketing and service management literature. In particular, this thesis links customization to learning, thereby providing managers in customization contexts with valuable support to facilitate learning within their organizations.

Keywords: customization; solution space; engineer to order; configure to order; mass customization; organizational learning.

Sammanfattning

Kundanpassning är ett viktigt inslag i dagens tillverkningsindustri. Även om det vanligen associeras med standardisering och massproduktion har hårdnad global konkurrens, teknisk utveckling, och kunders krav på variation drivit många tillverkande företag, från slutet på det senaste århundradet, att erbjuda kundanpassade produkter och tjänster. Det finns olika förhållningssätt till kundanpassning, från situationer där standardkomponenter monteras enligt kunders katalogval, till situationer där helt kundanpassade lösningar skräddarsys från första princip enligt kundunika behov.

Utgångspunkten för denna avhandling är en undersökning av konceptet *lösningsrymder*, och hur det kan användas för att beskriva olika sätt som kundanpassning kan omsättas i praktiken. Avhandlingen omfattar totalt fyra artiklar, varav två är konceptuella och behandlar det breda spektrumet av kundanpassningsansatser och erbjuder således en jämförande granskning av kundanpassning. Den empiriska delen av avhandlingen fokuserar specifikt på vad som brukar benämnas konstruktion-mot-order miljöer, och omfattar två artiklar som undersöker kundanpassningsrelaterade ledningsutmaningar som berör exempelvis lärande i organisationer, utvärdering av anbudsinbjudningar, och identifiering av kundbehov.

Flera nämnvärda bidrag görs till litteraturen. Tre typer av lösningsrymder föreslås som representerar olika kundanpassningsansatser. Genom en syntetisering av lösningsrymderna med en omfattande och multidisciplinär teoretisk referensram gör avhandlingen en insats för att främja kundanpassningsforskning till att bli ett mer sammanhållet forskningsfält, och sammanför viktiga kundanpassningskoncept inom till exempel verksamhetsstyrning, produktutveckling, organisatoriskt lärande, och marknadsförings- och tjänstelitteratur. I synnerhet bidrar avhandlingen med att koppla kundanpassning till lärande, och ger därmed värdefullt stöd för ledare i kundanpassningskontexter att möjliggöra för lärande inom deras organisationer.

Nyckelord: kundanpassning; lösningsrymd; konstruktion-mot-order; konfiguration-mot-order; masskundanpassning; organisatoriskt lärande.

Acknowledgement

I would like to extend my gratitude to the people that have made this journey possible. First, to my colleagues at the Department for Supply Chain and Operations Management at Jönköping University, School of Engineering, thank you! I could not have hoped for a more welcoming and familiar workplace than what I have experienced these five years.

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I am also grateful for the support I have received from scholarly colleagues, in particular the discussions led by Jonathan Gosling at the licentiate seminar and by Árni Halldórsson at the final seminar. Your feedback and suggestions have been valuable input for the finalization of this doctoral thesis.

Special thanks go to my supervisors Joakim Wikner and Annika Engström. Joakim, you are an endless source of research ideas and I have learned a great deal from working with you (I must admit I rarely understand your puns and wordplays though). Annika, you are a supervisor to the core, and in addition to your valuable support for my thesis work, you have also helped me develop as a researcher and teacher (although I still have to master the "högtryckstvätt"). Thank you both for having made this journey so challenging yet enjoyable!

Finally, I want to extend my sincere gratitude to my family. To my mother and father, thank you for always being there. To Sanna, my love and life companion, and to Julie and Sally, it is wonderful to come home to you, seeing your smiles (and wagging tail) makes all worries go away. Thank you for everything!

List of appended papers

Paper 1

Conceptualization of solution spaces for customization
Nikolas Käkelä and Joakim Wikner

Work distribution: Käkelä and Wikner initiated the paper. Käkelä conducted the literature review. Both authors jointly developed the conceptual material. Finally, Käkelä wrote a majority of the paper, while Wikner wrote certain sections.

Paper 2

Evaluating tendering invitations in engineer-to-order environments
Nikolas Käkelä and Joakim Wikner

Work distribution: Käkelä initiated the paper, designed the study, collected the data and conducted the analysis. Käkelä and Wikner developed the conceptual material. Käkelä wrote the paper, with feedback from Wikner.

Paper 3

Early steps in learning about organizational learning in customization settings
Annika Engström and Nikolas Käkelä

Work distribution: Engström and Käkelä initiated the paper, designed the study and collected data. Engström had the primary responsibility for the data analysis and received support from Käkelä. The paper was written together by both authors.

Paper 4

Ambidextrous learning in a customer order-based context
Annika Engström, Nikolas Käkelä and Joakim Wikner

Work distribution: Engström and Käkelä initiated the paper. Engström was responsible for the section on organizational learning, while Käkelä was responsible for the section on the customer-order-based context. Wikner provided comments and suggestions.

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1 Introduction

The focus of this doctoral thesis is customization and the different ways in which it can be put into practice. The concept of solution spaces is adopted here as a means to describe different customization approaches. The following section provides the background of the research problem (Section 1.1), which is followed by a description of the motivation behind this research (Section 1.2). This forms the basis of the purpose statement (Section 1.3), which is verified with regard to the scope and delimitations of the research (Section 1.4). The chapter is concluded with an outline of the thesis (Section 1.5).

1.1 Background

Customization is a vital practice for many manufacturers today. Competing based on customized instead of standard products is a highly relevant differentiation strategy (Amaro et al., 1999) and is seen as common practice in business-to-business markets, such as those of capital goods (Birkie & Trucco, 2016), machinery building (Cannas, Gosling, et al., 2020) and construction (Gosling et al., 2015), and consumer markets, such as the automotive (Brabazon et al., 2010) and apparel markets (Turner et al., 2020). The criticality of customization has also been noted in other contexts, such as for services (Brax et al., 2017), defense supply chains (Ekström et al., 2020) and pharmaceuticals (Ben-Jebara & Modi, 2021).

There are numerous practical challenges that accompany customization. One such major challenge is to understand customer-specific needs and undertake learning from and for customer commitments. Örtenblad (2004, p. 134), for instance, notes that *"the members of the organization need to be continuous learners in order to manage the customers' changing needs, wants and demands"*. Furthermore, customization implies that certain operations cannot be performed until the customer has provided their requirements, which limits the possibilities for planning ahead (see e.g., Mello et al., 2015; Tenhiälä & Ketokivi, 2012). The ability to cater to customer-specific requirements can also be dependent on external supply or resources with limited capacity (Little et al., 2000). Moreover, compared to standard products, customization entails an increase in product variety, which is likely to lead to increased costs and, thereby, warrant the analysis of the financial efficacy of customization practices (Wan & Dresner, 2015). As will be demonstrated throughout this thesis, many of these challenges manifest differently depending on the type of customization approach adopted.

> *"Customization and standardization do not define alterative models of strategic action but, rather, poles of a continuum of real-world strategies."*
> \- Lampel and Mintzberg (1996, p. 21)

As illustrated by the foregoing quote, customization can be implemented in different ways in a manufacturing context, including situations where standard components are assembled according to customer specifications and those where one-off solutions that are tailored to a customer's unique needs are developed from first principles (see e.g., Amaro et al., 1999; Lampel & Mintzberg, 1996; Wortmann et al., 1997). The first type of situation corresponds to an *assemble-to-order* (ATO) or *configure-to-order* (CTO) strategy (Hvam et al., 2008; Wemmerlöv, 1984) and is associated with the popularized business concept called *mass customization* (Fogliatto et al., 2012; Pine, 1993). The second type corresponds to an *engineer-to-order* (ETO) strategy, which has received increased scholarly attention in recent years (Cannas & Gosling, 2021; Gosling & Naim, 2009) and has also been referred to as *pure customization* (Gosling et al., 2017; Lampel & Mintzberg, 1996). In between these approaches are various customization applications that combine elements of the ATO, CTO and ETO strategies in different ways (see e.g., Cannas, Masi, Pero, & Brunø, 2020; Haug et al., 2019; Johnsen & Hvam, 2019; Pero et al., 2015). In this research, this spectrum of customization approaches is addressed to provide a comprehensive and comparative outlook on customization (see Figure 1).

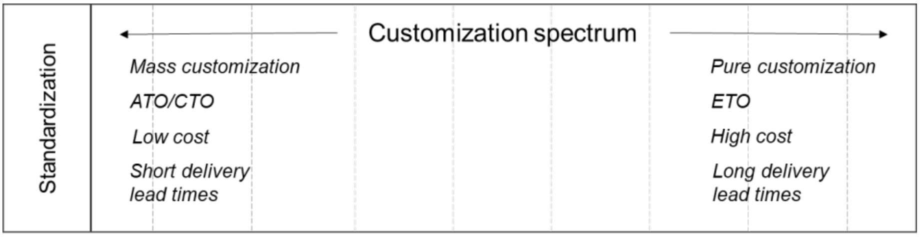

Figure 1. Customization spectrum

The interest in customization is perhaps the most evident in the context of mass customization, which has had a major impact on both research and practice (Fogliatto et al., 2012). Mass customization has been widely promoted as a means of circumventing the traditional manufacturing trade-off between flexibility and productivity, thus promising customized products at almost mass production efficiency (see e.g., Hart, 1995; Pine, 1993; Rudberg & Wikner, 2004; Tseng & Jiao, 2001). Typically associated with *modularization* (Da Cunha et al., 2010), *product platforms* (Galizia et al., 2020) and *product configuration* (Zhang, 2014), at its core, mass customization is based on the capitalization of predefined functions, components and their interrelationships. This implies that the product offering is clearly defined before the customer's order has been received to provide stability with respect to production (Salvador et al., 2009; Zhang, 2014). This process of defining clear limits for the product offering has been described in terms of a predefined *solution space,* which is considered to be a key component of mass customization (Piller, 2004; Salvador et al., 2009).

At the other end of the spectrum is pure customization (Lampel & Mintzberg, 1996) or, as it is more commonly called, ETO (Gosling & Naim, 2009). The competitive advantage offered by ETO is that it provides customers with tailor-made products as per their request, effectively including them in development, design and/or engineering activities (Gosling et al., 2017). Here, customization is taken to its extreme by engineering and producing one-of-a-kind products according to customer needs typically in project-based environments (Reid et al., 2019; Vaagen et al., 2017). An important distinction from mass customization is that ETO implies that the solution space is not clearly predefined such as that for mass customization (Piller, 2004). Further, the boundary of the solution space in ETO has been described as being "blurred" (ElMaraghy et al., 2013, p. 647). Although solution spaces have rarely been discussed in the ETO literature, as indicated by recent literature reviews (Cannas & Gosling, 2021; Gosling & Naim, 2009), they appear to represent an important departure from mass customization.

Regarding the customization spectrum overall, it is important to note that many companies cater for a combination of product offerings in parallel, with some offerings being highly customizable, and others being more standardized (Cannas, Gosling, et al., 2020; Duray et al., 2000; Lampel & Mintzberg, 1996). There is also a dynamic aspect to consider, as a company may, for instance, introduce more standardization for a product offering as a way of being able to customize more efficiently, possibly at the expense of the extent to which a customer's specific requirements can be met (Cannas, Masi, et al., 2020; Haug et al., 2009; Haug et al., 2019). To improve the efficiency and effectiveness of their customization practices, it is vital for companies to have a detailed understanding of the possibilities and limitations of different customization approaches. In this research, the notion of solution spaces is proposed as a means to describe how customization can be put into practice in different ways, highlighting factors that have been overlooked in previous research. To further describe the problem area and provide necessary explanations for the research problem addressed, the following sections describe the motives for this research.

1.2 Research motivation

The motivation for this research is to understand customization approaches from a solution space perspective (as explained in Section 1.2.1) and address customization as a practical and multifaceted phenomenon (as explained in Section 1.2.2).

1.2.1 *To understand customization approaches from a solution space perspective*

Prior to this research, there was a lack of studies that thoroughly address different customization approaches from the perspective of solution spaces. Solution spaces, which are also known as product spaces (Forza & Salvador, 2006), have primarily been studied in relation to mass customization and with a focus on its technical aspects (see e.g., Gembarski & Lachmayer, 2018; Grafmüller et al., 2018; Hermans, 2012). This research seeks to extend the solution space concept to encompass not only mass customization but also ETO and the span in between. With regard to the current classifications of customization approaches, these generally use the degree of customer involvement as an indicator of the level of customization (Duray et al., 2000; Lampel & Mintzberg, 1996), which, in many cases, is represented by the *customer order decoupling point* (CODP) (see e.g., Cannas et al., 2019; Gosling et al., 2017; Hoekstra & Romme, 1992; Wikner & Rudberg, 2005; Wortmann et al., 1997). The CODP divides the value-adding process into a speculation driven and a customer driven process segment, where the former represents the activities performed in advance (suitable for standardization) and the latter represents those performed in response to customer instructions (suitable for customization) (Wikner, 2014). The CODP has also been previously used as the basis of the classification of delivery strategies such as make-to-stock (MTS), ATO, make-to-order (MTO), CTO and ETO. However, as will be discussed in this research, the CODP is a flow-based concept and is limited when it comes to capturing the multifaceted nature of customization and does not consider, for example, how limits are set with respect to the extent to which a product offering can be customized. In this research, solution spaces are regarded as a representation of this aspect and are used to differentiate customization approaches not only based on the CODP but also from a solution space perspective. By comparing and contrasting customization approaches from a solution space perspective, a more detailed and nuanced understanding of customization practices can be attained. This intersection of the concepts of customization and solution spaces is addressed in this research (see Figure 2).

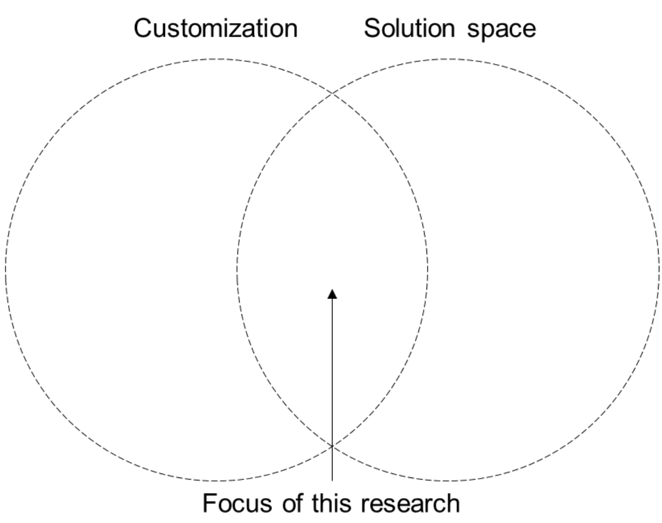

Figure 2. Research focus

1.2.2 *To address customization as a practical and multifaceted phenomenon*

This research is based on insights from a three-year research project performed in collaboration with five industrial companies that, while being heterogenous in terms of size, industry and scope, all provide customized products and associated services (see Chapter 3 for project and company descriptions). When initiating this research, the motivation was not to investigate a particular theoretical concept or theory per se but to first investigate customization as a practical phenomenon. Therefore, the premise of this research is that customization is a practical phenomenon rather than a theoretical concept, and that customization does not have a specific theoretical belonging. For instance, in operations and supply chain management, product development management, organizational learning and marketing and service management literature, various challenges related to customization have been addressed. Across these fields, previous research has, for example, focused on the *process* of providing a customized product in terms of engineering and production (Cannas et al., 2019; Dekkers, 2006; Wikner & Rudberg, 2005), the *product*-related capabilities that can be established in advance to enable customization, such as product configuration (Zhang, 2014) and product platforms (Galizia et al., 2020), the role of *learning* in customization (Kotha, 1996; Örtenblad, 2004, 2018) and the organizational and operational impact of the *customer interface* (Forza & Salvador, 2006; Wikner, Yang, et al., 2017). It appears, however, that customization research is scattered and fragmented and that the relationships between several of the customization concepts proposed in the literature of these fields are currently understudied and underspecified. To avoid fragmented and isolated streams of customization research, this research assumes a multidisciplinary viewpoint that takes into consideration all four aforementioned aspects of customization (*process*, *product*, *learning* and *customer interface*), as further accounted for in the frame of reference (see Chapter 2). Accordingly, this research is not limited to addressing a particular theory or theoretical concept, as is the case for a *theory-driven* research approach. Instead, the focus is on conceptualizing customization as a phenomenon in order to aid knowledge advancement in a more general sense, which Schwarz and Stensaker (2014) refer to as *phenomenon-driven* research.

There have been calls for phenomenon-driven (as opposed to theory-driven) management research (see e.g., Alvesson & Sandberg, 2013; Bartunek et al., 2006), as phenomenon-driven research has the potential to push a research field beyond incremental theoretical advancements to, instead, generate new and influential knowledge (Schwarz & Stensaker, 2014). Alvesson and Sandberg (2013, p. 131), for instance, criticize the *gap-spotting* inclination of theory-driven research, which they consider to be the most prevalent approach to theory development in management research, where the research is formulated by referring "*positively or mildly critically to earlier studies with the purpose of 'extend(ing) this literature' (Westphal and Khanna, 2003, p. 363), to 'address this gap in the literature' (Musson and Tietze, 2004, p. 1301), to 'fill this gap' (Lüscher and Lewis, 2008, p. 221)*" and so on. The problem with gap-spotting is that the foundations and assumptions of the pre-existing literature remain unchallenged (Alvesson & Sandberg, 2013). The phenomenon of interest that drives the formulation of the current research is customization. Instead of adhering to a specific theory, the phenomenon of customization has been taken as the point of departure, and various concepts from operations and supply chain management, product development management, organizational learning and marketing and service management have been utilized to define different approaches to customization from a solution space perspective. Consequently, valuable guidance has been provided for managers to address issues related to solution spaces in their organizations.

1.3 Purpose statement

To address the motives of this research, the research purpose is defined as follows: *to describe and define different approaches to customization from a solution space perspective.*

Customization is defined here as *the act of involving an individual customer in specifying the solution to be produced*, while the term "solution space" is defined as *a representation of how limits are set for the extent to which a company is willing to customize a product*. Note that this definition is broader than that used in prior studies, where solution spaces have been defined specifically in relation to mass customization (see e.g., Gembarski & Lachmayer, 2018; Piller, 2004; Salvador et al., 2009; Vos et al., 2018). By considering customization to encompass a range of different approaches, this thesis provides a comparative outlook on the same and extends the notion of solution spaces to be applied in a wider context than what has previously been the case. Furthermore, this research regards customization as a multifaceted phenomenon and takes into consideration different theoretical perspectives, as represented by the four customization aspects of *process*, *product*, *learning* and *customer interface*. Based on the acquired understanding of different approaches to customization from a solution space perspective, this thesis seeks to contribute insights that are of both theoretical and managerial relevance.

1.4 Research scope and delimitations

The research presented in this thesis addresses customization and how different approaches to the same can be described and defined from a solution space perspective. Set in a manufacturing context, the focus here is on customization in terms of physical goods and the associated services, which is also reflected in the empirical sample. While the results may be valid in other contexts as well, such as for services, the author does not claim that this is the case. Moreover, while customization inherently involves both a manufacturer (or "supplier") and a customer (or "buyer"), this research adopts the manufacturers' point of view, focusing on internal activities and the interface with the customer. The customers' point of view on customization and solution spaces is, therefore, beyond the scope of this research. Further, there are also certain terminological prerequisites that need to be noted. In this research, no distinction is made between "development", "design" and "engineering", and the term "engineering" is consistently used as a blanket term that encompasses development, design and engineering. The exception to this is the frame of reference, which aligns with the terminology adopted in the implicated body of literature (e.g., "product development"). In this regard, there is also a degree of inconsistency related to the terms "product", "service", "good" and "solution", as the frame of reference adheres to the terms used in the different fields considered. However, in the final chapters of this thesis (Chapter 5 and Chapter 6), the term "solution" is used as an umbrella term for customized goods and the associated services. A delimitation is also established regarding the focus on the four specific aspects of customization: *process*, *product*, *learning* and *customer interface*. These aspects are derived from an overall analysis of the literature, where customization is a phenomenon of interest. Although there may be other aspects, such as *resources*, that could have been presented separately, this research is limited to these four aspects. As for solution spaces, this research addresses the managerial rather than the technical aspects of solution spaces (see e.g., Gembarski, 2019; Gembarski & Lachmayer, 2018; Hermans, 2012).

1.5 Thesis outline

This thesis consists of six chapters and four appended papers. Chapter 1, *Introduction*, presents the background of the theme of the thesis and proceeds to discuss the research motivation along with the purpose statement and research scope. In Chapter 2, *Frame of reference*, the literature that is relevant to this work is outlined. It includes different theoretical perspectives on customization and connects it to a variety of research fields. The chapter is concluded with a theoretical framework that incorporates the key concepts of concern for this research. In Chapter 3, *Research methodology*, the research design, empirical context, research process and data collection and analysis are presented. Research quality is also discussed along with the associated ethical considerations. Chapter 4 presents a *summary of the appended papers*. Papers 1–4 are separately and briefly described, with a specific focus on the research's purpose and key findings. In Chapter 5, *a conceptual framework for customization and solution spaces* is outlined based on the findings of the appended papers and the frame of reference. In Chapter 6, *Discussion and conclusions*, a methodological reflection is carried out, the theoretical contributions are discussed, and managerial implications and suggestions for further research are addressed. The thesis ends with a concluding remark.

2 Frame of reference

This chapter first presents a selection of theoretical perspectives through which customization can be understood (see Section 2.1), accounting for customization in terms of process, product, learning and customer interface, as shown in Figure 3. Following this, the manner in which solution spaces are represented in the literature is described (see Section 2.2). The chapter is concluded with a theoretical framework for customization and solution spaces (see Section 2.3), which is subsequently used as a basis for the analysis conducted.

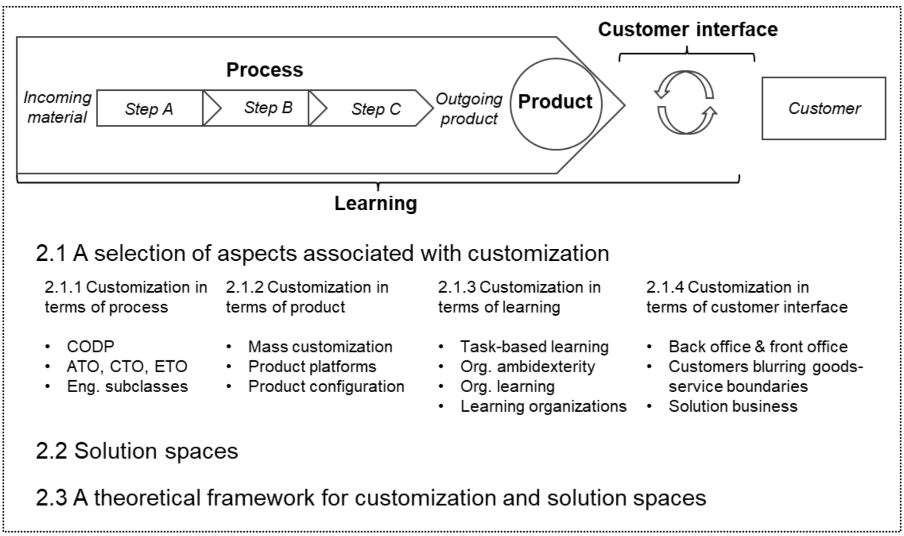

Figure 3. Key concepts in the frame of reference

2.1 A selection of aspects associated with customization

The following section outlines our current understanding of customization in terms of process, product, learning and customer interface. These aspects have been selected based on an overall analysis of the literature from different fields in which customization is addressed. The process aspect, which is accounted for in Section 2.1.1, is based on key concepts from the operations and supply chain management literature. Presented in Section 2.1.2, the product aspect is based on product development management literature. The learning aspect focuses on research on learning in organizations, as presented in Section 2.1.3. Last, the customer interface aspect in Section 2.1.4 explains how customization is viewed in the marketing and service management literature.

2.1.1 *Customization in terms of process*

To provide value to customers, companies perform value-adding activities, and, taken together, these activities can be regarded as a value-adding process. In a manufacturing context, the value adding process typically comprises activities such as engineering, fabrication and assembly, and a simplified illustration of this is shown in Figure 4 below. In cases of customization, some of these activities will be performed in response to a customer order, and this can be viewed in terms of the CODP (Wikner, 2014).

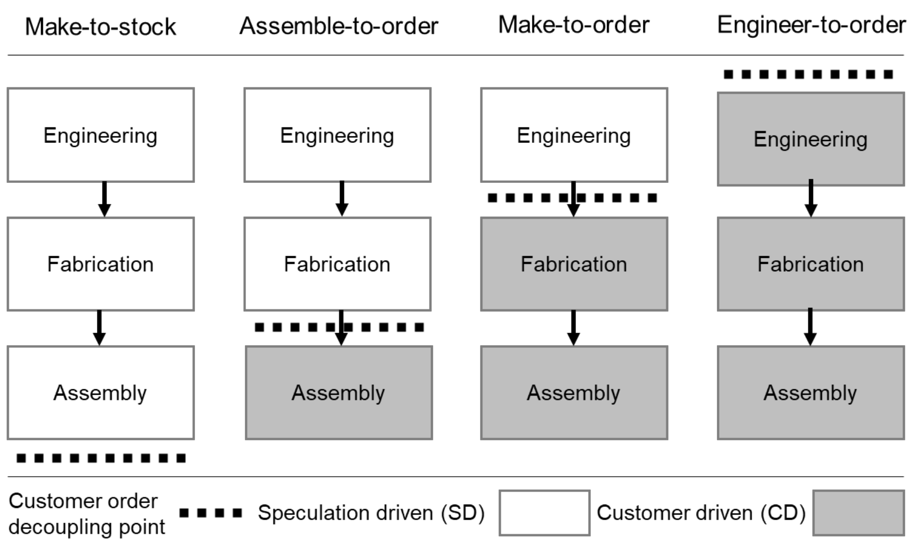

Figure 4. Simplified value-adding processes based on the CODP. Adapted from Lampel and Mintzberg (1996) and Yang et al. (2004).

2.1.1.1 The customer order decoupling point (CODP)

The CODP has had an important role in the operations and supply chain management literature and is defined as the point that "*separates decisions made under certainty from decisions made under uncertainty concerning customer demand*" (Rudberg & Wikner, 2004, p. 447). The CODP distinguishes between *speculation driven* activities, which are based on standardization, and *customer driven* activities, which can be based on standardization or customization. It is worth noting that speculation driven activities are sometimes referred to as forecast driven activities, while customer driven activities are sometimes referred to as customer order driven activities. The CODP has also been referred to using other terms such as the *decoupling point* (Hoekstra & Romme, 1992), the *customer order point* (Mason-Jones & Towill, 1999) and the *order penetration point* (Sharman, 1984).

The reason for distinguishing between speculation driven and customer driven activities is to enable more focused management throughout the value-adding process (Wikner, 2014). As customer driven activities are based on actual customer commitments, these can be customized. In contrast, speculation driven activities are performed before the customer comes into the picture and, thus, are standard. With the CODP positioned more upstream in the value-adding process, the ability to respond to individual customer needs is therefore increased and vice versa (see e.g., Hsuan Mikkola & Skjøtt-Larsen, 2004; Skipworth & Harrison, 2006). The CODP has been described in some cases as a *customization* or *product differentiation point* (see e.g., Pagh & Cooper, 1998; Vanteddu & Chinnam, 2014). Although the CODP is related to customization, it does not explicitly distinguish standardization from customization, and the point where a customization can be implemented can actually differ from the CODP (see e.g., Amaro et al., 1999; Holweg, 2005; Wikner & Rudberg, 2005). To represent the customization aspect of decoupling points, a *customer adaptation decoupling point* has been proposed. It is defined as the point that "*separates decisions about differentiating flow based on standardization for a market of different customers from adaptation against actual customer orders*" (Wikner, 2014, p. 196).

2.1.1.2 Delivery strategies based on the CODP

The CODP is a well-established basis for categorizing delivery strategies such as MTS, MTO, ATO and ETO (see e.g., Giesberts & Tang, 1992; Hoekstra & Romme, 1992; Sharman, 1984; Wortmann et al., 1997). In addition, CTO is a delivery strategy that has been discussed in the literature (Hvam et al., 2008; Myrodia & Hvam, 2014), as shown in Figure 5 below.

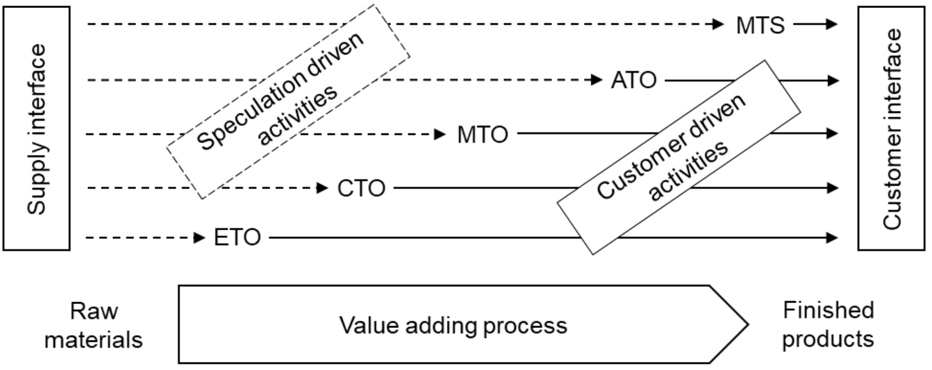

Figure 5. Linear perspective on delivery strategies relative to speculation and customer driven activities (adapted from Rudberg & Wikner, 2004)

MTS is based on a high degree of standardization and corresponds to mass production. In this context, products are engineered and produced based on speculations regarding future customer orders, and the customer is only involved in deciding when, where and how many of the units are to be delivered. MTO is similar to MTS in that the product is engineered in advance, but it differs in that the product is not produced to be stocked. The reasons for not basing the delivery on stocked products could be that it is expensive, impractical or undesirable to do so. Hence, MTO is a delivery strategy that supports standard products that are engineered-to-stock but produced-to-order (see e.g., Wikner & Rudberg, 2005). It is worth noting, however, that this definition differs from the cases where MTO is used synonymously with ETO (Stevenson et al., 2005) or as an umbrella term for non-MTS situations (Soman et al., 2004). In contrast to MTO and MTS, the other three delivery strategies imply customization. ATO is usually assumed to employ modularity, where customers can choose from interchangeable modules with standardized interfaces (Wemmerlöv, 1984), which means that the modules can be produced and stocked in advance before the customer has specified their order. The product is assembled based on the selection of modules made by the customer, and the customer will, therefore, not have to wait for the related engineering activities to be performed. In this way, ATO allows for customization while maintaining relatively short delivery lead times and low costs (Wemmerlöv, 1984; Wortmann et al., 1997). Similar to ATO is CTO, which, in addition to allowing for customization through modular design, can also accommodate customization through parametric design (Song & Zipkin, 2003). For CTO, the key organizer for customization is typically a product configurator, which essentially serves as a software support that dictates the offering based on a set of customization rules (Hvam et al., 2008). In terms of customization, ATO and CTO are similar, as they both limit customization to a predefined modular (ATO) and modular/parametric (CTO) offering (Song & Zipkin, 2003). However, ATO and CTO have been used inconsistently in the literature, and their precise definitions can vary (see e.g., Cheng et al., 2002; Hvam et al., 2008; Song & Zipkin, 2003). ETO differs from ATO and CTO, as the associated engineering activities are driven by customer requirements and are performed only after the customer has specified their requirements. The CODP is positioned at the engineering stage, which makes it possible for customers to receive a response for potentially unique individual needs; but this comes at the expense of longer delivery lead times (Giesberts & Tang, 1992; Hoekstra & Romme, 1992).

2.1.1.3 Engineering activities based on the CODP

Initially introduced to address the degree of customer involvement in material flows (Giesberts & Tang, 1992; Hoekstra & Romme, 1992; Sharman, 1984), the CODP was later applied to engineering activities (see e.g., Dekkers, 2006; Gosling et al., 2017; Wikner & Rudberg, 2005). The decoupling of engineering activities is particularly useful for understanding ETO, as it has provided certain nuances to the understanding of non-physical activities in this context. For example, with respect to the construction sector, Winch (2003) proposed concept-to-order and design-to-order as subclasses of ETO. For concept-to-order, the customer is involved in defining the functionality of the product, but there is a lack of clarity regarding the basis for proposing concepts to customers. Winch (2003, p. 112), for instance, stated that "*nothing happens until the client initiates production*", although it can be argued that there is always some type of engineering knowledge that has been established before a client/customer comes into the picture. For design-to-order, the product concept is already established but significant engineering design work is performed according to the customer's specifications (Winch, 2003).

Wikner and Rudberg (2005) proposed a differentiation between the production and engineering dimensions related to the CODP, where the engineering dimension comprises both existing designs that are kept in stock and new designs that are made to order, and, intermediately, the existing designs are modified to varying degrees. Following a similar line of reasoning, Dekkers (2006) made a distinction between the customer order entry point, which is the point at which an order enters the material flow, and the order specification entry point, which is the order entry point for the engineering dimension. More recently, a case study by Cannas et al. (2019) provided empirical support for the different decoupling configurations related to the production and engineering dimension of the CODP.

Building on the works of Wikner and Rudberg (2005) and Dekkers (2006), among others, Gosling et al. (2017) proposed a framework of three engineering categories that comprised nine engineering subclasses based on the CODP, as shown in Figure 6. The first category, *research*, implies that customization is taken to its extreme when research and development activities are customized and performed to order. The second category, *codes and standards*, refers to cases where research and development activities are standardized and carried out in advance but where the creation and integration of codes and standards is customized to create unique products according to customer specifications. In the third and last category, *existing designs*, the point of departure for customization is standard designs, drawings and subsystems that are modified based on customer-specific needs.

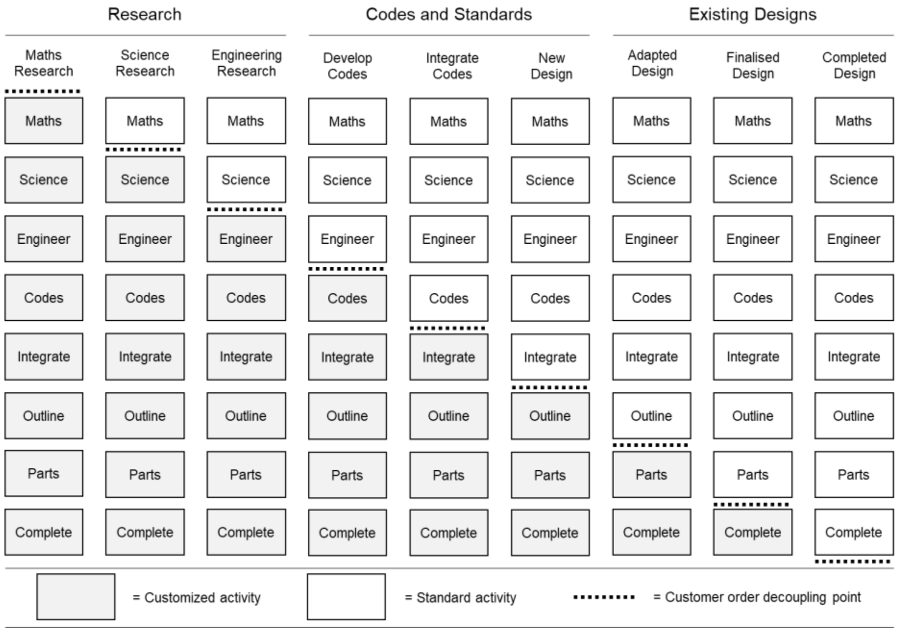

Figure 6. Engineering categories and subclasses (Gosling et al., 2017)

In summary, in the operations and supply chain management literature, customization has been primarily viewed from a process perspective by considering which activities are speculation driven, as opposed to customer driven, and the associated implications for planning and control. The actual product that is the outcome of the process has been given less attention, but this is addressed in further detail in the product development management literature.

2.1.2 *Customization in terms of product*

The product development management literature primarily focuses on the preparatory aspects of customization and the product-related capabilities that companies can set up before the customer comes into the picture. Product platforms have been advocated as a means of enabling mass customization (Jiao et al., 2007), and product configurators have been proven to be useful software supports for managing the product offering in mass customization contexts (Zhang, 2014). These concepts are discussed in the following sections.

2.1.2.1 Mass customization

The term "mass customization" was coined by Davis (1987) to describe how companies could overcome the either/or dilemma of economies of scale versus customization. Defined as "*the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the low cost of a standardized, mass production system"* (Hart, 1995), mass customization has since become a widely promoted business concept and is now seen as the dominant form of production (Fogliatto et al., 2012). However, while there has been a substantial interest in mass customization, it has been argued that there is a lack of meaningful conceptual boundaries for what mass customization actually refers to (Duray et al., 2000; Kaplan & Haenlein, 2006). Some have adopted more visionary definitions, while others have adopted more practical ones (Da Silveira et al., 2001; Fogliatto et al., 2012; Hart, 1995).

Rudberg and Wikner (2004) argue that there are two major elements that companies engaging in mass customization rely on: first, the means by which customer-specific requirements are incorporated in design and/or manufacturing and, second, the process through which the customer-specific product is manufactured and distributed at a price equivalent to a mass-produced equivalent. More specifically, Zipkin (2001) argued that there are three key capabilities related to mass customization: 1) *elicitation*, which refers to the interaction required to obtain customer-specific information, 2) *process flexibility*, which refers to the production technology required to manufacture products according to the customer specifications and 3) *logistics*, which refers to the subsequent stages and the distribution required. Salvador et al. (2009) further developed these capabilities, proposing that *solution space development*, *robust process design* and *choice navigation* are crucial for a company to engage in mass customization. Salvador et al. (2009, p. 5) define solution space development as the "*capability to identify the product attributes along which customer needs mostly diverge*". Further, robust process design refers to the "*capability to reuse or re-combine existing organizational and value chain resources to fulfill a stream of differentiated customers' needs*", while choice navigation refers to the *"capability to support the customers in identifying their own solutions while minimizing complexity and burden of choice*" (Salvador et al., 2009, p. 11). Moreover, Hvam et al. (2008) argue that mass customization is typically achieved through the use of module-based product offerings and with the support of product configuration systems.

2.1.2.2 Product platforms and product configuration

Two concepts that are closely associated with mass customization are product platforms and product configuration. A product platform basically refers to the technology, components and subsystems that are developed and implemented to be shared across multiple products and product lines (Meyer et al., 2018). Robertson and Ulrich (1998, p. 20) define a product platform as "*the collection of assets, such as components, processes, knowledge, people, and relationships, that are shared by a set of products*". The advantages enabled by product platforms are that differentiated products can be developed with increased efficiency and that the flexibility and responsiveness of the manufacturing processes involved can be increased (Robertson & Ulrich, 1998). Simpson et al. (2006) report that employing product platforms can lead to reduced costs and product development times.

Product platforms can be *module-based*, *scale-based* (Simpson, 2004; Simpson et al., 2014) or a combination of both, which Gao et al. (2009) refer to as *module-scale-based* product platforms. For module-based product platforms, the emphasis is on identifying the modules that are to be shared and combined to form multiple product variants. A considerable amount of research has sought to explain how such modules can be identified (see e.g., McAdams et al., 1999; Shooter et al., 2005; Stone et al., 2000). Scale-based product platforms focus on choosing scaling variables that can "stretch" or "shrink" the design to satisfy a variety of customer needs (Simpson, 2004), while module-scale-based product platforms combine both modular and scalable design (Gao et al., 2009).

Related to the product platform concept is that of product configurators, which refer to the use of configuration software as an organizer for customization. They can improve product quality (Trentin et al., 2012), shorten delivery lead time (Haug et al., 2011) and facilitate product variety management (Forza & Salvador, 2002). Generally, two types of product configurators are recognized in the literature. The first type is used in the order acquisition process, and these are referred to as commercial configurators (Cannas, Masi, et al., 2020) or sales configurators (Forza & Salvador, 2006). A sales configurator functions as an organizer for the product offering towards the customer interface, supports the identification of customer requirements and can rapidly generate estimates of price, lead times and product proposals (Aldanondo et al., 2003; Forza & Salvador, 2006). The second type of configurator is used in the order fulfilment process; these are referred to as technical configurators. A technical configurator uses the output of the sales configurator and translates it into documents and specifications that are necessary for initiating the manufacturing of the specific product variant (Forza & Salvador, 2006).

It is vital to note that product configurators can only be implemented in cases where customization is offered based on a set of predefined components and within well-defined constraints, such as for mass customization. This is explained by Zhang (2014, p. 6394) in the following quote, and this is related to the development of a predefined solution space, as discussed in Section 2.2:

> *"Product configuration capitalizes on predefined functions, components and their relationships, which results in the configured products known in principle even if not explicitly listable. Consequently, product configuration cannot help configure customized products to the full extent such that it covers all reasonable and perhaps unforeseen customer requirements"*.

In summary, the product development management literature has focused on customization in terms of products and how customized products can be realized efficiently. While learning has also been considered in this literature to a certain extent, for instance, in relation to knowledge reuse and knowledge-based engineering (Verhagen et al., 2012), the body of literature that explicitly focuses on learning in organizations provides a more comprehensive and detailed understanding of this issue.

2.1.3 *Customization in terms of learning*

The notion that learning is a fundamental aspect of an organization's success was popularized in the works of Nonaka and Takeuchi (1995). Prominent concepts from the literature that addresses learning in organizations include *organizational learning* (Dixon, 2017), *learning organizations* (Örtenblad, 2018) and *organizational ambidexterity* (O'Reilly & Tushman, 2013).

Further, certain studies have associated these concepts with customization (see e.g., Engström, 2014; Kotha, 1996; Örtenblad, 2013). The following section describes a task-based outlook on learning and its relationship with organizational ambidexterity, while the subsequent section describes the concepts of organizational learning and learning organizations.

2.1.3.1 Task-based and ambidextrous learning

Learning is closely linked with the tasks performed by individuals or groups (Ellström, 2005; Engström, 2014). Ellström (2005) proposed two types of logics for learning: adaptive learning (also referred to as *executional learning* (Engström & Wikner, 2017), which is the term that will be used in this work) and *developmental learning*. For tasks that are well understood and clearly defined in advance, the focus is on executional learning, where the learner performs the task according to existing procedures and protocols. As executional learning occurs, explicit knowledge is made implicit because the task becomes habitual, and the learner performs the task without much reflection (Engström, 2014). For tasks that require reflection and transformation rather than reproduction, the focus is on developmental learning, where the learner explores and questions existing procedures, which can form the basis for the identification of new tasks or the development of existing tasks (Ellström, 2005). The interdependency between executional and developmental learning was further discussed by Engström (2014), who described the relationship between the two learning logics and different task requirements, as illustrated in Figure 7.

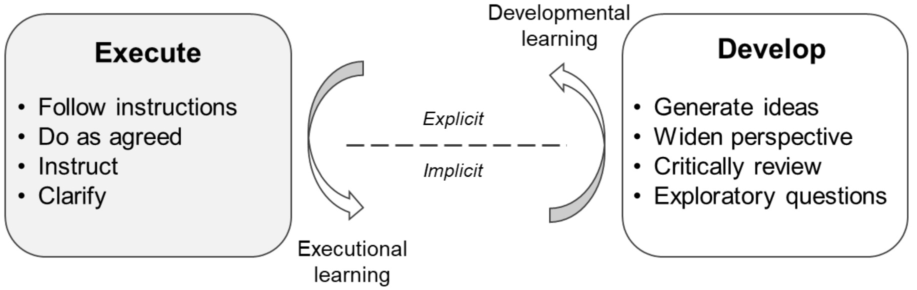

Figure 7. Executional and developmental learning related to task requirements (adapted from Engström, 2014)

The interplay between executional and developmental learning is related to the concept of organizational ambidexterity, which has received considerable attention in organizational studies (O'Reilly & Tushman, 2004). Organizational ambidexterity is based on the idea that organizations need to strike a balance between exploiting the existing knowledge, which corresponds to executional learning, and exploring new knowledge, which corresponds to developmental learning. The exploitation is based on efficiency, control, certainty and variance reduction, while the exploration is based on searching, discovery, autonomy and innovation (March, 1991). Exploitation is, therefore, primarily concerned with the short-term and the known, whereas exploration is associated with the long-term and the unknown. However, exploitation and exploration are considered to be two competing logics (Engström, 2014; March, 1991), and organizations need to heed to how these logics are harmonized. A common tendency observed is that of exploitation receiving more interest than exploration, as organizations prefer greater certainty and short-term success (Engström, 2014). If there is no room left for exploration, organizations run the risk of obsolescence and failure in the face of change (March, 1991; O'Reilly & Tushman, 2004).

Organizational ambidexterity has been studied at the company level, the project level and the individual level (O'Reilly & Tushman, 2013). Reviewing the literature on the effects of organizational ambidexterity on company performance, O'Reilly and Tushman (2013) noted that positive associations have been found between organizational ambidexterity and, for example, sales growth (see e.g., Lin et al., 2007), innovation (see e.g., Rothaermel & Alexandre, 2009), market valuation (see e.g., Uotila et al., 2009) and company survival (see e.g., Hill & Birkinshaw, 2014). Under certain circumstances, however, organizational ambidexterity can be inefficient and duplicative (Van Looy et al., 2005); but when there is uncertainty in terms of the marketplace and technology, the evidence suggests that organizational ambidexterity positively affects the performance of a company (Junni et al., 2013). Such uncertainty is a key characteristic in customization contexts, and some studies have investigated the relationship between organizational ambidexterity and customization. For instance, Kortmann et al. (2014) argued that mass customization capability can be seen as an ambidextrous operational capability, and Salvador et al. (2014) defined product configuration ambidexterity as the establishing of a balance between effectiveness and intelligence for product configuration. Moreover, to foster learning in the organization, Vos et al. (2018) argued for the need to strike a balance between a constrained solution space and solution space freedom.

2.1.3.2 Organizational learning and learning organizations

The concept of *organizational learning* has had a major impact on the literature from various fields, such as operations management (Zhu et al., 2018), innovation management (Migdadi, 2019) and marketing (Chung & Ho, 2021). Organizational learning can be broadly defined as "*the process of improving actions through better knowledge and understanding*" (Fiol & Lyles, 1985, p. 803), although there is a lack of consensus regarding its precise definition. Argyris and Schön (1978, p. 58), for example, described organizational learning as the development of contexts that enable learning, defining it as "*a process in which members of an organization detect errors and anomalies and correct them by restructuring organizational theory of action, embedding the results of their inquiry in the organizational maps and images*". The concept of consolidating the generated knowledge in the "organizational maps and images" was also stressed by Örtenblad (2001). The author reported a common misconception that organizational learning implies that individuals learn as agents of the organization; but to be considered valid as organizational learning, the knowledge must be consolidated into the organization's memory, for instance, through routines, procedures, processes or culture. This is in line with the work of Huber (1991), who identified four constructs of organizational learning: knowledge acquisition, information distribution, information interpretation and organizational memory. It is, however, not the organization itself that learns but, rather, the individuals and groups from the organization (Edmondson, 2012). The *organizational* aspect of organizational learning refers to the social setting established by the organization that enables employees to carry out error detections and corrections (Argyris & Schön, 1978). Furthermore, the creation of an organizational setting that fosters learning is related to the concept of the *learning organization*.

Besides organizational learning, the sibling concept of a learning organization likewise represents an increased focus on learning as a key issue for companies. However, a learning organization refers to a noun – an ideal organization to be achieved (Örtenblad, 2001). The term was popularized by Senge (1990), who, in the famous book *the Fifth Discipline*, argued that the main obstacle for companies with regard to surviving in an era of change and intensifying competition is their inability to learn. He argued that many organizations struggle to learn and that learning should be considered a key component for survival, as organizations are increasingly facing constant change. According to the definition proposed by Watkins and Marsick (1993), a learning organization is one that learns continually and has the capacity to transform itself. At an individual level, this requires organizational members to continually expand their capacity to achieve desirable results, to cultivate their innovative and expansive thinking and continuously enhance their ability to learn together as a collective (Senge, 1990).

To summarize, the literature on learning in organizations focuses on various issues associated with customization, as the recurrent need to adjust to customer specifications necessitates learning in the organization.

2.1.4 *Customization in terms of customer interface*

A key issue for customization is related to the customer interface and the implications of involving individual customers in activities that would otherwise be performed independent of them in the case of a standard product. This section provides an account of how this aspect has been discussed in the marketing and service management literature.

2.1.4.1 Direct or indirect customer contact

The manner in which customers can be involved in value-adding processes was discussed in Section 2.1.1 based on the CODP and primarily related to manufacturing. However, the service operations literature includes a corresponding way of decoupling processes that places greater emphasis on the organizational implications of the customer interface.

The decoupling of the *back office* and *front office* separates work that does not require direct customer contact (back office) from that which does (front office) (Metters & Vargas, 2000). Direct customer contact can occur both by the physical presence of the customer in the service system and by their virtual presence (see e.g., Wikner, Yang, et al., 2017). Chase (1978) explained that, in service systems that involve a low degree of direct customer contact and, hence, a comparably large proportion of back office operations, there is greater potential for the system to operate efficiently. In contrast, for service systems with a high degree of direct customer contact and, thereby, a relatively large amount of front office operations, there is less potential for the system to operate efficiently. This is because high-contact systems are faced with greater uncertainty, as customer-specific requirements can cause variation and disruptions in work processes (Chase, 1978). Similarly, Shostack (1984) identified processes that are invisible (back office) and visible (front office) for customers as she introduced service blueprinting. As exemplified in Figure 8, separating the back office operations from those of the front office enables one to recognize that they have different priorities and requirements with regard to how tasks are designed (Metters & Vargas, 2000).

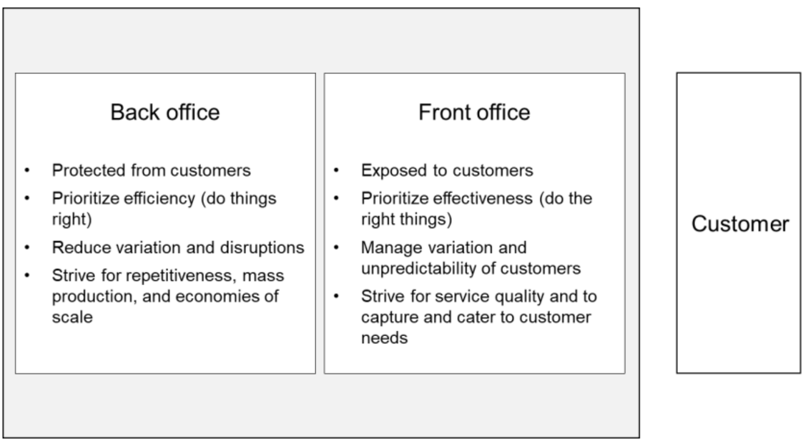

Figure 8. Back office and front office characteristics

The relative allocation of tasks to the back and front offices represents an important decision that relates to the balance between the internal efficiency of operations and the external effectiveness at the customer interface (Wikner, Yang, et al., 2017). In an environment characterized by high degrees of standardization and repetitiveness, such as that for mass production, a relatively large proportion of tasks are performed in the back office, whereas, in cases of high levels of customization, a relatively large proportion of tasks are performed in the front office. Considering that front office tasks include a service dimension regardless of whether it involves a tangible good or a service offering, it can be argued that having a large proportion of front office tasks, as required for high levels of customization, implies a substantial service element for the offering (Wikner, Yang, et al., 2017).

2.1.4.2 Customer contact blurring goods–service boundaries

The similarities and differences between tangible goods and services have been extensively discussed in the literature, particularly in the marketing literature. In the 1980s, marketing research was largely divided into goods-focused and service-focused marketing (Fisk et al., 1993). Since then, both service- and goods-related studies have argued that it is becoming increasingly difficult to separate goods and services (Sampson & Froehle, 2006; Vargo & Lusch, 2004; Wikner, Yang, et al., 2017). Customers have become involved to a greater extent in the value-adding processes of manufactured goods, and goods have, as a consequence, become more service-like. Further, customization has been highlighted as a key factor for the difficulties related to distinguishing between goods and services (Grönroos & Voima, 2013; Moeller, 2008).

> *"Due to the intensity of competition and advancements in technology, individual customers are being given greater consideration and product offerings are becoming ever more customized. Hence, some goods have morphed into offerings that resemble services"* (Moeller, 2008, p. 197)

This development is also evident in research that focuses on *solution businesses,* which is a business model that is primarily discussed in the marketing literature. Solution businesses refer to the exchange of solutions rather than stand-alone goods or services, as various industries have shifted from selling goods or services separately to selling functionalities or capabilities that combine or integrate these utilities (Biggemann et al., 2013; Petri & Jacob, 2016; Storbacka, 2011; Wei et al., 2019). Tuli et al. (2007, p. 14) explain that a key characteristic of solution businesses is the relational process required to tailor the suggested solution to the individual customer's point of view and further argue that "*selling solutions is a complex exercise that involves the consideration of conflicting requirements of multiple stakeholders in a customer organization and sales cycles lasting up to two years*". This means that, in this context, creating a customer-specific solution is a comprehensive and time-consuming task.

In summary, the growing proximity to customers has caused manufactured goods to become more service-like, and the need to integrate goods and services into a common concept has led to the emergence of the term “*solution*”, which basically refers to a value delivery package that consists of goods and/or services.

2.2 Solution spaces

The concept of solution spaces is not unique to customization and is, for example, central in the optimization theory (Beavis & Dobbs, 1990). However, in this thesis, the focus is on solution spaces for customization and this section will describe how solution spaces are represented in the literature.

In the current literature, solution spaces for customization have primarily been considered from a product perspective, where product platforms, product configuration and mass customization have been addressed. Piller (2004, p. 316) argues that a *fixed* or *stable* solution space is a key point for mass customization, stating that it is the “*major differentiation of mass customization versus conventional customization*”. Similarly, Salvador et al. (2009) argue that the development of a *clearly defined* solution space is a fundamental capability for companies engaging in mass customization. Several studies have focused on solution space development in the context of mass customization (see e.g., Gembarski & Lachmayer, 2018; Grafmüller et al., 2018; Hermans, 2012). Although, solution spaces are often only briefly mentioned instead of being analyzed in detail. Haug et al. (2009) argue that, to pursue mass customization in ETO contexts, the engineering aspect needs to become more standardized to attain a *predefined* solution space where customized solutions can be configured. Focusing on solution configuration, Zhou et al. (2008) discuss the optimization of *configuration* spaces. Vos et al. (2018) refer to the mass-customization type of solution space as a *constrained* solution space, while Lyons et al. (2013) use the term “*bounded* solution space”. Even though there is a lack of conceptual developments that explain the fundamental properties of the mass customization solution space, its distinctive characteristic is that it constrains the degrees of freedom for customization to a predefined discrete set of solutions.

With regard to ETO, solution spaces are rarely acknowledged in the literature – to a far lesser extent than for mass customization. Although being more oriented towards mass customization, ElMaraghy et al. (2013, p. 647) briefly mention that the boundary of an ETO solution space is “*blurred*” in contrast to a mass-customization solution space. Vos et al. (2018) use the term "*solution space freedom*" in contrast to the *constrained* solution space, while Johnsen and Hvam (2019) refer to a *non-standard customization solution space* in relation to ETO.

2.3 A theoretical framework for customization and solution spaces

Based on the discussion on solution spaces and the four selected aspects of customization, this section proposes a theoretical framework for customization and solution spaces that will serve as a foundation for further analysis. A summary of the key customization concepts described in the frame of reference is outlined in Table 1.

Table 1. Key customization concepts in the frame of reference

Customization aspect	*Key customization concepts*
2.1.1 Process	The CODP, ATO/CTO/ETO
2.1.2 Product	Mass customization, product platforms and product configuration
2.1.3 Learning	Executional and developmental learning, exploration and exploitation
2.1.4 Customer interface	Back office and front office, solutions and solution businesses
2.2 Solution spaces	Fixed, stable, clearly defined, constrained and bounded solution space, Solution space freedom and blurred boundaries

This research builds upon previous studies on customization in terms of process, product, learning and customer interface and adopts a solution space perspective that links to these four customization aspects. As the purpose is to describe and define different approaches to customization from a solution space perspective, the focus is on considering the different ways in which the customization aspects are put into practice. Figure 9 outlines the progression from the practical phenomenon (customization) to the theoretical domain (process, product, learning and customer interface) and, further, to the analytical and conceptual domain (solution space), which is accounted for in Chapter 5 as a conceptual framework.

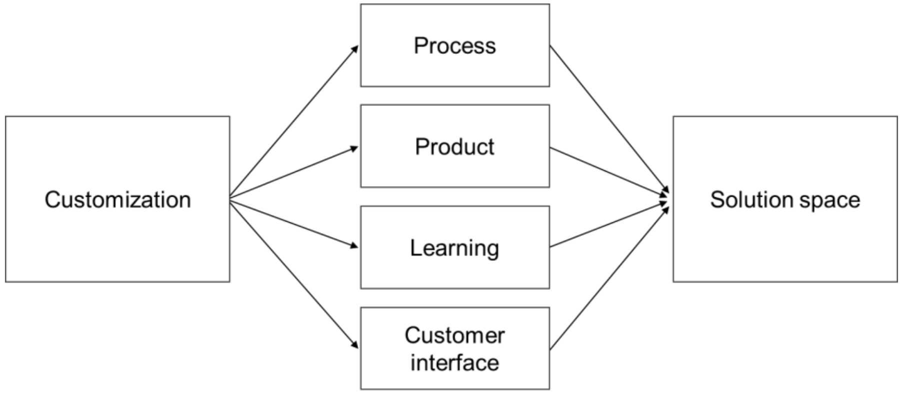

Figure 9. A theoretical framework for customization and solution spaces

3 Research methodology

This chapter presents the methodological decisions made throughout the research with regard to research design (Section 3.1), empirical context (Section 3.2), research process (Section 3.3), data collection and analysis (Section 3.4) and research quality and ethical considerations (Section 3.5).

3.1 Research design

The design of any research should be guided by the phenomenon under investigation (Alvesson & Skjöldberg, 2008). The phenomenon of interest here – customization from the perspective of solution spaces – is a nascent concept that has not been thoroughly investigated in any particular field of study and, hence, lacks a solid theoretical foundation. Due to the novelty of the research phenomenon, this research is oriented towards theory development rather than theory testing (see e.g., Arlbjørn & Halldorsson, 2002; Corley & Gioia, 2011). It comprises both conceptual and empirical papers, which is considered appropriate for theory-building research (Meredith, 1993; Wacker, 1998). The thesis is based on four studies and comprises four papers and a kappa, as indicated in Figure 10, which illustrates the relationships between the studies, the papers and the kappa (in the Swedish academic system a kappa basically refers to a synthesis of a thesis project, typically accompanying a set of articles for a compilation thesis).

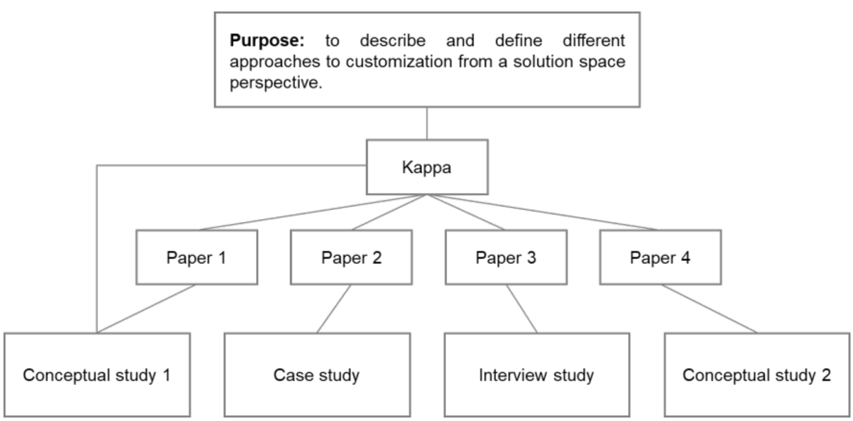

Figure 10. Relationships among the purpose, kappa, papers and studies

Conceptual Study 1 and *Conceptual Study 2* adopt a form of theory-building research that is similar to what Wacker (1998, p. 373) refers to as *analytical conceptual research*, which serves to "*add new insights into traditional problems through logical relationship-building*". For *Conceptual Study 1*, the traditional problem relates to how customization can be approached in different ways, and new insights are provided by considering solution spaces. This study was the basis for *Paper 1*, which differentiates and conceptualizes solution spaces, but is also applied in the remaining papers via the kappa, as indicated by the link between *Conceptual Study 1* and *Kappa* seen on the left side in Figure 10. This essentially means that the kappa serves to apply the solution space differentiation, as found in *Conceptual Study 1* and described in *Paper 1*, to the specific issues addressed in the remaining papers, which is why it can be seen as an extension of *Conceptual Study 1*. For *Conceptual Study 2*, which resulted in *Paper 4*, a similar analytical conceptual approach to theory-building was adopted to address key concepts within learning in organizations, customization and the customer-order-based context. For both *Conceptual Study 1* and *2*, the logical relationship-building was performed by analyzing, synthesizing and clarifying the terms and concepts used in the literature. For the *interview study*, which empirically investigates learning in customization settings, workshop data were utilized, and an in-depth qualitative interview study was conducted to provide rich empirical data on how organizations can learn while interacting with customers to understand customer-specific needs, as presented in *Paper 3*. For the *case study*, the evaluations of tendering invitations were investigated, and a case study methodology was chosen to enable the use of rich and contextually bound empirical descriptions for an in-depth analysis, resulting in *Paper 2*.

While all studies and papers focus on customization, it should be noted that solution spaces are explicitly discussed only in *Paper 1* and *2* and not in *Paper 3* and *4*. This is the reason for integrating *Conceptual Study 1* and the kappa, as this allows us to apply the solution space perspective in *Paper 3* and *4* via the kappa. It is also worth noting that *Paper 1* and *4* attend to a wide spectrum of different customization approaches, whereas *Paper 2* and *3* specifically focus on ETO environments.

3.2 Empirical context

The context for this research is provided by the five companies that participated in the interactive research project (further described in Section 3.3 below). These companies were selected based on the criterion that they all offer customized products and/or services. Outside this aspect, the companies significantly differed from each other, for example, in terms of size, industry and type of production system, which enabled a broad understanding of customization and how it can be put into practice in different ways (see Table 2).

Table 2. Information about the studied companies

	Company Alpha	*Company Beta*	*Company Gamma*	*Company Delta*	*Company Epsilon*
Business area	Engineering consultancy	Door manufacturer	Network solutions	Contract manufacturer	Heating equipment
No. of employees	100 employees	30 employees	100,000 employees	400 employees	150 employees
Business transactions	B2B	B2B and B2C	B2B	B2B	B2B
Market scope	Regional	National	Global	National	Global

Company Alpha, an engineering consultancy with approximately 100 employees, has a key business area called “commitment projects”, wherein the company takes responsibility for developing the customer’s product and the associated software and services. This can, for instance, be in the form of product prototypes. Its customers are usually businesses, and it is common for customer requirements to change during the development process, which calls for a continuous dialogue with the customer.

Company Beta is a manufacturer of custom-made doors and gates and employs approximately 30 employees. Its customers vary from large construction companies to housing corporations and private customers. These distinct customer segments require the company to work in different ways due to, for instance, the number of stakeholders involved from the customers' side and the varying degrees of specificity in customer requirements.

Company Gamma is a global company with more than 100,000 employees that develops and produces large-scale network solutions. Its production is complex, and product variety is high. Being a large and geographically scattered company, a recurring issue for the company's customization practices is the flow of information through the internal supply chain.

Company Delta is a contract manufacturer with 400 employees that develops and manufactures products in small- and medium-sized series for business customers. It is a global company, but the three plants considered in this research are all located in Sweden. These plants develop and manufacture products for a variety of purposes, such as medical devices, construction equipment and packaging machinery. In Paper 2, Company Delta is referred to as "FlexiCorp".

Company Epsilon is a manufacturer of heating equipment and has 150 employees. Its customers are located all around the world, and while the products are similar in terms of basic purpose and function, they differ in areas of application. In some cases, this requires the company to understand certain regulations that even the customer may not be aware of.

In summary, the empirical context of this research represents a heterogenous sample of customization applications. The focus is primarily on product-oriented companies, although the associated services have also been considered. It should be noted that while the companies are only explicitly referred to in the empirical papers (Paper 2 (featuring only Company Delta, "FlexiCorp") and Paper 3 (featuring all five companies)), the conceptual papers have also been informed by them, as these papers are still concerned with providing real-world descriptions despite not using empirical data as the basis of their analyses.

3.3 Research process

The research that is the basis for this thesis was conducted over a five-year period – from 2017–2022. It includes not only the four studies and the kappa, as described in the previous section, but also a research project, workshops and a licentiate thesis. The overall research process can basically be divided into two phases that were different in their respective focus. *Phase 1* lasted from 2017 to 2020, while *Phase 2* lasted from 2020 to 2022, as illustrated by Figure 11 and described in the following section.

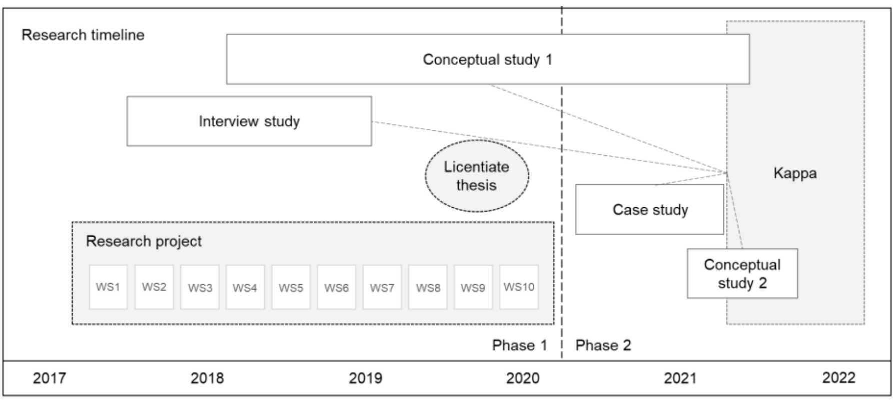

Figure 11. Research timeline

3.3.1 *Phase 1*

The starting point for this research and for Phase 1 was in April 2017 when the three-year research project called *the Whispering Game* was initiated. This project focused on the communication challenges in customization practices and engaged four researchers and representatives from five industrial companies. The project adopted a form of collaborative research, known as interactive research, where researchers develop knowledge and continuously refine the formulated research objectives through interactions with practitioners (Ellström, 2007; Ellström et al., 2020). The interactive element of the research project was realized through a series of ten workshops (WS1–WS10, shown in Figure 11) where the researchers and practitioners interacted with the intention of joint knowledge creation. In this manner, the research project provided an empirical setting that could be used as a basis for the formulation of the research topic, which resembled that of the iterations between empirical real-life observations and theory-matching as per an abductive research process, as explained by Kovács & Spens (2005). During the time between the workshops, research activities such as data collection and data analysis were performed. The workshop and interview data from the research project were used, for example, for the *interview study* and Paper 3, which were written and published during Phase 1.

In parallel to the interactive research project, a literature review was conducted to gain a broad understanding of the current research on customization. The review revealed that customization is a topic of interest in a wide variety of research fields and that different approaches to the same had primarily been categorized based on a linear perspective regarding the degree of customer involvement in value-adding processes (see Figure 4). In early 2018, the notion of solution spaces was identified as a phenomenon that, to a certain extent, represented an overlooked perspective on customization. Initiated in 2018, as shown in Figure 11, *Conceptual Study 1*, therefore, aimed to conceptualize solution spaces and extend the solution space concept. Thus, *Conceptual Study 1* was conducted in parallel to the interactive research project, and a conference version of the resulting paper was presented in August 2018 and published as a book chapter soon thereafter (Käkelä & Wikner, 2018). The interactive research project was finalized in May 2020 and coincided with the closure of Phase 1, which provided a foundational understanding of the practical and theoretical challenges related to customization. Aside from the publication of a licentiate thesis (Käkelä, 2019), Phase 1 guided the subsequent research efforts and helped recognize solution spaces as an important but improperly understood customization concept.

3.3.2 *Phase 2*

Following the finalization of the interactive research project and the licentiate thesis from Phase 1, Phase 2 ensued and involved further investigation into solution spaces for customization. An important part of this was the continuation of *Conceptual Study 1*, which is also the basis of the kappa. Moreover, with regard to *Conceptual Study 1*, a literature review was conducted to acquire a deeper understanding of how solution spaces were represented in the literature. As explained in *Paper 1*, the literature review confirmed that solution spaces are first and foremost associated with mass customization, mostly treated as a peripheral phenomenon and primarily viewed from a technical perspective. Further, at the beginning of Phase 2, a case study was also initiated, which is presented in *Paper 2*. The study was set in the context of one of the companies that had participated in the interactive research project from Phase 1. Interview data were collected in January 2020, and, after having first been written as a conference paper, *Paper 2* was finalized in the summer of 2021. Furthermore, *Conceptual Study 2* was initiated in the spring of 2021 and formed the basis for the finalization of *Paper 4* in October 2021. Finally, the kappa was written during the second half of 2021 and resumed *Conceptual Study 1*, as illustrated in Figure 11.

3.4 Data collection and analysis

This research is based on qualitative data, which is appropriate when the research phenomenon is not well understood (Edmondson & McManus, 2007; Eisenhardt, 1989). The data have been collected from workshops, interviews, documents and literature reviews. The conceptual studies used the literature as data, while the empirical ones used interview data, workshop data and documents. Table 3 provides an overview of the data collection and data analysis related to the studies. This is followed by brief descriptions of the data collection and analysis related to each study, while more detailed accounts can be found in the corresponding papers.

Table 3. Overview of data collection and analysis

Study	*Data collection*	*Data analysis*	*Publication*
Conceptual Study 1	Systematic scoping review and traditional literature review	Conceptual deduction	Paper 1 and Kappa
Case Study	Unstructured and semi-structured interviews, internal documents	"Gioia" analysis	Paper 2
Interview Study	Workshop data and in-depth qualitative interviews	"Gioia" analysis	Paper 3
Conceptual Study 2	Traditional literature review	Conceptual deduction	Paper 4

3.4.1 *Conceptual Study 1*

For *Conceptual Study 1*, the data were collected from a systematic scoping review and a traditional literature review. The systematic scoping review resembles a systematic literature review in that it uses a rigorous and systematic process, but the primary objective of a scoping review is the "*identification of the size and quality of research in a topic area in order to inform subsequent review*" (Booth et al., 2021). In this manner, the scoping review provides a snapshot of a specific topic and how its represented in the literature (Arksey & O'Malley, 2005). As recommended for systematic approaches to literature reviews (Jesson et al., 2011), the scoping review started with a clear purpose, which is to understand how solution spaces are represented in the literature. A protocol-driven search strategy was adopted (Greenhalgh & Peacock, 2005) and the search string used covered variations in terminology with respect to solution spaces and included the synonyms "design space" and "product space". Alternate spellings of the term "customization" were also included, resulting in the following search string: ((<solution space> OR <design space> OR <product space>) AND (<customization> OR <customization>)). The electronic databases used were Elsevier Scopus and Thomson Reuters Web of Science, which covered articles, reviews and book chapters. The search was conducted in May 2021 and returned 199 publications (109 in Scopus and 90 in Web of Science). Out of these, 52 were considered for a more detailed review, while the remaining

147 publications were excluded. The selection of publications was based on the assessment of their title and publication outlet, which revealed whether it could contain conceptual contributions to the understanding of solution spaces for customization. The articles that were excluded were primarily highly technical or mathematical, addressing aspects such as signal processing systems, computing systems and energy absorption. Based on the publications included, it was concluded that solution spaces for customization is a largely overlooked phenomenon, as there were only 52 relevant publications that referred to solution/product/design spaces in combination with customization in their title, abstract and/or keywords compared to the vast amounts of research addressing customization (see Table 4 below). Moreover, past research that refers to solution spaces almost exclusively addresses mass customization and does not consider ETO. Further, it was mainly the technical aspects of solution spaces that had been examined, with no studies focusing on solution spaces from a conceptual standpoint. Moreover, in the 52 included publications, solution spaces were treated as a peripheral phenomenon in most cases and not discussed in detail.

A traditional literature review was conducted to gain a more thorough understanding of the topic of customization. The traditional literature review was less structured than a systematic review and written in a narrative style with the objective of reviewing and synthesizing a large body of research (Denyer & Tranfield, 2006). Although based on a reference tracking search strategy (Greenbalgh & Peacock, 2005) and personal selection of materials and, hence, more subjective than a systematic review (Booth et al., 2021), the traditional literature review allowed for a wide range of customization-related concepts to be analyzed and synthesized with regard to solution spaces, as presented in *Paper 1* and the kappa. Regarding the analysis, the analytical approach employed is in line with what Meredith (1993) refers to as conceptual deduction, wherein a framework is formed based on a certain degree of inductive reasoning but where deductions begin with the ramifications and predictions of the conceptual framework. Accordingly, for *Conceptual Study 1*, the conceptualization of the solution spaces is indeed inspired by practical experiences and real-world descriptions and enables predictions and ramifications for reality.

Table 4. Results of the scoping review

Database	Search string	Resulting publications
Scopus	TITLE-ABS-KEY (("solution space" OR "design space" OR "product space" AND "customization" OR "customisation")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "ch"))	46 relevant (out of 109 search results): dos S. Hentschke, C., S. Echeveste, M.E., T. Formoso, C., D. Ribeiro, J.L. **(2021),** Shafiee, S., Haug, A., Shafiee Kristensen, S., Hvam, L.**(2020)**, Salvador, F., Piller, F.T, Aggarwal, S. **(2020),** Huang, J., Sun, H., Kwok, T.-H., Zhou, C., Xu, W. **(2020)**, Castro E Costa, E., Jorge, J., Knochel, A.D., Duarte, J.P. **(2020),** Noergaard, K., Pero, M., Nielsen, K., Brunoe, T.D. **(2020)**, Larsen, M.S.S., Lindhard, S.M., Brunoe, T.D., Nielsen, K., Larsen, J.K. **(2019)**, Okpoti, E.S., Jeong, I.-J., Moon, S.K. **(2019)**, Bianconi, F., Filippucci, M., Buffi, A. **(2019)** Zhao, H., McLoughlin, L., Adzhiev, V., Pasko, A. **(2019)**, Zhao, H., McLoughlin, L., Adzhiev, V., Pasko, A. **(2019)**, Vos, M.A., Raassens, N., van der Borgh, M., Nijssen, E.J. **(2018)**, Wang, G., Shang, X., Yan, Y., Allen, J.K., Mistree, F. **(2018),** Da Rocha, C.G., Miron, L.I.G. **(2018)**, Grafmüller, L.K., Hankammer, S., Hönigsberg, S., Wache, H. **(2018)**, Gembarski, P.C., Lachmayer, R. **(2017)**, Sandrin, E., Trentin, A., Grosso, C., Forza, C. **(2017)**, Sandrin, E. **(2017)**, Johannesson, H., Landahl, J., Levandowski, C., et al. **(2017)**, Mourtzis, D., Doukas, M. **(2015)**, Koch, S., Inanc, D. **(2015)**, Piller, F.T., Blazek, P. **(2014)**, Pitiot, P., Aldanondo, M., Vareilles, E. **(2014)**, Trentin, A., Perin, E., Forza, C. **(2014)** Kudsk, A., Grønvold, M.O., Olsen, M.H., Hvam, L., Thuesen, C. **(2013)**, Trentin, A., Perin, E., Forza, C. **(2013)**, Bettoni, A., Corti, D., Fontana, A., Zebardast, M., Pedrazzoli, P. **(2013)**, Canetta, L., Corti, D., Boër, C.R., Taisch, M. **(2013)**, Piller, F.T., Steiner, F. **(2013)**, Piller, F.T. **(2013)** Hermans, G. **(2012)**, Badurdeen, F., Liyanage, J.P. **(2011)**., Prasanna, L., Guhanathan, S., Agrawal, R. **(2010)**, Yimer, A.D., Demirli, K. **(2010)**, Björkman, H. **(2009)**, Zhang, Q., Tseng, M.M. **(2009)**, Zhou, C., Lin, Z., Liu, C.**(2008)**, Thuramalla, S., Badurdeen, F. **(2008)**, Gero, J.S., Sosa, R. **(2008)**, Tien, J.M., Berg, D. **(2007)**, Zhou, C., Lin, Z., Liu, C. **(2007)**, Kumar, R., Allada, V. **(2007)**, Antona, M., Savidis, A., Stephanidis, C. **(2006)**, Chen, G., Yin, J., Dong, J. **(2003)**, Dobrescu, G., Reich, Y. **(2003)**, Kim, J., Allenby, G.M., Rossi, P.E. **(2002)**.
Web of Science	TOPIC: ("solution space" AND "customisation") OR TOPIC: ("solution space" AND "customization") OR TOPIC: ("product space" AND "customization") OR TOPIC: ("product space" AND "customisation") OR TOPIC: ("design space" AND "customisation") OR TOPIC: ("design space" AND "customization") Refined by: DOCUMENT TYPES: (ARTICLE) AND DOCUMENT TYPES: (ARTICLE OR EARLY ACCESS)	6 additional relevant (out of 89 search results): Naik, H.S., Fritzsche, A., Moeslein, K. M. **(2021)**, Gembarski, P. C., Lachmayer, R. **(2018)**, Tsafarakis, S., Saridakis, C., Baltas, G., et al. **(2013)**, Liu, Z., Wong, Y.S., Lee, K.S. **(2010)**, Alptekinoglu, A., Corbett, C.J. **(2008)**, Franke, N; Piller, F. **(2004)**.

3.4.2 *Case study*

The *case study* investigated the evaluations of tendering invitations in an ETO environment and adopted a case study methodology that is in line with the process used by Eisenhardt (1989) for theory-building case study research. Set in the context of a single case company, the adopted approach allowed for rich descriptions of the evaluation processes and for an in-depth analysis. The data collection was based on two unstructured pilot study interviews, four semi-structured qualitative interviews with business development managers and a study of internal documents (see Table 6).

Table 5. Empirical data collected for the case study

Data collection	*Represented company*	*Date*
Pilot interview 1	Company Delta	2019-11-20
Pilot interview 2	Company Delta	2020-01-08
Semi-structured interview 1	Company Delta	2020-01-16
Semi-structured interview 2	Company Delta	2020-01-17
Semi-structured interview 3	Company Delta	2020-01-18
Semi-structured interview 4	Company Delta	2020-01-20
Project communication matrixes	Company Delta	2020
Project flow charts	Company Delta	2020
Tendering checklists	Company Delta	2020

The tendering invitations were studied in retrospect and were selected to demonstrate the varying business characteristics that the case company faces when evaluating tendering invitations. Audio recordings of the semi-structured interviews were transcribed, and the transcriptions were then codified and sorted into categories following the coding scheme used by Gioia et al. (2013), as further shown in Paper 2.

3.4.3 *Interview study*

The *interview study* is an in-depth qualitative interview study (Kvale, 2012), the data for which were collected from one workshop and seven critical incident interviews (Flanagan, 1954) (see Table 6). The collection of the workshop data was conducted during a workshop that was a part of the interactive research project, which focused on the challenges associated with capturing customer-order-specific information. The interviews focused on the customer commitments presented during the previous workshop. Both the workshop and the interview data were recorded and transcribed. The data analysis was inspired by the work of Gioia et al. (2013), where the initial coding of the transcribed workshop and interviews evolved into themes and aggregate dimensions, as further shown in Paper 3.

Table 6. Empirical data collected for the interview study

Data collection	*Represented companies*	*Date*
Workshop 1	All companies	2017-08-29/30
Workshop 2	All companies	2017-11-07/08
Workshop 3	All companies	2018-01-30/31
Workshop 4	All companies	2018-05-16/16
Workshop 5	All companies	2018-09-11/12
Workshop 6	All companies	2018-11-20/21
Workshop 7	All companies	2019-02-05/06
Workshop 8	All companies	2019-05-14/15
Workshop 9	All companies	2019-09-11/11
Workshop 10	All companies	2019-11-19/20
In-depth interview 1	Company Alpha	2017-09-20
In-depth interview 2	Company Delta	2017-09-26
In-depth interview 3	Company Delta	2017-10-13
In-depth interview 4	Company Beta	2017-10-23
In-depth interview 5	Company Epsilon	2017-10-24
In-depth interview 6	Company Epsilon	2017-10-24
In-depth interview 7	Company Gamma	2017-11-06

3.4.4 *Conceptual Study 2*

Conceptual Study 2 is based on a traditional literature review (Denyer & Tranfield, 2006), using the literature on learning in organizations and the customer-order-based context as data. In line with the approach of conceptual study 1, the traditional literature review was based on personal selection of materials and was less structured than a systematic review (Denyer & Tranfield, 2006). In terms of analysis, the focus was on linking key concepts within the field of learning in organizations to concepts within customization and the customer-order-based context based on logical reasoning.

3.5 Research quality and ethical considerations

To assess the quality of qualitative research, a suitable evaluation criterion is *trustworthiness* (Guba & Lincoln, 1989; Halldórsson & Aastrup, 2003). While the conventional quality criteria are internal validity, reliability, external validity and objectivity, the trustworthiness of conducted research can be assessed with the help of the following set of criteria: *credibility*, *transferability*, *dependability* and *conformability* (Guba & Lincoln, 1989). The following sections provide the descriptions of these terms and present how this research relates to them.

Credibility refers to ensuring that the author's representation and construction fit the view of the respondents, and this criterion can be compared to internal validity (Halldórsson & Aastrup, 2003). Based on the epistemological position that there is no single objective reality, the collected data can be constructions of the respondents' subjective views. As a way to ensure credibility, Korstjens and Moser (2018) suggest *prolonged engagement*, *persistent observation*, *triangulation* and *member check*. For this research, prolonged engagement has been exercised through the frequent workshop meetings during the interactive research project, while persistent observation has been implemented to the greatest extent for *Paper 1* to differentiate and conceptualize solution spaces. Regarding triangulation, various data sources and data collection methods have been used. Member check is basically a means for validation, and, for this purpose, all interview respondents (for *Paper 2* and *3*) and/or participants from the research project (for *Paper 2 and 3* and an early version of *Paper 1*) were asked to verify, falsify or correct the researcher's construction of their views.

Transferability refers to how well the author provides sufficient information to enable generalizations, and this criterion bears resemblance to external validity (Halldórsson & Aastrup, 2003). Erlandson et al. (1993) describe transferability as being dependent on the similarities between sending and receiving contexts. To ensure transferability, the researcher needed to describe the context studied in detail (Korstjens & Moser, 2018), including its interrelationships and intricacies (Erlandson et al., 1993). With regard to transferability, the conceptual and the empirical papers differ in terms of how they relate to these criteria. The empirical papers, i.e. *Paper 2* and *3*, include concrete descriptions of customization practices as manifested in the participating companies, which can allow for generalizations. In *Paper 2*, which is a single case study, transferability is carefully discussed, as the case company may not be representative of all types of ETO environments, entailing that the transference of the findings from *Paper 2* requires careful consideration. For the conceptual papers, there is no empirical context to describe, although both *Paper 1* and *4* have strived to provide sufficient information about the solution spaces (Paper 1) and the customer-order-based context (*Paper 4*) to ensure transferability.

Dependability is about ensuring that the research process is logical, traceable and well-documented (Wigren, 2007). It concerns issues related to reliability. For the sake of dependability, the researcher needs to document the logic behind the process employed and be able to explain the choice of methods, thus establishing a so-called audit trail (Korstjens & Moser, 2018). In this regard, the author has consistently strived to be transparent about the decisions made throughout the research, and the data structures of *Paper 2* and *3*, which demonstrate how the studies progress from the empirical data to the findings obtained, can serve as examples of such transparency. Moreover, all the workshops and interviews have been recorded and transcribed. As for the conceptual papers, the author has strived for dependability by ensuring that the conceptualizations and connections made between theoretical concepts have been sufficiently substantiated and explained.

Conformability is achieved by ensuring that the interpretations of data are not influenced by the author's opinions or, as Bryman (2008) describes it, by ensuring that personal values or theoretical orientations have not deliberately affected the execution or conclusions of the study. This is a constant challenge in qualitative studies, where complete objectivity is unattainable. The researcher's aim is to demonstrate how the findings of the research can be confirmed through the data (Halldórsson & Aastrup, 2003). Similar to dependability, conformability is ensured by providing an audit trail (Korstjens & Moser, 2018). The data structures outlined in *Paper 2* and *3* are, for example, tools for explaining how a study arrives at its findings.

In terms of the ethical considerations, this research has adhered to the recommendations of the Swedish Research Council (2017) for good research practices. For the empirical studies, the respondents provided their consent for the interviews and workshops to be recorded and transcribed. Further, the respondents were informed that the interviews and workshops were voluntary, and their role in the research was explained thoroughly. Personal data was processed in such a way that they cannot be accessed without authorization, and it was explained that the data collected from the respondents would only be used for research purposes.

4 Summary of the appended papers

4.1 Paper 1 – Conceptualization of solution spaces for customization

The purpose of Paper 1 is *to integrate the CODP and solution spaces to improve the understanding of customization*. The key concepts associated with the operations and supply chain management literature, represented by the CODP and the *degree of customer involvement* for customization, are integrated with those of the product development management literature, represented by solution spaces and the *degree of customer freedom* for customization. Three contributions are made to the literature.

First, Paper 1 provides *an improved description of the delivery strategies used for customization.* The point of departure for the study is the CODP-based delivery strategies ATO, CTO and ETO, which represent how customers can be involved to varying degrees in value-adding processes. An improved description of how customization is effectuated for these delivery strategies is proposed, arguing that the current delivery strategy classification is inaccurate with regard to the delivery strategies ATO and CTO; thereby, it is proposed that ATO and *fabricate-to-order* (FTO) are two different applications of CTO (see Figure 12), which is a key difference from previous classifications.

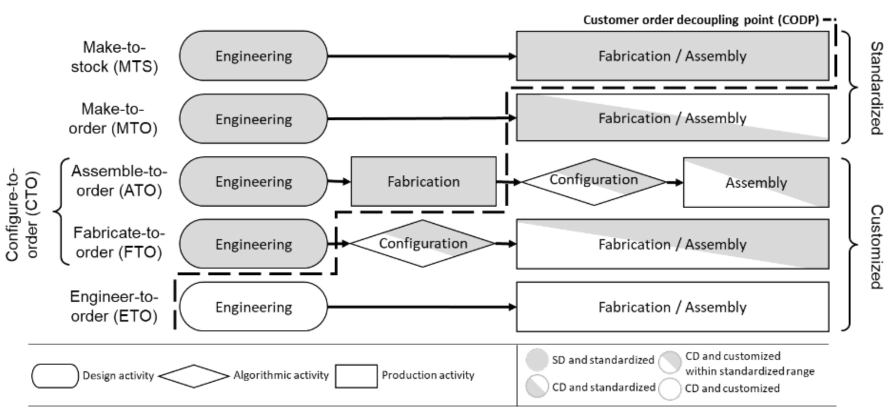

Figure 12. Improved outline of CODP-based delivery strategies

Second, Paper 1 provides a *differentiation of solution spaces based on the CODP*. Prior to Paper 1, solution spaces were primarily acknowledged in mass customization, product configuration and product development literature. Paper 1, however, extends the solution space concept by proposing a comparison between three types of solution spaces (see Figure 13 below): the *continuous solution space* (CSS), the *discrete solution space* (DSS) and the *hybrid solution space* (HSS). It also explains the dynamics between them. The comparison is based on the CODP and shows how companies set boundaries for their product offerings in different ways. The CSS is a solution space whose boundary is not clearly defined before engineering a solution, regardless of whether it is intended as a standard solution or a custom one formulated for a customer, and, thus, it relies on the use of engineering knowledge (instead of configuration rules) to define customer-specific solutions or a platform of rules that can be applied to generate a constrained set of solutions, such as for the DSS. The DSS is a solution space whose boundary is clearly defined before committing to a customer, effectively constraining the degree of freedom for customization for a predetermined offering. The DSS represents a rule-based approach to customization, where "discrete" implies that the rules generate a finite set of distinct separate solutions. Last, the HSS combines the inherent logics of DSS and CSS for the same offering, partially constraining the degree of freedom with respect to predetermined customization possibilities and taking into consideration customer-specific requirements beyond the discrete base offering.

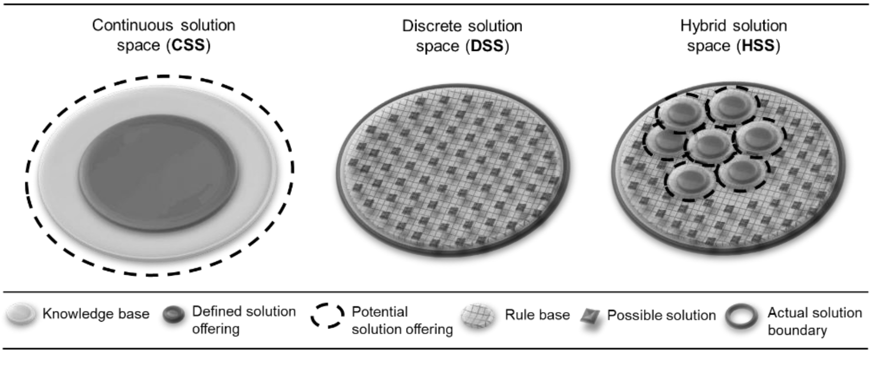

Figure 13. Differentiation of solution spaces

Third, Paper 1 provides *an integrative perspective on delivery strategies and solution spaces*. It integrates the degree of customer involvement (represented by the CODP-based delivery strategies) and that of customer freedom (represented by the CSS, DSS and HSS) for customization, thus synthesizing operations and supply chain management and product development concepts. The relationships between the solution spaces and delivery strategies are outlined in Figure 14 below. As for customization, the CSS is essential for ETO (it can be in one phase or two phases but both cases involve only CSS). FTO and ATO are based on a two-phase approach, where CSS and DSS are combined to work in tandem. Finally, to enable engineering adaptations in combination with an FTO or ATO strategy, the CSS is combined with HSS.

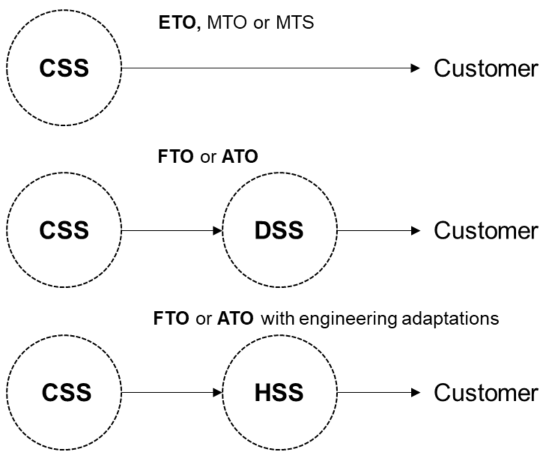

Figure 14. Solution spaces and delivery strategies

4.2 Paper 2 – Evaluating tendering invitations in engineer-to-order environments

Paper 2 is based on an empirical case study that aims *to explain how tendering invitations are evaluated in an ETO environment and outline the key principles that guide decision makers in this regard*. In doing so, the paper explains the nature of the tendering invitation evaluation process itself and identifies the specific circumstances prevalent in ETO environments that set the possibilities and limitations for how tendering invitations are evaluated in this context.

Set in the context of a single case company, Paper 2 examines the evaluation processes for five tendering invitation cases. The findings show that, during the evaluation of tendering invitations, decision-makers evaluate technical and financial aspects and consider both the strategic and the temporal implications. The tendering invitation evaluation process represents a critical process in ETO environments, as it determines which projects the company commits to; but as revealed in this research, the importance of the evaluation process extends further than this, as it can be used as a basis for long-term strategic decision-making. Specifically, by outlining a sequence of the considerations that managers take into account when evaluating the technical and financial feasibility of potential projects (see Figure 15), Paper 2 provides insights into the critical process of evaluating tendering invitations in ETO environments.

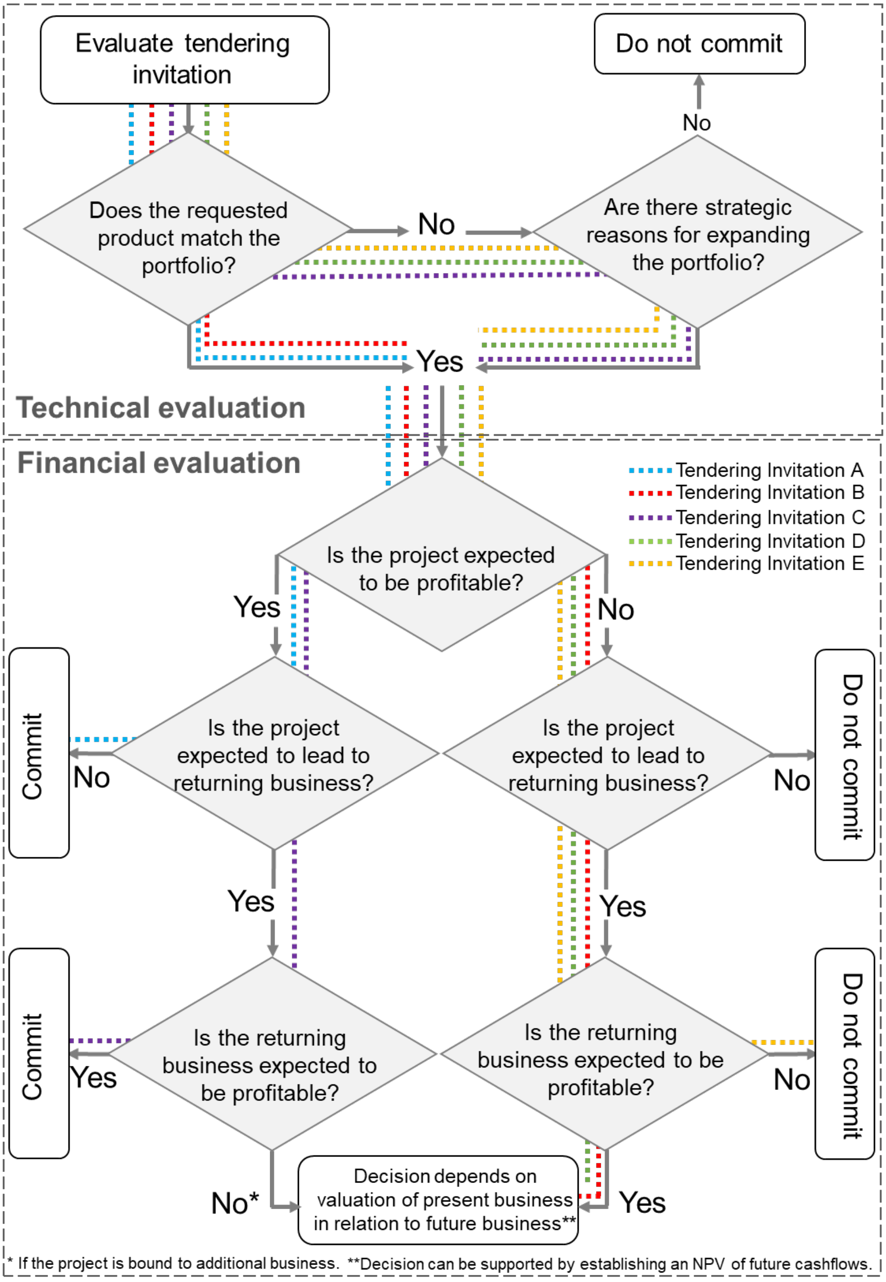

Figure 15. Tendering invitation evaluation process

4.3 Paper 3 – Early steps in learning about organizational learning in customization settings

Paper 3 is the first step in developing an understanding of the role of learning in customization settings. The purpose is to empirically investigate how companies can facilitate organizational learning by improving their communication processes and strengthen their capabilities as learning organizations by understanding customers' needs. For this purpose, customer order incidents from five companies that were experienced as complicated in terms of communication are studied. The customer order incidents were all outcomes of what Paper 1 refers to as CSS but are referred to as *individualized customization tasks* in Paper 3 to emphasize the task-oriented view of understanding customer needs. As illustrated in Figure 16, four categories of communication processes between companies and customers that stimulate learning are identified: the identification and confirmation of existing knowledge, the identification of knowledge gaps and the creation of new knowledge, the definition of relations and procedures and, finally, evaluation and learning.

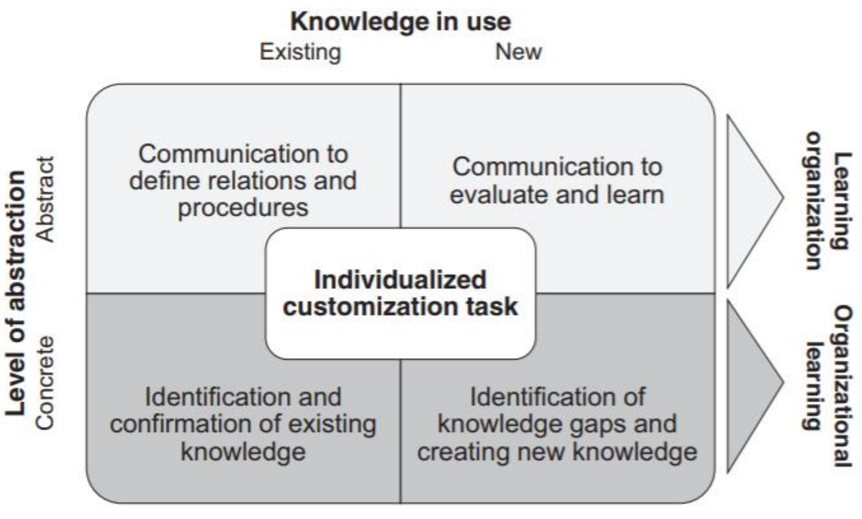

Figure 16. Categories of communication for learning in customization settings (Engström & Käkelä, 2019)

The analysis reveals that the companies both exploit existing knowledge and explore new knowledge when communicating with customers. Furthermore, it becomes apparent that learning is triggered by communication processes on different levels of abstraction.

Learning for the specific task at hand, i.e. for a particular customer commitment, occurs when company and customer communicate using existing knowledge or engage in dialogue and challenge each other to develop new knowledge. For example, learning can be triggered when problems occur that require new knowledge to be developed to complete the customer order fulfillment process. Learning at this level can also be elevated to a more general discussion and serve as the basis for the decisions made for the organization as a whole.

Learning also occurs without being triggered by a specific task. By taking a step back from the practical action, a more reflective and structural perspective on communication can be adopted, where the company internally, or together with its customers, reflects on, evaluates and agrees on specific procedures, roles and responsibilities to facilitate task management. Learning at this level can form the basis of new ways of working that can be subsequently put into action for specific tasks.

4.4 Paper 4 – Ambidextrous learning in a customer-order-based context

Paper 4 is an analytical conceptual paper that addresses ambidextrous learning in a customer-order-based context (COBC), wherein organizations are involved in multiple customer order fulfilment processes simultaneously that pose different requirements with respect to customization. This is related to the delivery strategies MTS, ATO, MTO, CTO and ETO, which suggests that the balance between the back office and the front office activities differs among these delivery strategies, hence posing challenges for the organization’s flexibility to adapt to the varying requirements and priorities of the specific customer orders. With a theoretical basis for how learning in organizations occurs depending on different levels of action in organizational work processes, the focus for Paper 4 is on how the dynamics of learning are manifested in the COBC and how organizations in this context can learn while working with customer orders. Hence, the purpose of this paper is to describe ambidextrous learning in organizations within the COBC based on a dynamic perspective on the associated work processes.

The paper suggests that the interplay between standardized and customized work, which is a key characteristic of the COBC, is an important factor for the type of learning that takes place. Moreover, as the balance between the back office and front office tasks varies across delivery strategies, it is argued that changes in priorities for functions within the organization can stimulate learning and that organizations can benefit from building a learning infrastructure that consists of a portfolio of structures, routines and procedures for learning that can be situationally applied.

5 A conceptual framework for customization and solution spaces

This chapter presents a conceptual framework for customization and solution spaces. The point of departure is the theoretical framework, but the conceptual framework also incorporates the findings of the appended papers and the overall solution space perspective proposed in the thesis. It is worth noting that, while the frame of reference largely conformed to the product and production-oriented terminology, the remainder of the thesis refers to *solutions* as a blanket term for customized goods and the associated services.

This research has, on the one hand, focused on describing different customization approaches, as done in Paper 1 and 4, and, on the other hand, has focused specifically on ETO environments (i.e., CSS), as done in Paper 2 and 3. This is shown in Table 7, where the CSS, DSS and HSS are defined in relation to Paper 1–4, indicating whether the solution space was explicitly or implicitly addressed. The subsequent sections describe the CSS (Section 5.1), DSS (Section 5.2) and HSS (Section 5.3) as approaches to customization. Each approach is explained in relation to the process, product, learning and customer interface aspects of customization based on the theoretical framework and the appended papers. For this, the conceptual framework provides a descriptive and comparative outlook on customization, featuring the contrasting characteristics of the polar-opposite solution spaces – the CSS and the DSS – and also demonstrates how they can be combined into the HSS.

Table 7. Explicit or implicit focus on solution spaces in the appended papers

	Paper 1	*Paper 2*	*Paper 3*	*Paper 4*
CSS	Explicitly addressed	Explicitly addressed	Implicitly addressed	Implicitly addressed
DSS	Explicitly addressed	Not addressed	Not addressed	Implicitly addressed
HSS	Explicitly addressed	Not addressed	Not addressed	Implicitly addressed

5.1 The CSS customization approach

The CSS represents a customization approach that implies high degrees of customer involvement and freedom. For this customization approach, the customer is involved in the engineering activities and is not constrained to a predefined offering. This is the approach that has been most extensively studied in the empirical body of this research, as four out of the five companies investigated (all except Company Epsilon) offered customization in line with the CSS and as both Paper 2 and 3 are set in a CSS context.

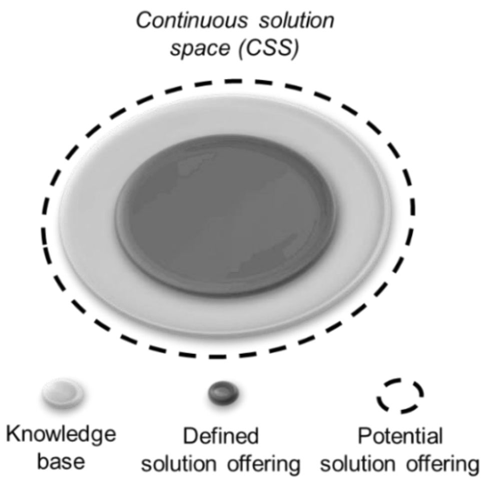

Figure 17. Conceptual model of the CSS

Addressed in Paper 1, a key characteristic of the CSS is the flexibility it provides to accommodate unforeseen customer requirements, which is illustrated by the *defined solution offering* and the *potential solution offering* (see Figure 17). The defined solution offering represents the vaguely delineated, or "blurred" (ElMaraghy et al., 2013, p. 647), offering that can be expressed in terms of, for instance, a business area or area of expertise, while the potential solution offering represents the possibility of extending beyond the defined offering and current knowledge to accommodate customer requirements, which differs from the previous experience. An analysis of how the CSS approach relates to customization in terms of process, product, learning and customer interface is presented in the following sections.

5.1.1 *CSS in relation to process*

A concept that is closely related to the CSS is ETO, which has received an increasing amount of attention from researchers in recent decades (see e.g., Cannas & Gosling, 2021; Gosling & Naim, 2009). The CSS customization approach corresponds to the descriptions of ETO environments and their associated characteristics, such as long delivery lead times, high costs and an extensive dialogue with the customer. For ETO settings, the CODP is positioned in the engineering stage, and both engineering and production activities are performed for the individual customer rather than for an aggregate of customers (Wikner, 2014), which is in line with the assumptions of the CSS. Contrary to the DSS approach, where customization is constrained to a set of predefined rules, the basis for customization in the CSS context is some kind of engineering knowledge, in line with the CODP-based framework of engineering subclasses proposed by Gosling et al. (2017). The customization scenarios proposed there, namely customized 1) research, 2) codes and standards and 3) existing designs, provide an understanding of the types of knowledge held "in stock" for the CSS customization approach.

In Paper 1, the process of realizing a solution in the context of the CSS is referred to as a *monolithic solution realization*, which is described as an end-to-end integrated process instead of being split into a two-part biramous process, such as that used for the DSS and HSS (as outlined in Figure 12). This highlights the differences between determining solutions in the CSS context compared to the DSS one.

5.1.2 *CSS in relation to product*

Research that addresses the product aspects of customization typically does so by focusing on the product-related capabilities that companies can establish prior to making a commitment to the customer. However, in contrast to the DSS and HSS, solutions in the CSS context are not specified – not even in principle – until after customer commitment and are tailored to individual customer needs. The key concepts related to the product aspect of customization, such as *mass customization* (Fogliatto et al., 2012), *product platforms* (Jiao et al., 2007) and *product configuration* (Zhang, 2014), are, therefore, arguably less applicable for CSS than for the other solution spaces, as they necessitate having a predefined offering (Salvador et al., 2009; Zhang, 2014). However, a great deal of research has focused on how companies in a CSS context can implement these concepts (Cannas, Masi, et al., 2020; Haug et al., 2013; Haug et al., 2019; Johnsen & Hvam, 2019; Kristjansdottir et al., 2017), although, from a solution space perspective, this would imply a shift from a CSS customization approach to a DSS or HSS approach.

In this research, conceptual developments have been proposed that relate to the product aspect of the CSS. The composition of a solution offering, its constituent parts and how it can be used to provide a customer-specific solution is discussed in Paper 1 through the use of the term "*solution structures*". For the CSS, each solution structure is engineered for a specific delivery, which is referred to as a *monolithic solution structure*. With regard to customization, a monolithic solution structure means that the point of departure for customization is not for the customer to choose from a set of predefined components or modules, such as for the DSS, as the customer is not bound to a pre-established solution structure. The extent to which the offering can be customized is, therefore, more vaguely delineated in this context; by these means, the CSS approach can accommodate unforeseen customer needs, providing flexibility to take on projects that require solutions that differ from previous experiences, which are represented by the space between the defined solution offering and potential solution offering boundary in Figure 17. This flexibility has been empirically verified. Paper 2 demonstrated that the studied company was willing to extend beyond its typical offering and commit to projects that involved solutions that were quite different from its previous experiences if this would, for instance, introduce them to a new market or generate returning business from the customer. Paper 3 illustrated that the five companies investigated had to extend beyond their current knowledge and explore new knowledge in their interplay with customers to define the solutions to be produced. In this regard, both Paper 2 and 3 provided empirical insights regarding the challenges associated with customization when not constrained to a predefined offering.

5.1.3 *CSS in relation to learning*

Regarding the learning aspect of customization, the CSS customization approach can be considered on the basis of its relationship to *executional learning* and *developmental learning*, building on, for instance, the works of March (1991), Ellström (2005) and Engström and Wikner (2017). An important difference between the CSS and the DSS approaches is that, in the CSS context, *developmental learning* is required for customer driven activities, possibly during the interplay with customers, as each customer commitment requires reflection, transformation and idea generation instead of simply customizing based on the established customization rules. This is not to say that there is no need for *executional learning*, as customization in the CSS context may still benefit from pre-existing routines, procedures and ways of working for both engineering and production activities. Developmental learning is also required for speculation driven activities to define the overall offering. However, the significant aspect of CSS customization compared to the DSS is the emphasis on the exploration of new knowledge for customer driven activities.

The learning aspect of the CSS has been thoroughly investigated in this research, and it was found that the CSS demands considerable exploration of new knowledge for each customer commitment. As demonstrated in Paper 3, in this context, knowledge is created through an interplay with individual customers and is linked to specific customer commitments. It is suggested that exploration is required for customer driven activities in the CSS context, as each customer commitment requires reflection, transformation and idea generation instead of being solely based on the reproduction of these activities, such as the case for the DSS. Examples of customer driven activities that require exploration in the CSS context have been provided, with, for instance, Paper 2 demonstrating that tendering invitation evaluation processes comprised a substantial amount of exploration to learn about potential projects' technical and financial implications. Furthermore, Paper 3 showed that learning is triggered by the task of understanding individual customer needs and that companies explore new knowledge during the interplay with customers when defining the solution to be produced. For example, when interacting with the customer to understand their wishes and requirements, there could be substantial room for misinterpretation, and, in some cases, the customer themselves do not have a detailed understanding of the functionalities they required. This type of situation called for the exploration of new knowledge in the interplay with customers to identify the knowledge gaps that need to be addressed. Paper 3 also indicated that the companies explored new knowledge that was unrelated to a specific customer commitment, as knowledge was created without being related to a specific customer when employees took a step back from day-to-day operations to evaluate and reflect upon the current procedures to improve their ways of working.

5.1.4 *CSS in relation to customer interface*

Solution spaces have implications for the customer interface, and the front office and back office separation can be linked to the CSS customization approach. With a variety of activities being impacted by direct customer contact, CSS customization suggests that a high amount of front office operations is required. As has been argued for in the marketing and service management literature (see e.g., Chase, 1978; Metters & Vargas, 2000; Wikner, Yang, et al., 2017), a high proportion of front office operations can make it difficult to achieve internal efficiency of operations, as customer-specific requirements can create variations and disruptions in work processes. In line with this, the CSS approach cannot replicate the efficiencies of the DSS approach, as a majority of the tasks are allocated to the front office. However, the benefit of this front-office orientation is that the CSS approach can attain superior external effectiveness with respect to the customer interface (Wikner, Yang, et al., 2017), with the ability to meet customer needs more precisely than the DSS.

For the CSS customization approach, the engineering and production activities are impacted by direct customer contact. This is discussed in Paper 4, where it is suggested that a variety of different organizational functions are exposed to customers, and that front-office priorities such as managing variation and the unpredictability of customers are adopted. With a high degree of customization, such as for the CSS, more functions involve direct contact with the customer, and these functions usually need to collaborate with each other to create shared knowledge regarding the customer's needs. This is also in line with the typical characteristics of *solution businesses* (Storbacka, 2011; Tuli et al., 2007), which corresponds to the CSS in terms of the extensive and cross functional efforts required to provide a customized solution.

In Paper 2 and 3, the back office and front office terminology is not explicitly used, but both papers focus on the nature of the front office activities for CSS customization. Paper 2 shows the strategic significance of the front office in this context, as the evaluation of tendering invitations can serve as the basis for investments and long-term strategic decision-making. Paper 3 focused on the front office employees' patterns of communication with customers when attempting to understand individual customer needs, which demonstrated the importance of adaptiveness of the front office in this context, as certain customer commitments required the employees to be rather assiduous towards customers to identify knowledge gaps, while others mainly required attentiveness to grasp existing knowledge.

5.2 The DSS customization approach

The DSS represents a customization approach that, compared to the CSS, implies a lower degree of customer involvement and freedom. For DSS customization, the customer is involved in the configuration of predefined customization rules and is limited to a predefined offering, which is in line with principles of mass customization (Piller, 2004; Salvador et al., 2009). Compared to the CSS, the DSS has received less empirical attention in this research, with only one out of the five companies catering for this type of offering (Company Epsilon). This is, however, not representative of its occurrence in practice, and mass customization, which is related to the DSS, has been argued to be the current dominant form of production (Fogliatto et al., 2012).

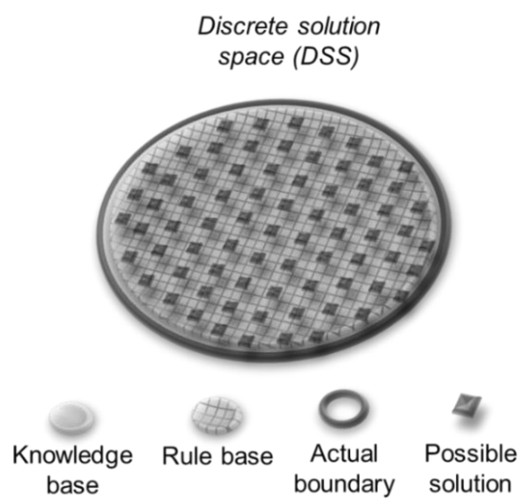

Figure 18. Conceptual model of the DSS

The DSS was proposed and conceptualized in Paper 1 (see Figure 18). A key feature of this solution space is the *rule base* for customization, which represents the associated components, modules and scalable variables and how they can be combined into *possible solutions*. The *actual boundary* indicates that the rule base can generate a finite set of possible outcomes, which entails that all possible solutions are principally known before receiving a customer order. In following sections, an analysis of how the DSS approach relates to customization in terms of process, product, learning and customer interface is presented.

5.2.1 *DSS in relation to process*

The DSS customization approach is associated with the delivery strategies ATO and CTO. For DSS customization, a larger proportion of activities are performed in advance, based on speculation, as compared to the CSS. The engineering activities are performed based on speculation, and the components and modules may be produced in advance and stocked to be assembled later according to a customer-specific configuration (Song & Zipkin, 2003; Wemmerlöv, 1984). As the engineering activities are carried out for an aggregate of customers, the customers do not individually pay a premium for the customized engineering solutions, which enables relatively low prices compared to the CSS approach. Moreover, as customers do not have to wait for the engineering activities to be performed, delivery lead times can be kept relatively short. It also enables the variability among customers to be reduced, as they are constrained to engineering activities that have already been executed, which allows for a stable production environment that is in line with mass customization (Piller, 2004; Salvador et al., 2009).

Conceptual developments that relate to the process aspect of DSS customization have been proposed in this research. In Paper 1, the process of realizing a solution within the DSS customization approach is described as a two-part biramous process, wherein the first step is to establish a solution structure in terms of a set of rules, based on speculation, that are to be used in the second step for the configuration of a customer-specific solution based on a customer commitment (see Figure 12). This process of realization is referred to as a *biramous solution realization* in Paper 1 and demonstrates the differences between realizing solutions in the DSS context compared to the

CSS approach. Paper 1 also proposes a clarification regarding the ATO and CTO terminology, which has been defined inconsistently in the literature. Based on the distinction between the biramous and monolithic solution structures, it is suggested in Paper 1 that configuration-based customization can be either ATO or FTO depending on whether fabrication precedes configuration or vice versa, while CTO is regarded as an umbrella term for these configuration-based strategies (see Figure 12).

5.2.2 *DSS in relation to product*

By clearly constraining product variety, a key benefit of the DSS customization approach is that it provides stability for production, allowing for customization with almost mass production efficiency. This is in line with the principles and promises of mass customization (Fogliatto et al., 2012; Hart, 1995). In the mass customization literature, solution spaces are an established concept, and solution space development has been advocated as a key capability for companies engaging in mass customization, which is described as "*the capability to identify the product attributes along which customer needs mostly diverge*" (Salvador et al., 2009, p. 5). This aligns with the description of the DSS customization approach as proposed in this research, as this capability is required to establish a *rule base* and an *actual boundary* that caters to the idiosyncratic needs of the intended customers.

Further, the clearly defined product offering of the DSS customization approach provides the benefit of the possibility of utilizing product configuration systems, which necessitates that customization be offered based on a set of predefined variables and values and within well-defined constraints (Zhang, 2014). The DSS is also closely related to product platforms and can incorporate module-based, scale-based (Simpson, 2004; Simpson et al., 2014) and module-scale-based product platforms (Gao et al., 2009) to form *actual solutions* by identifying modules that can be shared and combined and scaling variables that can be stretched or compressed to satisfy varying customer needs.

Fundamental for the DSS customization approach is the clearly predefined offering; but this research has highlighted certain nuances regarding the solution structures in the DSS context. As proposed in Paper 1, the composition of a solution in the DSS context can be either a *biramous* or a *monolithic solution structure*. It has been explained that a biramous solution structure is in line with ATO, where the modules are defined in the first phase to establish a rule base, whereas the final solution is defined in the second phase based on the selections made by the customer. Alternatively, in FTO situations, where scale-based customization at the item level affects the design of components, which requires fabrication following the configuration, the solution structure needs to be generated for the specific delivery, implying a monolithic solution structure. This proposed distinction between solution structures in the DSS context highlights the differences between module-based and scale-based customization even though both are derived from a predefined offering.

5.2.3 *DSS in relation to learning*

Learning manifests itself differently in the DSS context compared to the CSS one. While the learning aspect of the DSS has not been as thoroughly investigated in this research as that of the CSS, there are still some relevant arguments to be made based on the findings of Paper 1 and 4. An important difference from the CSS approach is that, for the DSS, there is limited exploration of new knowledge for customer driven activities. By limiting customers to a pre-established rule base, the DSS customization approach can readily execute the same to generate the customer-specific solution, which is in line with the logic of executional learning (Ellström, 2005; Engström & Wikner, 2017) and exploitation (March, 1991). Thus, there is no need for an extensive and time-consuming dialogue with the customer to generate knowledge about their needs and requirements. Instead, the customer may make their choices from lists of options, catalogues or web-based platforms, which can be directly linked to production and, therefore, enable timely and cost-efficient customization (Forza & Salvador, 2006). Furthermore, the predefined offering of the DSS approach also allows production processes to be stabilized and benefit from repetitiveness, which enables exploitative work. However, this does not mean that there is no developmental learning or exploration for DSS customization. The explorative work is allocated to the preparatory stage, i.e. before committing to a customer and based on speculation, to define the rules and constraints of the DSS. By performing the explorative activities in advance and based on speculation, the DSS can employ exploitation to perform the customer driven activities in an efficient manner, since the work can be performed routinely or automatically, as further explained in Paper 4.

5.2.4 *DSS in relation to customer interface*

The DSS customization approach also differs from CSS with regard to the customer interface. By limiting customization to a predefined offering, the DSS customization approach can prevent customer unpredictability and enable a high number of back office operations. With a majority of activities allocated to the back office, the DSS customization approach can attain internal efficiencies that exceed those of the CSS, as the variations and disruptions that arise from unforeseen customer needs can be eliminated. This is in line with the priorities of a back-office orientation, as proposed in the literature (see e.g., Chase, 1978; Metters & Vargas, 2000; Wikner, Yang, et al., 2017), and is associated with both engineering and production as both of these are back-office responsibilities in the DSS context. A key responsibility for the back office related to the DSS is to attain a sophisticated understanding of the needs of potential customers to establish a DSS that covers a wide range of customer requirements. The back office is also responsible for the majority of production, whereas the front office in the DSS is responsible for guiding customers through the possible solutions.

5.3 The HSS customization approach

The HSS represents a customization approach that combines the inherent logics of the CSS and the DSS, where the offering is partly predefined but there are also possibilities for customized engineering. This is an intermediate customization approach that has been extensively discussed in the literature (see e.g., Cannas, Masi, et al., 2020; Haug et al., 2019; Johnsen & Hvam, 2019; Kristjansdottir et al., 2017) and is supported empirically in this research by two of the five companies considered (Company Gamma and Company Epsilon). Figure 19 shows an illustration of the HSS as proposed in Paper 1, comprising features of both the CSS and the DSS.

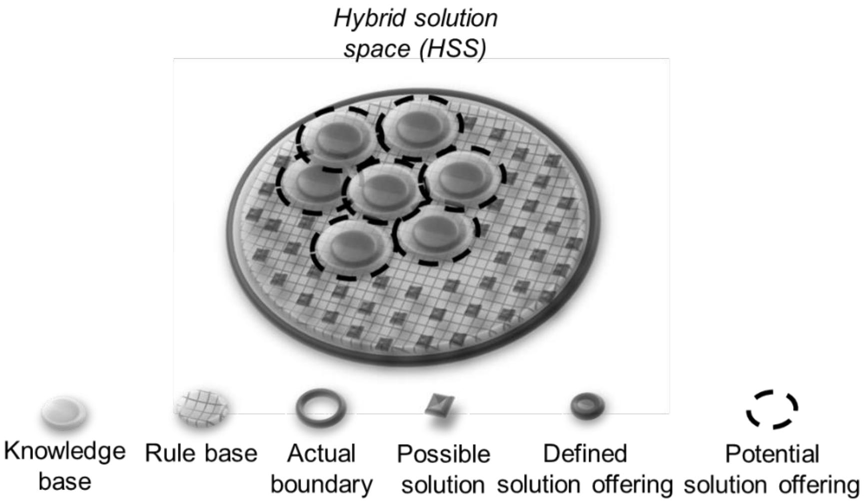

Figure 19. Conceptual model of the HSS

The HSS was proposed and conceptualized in Paper 1, as shown in Figure 19. It comprises features of the DSS, namely the *rule base* and *actual boundary*, where the former represents the components, modules and scalable variables and how they can be combined into *possible solutions*. It also suggests that the HSS approach implies a relatively strict delineation of the offering, in that it is more clearly defined than in the CSS approach, although it is less clearly defined as compared to the DSS. This is due to the fact that it also contains features of the CSS, as customized engineering is made possible for some specific functionalities, which is illustrated by the "miniature" CSSs. The following section presents an analysis of how the HSS approach relates to customization in terms of process, product, learning and customer interface.

5.3.1 *HSS in relation to process*

The HSS customization approach does not perfectly correspond to the CODP-based classification of delivery strategies. This is discussed in Paper 1, where it is explained that the HSS represents a customization approach that is positioned between ATO/FTO (CTO) and ETO, but this type of situation has been referred to as both ETO and mass customization in the literature (Cannas, Masi, et al., 2020; Haug et al., 2019; Johnsen & Hvam, 2019; Kristjansdottir et al., 2017). The HSS customization approach can indeed be linked to ETO, as by definition only *some* engineering activities need to be performed to order (e.g., 1% of the total engineering performed) for it to classify as ETO. The remainder of the engineering activities may be performed based on speculation and form the basis for rule-based customization and product configuration, which is in line with the HSS customization approach. However, this addresses a weakness of the ETO definition, as situations labelled ETO may be in line with CTO in terms of customization to the largest extent. The HSS, therefore, has an important impact on the definition of ETO, as it implies a distinction between ETO according to the CSS and that according to the HSS. In this research, conceptual developments have been proposed that relate to the process aspect of the HSS. Similar to the DSS, the HSS approach represents a *biramous solution realization*, as explained in Paper 1. A customer-specific solution that stems from an HSS can be based on standard modules and values within the scales of predefined variables and, by definition, also comprise some degree of customized engineering.

5.3.2 *HSS in relation to product*

The HSS customization approach can be linked to product platforms and product configuration in a similar way as the DSS, as customization in the HSS context is largely based upon configuration, although there are also some possibilities for customized engineering. This was, for instance, addressed by Johnsen and Hvam (2019), who focused on how the accommodation of customized engineering in an HSS context impacted profitability. As for whether the HSS approach corresponds to mass customization is debatable and is subject to the definition of mass customization, which has both visionary and practical definitions (Hart, 1995). The benefit of mass customization is to enable customization with *near* mass production efficiency (Fogliatto et al., 2012; Hart, 1995), which may be difficult to achieve when allowing for customized engineering, although this depends on the precise meaning of "*near*". Regarding the conceptual developments related to the product aspect of the HSS, Paper 1 argued that the HSS approach implies a *monolithic solution structure*. This is because the engineering adaptations require each solution structure to be engineered for the specific delivery.

5.3.3 *HSS in relation to learning*

With regard to learning, the HSS customization approach incorporates the characteristics of both the DSS and the CSS. Combining the logics of the two, the HSS demands both exploration and exploitation for both customer driven and speculation driven activities. It can be argued that the HSS customization approach is the most "balanced" solution space from an ambidexterity perspective (O'Reilly & Tushman, 2004), in that it necessitates exploration and exploitation for both customer driven and speculation driven activities (Engström & Wikner, 2017). To deliver a solution in the context of the HSS, exploration is required to establish the rule base (i.e., during the first phase of the biramous solution realization), which can be subsequently exploited during configuration to generate a customer-specific solution (i.e., during the second phase of the biramous solution realization). This is in accordance to the work of Vos et al. (2018), who demonstrated that a balance between modularity (i.e., discrete offering) and solution space freedom (i.e., a continuous offering) fosters learning in an organization.

5.3.4 *HSS in relation to customer interface*

The HSS customization approach, on the one hand, requires back office attention to develop rules, which can later be used for customer-specific configurations, which is similar to the DSS approach; but on the other hand, it requires front office attention to accommodate customized engineering, which is similar to the CSS, although only for specific subsets of functionalities. This means that the HSS approach can attain external effectiveness at the customer interface that is superior to that of the DSS (although less so than for the CSS) and achieve internal efficiency of operations that is superior to that of the CSS (although less so than the DSS) (see e.g., Chase, 1978; Metters & Vargas, 2000; Wikner, Yang, et al., 2017). An important difference between the HSS and the CSS approaches is that the stability provided by the partially predefined offering for the HSS means that the need for cross-functional collaboration and extensive customer interaction required to provide a customized solution is lesser than for the CSS and, for instance, solution businesses.

5.4 Defining customization approaches from a solution space perspective

Based on the descriptions of the customization approaches in relation to the four aspects, this section proposes more concise definitions for each customization approach:

- The CSS approach is defined as *a knowledge-based approach to customization in which decisions regarding customization are made on a customer commitment basis.*

- The DSS approach is defined as *a rule-based approach to customization in which clear limits are set in advance regarding the extent to which the offering can be customized.*

- The HSS approach is defined as *a hybrid approach to customization in which the offering is partially predefined but allows for customized engineering for a specific subset of functionalities.*

6 Discussion and conclusions

The purpose of this research is *to describe and define different approaches to customization from a solution space perspective*. Solution spaces have been highlighted as an important customization phenomenon, representing how limits are set based on the extent to which a company is willing to customize an offering. By adopting a solution space perspective and linking it to the previous understanding of customization in terms of process, product, learning and customer interface, this research makes several notable contributions both to the theory and the practices. However, before discussing the theoretical contributions and managerial implications, methodological reflections are made.

6.1 Methodological reflections

The research presented in this thesis is based on insights from a three-year interactive research project. There are some important benefits of this, as it enabled extensive and frequent engagement with managers and practitioners in customization settings and granted access to the participating companies. By these means, the practical relevance of the research has been affirmed, as the direction of the research has been guided by the practical challenges faced among the participating companies. These companies have also provided a contextual understanding of customization as a practical phenomenon, which has been taken into consideration for the development of the conceptual material of this research. However, in this regard, there is a limitation regarding the lack of empirical testing for the solution spaces. The proposed solution spaces are the result of logical relationship-building and based on the analysis of the literature and on real-world descriptions. The solution spaces have also been validated by both practitioners and scholarly colleagues. However, the research design has primarily enabled the development of theory as opposed to its testing with respect to solution spaces, which remains a limitation of this research.

As for the sampling decisions, a heterogenous set of companies had been selected that differ markedly in terms of company size, type of product, industry and so forth, hence providing a broad outlook on customization practices. Taking this into consideration, it can be argued that the proposed solution spaces are widely applicable for various industries and company sizes and for both B2B and B2C transactions. However, a shortcoming of this research is the limited number of participating companies. Care should be taken in applying the findings of this research to other types of customization contexts (e.g., services), as there may be contextual factors at variance from those of the companies addressed in this research. Therefore, the extent of the implications of this research has not yet been clearly established.

6.2 Theoretical contributions

The theoretical contributions do not concern a specific theory but relate to an overall theoretical understanding of customization and solution spaces in combination. As has been argued throughout this thesis, customization has in previous research been discussed in, for instance, the operations and supply chain management, product development management, organizational learning and marketing and service management literatures. As customization is a topic of interest in a variety of research fields, there is a need for research that bridges the terms and concepts proposed in these research fields. This thesis has presented solution spaces as an integrative customization concept that is related to the process, product, learning and customer interface aspects of customization. By these means, this research first contributes to the understanding of solution spaces in relation to each customization aspect, and, second, contributes to the understanding of the four customization aspects by viewing them from a solution space perspective. This is illustrated in Figure 20, where the interrelationships between the CSS, DSS and HSS and the customization aspects are represented by the two-sided arrows. In the following sections, a more detailed discussion regarding the theoretical contributions of this research is presented.

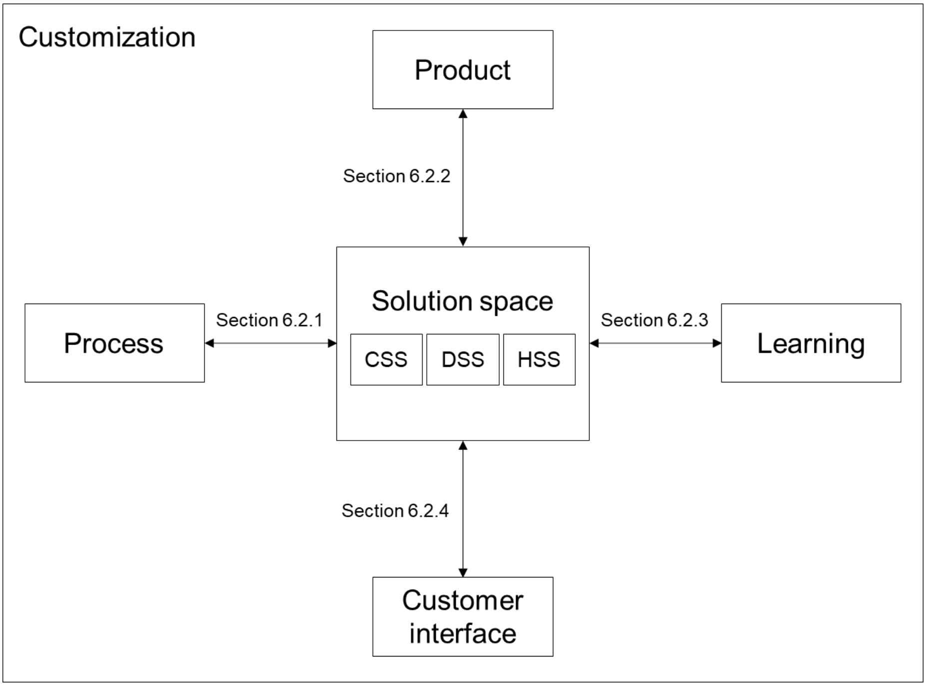

Figure 20. Theoretical contributions related to process, product, learning and customer interface.

6.2.1 *Integrating solution spaces and the CODP*

This research has enhanced the understanding of different customization approaches by integrating solution spaces and the CODP. The CSS, DSS and HSS links to the established classification of CODP-based delivery strategies, such as ATO, CTO and ETO. By adopting a solution space perspective and accounting for how limits are set with regard to the extent to which an offering can be customized, this research challenges the assumptions of linearity that form the basis of the CODP and, consequently, the definition of the delivery strategies. This is a particularly important contribution to the ETO literature, as the ETO definition arguably lacks meaningful conceptual boundaries in that no clear distinction is made between situations where only a minor proportion of the engineering is customized and those that require extensive customized engineering (Gosling et al., 2017). While the "traditional" view on ETO is more in line with the latter situation (see e.g., Hicks et al., 2000; McGovern et al., 1999), recent research has pointed to the width of the ETO definition, highlighting situations that almost entirely comprise speculation driven engineering but include a very limited amount of customized engineering as ETO (Cannas, Gosling, et al., 2020; Willner et al., 2016). This tendency can also be seen in research that focuses on introducing product configurators in ETO environments to achieve mass customization (Cannas, Masi, et al., 2020; Haug et al., 2019; Kristjansdottir et al., 2017; Shafiee et al., 2014). In this regard, the findings of this research, specifically the distinction between the CSS and the HSS, can contribute to the conceptual rigor of ETO, where the CSS represents the traditional view of ETO whilst the HSS represents a hybrid approach between ETO and CTO (which is in line with, for instance, Johnsen & Hvam, 2019).

6.2.2 *Augmenting solution spaces*

Solution spaces have been highlighted in this research as a key concept for customization, augmenting the solution space concept to be applied not only for mass customization but also for ETO. Prior to this research, solution spaces have primarily been acknowledged in relation to mass customization (Piller, 2004; Salvador et al., 2009), and, generally, their technical aspects have been focused upon (Gembarski, 2019; Gembarski & Lachmayer, 2018; Hermans, 2012). There has been a lack of research that explains in detail what solution spaces are and what implications they have for customization. The findings of this research significantly improve the understanding of solution spaces – both by extending the solution space concept, and by providing rich descriptions of each solution space and relating them to a multidisciplinary frame of reference. This contributes to the mass customization literature by providing a more nuanced outlook on solution spaces and to the ETO literature by proposing how solution spaces can be understood in this context. As for mass customization, there has been a long-standing discussion regarding its definition. There have been both visionary and practical definitions (Da Silveira et al., 2001; Hart, 1995), and the difference between mass and "conventional" customization has not been perfectly clear. In line with Piller (2004), who argue that a core capability for mass customization is a clearly defined solution space, the differentiation of the CSS, DSS and HSS provides conceptual support for this claim, contributing to the definition of mass customization by proposing the DSS as a key component of the same and the HSS as a representation of when mass customization can be partially achieved.

6.2.3 *Integrating solution spaces and learning*

The relationship between solution spaces and learning has been addressed in this research. Among the scholars within the field of learning in organizations, there have been calls for context-specific research that addresses learning in close proximity to specific contexts (Örtenblad, 2013; 2018). This research has illustrated the role of learning with respect to customization and how the different logics of learning are manifested in customization practices by building on, for instance, the works of Ellström (2005) and Engström and Wikner (2017). The CSS, DSS and HSS distinction shows that the prerequisites and requirements for learning can differ depending on the customization approach employed. This adds to the understanding of customization by arguing for the criticality of learning in customization contexts, which is in line with, for instance, the works of Kotha (1996) and Örtenblad (2013) and suggesting that the variation in tasks caused by customization have important implications for learning. This also adds to the understanding of learning by showing how customization is a practical context wherein the ability to create knowledge and learn is continuously put to the test and where the CSS, DSS and HSS represent different circumstances for learning.

6.2.4 *Integrating solution spaces and the back and front office*

By considering the back office and front office distinction in relation to customization and solution spaces, this research has contributed to an understanding of the organizational implications of different customization approaches. Building on, for instance, the studies of Wikner, Yang, et al. (2017) and Metters and Vargas (2000), the findings indicate that the relative allocation between the back office and the front office significantly differs for different customization approaches, which is explained in this research in relation to solution spaces. This is an important contribution to both the mass customization and the ETO literatures and the research that addresses the scope in between ETO and mass customization, as it clarifies the differences between organizational implications and priorities for back-office-oriented (particularly DSS but also HSS) and front-office-oriented (CSS in an ETO context) customization approaches. Additionally, by addressing the organizational implications of solution spaces, supported by the back office and front office distinction, this research also establishes a link between the

ETO literature (Cannas & Gosling, 2021; Gosling & Naim, 2009) and the solution business literature (Storbacka, 2011; Tuli et al., 2007), as it appears that ETO, in line with the CSS approach, is comparable to solution businesses in various regards. Furthermore, this research also makes an important contribution to the understanding of companies that offer multiple product offerings simultaneously (see e.g., Cannas et al., 2019; Cannas, Gosling, et al., 2020; Fernandes et al., 2012), proposing the CSS, DSS and HSS as a means of categorizing different offerings and demonstrating how each solution space is related to the process, product, learning and customer interface aspects of customization.

6.3 Managerial implications

This research has both addressed a spectrum of different customization approaches, as represented by the CSS, DSS and HSS, and has focused specifically on the CSS. Accordingly, the managerial implications of this research are, on the one hand, based on contrasting, comparing and differentiating the various customization approaches (see Section 6.3.1) and are, on the other hand, based on an in-depth analysis of the CSS customization approach (see section 6.3.2).

6.3.1 *Managerial implications related to the differentiation of customization approaches*

This research has illustrated several important differences between customization approaches, as represented by the CSS, DSS and HSS. For managers in customization contexts, it is vital to possess a detailed understanding of the possibilities and limitations of different customization approaches. These approaches are characterized by specific challenges, where, for instance, customization in the context of the DSS revolves around the development of specific rules for customization by performing engineering activities independent of customers and targeting an aggregate of customers. In contrast, in the CSS context, the focus is on providing one-of-a-kind solutions on a customer-to-customer basis, which may require engineers and product developers to engage directly with individual customers to understand their specific needs. In this regard, the proposed conceptualization of solution spaces can help managers understand the factors involved in their specific context and, at least, contribute with terminology that can enable joint organizational action related to customization practices and solution spaces.

The managerial relevance of this research is perhaps particularly evident in cases where a combination of CSS, DSS and/or HSS offerings are catered for in parallel from the same organization. In these circumstances, managers are faced with the challenge of aligning priorities and competences among the organization's different offerings. Competences that are useful for the CSS, such as customer service skills among engineers, may be less useful for the DSS, and vice versa. By understanding the implications of the different types of offerings, as represented by the CSS, DSS and HSS, managers can make sound decisions when taking organizational action related to customization.

This research also contributes managerial guidance related to transitions between customization approaches. The CSS, DSS and HSS are not static, and, as discussed previously, the introduction of product configuration in a CSS context could, for example, imply a transition from a CSS to a HSS customization approach (Cannas, Masi, et al., 2020; Haug et al., 2019; Kristjansdottir et al., 2017; Myrodia & Hvam, 2014; Shafiee et al., 2014). When considering a transition between customization approaches, it is important for managers to understand the strategic benefits and trade-offs related to the transition. With the help of the CSS, DSS and HSS distinction, this research provides a solid basis for such an understanding, having linked the solution spaces to the process, product, learning and customer interface aspects. Thus, this research can support better benchmarking for managers in customization contexts.

6.3.2 *Managerial implications related to the CSS customization approach*

This research has managerial implications that specifically address the CSS approach (in line with ETO), as the two empirical papers are set in a CSS customization context. This research has shown that, in for CSS customization, several important decisions are made in relation to actual and potential customer commitments. The strategic importance of these decisions has been demonstrated, as these may determine which projects are carried out, which investments are made and how the company defines its offering. If managers in the CSS context are aware of the strategic importance of some of the decisions that are made in direct relation to individual customer commitments, it may allow them to involve relevant functions and competences for the specific decision and, as a result, allow for well-founded strategic action.

The CSS customization approach implies that a variety of organizational functions perform activities according to individual customer needs. This research has provided detailed insights regarding the customer interaction that is required to understand their unique requirements and how to respond to them. In contrast to the DSS and HSS, where customer interaction can be fully or partially rationalized, the CSS approach entails distinctly different circumstances for customer interaction. This research has shown that, in the CSS context, there is typically an extensive, complex and back-and-forth dialogue with the customer to create shared knowledge about the solution to be produced. This may require the involvement of various functions and competences from both the manufacturer and the customer side. As organizations in the CSS context are often faced with new customer requirements in this manner, it is important for managers to develop routines, procedures or ways of working that can support customer interaction processes. This research provides some useful tools for managers in this regard, outlining a tendering invitation evaluation process (see Figure 15) that can serve as guidance when evaluating whether to commit to a tender based on a customer inquiry and providing a categorization of communication patterns that characterizes customer interaction in the CSS context (see Figure 16), which can be used to support the interaction with customers to understand their specific needs.

6.4 Further research

This research has presented three types of solution spaces as representations of different customization approaches and linked these solution spaces to a multidisciplinary frame of reference. While many possible avenues for further research can be pursued to improve the understanding of solution spaces and customization, five overall focus areas for further research are proposed here.

First, there is a need for further empirical support for the solution spaces. This is particularly the case for the DSS and HSS. In terms of suitable research methods, case studies could be appropriate as a means of studying solution spaces in detail while taking contextual factors into consideration. Theory-testing research could also prove valuable for verifying the validity of the solution spaces and their occurrence in practice.

Second, this research has focused on customization and solution spaces from the point of view of the supplying company (i.e., the manufacturer). It is, however, important to note that solution spaces are inherently a space in which the supplier and the customer interact with each other. Thus, a possible avenue for further research is to study customization and solution spaces from the point of view of the customer or, alternatively, by considering the customer's and the supplier's perspectives together. It could also be suitable to adopt a triadic rather than a dyadic perspective on customization to account for supply and demand dependencies (see e.g., Wikner et al., 2017; Wikner & Bäckstrand, 2018), although with a specific focus on solution spaces.

Third, the HSS approach has in this research been proposed as a representation of situations where the logics of the CSS and HSS approach are combined. A possible area for future research is to provide a more detailed analysis of what the HSS approach can imply in terms of for example different alternatives for application.

Fourth, the basis for this thesis is the manufacturing industry, and it has not been claimed that the findings are valid in other contexts, such as for services. Nonetheless, the conceptual material proposed in this research, particularly with regard to the solution spaces, is fairly abstract and could prove to be of relevance in a service context as well. Although services would generally perhaps be associated with the CSS approach, the introduction of service modularity (Brax et al., 2017) and the mass customization of services (Silvestro & Lustrato, 2015), for instance, indicates a more diverse customization spectrum. Further research is needed to investigate solution spaces in service contexts, where, for example, solution spaces in health care would represent an interesting possibility for future studies.

Finally, another direction for further research is to consider emerging technologies in relation to solution spaces. There are a variety of emerging technologies that will inevitably have consequences for customization practices and, thereby, solution spaces. Among the technologies that belong to the fourth industrial revolution, such as the internet of things, additive manufacturing and three-dimensional printing (Dalenogare et al., 2018), perhaps artificial intelligence (AI) is the technology that seems most likely to impact solution spaces, i.e. in terms of how the extent to which a company is willing to customize its offering is decided. While there are studies that have discussed the implications of AI on customization (see e.g., Grandinetti, 2020; Tien, 2020), future studies can examine this aspect from a solution perspective by considering the possibilities and limitations of AI in relation to the CSS, DSS and HSS. Such studies could provide valuable inputs for managers in customization contexts.

6.5 Concluding remarks

This research has highlighted solution spaces as a key issue in customization, representing how limits are set for the extent to which a company is willing to customize its offering. Three types of solution spaces have been described and defined – the CSS, DSS and HSS – while also relating them to a multidisciplinary frame of reference, which comprises concepts from operations and supply chain management, product development management, organizational learning and marketing and service management literature. In this way, the research has contributed to the understanding of customization as a multifaceted phenomenon and provided means for the consolidation of customization concepts spread across different fields of research. The managerial relevance of solution spaces has been demonstrated, showing that each solution space is subject to different types of managerial challenges. In conclusion, the proposed solution space perspective on customization illustrates the importance of considering how offerings are defined and delimited, and there are considerable opportunities for further research on this contemporary issue.

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A Solution Space Perspective on Customization

Customization is an important feature in today's manufacturing industry. Although this sector is typically associated with standardization and mass production, the increase in global competition, technological development and demand for product variety has driven many manufacturers, starting from the end of the last century, to offer customized products and services. There are various approaches to customization, ranging from situations where standard components are assembled according to customers specifications to situations where one-off solutions are developed from first principles to customer specific needs.

The point of departure of this doctoral thesis is an inquiry into the concept of solution spaces and how it can be used to explain different practical applications of customization. The thesis comprises a total of four papers, two of which are conceptual and address the broad spectrum of customization approaches, providing a comparative outlook on customization. The empirical body of the thesis specifically focuses on what is commonly known as engineer-to-order (ETO) environments, comprising two papers in which the managerial challenges associated with customization, such as learning in organizations, evaluation of tendering invitations and the elicitation of customer needs, are empirically investigated.

This work makes several notable contributions to the literature. Three types of solution spaces are proposed, representing distinct customization approaches. By synthesizing the solution spaces according to a comprehensive and multidisciplinary frame of reference, this thesis attempts to advance customization research and render it a coherent research field, consolidating key customization concepts within, for instance, operations and supply chain management, product development management, organizational learning and marketing and service management literature. In particular, this thesis links customization to learning, thereby providing managers in customization contexts with valuable support to facilitate learning within their organizations.

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