Master's thesis

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Product configurators for engineer-to-order products

Master's thesis in Engineering and ICT
Supervisor: Erlend Alfnes, Marco Semini
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Summary

Product configurators (PCs) are software systems that automate work in sales and engineering processes and can bring benefits such as time and resources reductions and quality improvements. Companies that manufacture Engineer-to-Order (ETO) products are increasingly becoming interested in using PCs in the sales process to increase efficiency. ETO products have unique characteristics, such as a high degree of customization, order specific engineering, and complex structures, that present additional challenges when developing PCs for ETO products. Many of these challenges are related to the need for partial configuration, which entails only determining parts of the product with the PC, leaving the remaining parts for manual engineering. The need for partial configuration is unique to ETO products and is a result of the ETO characteristics.

Several procedures exist to guide the development of PCs, but none are specific for ETO products. Additionally, few studies investigate the challenges induced by the ETO characteristics, and no studies were found that investigate partial configuration. *The purpose of this study is to help fill the research gap regarding the challenges companies face when developing PCs for ETO products and provide knowledge to aid the development.* This thesis focuses on PCs in the sales process of ETO products and on the three first phases in a PC project; configurator scoping, configurator specification, and configurator development.

The following objectives are formulated to guide the research:

1. Perform a state-of-the-art analysis of product configurators for ETO products.
2. Explore challenges that occur during the development of PCs for ETO products.
3. Provide recommendations for developing PCs for ETO products.

To meet objective 1, a literature review of ETO, PCs, and the development and use of PCs for ETO products is conducted. As the literature is scarce on challenges and how to address them, more empirical investigation was needed.

Therefore, to meet objective 2, two exploratory case studies in two companies that manufacture ETO products are conducted. In each case study, a development project for a PC prototype is conducted. The development approaches are based on state-of-the-art development approaches from the literature. Each project is analyzed separately, and the findings are categorized into the challenges encountered and the learnings of how development can be conducted to address the challenges.

To meet objective 3, a cross-case analysis is performed and discussed. Based on this, recommendations for how PCs can be developed for ETO products to help overcome the challenges are provided. The recommendations supplement existing development approaches and detail the activities that can be performed and how they can be conducted using an agile development approach.

The contribution of this study includes; 1) Increase the understanding of the challenges of developing PCs for ETO products and how they may be overcome 2) Extend the knowl-

edge of partial configuration 3) Extend previous research on agile development approach for PC development.

Sammendrag

Produktkonfiguratorer (PCer) er systemer som automatiserer arbeid i salgs- og ingeniørprosesser og gir fordeler som tids- og ressursreduksjoner og kvalitetsforbedringer. Selskaper som produserer Engineer-to-Order (ETO)-produkter blir stadig mer interessert i å bruke PCer i salgsprosessen for å øke effektiviteten. ETO-produkter har unike karakteristikker, slik som høy grad av tilpasning, ordrespesifikt ingeniørarbeid og komplekse produktstrukturer. Dette byr på ytterligere utfordringer under utviklingen av PCer for ETO-produkter. Mange av disse utfordringene er knyttet til behovet for delvis konfigurasjon som innebærer å kun bestemme deler av produktet med PCen. De resterende delene er overlatt til manuelt ingeniørarbeid. Behovet for delvis konfigurasjon er unikt for ETO-produkter og er et resultat av ETO-karakteristikken.

Det finnes flere prosedyrer for å veilede utviklingen av PCer, men ingen er spesifikke for ETO-produkter. I tillegg undersøker få studier utfordringene forårsaket av ETO-karakteristikkene og ingen studier ble funnet som undersøker delvis konfigurasjon. *Formålet med dette studiet er å bidra til å fylle forskningsgapet angående utfordringene selskapene står overfor når de utvikler PCer for ETO-produkter og bidra med kunnskap for å støtte utviklingen.* Studiet fokuserer på PCer i salgsprosessen for ETO-produkter og på de tre første fasene i et PC-prosjekt: konfigurator-omfang, konfigurator-spesifikasjon og konfigurator-utvikling.

Følgende forskningsmål er formulert:

1. Utfør en state-of-the-art analyse av PCer for ETO-produkter.
2. Utforsk utfordringer som oppstår under utviklingen av PCer for ETO-produkter.
3. Gi anbefalinger for utvikling av PCer for ETO-produkter.

For å oppfylle forskningsmål 1 utføres et litteraturstudie på ETO, PCer og utvikling og bruk av PCer for ETO-produkter. Siden litteraturen er knapp på utfordringer og hvordan man skal håndtere dem, var det behov for mer empirisk undersøkelse.

Derfor utføres to case-studier i to selskaper som produserer ETO-produkter for å oppfylle forskningsmål 2. Hver case er et utviklingsprosjekt hvor en PC-prototype utvikles. Utviklingsmetoden er basert på state-of-the-art utviklingsmetoder fra litteraturen. Hvert prosjekt analyseres hver for seg og funnene kategoriseres under utfordringer som oppstår og lærdommer om hvordan utvikling kan gjennomføres for å håndtere utfordringene.

For å oppfylle forskningsmål 3 utføres ”cross-case” analyse og funnene blir diskutert. Basert på dette foreslåes anbefalinger for hvordan PCer kan utvikles for ETO-produkter. Anbefalingene har som mål å bidra til å håndtere utfordringene. Anbefalingene supplerer eksisterende utviklingsmetoder og beskriver aktivitetene som kan utføres, og hvordan, ved hjelp av en smidig utviklingsmetode.

Bidraget fra dette studiet inkluderer; 1) Øke forståelsen av utfordringene med å utvikle PCer for ETO-produkter og hvordan de kan håndteres 2) Utvide kunnskapen om delvis konfigurasjon 3) Utvide tidligere forskning på en smidig utviklingsmetode for PC-utvikling.

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List of Abbreviations

ATO	Assemble-To-Order
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CODP	Customer Order Decoupling Point
CPM	Center Product Modeling
CRC	Class-Responsibility-Collaboration
CTO	Configure-To-Order
ERP	Enterprise Resource Planning
ETO	Engineer-To-Order
IT	Information Technology
MC	Mass Customization
MTO	Make-To-Order
MTS	Make-To-Stock
OM	Operations Management
PC	Product Configurator
PDM	Product Data Management
PIM	Product Information Management
PLM	Product Lifecycle Management
PVM	Product Variant Master
RUP	Rational Unified Process
UI	User Interface
UML	Unified Modeling Language
VP	Vice President

1 Introduction

1.1 Background and motivation

A product configurator (PC) is a software system that can be used to automate work traditionally performed by engineers and sales personnel (Haug, Hvam, & Mortensen, 2011; Forza & Salvador, 2006; Blecker et al., 2004). It supports activities from the collection of customer's needs to the release of product documentation necessary to produce the requested product (Haug, Shafiee, & Hvam, 2019a; Forza & Salvador, 2006; Aldanondo, Guillaume, & Hadj-Hamou, 2000; Soininen, 1996). PCs are widely used in various industries and can bring substantial benefits such as time and resource reductions and quality improvements (Haug, Shafiee, & Hvam, 2019b; Hvam et al., 2013; Trentin, Perin, & Forza, 2012). Manufacturing companies have successfully used PCs to offer customized products fulfilling specific customer's requirements without the need for manual design (Christensen & Brunoe, 2017; Hvam, Mortensen, & Riis, 2008). This is achieved by modeling information about product features, structures, production processes, costs, and prices into the PC (T. Petersen, 2007; Forza & Salvador, 2006).

Engineer-to-Order (ETO) products are highly complex and are designed and engineered to each customer's requirements, which demand considerable time and effort (Gosling & Naim, 2009; Amaro, Hendry, & Kingsman, 1999; Bertrand & Muntslag, 1993). In today's business environment with growing competition, short delivery time requirements, and new technologies, companies offering ETO products have become increasingly interested in PCs to cut time and resources spent in sales and engineering processes (Willner et al., 2012; Haug, Ladeby, & Edwards, 2009). The sales process for ETO products usually involves back and forth communication with potential customers during which a quotation, including high-level design, price, and other details, is presented before a contract is signed (Haug, Hvam, & Mortensen, 2011; Hicks, McGovern, & Earl, 2000). This requires spending extensive time and resources, which will be wasted if the quotation is not accepted (Elgh, 2012; Gosling & Naim, 2009; Amaro, Hendry, & Kingsman, 1999). When applied during the sales process, PCs can reduce the lead time for generating quotations, reduce errors in the design, and increase sales (Cannas et al., 2020; Haug, Shafiee, & Hvam, 2019b; Duchi et al., 2014). These PCs are termed sales configurators (Zhang, Vareilles, & Aldanondo, 2013; Haug, Hvam, & Mortensen, 2011; Arana et al., 2007; Forza & Salvador, 2002a).

However, developing a PC for ETO products presents several challenges due to their unique characteristics (Cannas et al., 2020; Haug, Shafiee, & Hvam, 2019b). The reported challenges during development may reduce performance and efficiency and even make the project fail (Haug, Shafiee, & Hvam, 2019a). ETO products are characterized by complex structures, a high degree of customization, and order specific engineering, resulting in infinite potential variants (Olhager, 2010; Amaro, Hendry, & Kingsman, 1999; Bertrand & Muntslag, 1993). Therefore, defining some limits on what products and what parts of the product will be designed using the PC is necessary. All products and product details designed using the PC is referred to as the PC solution space (T. Petersen, 2007). Using the PC to design a product will limit the ability to provide customization. Hence, companies should be careful when deciding which products to include in the PC solution space (T. Petersen, 2007; Forza & Salvador, 2002b). Additionally, they should aim for partial configuration, including only parts of the product design in the PC solution space. The rest of the design is left to be manually engineered to keep the flexibility to provide highly customized products (Johnsen & Hvam, 2019; Haug, Ladeby, & Edwards, 2009; T. Petersen, 2007; Forza & Salvador, 2006). Deciding what to include in the PC solution space is highly challenging because the decisions have to be made based on the anticipation of what customers request in the future (Cannas et al., 2020; Duchi et al., 2014; Haug, Ladeby, & Edwards, 2009). Additionally, implementing a PC requires redesigning and standardization of the products and sales and engineering processes (Cannas et al., 2020). The correctness of the designs generated by the PC is critical, but making the engineer's tacit knowledge explicit is challenging. Moreover, it can be hard to formulate clear and realistic goals and requirements for the PC (Cannas et al., 2020; Kristjansdottir, Shafiee, & Hvam, 2016). These challenges make it difficult to exploit the potential of PCs for ETO products.

The need for partial configuration differentiate PCs for ETO products from other types, such as for Make-to-Order (MTO) products. The development practices for PCs for ETO products are still immature, and companies struggle to develop and implement them successfully (Haug, Shafiee, & Hvam, 2019a). Unfortunately, the literature is scarce on the specific challenges of the development of PCs in ETO; what they entail, their consequences, and how to address them (Cannas et al., 2020; Kristjansdottir, Shafiee, & Hvam, 2016). Therefore, to reduce the number of failed projects (Haug, Shafiee, & Hvam, 2019a), more research is needed.

1.2 Purpose and research objectives

The purpose of this study is to help fill the research gap regarding the challenges companies face when developing PCs for ETO products and provide knowledge to aid the development. This is done by exploring the challenges that companies face when developing PCs for ETO products and how they may be addressed. To guide the research, the following objectives are formulated:

Objective 1: Perform a state-of-the-art analysis of product configurators for ETO products

A state-of-the-art analysis of existing literature presents an overview of the existing knowledge and the current trends in the field of PCs for ETO products and for developing PCs. Identifying the characteristics of ETO products is important to investigate if existing general knowledge about the development of PCs can be directly applied to ETO products or if there are specific challenges. This will identify where more knowledge is needed in the configurator literature and guide the researchers for the next objectives.

Objective 2: Explore challenges that occur during the development of PCs for ETO products

The literature review showed that further in-depth investigation of the challenges is needed. Therefore, two case studies in two companies that manufacture ETO products are conducted. In each case study, the researchers conduct a development project for a PC prototype in collaboration with the company to explore the challenges in a real-world setting. The projects are conducted using the knowledge identified in the literature. Through observation of and participation in the development activities and using a cross-case analysis of the challenges encountered in the case studies, the challenges are explored and seen in relation to the literature.

The findings from the case studies are divided into two categories; (1) Challenges, which are connected with objective 2, (2) Learnings, which is the knowledge gained about how development should be conducted and how the challenges can be addressed and overcome. The learnings, together with the knowledge from literature, are the basis for meeting objective 3.

Objective 3: Provide recommendations for developing PCs for ETO products

By applying the existing knowledge in the literature and the findings from the case studies, the challenges can be better understood. The cross-case analysis is continued, focusing on the learnings from the case studies of how development can be conducted to overcome the challenges of developing PCs for ETO products. This is then used to provide recommendations for development. These recommendations are structured around the development activities from the case studies and the overarching approach to the development.

1.3 Research scope

This thesis focuses on products within the engineer-to-order (ETO) manufacturing strategy. These products, referred to as ETO products, are partly- or completely engineered to customer specifications and are produced in low volumes (Willner et al., 2015; Gosling & Naim, 2009). The sales process for companies offering ETO products is the focus of this study. The sales process includes interaction with customers and the response to a request for quotation, describing the product the customer is willing to buy, and the company agrees to supply (Shafiee, Forza, et al., 2018; Hicks, McGovern, & Earl, 2000). In this phase, high-level designs, including major components and systems of the product, is developed, and process planning for manufacturing is done (Haug, Hvam, & Mortensen, 2011; Hicks, McGovern, & Earl, 2000). If the customer accepts the offer, detailed design starts, and the product is manufactured.

PCs can be divided into two types according to the business process they support (Forza & Salvador, 2006): sales configurators and engineering configurators. The sales configurator supports the sales process by identifying products that fulfill customer's needs, determining the main characteristics of the products, and producing a price quotation (T. Petersen, 2007; Forza & Salvador, 2006; Blecker et al., 2004). Engineering configurators consists of all technical details of the product and relevant calculations and links the commercial characteristics and the documents that describe each variant (Forza & Salvador, 2006). This study investigates how a PC can be applied in the sales process for ETO products to reduce time and resources.

A PC project can be divided into five phases; configurator scoping, configurator specification, configurator development, organizational implementation, and operation and maintenance (Haug, Shafiee, & Hvam, 2019a). This thesis focuses on the three first phases. Partial configuration is a special challenge when developing PCs for ETO products (Hvam, Mortensen, & Riis, 2008; T. Petersen, 2007; Forza & Salvador, 2006) and is connected to the PC solution space. Therefore, the PC solution space is a central theme in this study and is investigated in all three phases of the PC development project.

1.4 Thesis structure

The thesis structure is described in this section and illustrated in Figure 1.

Chapter 1 introduces the background and motivation for this study and the problem that justifies that this research area is of interest. It defines the research objectives and research scope.

Chapter 2 provides the theoretical background of this study. It begins with the core elements of ETO and PCs. The chapter further explores various development approaches of PCs before presenting the state-of-the-art of PCs for ETO products and the challenges that can occur during development.

Chapter 3 presents and justifies the research method (case research) and relates it to the research objectives, and describes the data collection and analysis procedures applied.

Chapter 4 and Chapter 5 presents the case studies. Each chapter starts with a brief introduction to the company, followed by information about the products considered in this study. The prototype development approach is then presented, motivated by the findings summarized in Chapter 2. For the second case study, the development approach is also motivated by the findings from case study one. Finally, the prototype and the case studies' findings are presented according to the research objective they are connected with: challenges (objective 2) and learnings (objective 3).

Chapter 6 includes a cross-case analysis that discusses the findings from the case studies and findings of the literature review. It starts by discussing the challenges from the case studies in Section 6.1 (objective 2). Following is a discussion on how to address these challenges, using the learnings from the case studies and the knowledge from the literature, in Section 6.2, laying the basis for meeting objective 3. Finally, limitations of the research are discussed, and reflections on the research process are presented.

Chapter 7 presents a set of recommendations developed based on the discussion in the previous chapter to meet objective 3.

Chapter 8 presents the main conclusions of the study, its contributions, and suggestions for further research.

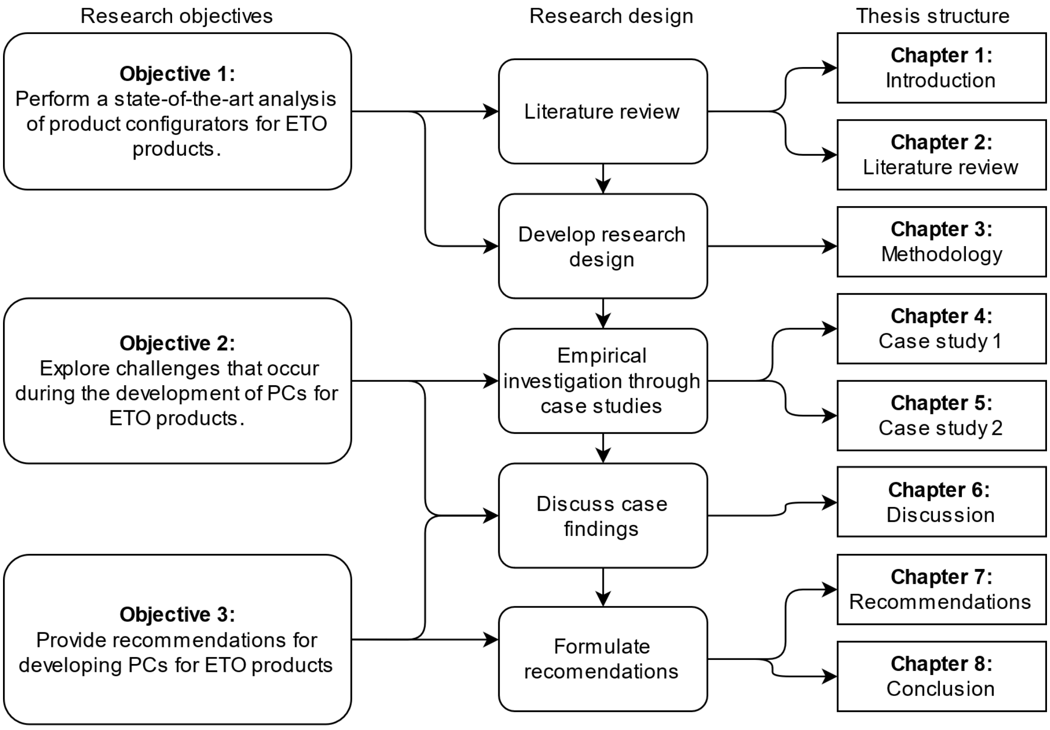

Figure 1: Thesis structure

2 Literature review

This chapter presents a state-of-the-art analysis of the existing literature (objective 1). An overview of ETO is given, along with a description of ETO characteristics and the ETO sales process. Following is a description of PCs and the existing development approaches, before the current trends in the field of PCs for ETO products and the benefits and challenges are presented. Finally, a summary of the literature review, including the main activities in the development of PCs, is given.

2.1 Engineer-to-Order

2.1.1 Overview of ETO

Various authors describe ETO in the operations management literature(OM). However, there is no general consensus on the definition of ETO (Willner et al., 2015). Porter et al. (1999) defines ETO as: "a standard product range is offered with the added availability of modifications and customizations being made to request" whereas Rudberg and Wikner (2004) defines ETO as "a new product is designed and engineered to order" (Rudberg & Wikner, 2004). The concept of ETO is closely related to the Customer Order Decoupling Point (CODP). The CODP describes where the product and material flow in the supply chain becomes driven by actual customer orders (Olhager, 2010). Operation strategies are generally classified into four different types, all of which are connected to the location of CODP (Amaro, Hendry, & Kingsman, 1999), as illustrated in Figure 2:

- Make-to-stock (MTS): Products are produced and stocked independently of actual customer orders; production volume is based on forecasts.
- Assemble-to-order (ATO): Standard parts are stocked, and products are assembled for each customer order.
- Make-to-order (MTO): Materials and parts are stocked, and products are produced according to standard designs to each customer order.
- Engineer-to-order (ETO): Products are partly or completely designed and engineered for each customer order.

ETO is the situation where the CODP is situated in the design and engineering phase. In ETO, these and all subsequent activities are coupled with a specific customer order (Willner, Gosling, & Schönsleben, 2016). An ETO manufacturing strategy is commonly used in the capital goods industry, where the customer is an industrial company. ETO products may be used in the customer's own production processes, such as a processing machine at a manufacturing plant, or be a component of the customer's own end product, such as an engine in a ship.

Wikner and Rudberg (2005) extends the traditional CODP with two dimensions, engineering and production. Johnsen and Hvam (2019) argues that ETO companies do not

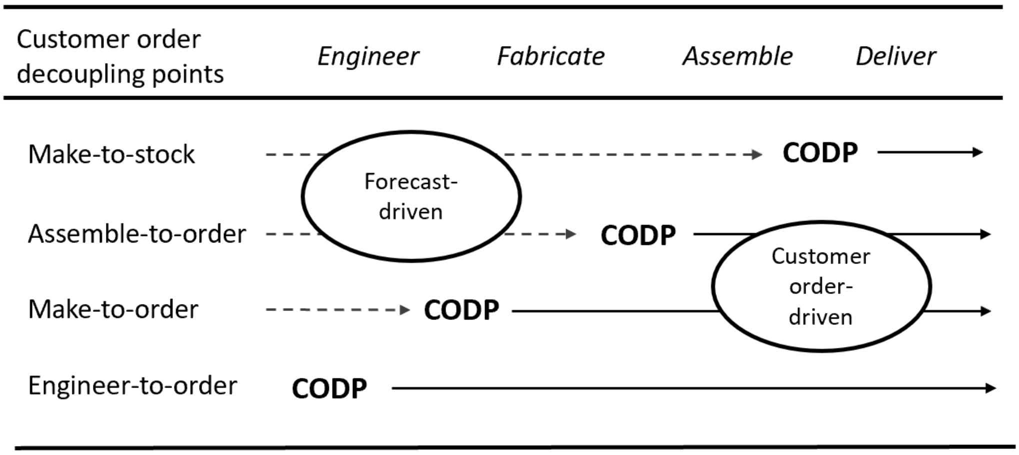

Figure 2: CODP (Olhager, 2010; Sharman, 1984)

necessarily fall into one of the engineering dimension categories (CTO, MTO, or ETO) within the ETO CODP. Where CTO is configure-to-order and describes the situations were the product is designed by the use of standard parts and modules, which can be put together by a set of predefined rules (Hvam, Mortensen, & Riis, 2008). They suggest that ETO companies may operate within the range and, even within the same ETO product, apply different CTO, MTO, and ETO elements. They use an example of an ETO company that produces cement plants to illustrate that an ETO product can contain both standard modules/parts and modified and completely new modules/parts.

Nevertheless, manufacturing must be aligned with the business strategy to contribute to performance (Skinner, 1969). The purpose of a business strategy is for a company to know how it should position itself compared to its competitors and to develop a set of capabilities it excels in. It should determine what basis the business competes in terms of, for example, cost, availability, and quality (Brown & Blackmon, 2005). Decision-makers are the people within a company who can make strategic decisions at a high level in an organization. The company's functional level, such as operations strategy, marketing, and sales strategy, must contribute to and support the business strategy. The aim is to have a fit between the company's capabilities and the requirements of the market (Brown & Blackmon, 2005; Skinner, 1969).

The role of the Information Technology (IT) strategy in a manufacturing company is to achieve competitive advantages through IT investment. The chances of achieving competitive advantages with IT increase when investments are used to support the business strategy. IT affects how individual activities are performed and enhances a company's ability to exploit linkages between activities (Porter et al., 1999). IT is seen as an enabler for the organization's goals and targets, which is reflected in IT planning. By working with business management to translate strategy into performance indicators, the relationship between business goals and IT applications is strengthened (Silvius, 2007).

2.1.2 Characteristics of ETO

The ETO manufacturing environment has a range of characteristics that differentiate ETO from other strategies (MTO, MTS, ATO). Two of the most central characteristics of ETO products are the high degree of customization and a high degree of product variety. Each customer order may require new designs and variations, resulting in wide product variety and low sales volumes (Olhager, 2010; Hicks, McGovern, & Earl, 2000; Amaro, Hendry, & Kingsman, 1999; Bertrand & Muntslag, 1993). ETO products tend to have deep and complex product structures with a large diversity of components. The components also differ in degree of standardization, where some components are standardized and unaltered across many products and others may be changed and redesigned for each customer order (Hicks, McGovern, & Earl, 2000). ETO products vary in the degree of customization, ranging from products that require entirely order specific engineering to more standard products requiring minor order-specific engineering (Johnsen & Hvam, 2019).

Since each product is manufactured to customer specifications, ETO manufacturing is often project-based and has long lead times. The activities carried out in each project may differ according to the product but can generally be divided into a non-physical and physical stage (Wikner & Rudberg, 2005; Amaro, Hendry, & Kingsman, 1999). Non-Physical activities include tendering, design, engineering, and process planning. Physical activities include component manufacturing, assembly, and installation. However, in ETO projects, the activities are overlapping and are highly integrated.

Uncertainty is a dominating feature of ETO manufacturing and is present in both the physical and non-physical processes. Since details of the product are unknown in the planning stage, the time and resources required for the design and manufacturing are also unknown. Making decisions about capacity, lead time, and price are difficult to assess (Bertrand & Muntslag, 1993). Additionally, since several projects may run in parallel and depend on the same resources, each project's processes can affect the others. For instance, if one project requires more engineering hours than anticipated, other projects can be delayed because the engineers are tied up in the first project (Bertrand & Muntslag, 1993). Thus, ETO companies must be flexible and responsive to cope with the uncertainty in processes and the market.

The ETO market is characterized by uncertainty in mix and demand volume. ETO companies are highly affected by macroeconomic fluctuations, which means that the demand can vary significantly from year to year. Both demand volumes and product mix may change rapidly and are difficult to forecast. The product mix also varies because each product is customized, and there are often new and unique customer specifications (McGovern, Hicks, & Earl, 1999; Bertrand & Muntslag, 1993).

Table 1 summarizes and categorizes the characteristics of the ETO manufacturing environment into product, process, and market characteristics.

Category	Characteristics	References
Product	High degree of customization Wide product variety Uncertain product specification in early stages Deep and complex product structures Components differ in degree of standardization Order specific engineering	Bertrand and Muntslag (1993), Amaro, Hendry, and Kingsman (1999), Bertrand and Muntslag (1993) Hicks, McGovern, and Earl (2000), Olhager (2010)
Process	Project based Process uncertainty Parallel projects dependent on the same resources Long lead times Requirements to flexibility and responsiveness Integrated and overlapping activities	Amaro, Hendry, and Kingsman (1999), Wikner and Rudberg (2005), Bertrand and Muntslag (1993)
Market	Fluctuating Volume Fluctuating Mix Low demand per product variety	Bertrand and Muntslag (1993), Bertrand and Muntslag (1993)

Table 1: ETO characteristics

2.1.3 Classification of ETO products

In the OM literature, classifications are used to reduce the complexity of empirical phenomena by providing groups used as the unit of analysis for understanding competitive behavior (Miller & Roth, 1994). Classification is considered appropriate when studying strategic fit, and several studies use classifications to describe and explain different types of ETO. Willner et al. (2015) conceptualized four archetypes of ETO and classified ETO products using annual sales volume (in reference to a specific product family) and engineering complexity (the order-specific engineering hours required per unit). They defined a 2x2 matrix, illustrated in Figure 3. The four quadrants represent different organizational structures and processes, and Willner et al. (2015) suggest different standardization and automation strategies for each quadrant.

The first quadrant is Complex ETO; products ordered in low volumes and have high engineering complexity. This archetype covers the classical definition of ETO products described in the literature (Olhager, 2010; Gosling & Naim, 2009), "one-of-a-kind" products which require large engineering and design effort for every customer order. Examples of such products are ships, oil rigs, and large bridges. Increasing production volume is typically not sustainable because of limited demand, and decreasing engineering complexity would require standardization, which is not feasible because of no order repetition.

The second quadrant is Basic ETO; products ordered in low volume and have low order

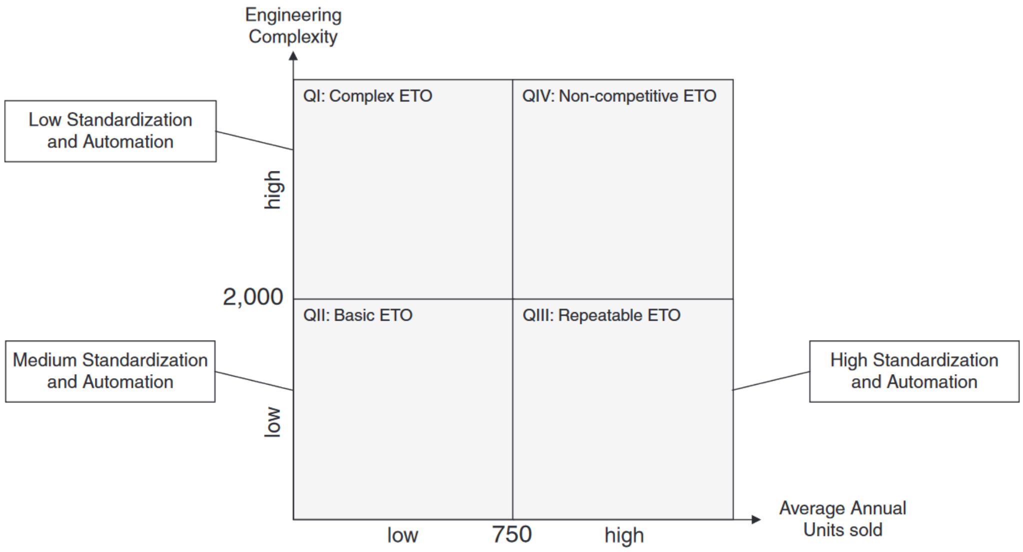

Figure 3: Classification of ETO companies (Willner et al., 2015)

complexity. Products require limited custom design per customer order because they have standard designs that can be altered to fit the customer requirements. Products may even be manufactured using an MTO strategy, and requests outside the MTO spectrum is realized by modifying the MTO product. An increase in annual orders sold is not feasible due to the market, but engineering complexity can be kept low through standardization and automation in tendering. The company can benefit from MTO's supply chain strategies, as their products are close to MTO. Examples of products belonging to the second quadrant are asphalt mixing plants and ropeways.

The third quadrant is Repeatable ETO, products with low engineering complexity and high annual volume. Similarly to basic ETO, these products are close to MTO and is regarded by some to be a variant of MTO (Alderman, Thwaites, & Maffin, 2001). Willner et al. (2015) classifies these as ETO because they claim that MTO manufacturing concepts are not sufficient to guide engineering to specific customer orders. Companies use Mass Customization strategies to keep the engineering complexity of these products low (Salvador, Martin de Holan, & Piller, 2009) and standardization and automation are relatively high because processes and components are quite repetitive. Willner et al. (2015) place high-rise elevators, radiators, and roller mills in this quadrant.

The last quadrant is Non-competitive ETO, products with high engineering complexity and high production volume. Willner et al. (2015) did not identify any companies fitting this archetype and argues that it is not strategically favorable to stay in this quadrant. They suggest that companies are only positioned here under very special circumstances. If companies do not reduce the engineering effort per unit, others will, which will weaken their competitiveness. Willner et al. (2015) argue that this quadrant is unprofitable because the overall savings generated by automation grow proportionally with the number of units affected by the automation. In contrast, the cost of automation grows exponentially with the engineering complexity.

2.1.4 ETO sales process

In ETO companies, the sales process usually involves back and forth communication with the customer. A potential customer establishes contact through a request for a quotation (also referred to as tender), including their needs and specifications for a product. The customer may have obtained information from the company's website or in white papers or catalogs in advance. The company then decides whether to respond to the invitation. If the company decides to respond, the quotation preparation process is initiated. In this phase, high-level design, including major components and systems of the product is developed, and process planning for manufacturing is done (Haug, Hvam, & Mortensen, 2011; Hicks, McGovern, & Earl, 2000). Additionally, important suppliers are contacted to determine costs and lead times. The quotation preparation process usually requires staff involvement from several departments, and considerable resources are needed to coordinate and check the information flowing between the different departments. The quotation includes price, delivery date, terms, technical specification, and commercial terms (Hicks, McGovern, & Earl, 2000). If the customer accepts the offer, detailed design starts, and the product is manufactured. The sales process is illustrated in Figure 4. Hvam, Malis, Hansen, et al. (2004) and Hvam (2006b) point out that the sales process in an ETO company may vary from one offer to another, depending on the nature of the offer and the persons involved. They further describe that the differences in working out the offers mean that the offers produced and the quality can vary.

Customers in the ETO market usually send several requests for quotation to different companies, and the company must respond quickly to stay competitive and "win" orders. Thus, the quality of the quotation and the fit to customer needs are critical. Simultaneously, many offers are declined by the customer, which means that there will be no profit from the effort spent in this process (Elgh, 2012; Haug, Hvam, & Mortensen, 2011). Consequently, ETO companies should reduce the amount of time and resources spent on these activities.

A fundamental difference between the sales process in ETO companies and non-ETO companies is that the product's detailed design is not carried out before the contract is signed. Moreover, much technical knowledge is needed to sell the product since it must fit the customer's needs (T. Petersen, 2007). The sales department often must ask the engineering department for technical feasibility and appropriateness of a given solution and price consequences. Another important aspect of the sales process is that the information obtained controls the processes in the detailed design phases. This means that if the quality of the information is low, there will be a risk of error in the later phases, which can cause delays (T. Petersen, 2007). Examples of this could be a lack of information, which means that the product may not meet customer expectations. Another risk is that the cost price of the final order exceeds the budget price. A final risk is that the sales department has promised a product that shows to be unfeasible to engineer.

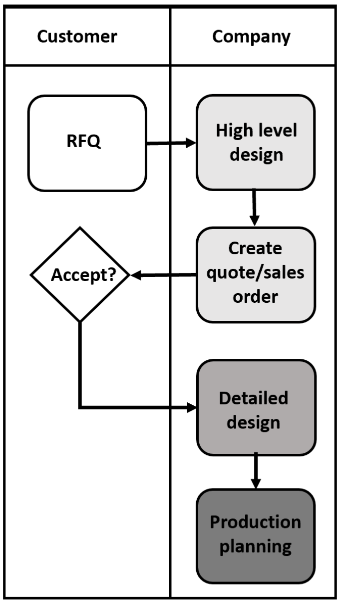

Figure 4: Sales process in ETO companies (Haug, Hvam, & Mortensen, 2011)

2.1.5 Automating the ETO sales process

In recent years, globalization, shrinking profit margins, increased competition, lead time pressure, and technological innovations have pressured ETO companies' competitiveness. To cope with these changes, companies have made efforts to adopt strategies from Mass Customization (MC) (Duchi et al., 2014). The Mass Customization term was coined in "Future Perfect" (Davis, 1989) and is defined as the low-cost, high-volume, and efficient production of personalized products, meeting all customer order requirements (Hvam, Mortensen, & Riis, 2008; Forza & Salvador, 2006; Da Silveira, Borenstein, & Fogliatto, 2001). MC encompasses the idea of producing customized goods at the price of and within similar time-frames as mass-produced products and strategies to achieve this. MC has become a central concept in many industries, and the strategies are used to produce a broad range of variants by increasing process agility, flexibility, and integration (Willner et al., 2012; Piller, Moeslein, & Stotko, 2004; Da Silveira, Borenstein, & Fogliatto, 2001).

MC strategies may help ETO companies streamline processes and products, increase productivity, and shorten lead times (Duchi et al., 2014). One way to do this is to automate time-consuming activities. Automation in ETO does generally not mean automating physical activities but non-physical activities like engineering and design, which is often called design automation. Design automation can be achieved by implementing IT systems that facilitate the reuse of product and process knowledge and automation of repetitive design tasks. Product configurators are one such type (described in Chapter 2.2) (Willner, Gosling, & Schönsleben, 2016; Duchi et al., 2014; Edwards, 2010; Forza & Salvador, 2002a). In Figure 4, the light gray boxes symbolize the processes that are usually automated by a product configurator. The darkest gray box shows the process that could be automated but typically is not. Detailed design is usually partly automated (not necessarily by a product configurator) because of the overlap between high-level design and detailed design (Haug, Hvam, & Mortensen, 2011).

Elgh and Cederfeldt (2010) describes a company producing custom engineered products. The company responds to a request for quotation with design drawings and the final price. If the quotation is accepted, all documents and manufacturing programs are generated automatically without any manual interaction through custom IT applications. The specialized software has facilitated efficient processes by automating the design of 3D-models and drawings with CAD (computer-aided design), production preparation with CAM (computer-aided manufacturing), steer information to production cells, and measuring preparation. However, the authors specify that the products did not have overly complex product structures even while there were many variants (Elgh, 2012).

Willner, Gosling, and Schönsleben (2016) established a maturity model for design automation in the sales process for ETO products. The maturity model aims to guide design automation approaches and support the assessment of design automation opportunities. They derive five distinct maturity levels, ranging from ultimate freedom to full automation, see Figure 11 in Appendix A. Through four case studies, the authors reported the necessity of mature product structures for successful design automation. To achieve a higher level of maturity, a change of activities must occur across all four dimensions; strategies, processes, systems, and people. Willner, Gosling, and Schönsleben (2016) state that ETO companies must formalize the solution space through product structures in product configurators to achieve a higher level of automation. See Section 2.2 for a description of solution space and product configurators. This requires standardization of products and engineering work. Product standardization in ETO is to engineer standard products and component variants. Standardizing engineering is to formalize engineers' tacit knowledge as configuration rules governing the design of the product. These configuration rules can be used to design valid products that fulfill product requirements without technical understanding (Haug, Ladeby, & Edwards, 2009; Hvam, Mortensen, & Riis, 2008). For example, a car's speed can be formalized as a function of the engine power and its weight. This function can later determine the engine power given the speed requirements, without understanding calculation. This standardization work means moving engineering work from order specific to non-order specific (ref ETO product characteristics in Section 2.1.2), enabling design automation through product configurators (Willner, Gosling, & Schönsleben, 2016; T. Petersen, 2007). However, ETO companies moving towards standardized products must consider the tradeoff between standardization and flexibility. Applying standardization may lead to solely focusing on efficiency and failing to meet customer requirements, which is the core capability of ETO (Willner, Gosling, & Schönsleben, 2016; Duchi et al., 2014; Haug, Ladeby, & Edwards, 2009).

2.2 Product Configurators

PCs are a subclass of expert systems and represent one of the MC strategies' most successful applications. PC systems were originally developed for mass customization environments to gain differentiation and competitiveness by introducing increased product variety at a price near mass production (Gilmore, Pine, et al., 2000). In recent years, literature has shown that companies already characterized by high product variety can successfully apply such systems (Duchi et al., 2014). Aldanondo, Guillaume, and Hadj-Hamou (2000) defined a PC as "A configurator is a software that assists the person in charge of the configuration task. It is composed of a knowledge base that stores the generic model of the product and a set of assistance tools that help the user finding the solution or selecting components" (p.1). The definition of a PC has gradually evolved along with IT development, Haug, Shafiee, and Hvam (2019a) described PC as "a knowledge base with information about product features, product structure, production processes, costs, and prices, allowing them to simulate work normally carried out by product experts, such as sales staff and engineers" (p.1). They support companies in carrying out the activities from collecting information about the customer's needs to releasing product documentation necessary to produce the requested product. Forza and Salvador (2006) refers to the configuration engine, which performs the computations necessary to produce the outputs. These computations are called configuration rules, and the order in which they are carried out is called PC decision flow. The decision flow can also be described as the process of how the configurator determines the product within the PC solution space and the configuration rules as formalized product dependencies. The common term for the configuration rules and the PC decision flow in this thesis is configurator logic.

2.2.1 Product configurator systems

The PC system is the set of product configurators and the set of the human and organizational resources that interact with it (Forza & Salvador, 2006), and is viewed as an expert system. Soininen (1996) described it as "The configurators with the capabilities for checking and producing configurations on the basis of an explicitly represented configuration model are expert systems or knowledge based systems. They automate tasks previously done by human product experts and use the explicit knowledge to reason about product configuration models and configurations", as cited in Hvam, Mortensen, and Riis (2008, p. 199). The expert systems offered by companies selling standard software for PCs can roughly be divided into independent applications, integrated systems, and independent cores (Hvam, Mortensen, & Riis, 2008; Blecker et al., 2004). PCs provide the most added value by integrating with existing IT architecture since it enables automation of processes and efficient data exchange (Willner et al., 2012). PCs can be integrated into other IT systems, such as CAD, PDM (Product Data Management), PIM (Product Information Management), PLM (Product Lifecycle Management), and ERP (Enterprise Resource Planning) systems. The other IT systems will deliver input to the PC system and be fed with the PC system's output. This integration enables more efficient data exchange and is necessary to avoid data redundancy, which requires more maintenance work and presents a higher risk of error.

CAD drawings can be generated from the PC system (Blecker et al., 2004) and can be transferred directly to the technical department. CAD integration can be utilized in the visualization aspects of the PC. A 2D or 3D model of the product is created and visualized in the user interface, allowing the user to see the product in real-time (Hvam, Mortensen, & Riis, 2008).

In terms of data integration for PC systems, common sources can be found for master data in the other IT systems. The PC operates before order entry, supporting the generation of the offer in the tendering process. It feeds the tendering process with two key information elements: product characteristics and price. If the tender is successful, the data generated by the PC can be transferred directly into the ERP system (Forza & Salvador, 2006) for order fulfillment. The ERP system can then feed the delivery date back to the PC and incorporate it into the tender.

The PIM, PDM, and PLM systems are used to maintain product and production relevant data. The system will feed the PC with items and item variants that fulfill the selected properties defined by the PC. For example, the physical product structure can be created in the PLM with those variations that satisfy the product properties defined in the sales configuration (Saaksvuori & Immonen, 2008).

PC systems can also be integrated into suppliers' systems to retrieve the required data from them. Furthermore, the different PC types can be integrated (sales and engineering PC) to increase the level of automation in the overall process (Forza & Salvador, 2006).

Based on the description above, it is illustrated that a PC system is a set of IT systems comprising the PC and the human or organizational resources interacting with these systems (Forza & Salvador, 2002a). Implementing a PC may change the company's organizational structure, supply chain, and product and business strategy. Thus, a PC system is not just an IT system. It is also an organizational structure, a marketing strategy, and in many cases, a pure innovation for the company.

2.2.2 Product configurator types

PCs can be divided into two main types, by whether the PC is applied during the order acquisition process or the order fulfillment process (Forza & Salvador, 2006): sales configurators and engineering configurators (Zhang, Vareilles, & Aldanondo, 2013; Haug, Hvam, & Mortensen, 2011; Arana et al., 2007; Forza & Salvador, 2002a). However, a PC can be fully integrated, i.e., a PC that includes both types. Depending on the PC type, the system can provide functionality such as price and delivery time calculation, layout drawing, and bill of material generation.

Sales configurators
Forza and Salvador (2006) refers to configuring products during the order acquisition process as the commercial configuration process. Other authors refer to the commercial configuration process as sales configuration and high-level design (Zhang, Vareilles, & Aldanondo, 2013; Haug, Hvam, & Mortensen, 2011; Arana et al., 2007). A sales configurator aims to collect and clarify customer requirements, in terms of functions and technical characteristics, into a product solution within a company's solution space. It supports the customer or the company's sales staff, depending on the configurator is meant for internal or external use (Blecker et al., 2004), by presenting available options within a company's solution space (Forza & Salvador, 2006). Sales configurators can be divided into two; sales configurator and lead generator. The sales configurator generates a product description and a price quotation, which can be used for order fulfillment. Whereas the lead configurator aims to capture the customer so that the company can follow up in other ways.

Engineering configurators
Forza and Salvador (2006) refers to configuring products during the order acquisition pro-

cess as the technical configuration process. Other authors refer to the technical configuration process as engineering configuration, low-level design, and product configuration (Zhang, Vareilles, & Aldanondo, 2013; Haug, Hvam, & Mortensen, 2011; Arana et al., 2007). The technical configuration process focuses on engineering activities and generates the final product variant description and its product documents. The engineering configurator translates the sales configurator's output into a full set of the technical specifications necessary for manufacturing the specific variant (Arana et al., 2007).

2.2.3 Product configurator solution space

The company's solution space, also referred to as product space and product offer (Trentin, Perin, & Forza, 2014), is what the company is potentially ready to offer (Forza & Salvador, 2006). Thus, the solution space consists of all product variants. For ETO companies, where the product is designed and engineered for a specific customer order, the number of possible unique product variants is more or less infinite (Haug, Hvam, & Mortensen, 2013).

In the context of building a PC system, it is necessary to define the PC solution space. The PC solution space describes the different variants the PC can produce by defining a predefined set of modules that can be combined in different ways (T. Petersen, 2007). In addition, the relationships between the components and the constraints and incompatibilities of the different solutions must be defined (Forza & Salvador, 2006). Parameterization of the components allows the PC to execute dimensioning tasks such as adaptions of lengths and angles of a component. In this way, the solution space does not describe all variants, but the rules of generating them (Frank et al., 2014). Often, the solution space of the product families in focus is too extensive to be implemented into a PC (Hvam, Mortensen, & Riis, 2008). Thus, it is necessary to reduce the variety of parts in a product family and push customers towards choosing more similar modules and components. In return, this work can produce benefits, such as less component management and reduced item costs through larger purchase quantities (Haug, Shafiee, & Hvam, 2019a; Haug, Hvam, & Mortensen, 2013). However, if the PC only supports a small part of the company's solution space, it does not become the norm to use it when specifying products. In other words, it must support a certain amount of variety for it to be useful. The relationship between the company, the PC solution space, and the product instances is illustrated in Figure 5.

A widely used method for determining and modeling the PC solution space is the Product Variant Master (PVM) technique (described in Section 2.2.5) (Hvam, Mortensen, & Riis, 2008; T. Petersen, 2007), which describe the possible attributes, product structure, and dependencies. Analyzing the product for determining the solution space can be done in a bottom-up or top-down manner (Forza & Salvador, 2006). The top-down strategy is typically more conceptual and hence used for projects of high complexity. The whole system is divided into a few main components and then into smaller components until a satisfactory understanding is gained. The bottom-up strategy is normally more detailed at the product level and more suitable for relatively smaller projects with lower complexity levels. The smallest parts and components are examined first and then combined into larger components or parts until a satisfactory understanding is achieved (Shafiee,

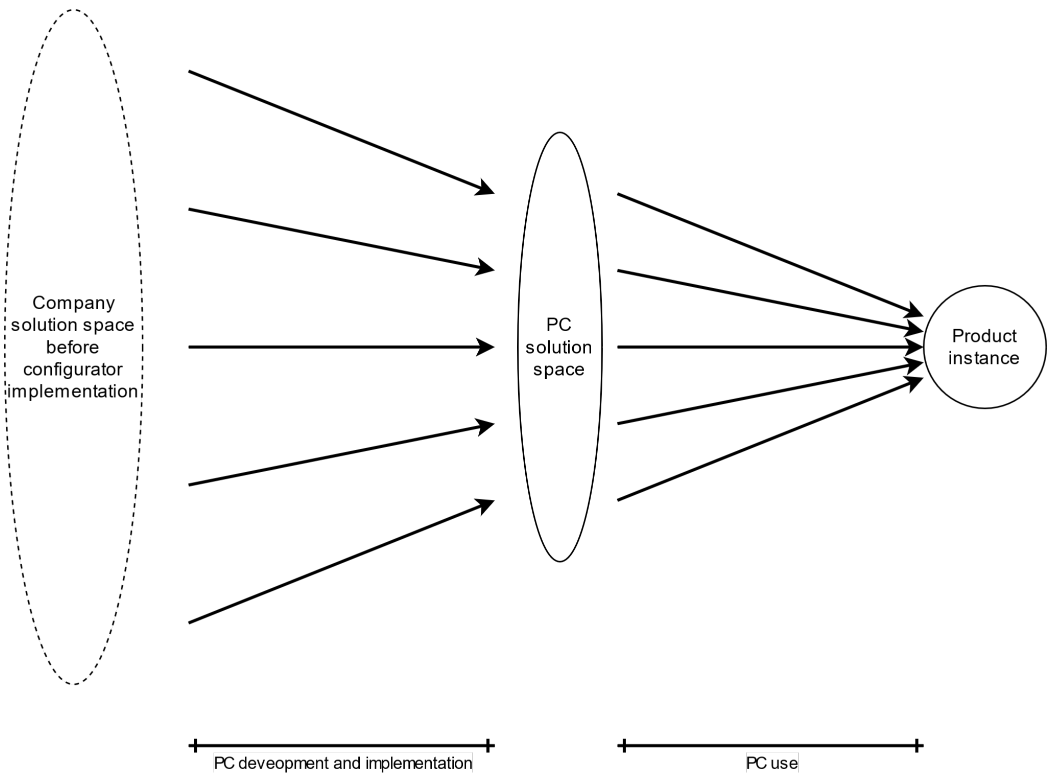

Figure 5: Solution space, adapted from Shafiee, Haug, et al. (2020)

Piroozfar, et al., 2020; Kudsk, Hvam, et al., 2013). However, the two strategies can be used in conjunction, using the top-down approach to obtain an overview and find areas. These areas are then studied using a bottom-up approach (Kudsk, O'Brien Grønvold, et al., 2013).

Partial configuration

For ETO companies with an infinite solution space, defining some limits of the PC solution space within which most customers' specific needs can be met is highly challenging. They need to eliminate particular components, modules, or construction principles while predicting the consequences concerning future customer requirements (Haug, Ladeby, & Edwards, 2009). Additionally, this activity is also a challenge because the PC affects the core processes of ETO companies, i.e., sales, engineering, and manufacturing. Forza and Salvador (2002a) and T. Petersen (2007) argue that solutions outside the PC solution space are required to a large extent because customers may specify product characteristics that can be highly unpredictable. As is illustrated in Figure 5, the company's solution space can be greatly limited if only solutions supported by the PC is allowed. Moreover, since a complete design of the ETO product cannot be determined at the time of the sales agreement, companies should aim at partial configuration (Hvam, Mortensen, & Riis, 2008; T. Petersen, 2007; Forza & Salvador, 2006). Partial configuration means having parts of the product design determined by the PC and leave the other parts for manual engineering.

2.2.4 Product configurator projects

A PC project, whether the PC is a sales configurator or an engineering configurator, is composed of various steps, like any IT system (Cannas et al., 2020). Haug, Shafiee, and Hvam (2019a) identified five distinct phases in a PC project: (i) configuration scoping (ii) configurator specification (iii) configurator development (iv) organisational implementation (v) operation and maintenance. The authors note that the different phases may be carried out simultaneously or in an iterative manner (Haug, Shafiee, & Hvam, 2019a).

The first phase concerns relevant decision-makers defining the scope of the project. Throughout the project's course, the initial scope may be redefined and adjusted as more experience is gained. This phase clarifies the project's knowledge requirements. It establishes a common understanding of the PC system to be developed and project goals, outputs, and objectives, which is necessary before knowledge modeling (Shafiee, Kristjansdottir, Hvam, & Forza, 2018; Shafiee, Hvam, & Bonev, 2014; Hvam, Mortensen, & Riis, 2008). The second phase includes both knowledge acquisition and PC design. Relevant product information is gathered from domain experts and system requirements from future users to develop the PC's knowledge base. In PC projects, two diagramming techniques are frequently used to represent product information, namely the PVM technique (see Section 2.2.5), and class diagrams. The purpose of such models is to make the engineer's technical knowledge explicit to the rest of the organization (Hvam, Malis, Hansen, et al., 2004). This information is formalized into configurator logic (PC decision flow and configuration rules), before being implemented into the PC software. In the third phase, the company has two basic options about the PC software; use a PC software shell or code the PC from scratch (Haug, Hvam, & Mortensen, 2012). Using a PC software shell is often an easier and faster approach, but the company is limited to the software shell's functions and looks. The fourth phase, organizational implementation, is concerned with informing relevant parties to ensure that users are adequately motivated to use the system. Researchers highlight the importance of involving the system's users from the beginning of the project for successful implementation (Hvam, Mortensen, & Riis, 2008; Forza & Salvador, 2006). This phase also includes teaching future users how to use the PC. The PC is in operation in the final phase and involves continuously updating information and further developing and maintaining the PC. The more details, the more need for documentation, and the maintenance effort increases (Shafiee, Hvam, & Bonev, 2014). Studies have shown that companies often become unable to use the PCs without proper documentation and have had to abandon or rebuild them (Shafiee, Kristjansdottir, Hvam, & Forza, 2018; Haug, Ladeby, & Edwards, 2009).

There are some differences between general software development and PC projects, mainly related to the knowledge complexity (Shafiee, Wautelet, et al., 2020; Shafiee, Kristjansdottir, Hvam, & Forza, 2018). The knowledge diversity and complexity make scoping of the PC and communication of product knowledge between the configuration team and the product experts challenging. This means that, compared to general IT projects, knowledge in PC projects must be formalized and communicated very differently, such as with the use of PVM (see Section 2.2.5). Moreover, PC projects need specific comprehensive documentation and maintenance of the knowledge (Hvam, Mortensen, & Riis, 2008). The knowledge must be clear and understandable to all stakeholders in a non-IT-language. Since product knowledge is incorporated in the system, changes to the product require updating and maintaining the knowledge in the system. In contrast, most IT other projects are not required to work with complicated product knowledge, and the documentation is often merely a summary of the code (Shafiee, Kristjansdottir, Hvam, & Forza, 2018).

2.2.5 Product configurator development

There are several different ways to carry out the project of developing a PC. The chosen approach will impact cost, development time, and the quality of the PC (Shafiee, Kristjansdottir, & Hvam, 2016; Haug, Hvam, & Mortensen, 2012). In addition, a PC project requires consideration regarding process reengineering and organizational change management. Some strategies deal with such issues to varying extents.

Studies in the field of PCs have proposed frameworks to guide the development of PCs. Haug, Hvam, and Mortensen (2012) defined strategies for PCs in ETO companies by focusing on the involvement of different domain experts in the different processes of a PC project.

Shafiee, Hvam, and Bonev (2014) propose a framework for scoping PC projects in ETO companies. The framework helps to identify the following at the beginning of a PC project:

- Aims and purpose of the PC system and overall process flow
- The identification of stakeholders and their requirements
- IT-architecture: including decision and information flow in the PC system, user interface (UI), input, output, integrations, and main functionalities of the PC system
- Product and product features to include in the configuration system, including the level of detail
- A project plan including resources, time table, modeling approach, test and development, system maintenance, etc.

Felfernig, Friedrich, and Jannach (2001) propose a development strategy based on the standard Unified Modelling Language (UML) design language to develop and cope with the increasing complexity of the knowledge base. The strategy defines the three main components of the configuration environment: knowledge acquisition, configuration, and reconfiguration, and focus on the system's design.

Forza and Salvador (2006) gives a structured approach to the implementation of a product configuration system and provide an overall five-phase reference process consisting of a logical sequence of activities. Forza and Salvador (2006) point out three key activities when implementing a PC:

- Analyze the benefits of a PC and contrast them with its costs
- Plan for PC implementation

- Execute implementation activities following the best implementation practices

However, they do not detail product modeling techniques and strategies of knowledge representation and information transfers.

Shafiee, Haug, et al. (2020) investigate the application of design thinking to support the development of PCs. They provide a design thinking framework illustrating how methods and techniques can be integrated into PC projects. The authors specify that the design thinking approach is novel for PC projects and requires further investigation by future research.

Hvam, Mortensen, and Riis (2008) provides a seven-step procedure for developing and implementing a PC, also known as the Center Product Modelling (CPM) procedure. The procedure starts with a business process analysis and ends in a configurator maintenance phase, and includes techniques and tools for each phase. The procedure builds on theories and methods from several different technical areas, such as the object-oriented project life cycle model, MC, and modularization of products. Hvam, Mortensen, and Riis (2008) suggest a tool called PVM for modeling and visualizing the product range during development and Class-responsibility-collaboration (CRC) cards for additional information. Both the procedure and the PVM are widely used in the configurator literature (Kristjansdottir, Shafiee, & Hvam, 2016; Mortensen, Hvam, & Haug, 2010). The PVM consists of two parts, the generic "part-of" structure on the left-hand side and the generic "kind-of" structure on the right-hand side. Figure 6 illustrates the PVM for a toy car. The left side shows the modules or components included in the entire product family, marked with a circle. Each circle is class, defined by the object-oriented paradigm, with unique names and can include attributes and constraints that describe their properties. The other side describes how the product part can appear in different variants.

Shafiee, Wautelet, et al. (2020) investigate the application of the agile development approach Scrum, which is presented in the next section, together with an overview of agile development approaches that are highly used in other software development projects.

Agile development approach in PC projects

Agile software development approaches have become more popular in recent years (Paetsch, Eberlein, & Maurer, 2003). The Agile Manifesto outlines the values and principles that should be supported by the various agile processes applied in software development (Fowler, Highsmith, et al., 2001). Agile principles emphasize customer satisfaction, change, and collaboration between domain experts and developers (Paetsch, Eberlein, & Maurer, 2003). Agile methods are adaptive and iterative. The more traditional software development approaches are predictive, such as the waterfall, where everything is documented upfront and then moved through stages until the product was finally ready. There are several different agile methods, such as Extreme Programming, Scrum, The Crystal Methodologies, and Feature Driven Development.

A core feature of the agile development methods is the design sprint (Banfield, Lombardo, & Wax, 2015), where the development work is divided into small sprints to minimize the amount of up-front planning and design. Sprints have short time frames and typically last from one to four weeks. Each iteration involves a cross-functional team working in all functions: planning, analysis, design, coding, and testing (Schwaber & Beedle, 2002).

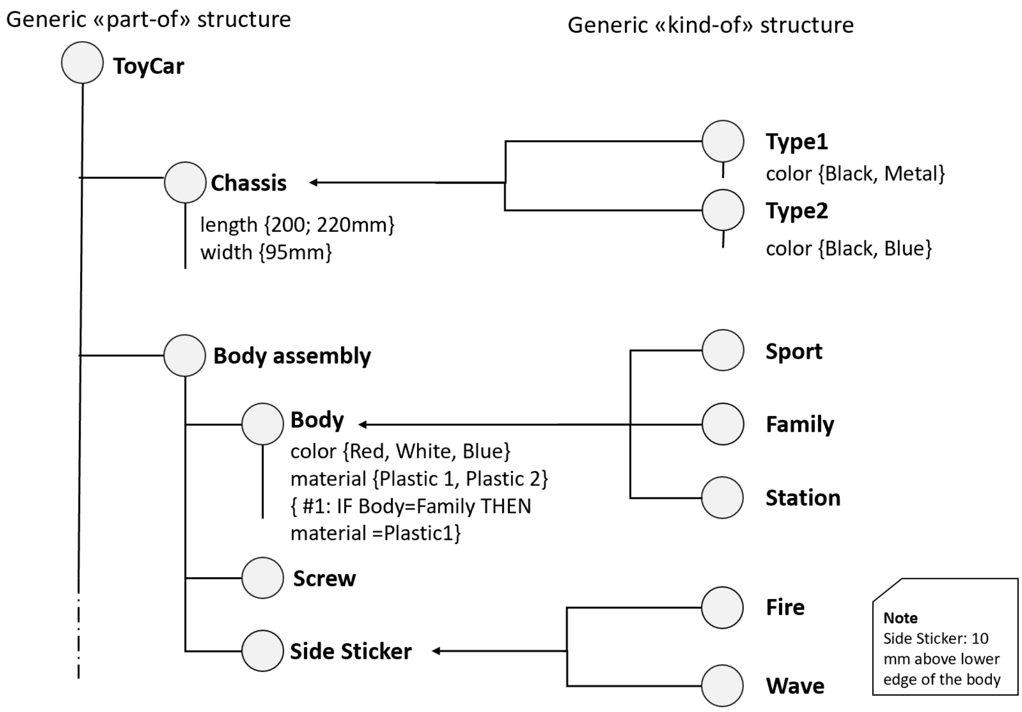

Figure 6: Product Variant Master (Haug, Hvam, & Mortensen, 2009)

As an outspring from agile development methods, Google Venture developed *The Design Sprint*, a flexible product design framework (Knapp, Zeratsky, & Kowitz, 2016; Banfield, Lombardo, & Wax, 2015). The design sprint is a five-day process for answering business questions through design, prototyping, and testing ideas with customers. The sprint's idea is to short-cut the debate cycle and to compress months of development into a single week. Instead of using resources to launch a minimal product to understand if the solution is good, companies applying the spring get clear data from a realistic prototype within a week (Knapp, Zeratsky, & Kowitz, 2016). A design sprint can be used to initiate a change in process or start the innovation of a new product to explore opportunities. For enterprises, a design sprint can reduce resource investments to explore an idea and concepts (Banfield, Lombardo, & Wax, 2015). The literature provides evidence for the successful application of design sprints to tackle complex software systems, such as developing cyber-technical systems (Wagner, 2014).

The greatest difference with the CPM procedure, which is built on the spiral model, compared with agile methods, is that CPM is managed in an end-to-end fashion. Each iteration and phase are predetermined (in number and length) during the earliest stages of the project (Shafiee, Wautelet, et al., 2020). A typical iteration will be somewhere between 6 months and 2 years. It will include all aspects of the lifecycle, including requirement analysis, planning, design, and architecture, and then a release of either a prototype or working software (Hvam, Mortensen, & Riis, 2008). These steps are repeated until the project is either ended or finished. In contrast, agile methods determine the scope of the iteration at the end of the previous one. Moreover, the CPM procedure covers the entire development life cycle with defined roles, activities, and supporting tools, whereas Scrum only defines roles, management principles, and basic requirements artifacts (Ambler, 2002).

There is little knowledge in the configurator literature concerning agile methods in PC projects (Shafiee, Wautelet, et al., 2020). As described in Section 2.2.4, there are several differences between PC projects and other software development projects. Since PC projects are of great complexity and can be unpredictable, the project requires flexibility in the development process for it to be able to respond to the changes, which agile methods present. Shafiee, Wautelet, et al. (2020) illustrated the application of the rational unified process (RUP), an iterative and incremental software development framework, and Scrum, and compared their contributions to addressing the PC development challenges. The study took place at a large ETO manufacturing company and showed that moving to Scrum positively affected the organizational, IT-related, and resource constraint challenges. However, Scrum lacks in the areas of documentation and visualization of PC system knowledge. Shafiee, Wautelet, et al. (2020) suggest the possibility of integrating PVM into Scrum to bypass this shortcoming. They further state that future studies in different research settings are necessary to validate the results and identify relevant contingencies.

2.2.6 Product configurators for ETO products

PCs in ETO have been addressed in the configurator literature, including successful and failed projects. The level of detail concerning the development strategy that the academic journals provide is highly variable. More specifically, most cases do not go into details about the specific activities for development and implementation. Table 2 summarizes the cases of PCs in ETO found in the configurator literature during the literature review and specifies the development approach if it is described. The numbering of the table is used for reference in the following sections.

[1] T. Petersen (2007) describes the case of Aalborg Industries, which makes steam and heat-generating equipment for maritime and industrial applications. The company successfully implemented a sales configurator by gradually implementing one or two product families at a time. T. D. Petersen (2007) described the difficulties with predicting the requested variety, thereby developing a PC system encompassing all the products.

[2] Shafiee, Hvam, and Bonev (2014) presents a framework for scoping PCs in ETO companies and validates the framework at a company specialized in the production of heterogeneous catalysts and the design of process plants based on catalytic processes. The framework was used as a checklist of issues to clarify in the initial phase of the project. The case company wanted to introduce a sales configurator to reduce the lead time for generating quotations. They used PVM as the modeling approach and used a component-based structure, and compared various component information to give a sense of the components' importance regarding different aspects. However, the article does not specify whether the implementation was successful. Later, Shafiee, Wautelet, et al. (2020) discusses the use of Scrum vs. RUP in the development phase in the same case company. For the RUP development project, the case company applied use case diagrams, AS-IS and TO-BE flowcharts, PVM, class diagrams, and CRC-cards, corresponding to the tools suggested in the CPM procedure. For the Scrum development project, the company used sprint tools such as backlogs, task prioritization, and user stories. However, the research does not describe how technical aspects or how the company used the abovementioned

tools. The authors specify that the company had already successfully implemented sales configurators.

[3] Arana et al. (2007) presents a practical case of implementing a sales configurator at a lift-manufacturing company. The sales configurator provides certain elements that serve as the basis for the project's development, based on the customer's initial requirements. Arana et al. (2007) described the modeling of the product's functional and technological view. The company described the product through functional parameters with associated attributes, domains, and constraints. The technological view takes into account the different modules that comprise the product to a high-level design. The case company's development process is based on a system developed by the IKERLAN Technological Research Centre, and the implementation was successful.

[4] The case of FLSmidth gives the most comprehensive description of the development and implementation process at an ETO company. FLSmidth is a large manufacturer of cement plants and has applied sales configurators with great success. Hvam, Malis, Hansen, et al. (2004), Hvam (2006b), and Hvam, Mortensen, and Riis (2008) provide a detailed description of the application of the CPM procedure, while Felfernig et al. (2014) documents the integration of a Tacton configurator with various other systems such as CAD programs and ERP systems. Tacton is a software vendor that delivers PC solutions.

[5] Haug, Hvam, and Mortensen (2013) proposes a procedure for reducing product solution space using PVM and carried it out at Novenco. This company develops and manufactures heating, ventilation, air-conditioning, and refrigeration solutions for land and marine applications. The research paper documents that Novenco has already successfully implemented a sales configurator but does not elaborate on the development and implementation strategy, other than the use of PVM.

[6] Shafiee, Hvam, and Piroozfar (2019) describes a company implementing a web-based PC to reduce time and resources for sales and after-sales processes. The company provides specialized solutions within marine tank management for marine and offshore industries. The study focuses on using ABC analysis to estimate the importance of the products sold at the after-sales department to identify the most profitable product to include in the PC solution space. However, the article does not specify whether the company has successfully implemented a sales configurator.

[7-12] A study conducted by Haug, Shafiee, and Hvam (2019a) focuses on a set of case studies that failed in implementing a PC. The authors identify the possible causes of these failures and convert these causes into a set of guidelines to prevent future failures in the different phases of a PC project in ETO companies. The research was limited to PCs aimed at internal users and the application of standard PC software shells. Thus, the research provides few technical details concerning the development. An important finding in the research was that many of the issues found in the failed PC implementation projects were related to the initial scoping phase and demonstrated that ETO companies must be ready for a profound change of their organization, processes, and products.

[13] Forza and Salvador (2002b) describes the product modeling challenges when developing a sales configurator for a small manufacturing company making mold-based for plastic molding and punching-based for metal sheet punching. High product variety re-

sulted in a complex product model and caused project delays. The paper suggests that the sales configurator's effect propagates to parts of the company not directly involved in the implementation, such as the production department.

[14] In another study, Forza and Salvador (2002a) describes the main challenges of implementing a sales configurator in a small manufacturing company delivering voltage transformers. The implementation was successful, but the company did not implement the most complex products because of considerable time and resource requirements. The company used a commercial configurator; thus, the article does not provide details about the development.

[15-17] Willner, Gosling, and Schönsleben (2016) establish a maturity model for design automation in ETO companies by using a selection of ETO companies. The case companies have successfully implemented a sales configurator to generate quotation documents. They all report that it was necessary to standardize the product structure and have pre-engineered solutions in the PC—however, neither elaborate on the strategy to get there.

[18,19] Mortensen, Hvam, and Haug (2010) presents two ETO companies that have successfully applied the PVM and CRC-cards for modeling product families for PC systems. Both companies initiated a project on developing a PC system to be used in the early sales phase for making budget quotations. The case study at the first company proved that using the three views in the PVM can be useful when modeling complex products. For the second company, only the whole part structure on the right side of the PVM was applied.

[20] Hvam (2004) describe the use of the CPM procedure at Demex-electric, a Danish manufacturer of electronic switchboards, to build a PC with automatic dimensioning and the specification of complex switchboards. The article provides no insight into challenges with the PC project.

Case number	Number of employees	Product type	Project Result	Development approach
1	1683	Marine boiler plants for ships	Success	Gradually implementing one product family at the time. Few details.
2	N/A	Catalyst and process plants	N/A	RUP with the use of tools suggested in CPM and Scrum with sprint documents.
3	N/A	Elevator	Success	Technical and functional view of product model and IKERLAN development process.
4	110000	Cement productions plants and heavy machinery equipment	Success	The CPM procedure.
5	650	Heating, ventilation and AC for land and marine applications	Success	PVM
6	N/A	Marine tank management for marine and offshore industries	N/A	Use of ABC to define the PC solution space.
7	15000	Building contractor	Failure	N/A
8	100	Moulding modules	Failure	N/A
9	8000	Flow control equipment	Failure	N/A
10	3000	Chemical process system	Failure	N/A
11	100	Industrial electronic products	Failure	N/A
12	2000	Electronic components for industrial use	Failure	N/A
13	45	Mould bases and punching bases	Success	N/A
14	N/A	Voltage transformers	Success	N/A
15	160	Turbo machine	Success	N/A
16	N/A	Asphalt mixing plant	Success	N/A
17	250	High-rise elevator	Success	N/A
18	N/A	Cement plant	Success	Use of PVM and CRC-cards for product analysis
19	N/A	Spray drying plants	Success	Use of PVM and CRC-cards for product analysis
20	100	Electronic switchboards	Success	The CPM procedure

Table 2: ETO cases in the literature

Benefits
Various benefits of the use of PCs for ETO products have been reported in the literature. They can generally be grouped into four categories: (1) time reduction, (2) costs reduction, (3) quality improvement, and (4) sales increase (Cannas et al., 2020; Haug, Shafiee, & Hvam, 2019b).

Time and cost reduction
Time reduction, meaning reduction of man-hours, and shorter lead times of quotations or deliveries, is often reported. For example, Forza and Salvador (2002b) showed a reduction in activities in the quotation generation from 5 to 6 days to 1 day in a manufacturer of molding-bases for plastics and punching-bases for metals by implementing a sales configurator. Hvam, Malis, Hansen, et al. (2004) demonstrated drastic improvements in lead time for quotation generation (reduced from 15 to 25 days to 1–2 days) and time spent on engineering tasks in this process (reduced from 5 weeks to 1–2 days) in the processing plant manufacturer FLSmidth. Similar findings has been reported in several other cases (Forza & Salvador, 2006; Hvam, 2006a, 2006b) but perhaps the most notable are the studies by Hvam et al. (2013) and Haug, Hvam, and Mortensen (2011). These were both multiple case studies that showed the average lead time for offers were reduced by 94–99%, a reduction in resource usage for the generation of product specifications with 50–95%, the average time spent making offers reduced by 85.5%, the average number of man-hours used in the configuration process reduced by 78.8%, respectively. Hvam et al. (2013) also showed that engineering costs could be reduced because all needed information can be collected via the PC system.

Quality
An increase in quality of solutions, products, and product specifications has been demonstrated in several cases. It has been speculated that this is because fewer ad-hoc solutions are used, products are improved incrementally, more standardized and exact calculation methods, and a reduced need for communication occurs when PCs are used in ETO companies (Cannas et al., 2020; Haug, Shafiee, & Hvam, 2019b; Trentin, Perin, & Forza, 2014, 2012). Hvam et al. (2013) showed an increase in the quality of specifications made during the order acquisition phase and an increase in the quality of the final solutions sold. Some case studies have reported increased accuracy of product specifications, Yu and Skovgaard (1998) reported a case where the accuracy was increased to 100%, and Sviokla (1990) showed an increase from 65-90% to 95–98%. Additionally, errors in specification has also been reported as decreased (Forza & Salvador, 2002a, 2002b) along with errors in assembly (Hvam, 2006a) from the use of PCs. Trentin, Perin, and Forza (2012) argues that with a PC, designers and engineers can devote more time to value-added activities, such as developing new products or resolving existing quality problems.

Sales increase
By making quotation generation faster, companies can respond to more requests from customers when using PCs, resulting in higher sales (Hvam et al., 2013; Heiskala et al., 2007; Hvam, 2006b; Heatley, Agarwal, & Tanniru, 1995).

Challenges
While there are many reports of the benefits of PCSs in ETO, there are fewer describing the challenges involved. Many of the challenges are found in the literature are present in all PC projects, while some are more specifically for ETO products.

As noted by Cannas et al. (2020), challenges for PCs are typically related to complex IT systems implementation, but also organizational changes, since the roles and tasks of the employees may be changed. Often the scope of the PC may be too large and unclear (Shafiee, Kristjansdottir, Hvam, & Forza, 2018). Haug, Shafiee, and Hvam (2019b) specifies that the scope often can involve inaccessible product knowledge, unsuitable software shell, not being in line with organizational wants and needs, and lack of adequate maintenance procedures. This may result in unrealistic estimated costs and benefits, which has been reported as an indirect cause of project failures (Haug, Shafiee, & Hvam, 2019a).

The high technological complexity of PCs may lead to additional organizational problems. More precisely, a major organizational issue is that employees may be resistant to the introduction of the PC and the lack of support from management (Kristjansdottir et al., 2018; Haug, Hvam, & Mortensen, 2012). PCs can be viewed as a threat to employees because they fear the system will replace them, and lack of sufficient training in using the PCs cause resistance towards the PC system (Zhang et al., 2015).

Cannas et al. (2020) stress that companies must alter their product design and the sales and engineering processes to enable a PC for ETO products. Without adapting the product and processes, the company risks implementing a PC that may be unstable or even counter-productive. In the case study conducted by Cannas et al. (2020), one case company reported the following: *"Usually, in our industry, companies start developing products only when there is a customer's order... This makes the engineering and production processes very expensive...Therefore, we need to move towards design concepts that are different from the past, and which make the engineering and production process less expensive and allow us to acquire benefits from the product configurator"*. However, the job of (re)designing the product and processes are highly complicated and expensive because of high product complexity and wide product variations, and thus requires extensive engineering to (re)design (Cannas et al., 2020; Christensen & Brunoe, 2017; Kristjansdottir, Shafiee, & Hvam, 2016). Companies have to consider several factors that can affect the redesign, such as product characteristics are gradually determined over time, long order horizons increase product demand mix uncertainties, different customized variants for different customers, PCs drive supply chain activities, and solutions outside the PC solution space are required to a large extent.

Knowledge acquisition is also frequently considered a challenge in PC projects (Kristjansdottir, Shafiee, & Hvam, 2016; Shafiee, Hvam, & Bonev, 2014). In the early phases of the project, it is difficult to identify and retrieve the right information (Shafiee, Hvam, & Bonev, 2014). Much time and resources are spent on gathering irrelevant additional information and asking questions due to misunderstandings. Moreover, difficulties communicating with domain experts are often reported (Zhang et al., 2015). Transforming product knowledge into a product model to be implemented in the PC presents additional challenges. If the product model does not accurately present the product, the PC's output will contain errors (Kristjansdottir, Shafiee, & Hvam, 2016). A lack of overview of the product range may present difficulties when formalizing the configurator logic and model. Finally, unfamiliarity with product modeling is a challenge when building a model correctly that can be transferred into the PC (Cannas et al., 2020; Kristjansdottir, Shafiee, & Hvam, 2016).

The challenges related to the technical aspects of developing and implementing a PC and integrating the PC with other IT systems are similar to challenges faced in more general IT system development projects (Kristjansdottir et al., 2018). However, these activities require technical experts, which the company may lack (Kristjansdottir et al., 2018; Zhang et al., 2015; Haug, Hvam, & Mortensen, 2012). This may lead to an additional challenge during product modeling since the IT system designer needs access to product experts, and they may not be able to communicate well.

A central challenge in the operation and maintenance phase is that the PCs may require high maintenance costs (Haug, Shafiee, & Hvam, 2019b; Kristjansdottir et al., 2018; Heiskala et al., 2007). Maintaining the PC includes introducing updated product models, extending the updates to the entire organization, and checking the PC knowledge's correctness after such updates, which may require additional configuration-specific expertise (Heiskala et al., 2007). If it lacks an overview of what has been implemented in the PC due to the complexity (Haug, Hvam, & Mortensen, 2012), the maintenance phase becomes very resource demanding.

2.2.7 Relationship between industry and academia

A recurring topic in the discussions during the 22nd International Configurator Workshop was the gap between industry and academia (Workshop proceedings: Forza, Hvam, and Felfernig (2020)). In the configurator literature, few research papers show how real-world problems are solved.

There are several software vendors on the market that deliver solutions for ETO companies, such as Tacton and Configit. Moreover, in 2007, The Configurator Database Project was established to give an overview of the world of web-based customization tools. The database is updated with new PC solutions continuously and is the biggest online collection of PCs with more than 1200 entries listed and categorized in 17 different industries (www.configurator-database.com/about).

After discussions with an industry expert, the following insight was obtained: PC technology can be viewed as a system that handles the company's intellectual property and stands for an important share of the company's value creation. Implementing such a system requires significant resources, but in return, it contributes to the company's competitive advantage. ETO companies tend to be unwilling to share information about what they are doing with anyone outside of their company, even scientific advisors from academia. This results in academia not knowing the presence of PCs in ETO, and it is difficult to obtain insight into how challenges are solved.

In the market, several software vendors provide both consulting and systems to ETO companies. However, non of these companies share their technology nor development methods. Consequently, the research will lag behind the current business practices, and few commercial cases with used modeling mechanisms will be available.

2.3 Literature summary

As a result of the literature study, an understanding of the challenges involved when developing PCs for ETO is obtained, which is necessary for developing more suitable methods and tools (Haug, Shafiee, & Hvam, 2019a). The application of product configurators for ETO products is not a new phenomenon. Several studies report on the benefits that ETO companies can achieve with a PC. However, the configurator literature provides few detailed cases of the development of PCs for ETO products and the challenges, which may result from the separation between industry and academia described in section 2.2.7.

Challenges
PCs project differs from traditional software development projects, mainly because of the knowledge complexity and diversity. Developing a PC for ETO products presents additional challenges due to their unique characteristics. Table 3 summarizes the challenges related to PC development, not all specific to ETO products. ETO products are characterized as complex and with a high degree of customization, resulting in an infinite solution space. Thus, defining some limits of the PC solution space without losing the flexibility of meeting customer requirements is highly challenging (Cannas et al., 2020; Duchi et al., 2014; Haug, Ladeby, & Edwards, 2009). Solutions outside the PC solution space are thus necessary, and companies should therefore aim at partial configuration (Hvam, Mortensen, & Riis, 2008; T. Petersen, 2007; Forza & Salvador, 2006). This often requires redesigning and standardization of the products and processes involved, and companies have to consider changing customer requirements and new technologies that may require frequent updates and maintenance.

Challenges related to knowledge acquisition and modeling are often reported in the literature (Kristjansdottir, Shafiee, & Hvam, 2016; Shafiee, Hvam, & Bonev, 2014). In the early phases of the project, it is difficult to identify and retrieve the right information to meet users' and customers' needs. Much time and resources are spent on gathering irrelevant additional information and asking questions due to misunderstandings. This is often a result of communication difficulties between the configuration team and product experts.

The literature review revealed that the literature is scarce on specific challenges for ETO products. Some research has indicated various challenges concerning the development and implementation of PCs for ETO products and analyzed the relation between the specific challenges and managing those successfully. Kristjansdottir, Shafiee, and Hvam (2016) and Cannas et al. (2020) suggest that more research should be devoted to eliminating or reducing the impact of the challenges presented by the ETO characteristics. This indicates that the existing knowledge of PCs is insufficient when developing PCs for ETO.

Main activities in PC development
Five main activities in the development of PCs for ETO products can be extracted from the literature. A summary is given in Table 4. Shafiee, Hvam, and Bonev (2014) emphasize the importance of scoping the PC early in the project for ETO products and propose five elements that should be included. This is also supported in the first phase of the CPM procedure and the procedure by Forza and Salvador (2006). Scoping contributes to a clear understanding of the aim and purpose, and functionalities of the PC and sets the

stage for the next activities. Both Hvam, Mortensen, and Riis (2008) and Shafiee, Hvam, and Bonev (2014) suggest that for products with high complexity, the scoping should happen in parallel or within the same iteration as the product analysis.

Product analysis includes identifying priorities among the different product families to identify candidate families for the PC. Cannas et al. (2020) recognize including the product variants and families with expected high demand is necessary as the volume will influence the number of products the costs are divided by, thus the PC's profitability. Already at this step, decisions regarding the PC solution space is made.

Product modeling includes defining the product incorporated in the PC and thus defining the PC solution space. As described above, product modeling is one of the most reported challenges, but a considerable amount of research is devoted to these challenges (Kristjansdottir, Shafiee, & Hvam, 2016). The PVM tool is the most used modeling tool applied in the literature, and several ETO companies have applied PVM with a top-down approach (as can be seen in Table 2).

Developing configurator logic includes defining the PC's decision flow and the configuration rules incorporated in the PC, which are independent of the PC software (Haug, Shafiee, & Hvam, 2019a; Hvam, Mortensen, & Riis, 2008; Felfernig, Friedrich, & Jannach, 2001). This activity is also referred to as the configurator design in the configurator literature (Haug, Shafiee, & Hvam, 2019a)

Developing configurator software includes translating the configurator logic into programming code. The company can decide to use a software shell provided by configurator software vendors or develop the software in-house. Both Forza and Salvador (2006) and Hvam, Mortensen, and Riis (2008) describes the process of selection software vendor, while little focus is given to developing the system in-house.

Agile development
There is little knowledge in the configurator literature concerning the application of agile methods in PC projects. A recent study in the configurator literature investigates the advantages of the agile development method Scrum in complex PC projects (Shafiee, Wautelet, et al., 2020). Shafiee, Wautelet, et al. (2020) indicate that agile methods are more adaptive than other methods and face the challenges related to knowledge acquisition and communication. They further state that research is needed for investigating the integration of PVM into Scrum to bypass the lack of documentation and visualization. An agile development approach for PC development in this study can elaborate on Hvam, Mortensen, and Riis (2008), Shafiee, Wautelet, et al. (2020), Haug, Shafiee, and Hvam (2019a) and Shafiee, Hvam, and Bonev (2014) reflection on iterative activities. Combining ideas from agile development methods, especially the idea of sprints, and the existing development approaches in the configurator literature (Table 4) may help to overcome some of the challenges that ETO products present (Table 3).

Category	Challenge	Author (year)
IT-related	All technical challenges related to complex software development. Not user-friendly system design development.	Cannas et al. (2020), Kristjansdottir, Shafiee, and Hvam (2016)
Organizational	Lack of support from top management. Resistance to using the PC.	Zhang et al. (2015), Haug, Hvam, and Mortensen (2012), Kristjansdottir, Shafiee, and Hvam (2016)
Scoping	Disagreements between stakeholders. Unrealistic or unclear scope.	Shafiee, Hvam, and Bonev (2014), Shafiee, Kristjansdottir, Hvam, and Forza (2018), Cannas et al. (2020), Haug, Shafiee, and Hvam (2019a)
Resources	Lack of resources (time, money, experts etc.). High maintenance costs.	Kristjansdottir, Shafiee, and Hvam (2016), Shafiee, Hvam, and Bonev (2014), Cannas et al. (2020), Haug, Shafiee, and Hvam (2019b), Heiskala et al. (2007)
Product related	Product complexity. Continuous change in product offerings. Products may require redesign.	Cannas et al. (2020), Kristjansdottir, Shafiee, and Hvam (2016)
Knowledge acquisition	Difficult to acquire the right information. Communication difficulties between experts. Unnecessary information gathering and analysis.	Zhang et al. (2015), Shafiee, Hvam, and Bonev (2014), Shafiee, Kristjansdottir, Hvam, and Forza (2018), Kristjansdottir, Shafiee, and Hvam (2016)
Product modeling	Correctness of specification generated by the PC. Complexity due to lack of overview over product range. Lack of knowledge related to product modeling.	Cannas et al. (2020), Kristjansdottir, Shafiee, and Hvam (2016)

Table 3: Challenges adapted from Kristjansdottir et al. (2018)

Main activities	Reference
Scoping Aims and purpose of PC Business and standardization strategy Requirements and functionality Current situation and future scenario Structure of the PC Cost/benefit analysis Project plan	Hvam, Mortensen, and Riis (2008) Forza and Salvador (2006) Shafiee, Kristjansdottir, Hvam, and Forza (2018) Shafiee, Hvam, and Bonev (2014) Haug, Shafiee, and Hvam (2019a)
Product Analysis Information about product families, models and variants Identify product families/variants that are expected to have a large demand *Define solution space*	Forza and Salvador (2006) Haug, Ladeby, and Edwards (2009) Cannas et al. (2020) Hvam, Mortensen, and Riis (2008) Haug, Shafiee, and Hvam (2019b) T. Petersen (2007)
Product modeling PVM Top-down approach *Define solution space*	Hvam, Mortensen, and Riis (2008) Shafiee, Hvam, and Bonev (2014) T. Petersen (2007) Shafiee, Piroozfar, et al. (2020) Forza and Salvador (2006) Haug, Ladeby, and Edwards (2009)
Develop configurator logic Decision flow Configuration rules	Haug, Shafiee, and Hvam (2019a) Felfernig, Friedrich, and Jannach (2001) Hvam, Mortensen, and Riis (2008)
Develop configurator software Software selection or develop in-house	Forza and Salvador (2006) Hvam, Mortensen, and Riis (2008) Haug, Shafiee, and Hvam (2019a)

Table 4: Main activities of PC development

3 Methodology

Research methodology describes the way the research problem has been systematically approached. The methodology is a justification for using a particular research method(s), where the term method refers to data collection and analysis technique (Croom, 2010). The methodology is more an overall understanding of the research's nature and the research strategies used to meet the research objectives (Wacker, 1998). In the following sections, a presentation of the methodology is given, followed by the approach taken and the research methods.

In general, there are two types of research methodologies, qualitative and quantitative. The type of research determines the methods used, as well as the type of data that is collected. Quantitative research emphasizes quantification in the collection and analysis of data, and is based on statistical data, and deals with numbers. Qualitative research is more explanatory and descriptive and is appropriate when assessing problems that are difficult to quantify (Croom, 2010; Miles & Huberman, 1994). However, Croom (2010) points out that: "..qualitative approaches are not devoid of quantification. Numbers can be ascribed to subjective and 'qualitative' variables" (p.26).

Another important aspect of research is the method of reasoning, as it describes the relationship between theory and research. There are three sets of logic: deduction, induction, and abduction (Karlsson, 2010; Dubois & Gadde, 2002; Peirce, 1960), as illustrated in Figure 7. The deductive approach starts with a theory, and the researcher develops hypotheses from that theory. The hypotheses are then tested, often with quantitative data. The inductive approach starts with a set of empirical observations and works toward a theory by testing rules. Lastly, the abductive approach starts with the result or conclusion and then tests the rules to find out about the precondition (Karlsson, 2010; van Hoek et al., 2005). The nature and purpose of a study determine which approach is best suited. The inductive and abductive approach aims to develop theory and are more exploratory, while the deductive approach tests or evaluates this theory (van Hoek et al., 2005).

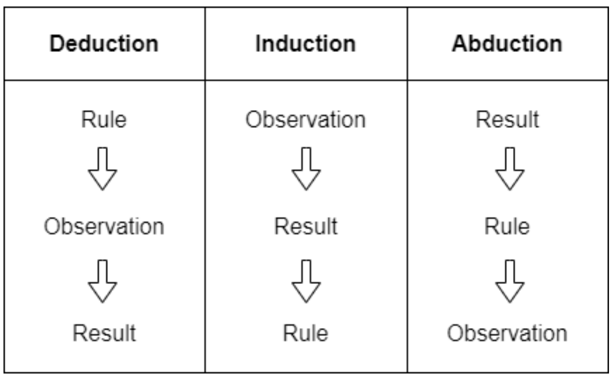

Figure 7: Deduction, induction and abduction (Karlsson, 2010)

3.1 Research design

The research design is the overall plan of how the research is conducted and presents how the research data is connected with the research purpose (Yin, 2014). Three main categories of research design that influence the research strategy and data collection can be identified in the literature: exploratory, descriptive, and explanatory (Yin, 2014; Karlsson, 2010). An exploratory design is appropriate when the problem description is not clear, and there is little to base the theoretical development. A descriptive design is appropriate when describing different variables and the interactions between the variables. This requires a better description of the field, and the research is based on hypotheses. The explanatory design is appropriate when understanding how one condition or variable will cause a certain effect. Although each design has its distinct characteristics, the different research designs overlap, and research work can include combinations of these approaches (Karlsson, 2010).

The purpose of this study is to help fill the research gaps regarding the challenges companies face when developing PCs for ETO products and provide knowledge to aid the development. As the literature is lacking, the research design in this study has been exploratory, not starting with a clear hypothesis. The literature review was carried out to obtain an overview of the existing knowledge and frame the research objectives and scope. It revealed that a an understanding of challenges during the development of PCs for ETO is lacking. Thus, an empirical investigation of developing PCs for ETO product is necessary, using a exploratory case study with the unit of analysis as project. Two case studies were planned, and carried out sequentially, in order to apply learings from the first case study in the second case study. Finally, the findings of the literature review and the case study research are discussed in relation to how to address the challenges that occur when developing PCs for ETO products. Hence, the research design is based on an approach combining existing literature and empirical observations. Given the exploratory and inductive nature of the research, it is most suitable, with a qualitative approach (Croom, 2010; Karlsson, 2010; Miles & Huberman, 1994).

Figure 8 illustrates the link between research activities and outcomes, with emphasis on the fact that most outcomes rely on several activities. As can be seen, for example, existing literature provided knowledge for most outcomes.

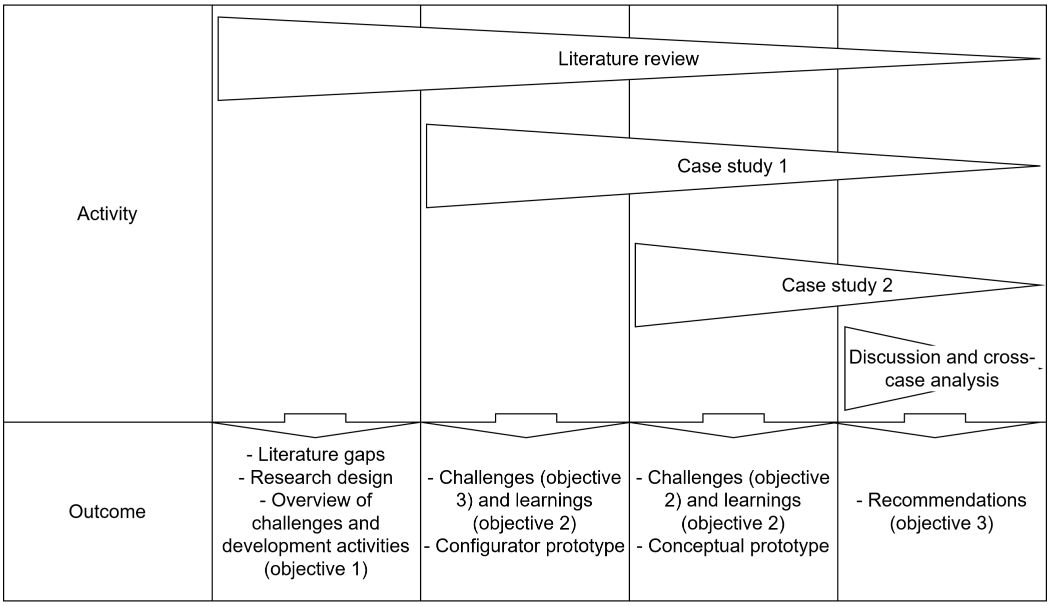

Figure 8: The link between research activities and outcomes

3.2 Literature review

A literature review is a fundamental part of any research (Croom, 2010). The literature review is carried out to map existing knowledge within the research topic and discuss the strengths and weaknesses. It contributes to the familiarization of the basic terms and concepts used in the field and understanding the fundamental interaction of concepts, such as ETO and product configurators. Findings of the literature review contribute to the process of identifying and clarifying the research topic and objectives (Croom, 2010), limit the scope (Yin, 2014), elect and justify the appropriate research methods, clarify the possible contribution of the proposed research, and meet objective one.

A structured search strategy was applied, including a primary set of keywords to define the main subject and secondary keywords to narrow the search and return more specific topics. The keywords are given in Table 5. More literature was needed during the empirical part of the research, and new search keywords were added accordingly. However, specific keywords that were not a part of the state-of-the art analysis are not included in the table. Literature was found using online databases such as Scopus, Web of Science, NTNU Oria, and Google Scholar and from supervisors and contact persons. For each research paper, the following information was extracted: keywords, a summary of key points, methodology, and cited references to follow up. Within the relevant papers, a forward and backward search was performed to detect additional materials. In addition to published literature, current research problems and ideas regarding product configurators were acquired from participating in the 22nd International Configuration Workshop (Forza, Hvam, & Felfernig, 2020).

Since the literature review is conducted over a longer period and revisited numerous times, a clear process for taking notes was established. Worksheets in the form of a table for mapping the literature in common fields and themes were used. It also allowed for comparison across various fields, for example, author and theme.

Primary keywords	Secondary keywords
ETO or engineer-to-Order	Characteristics Strategy Classification Customization Specification Tendering
Product configurator	Sales Knowledge management Documentation Solution Space Strategies Quotation ETO Scope Challenges

Table 5: Primary and secondary keywords

3.3 Case study research

This study's empirical foundation is based on case research that enables comparisons of different theories and observations from empirical data. Using the case research method increases the possibility of understanding the latent and non-obvious issues (Yin, 2014). According to Yin (2014), case research can be used for studying general phenomenons in a real-life context. A case study allows for direct observations of the events being studied and interviews of the persons involved, giving a full variety of evidence, such as documents, artifacts, interviews, and observations (Yin, 2014; Voss, Tsikriktsis, & Frohlich, 2002). The purpose of the research is to understand the complex, temporal processes of developing a PC for ETO products. Developing PCs for ETO products involves multiple participants and interacting sequences of events. Yin (2014) argues that case research is suited for answering "why" and "how" questions. The purpose of this study is to provide knowledge about the development of PCs for ETO products and the accompanying challenges. As this requires an in-depth understanding of the development, case research seemed appropriate. This understanding is difficult to obtain through interviews and surveys, as the researchers would lack the practical understanding to pose the right questions and would likely be unable to understand and interpret the answers. Therefore, the case studies were conducted as development projects where the researchers participated as configurator designers.

According to Yin (2014), a limitation with case research is that it provides little basis for scientific generalization since they use a small number of subjects, some conducted with only one subject. He further argues that case research is often accused of a lack of rigor: "Too many times, a case study researcher has been sloppy, has not followed systematic procedures, or has allowed equivocal evidence to influence the direction of the findings and conclusions" (Yin, 2014, p. 14). However, he justifies the academic value of case research;

the case study research takes its rigor from the fundamental and substantial difference in its knowledge claims, and that analytical generalization increases the validity of the research (Yin, 2014).

Using multiple cases for case research to replicate the findings can strengthen the validity and generalizability of the conclusions drawn (Yin, 2014). Thus, the case research for this thesis was conducted as a multiple case study. Two case studies in two case companies were conducted as this was the maximum number possible within the time restrictions. Each consisted of a "whole" study (Yin, 2014), in which a development project for a sales configurator prototype for each case company was conducted. Thus, the unit of analysis in this study is development project. This way, the researchers can explore challenges occurring in their natural setting and generate an understanding through observation and participation in actual practice to meet objective 2. The projects were examined and a cross-case analysis was performed to meet objective 3. The validity of the results is increased by having two case studies, where the case companies have different characteristics, see Table 6. In case study 1, the development of the prototype included all five main development activities found in the literature review (see Table 4 in Section 2.3) and was carried out over nine weeks. In case study 2, only a conceptual prototype (equal to the configurator logic) was developed because of time restrictions, as explained in Section 6.4. All main development activities except the "Develop configurator software" activity were carried out to develop the conceptual prototype. Case study 2 was conducted over two weeks.

The researchers had two criteria for selecting a case companies (1) The company manufactures ETO products, (2) Companies must have different design automation maturity level (Willner, Gosling, & Schönsleben, 2016). Criterion (2) aids in making the research contribution more generalizable to more situations.

The first case company contacted NTNU during the fall of 2019, interested in exploring the possibility of introducing a product configurator. The second case company was contacted since they have a collaborative project with NTNU and the topic of the research fits in with the project's overall purpose. They were just in the start phase of standardizing the design of a new product and had seen the opportunities of introducing a sales configurator.

	Case company 1	**Case company 2**
Products	Complex, basic and repeatable ETO	Complex ETO
Design automation maturity level	Level 2	Level 3

Table 6: Case company characteristics (Willner, Gosling, & Schönsleben, 2016; Willner et al., 2015)

The same approach for data collection was used in both case studies. The primary data source was weekly digital meetings with the case representatives. From case company 1, the representatives were technical engineers, whereas from case company 2, the representatives were the Vice President (VP) Developer, a Technical Manager, and the VP System Sales. A meeting protocol, including main topics and questions, was prepared in advance of each meeting, and open discussions concluded each meeting. Every meeting was recorded on video, and a written summary was produced. The summary included ideas and new insights that arose during and after the meetings. Additional documents and materials were sent from each case company and were categorized and stored. At the beginning of the case study, questions and topics focused on general product information and an overview of the specification process. At each subsequent meeting, the scope narrowed, and the questions were directed at more specific details. Product information was coded into specific analytical tools suggested in the literature. This process is further described in each case study chapter. In case 2 study, an interview concerning the existing configurator was also conducted to provide more empirical data. It followed the protocol in Appendix B (removed to preserve confidentiality).

As each case study demanded the researcher's full involvement, the case studies were conducted sequentially. This, however, allowed the researchers to apply the learning from the first case study and observe whether they eased the development.

An analysis of data gathered through multiple case studies typically consists of two parts: first, a within-case analysis for each case, second, a cross-case analysis (Yin, 2014; Voss, Tsikriktsis, & Frohlich, 2002). Each development project was analyzed separately in Section removed and removed. Then a cross-case analysis is presented in Chapter 6 where the findings of the cases are discussed. The findings are also discussed in relation to the literature. The first case was informed by the concepts and challenges found in the literature review. In the second case study, both theory and findings from the first case study were applied.

4 Case study 1

Removed to preserve confidentiality

5 Case study 2

Removed to preserve confidentiality

6 Discussion

This chapter discusses the findings of the case studies and is seen in relation to the existing literature. Beginning with a cross-case analysis of the challenges of developing PCs for ETO products (objective 2), and continuing with a cross-case analysis of the learnings, laying the basis for meeting objective 3. This is followed by an assessment of this study's limitations and the research process.

The development activities found in the literature review were grouped into five main activities in Section 2.3. In the case studies, the activities used for developing the prototype were inspired by the activities derived from the literature review but were altered to fit the needs of the projects. They are listed and described in Table 7. The discussion is organized according to each of the four activities.

The "Developing configurator software" activity is omitted from the discussion because in case study 2, the activity was not conducted because of time restrictions, as described in Section 3.3. Also, during case study 1, the challenges that occurred while developing the configurator software were mainly related to the specific technology used for the development. Thus, the cross-case analysis omits this activity, as the researchers deemed the findings from this activity to have little to no generalizability.

Activity	**Description**
Knowledge acquisition	Using Top-down approach to guide the process of acquiring product information Using PVM to structure the product information acquired
Scoping	Define: Aims and purpose of PC PC requirements and functionality Current situation and future scenario Structure of the PC
Defining solution space	Conducting product family and variant analysis to decide what variants to include in the solution space Conducting product modelling guided by Top-down approach and PVM to decide what design parts to include
Developing configurator logic	Includes defining the configurator logic and programming. Configurator logic is a collective term for the configuration rules and the decision flow in a PC.

Table 7: Activities of PC development

6.1 The challenges of developing PCs for ETO products

In this section, objective 2 is met through a cross-case analysis where the challenges encountered in the case studies are discussed and compared to the literature.

Knowledge acquisition
Two reoccurring challenges during knowledge acquisition were found in both case studies: (1) Communication challenges between product experts and the researchers (acting as configurator designers), and (2) Challenge to understand what product knowledge is relevant.

The first challenge is tightly connected with the deep and complex product structures of ETO products and is reported as a challenge in PC projects in the literature (Cannas et al., 2020; Kristjansdottir, Shafiee, & Hvam, 2016). In both case studies, the company representatives had to spend much time explaining the product's functions and technical details, which required a substantial amount of time since it was difficult for the researchers to understand the product knowledge. In case study 1, the knowledge of how different parts could be combined was the greatest challenge, as it was difficult for the researchers to keep track of the components and their variants. It was difficult for the researchers to communicate how the information given by the engineers was incomplete from a product modeling point of view as they were unable to formulate the right questions. This resulted in the product experts were not able to provide the right product knowledge. In case study 2, the same challenges occurred. During knowledge acquisition, the case representatives often discussed the product itself and its design, and it was difficult for the researchers to guide the conversations.

The second challenge is related to the uncertainty of the PC solution space and the scope. As a result of this, it is difficult to determine what information is relevant, as this depends on the scope and PC solution space. Therefore, much time may be used to collect information that later in the project turns out to be unnecessary. This is compounded by the deep and complex product structures which require extensive time to understand, as described above. Some understanding of it is required, but it is hard to know which area of the design to focus on because of the uncertain scope and PC solution space. This was shown in case study 1, where the product description went into too much technical detail that was later found to be unnecessary for the researchers to know to develop the prototype. Although the literature suggests that unnecessary knowledge gathering is a challenge (Shafiee, Kristjansdottir, Hvam, & Forza, 2018), it is not seen as a result of uncertainty in the PC solution space and scope as this study suggests.

Scoping
A challenge when scoping a PC for an ETO product is that it is difficult to make a realistic scope early in the project because of uncertainty in the PC solution space and because of the ETO product characteristics. However, a scope is needed to set the knowledge requirements and establish a common understanding of the PC system, project goals, outputs, and objectives. Because of the product complexity and high level of order specific engineering currently needed in the sales process, it was unclear what was possible to achieve using a PC at the beginning of each case study. Additionally, neither of the companies knew beforehand which parts of the product design were possible or most beneficial to include in the PC solution space, making the scoping activity challenging at the beginning of each project. Though, it became easier over the course of the projects as solution space became better defined. This is illustrated by how the scope changed as new insight into the potential of a PC was formed while defining solution space in case study 1. The functionality of making a price estimate was added in the middle of the

project. A consequence of defining the scope too rigorously too early can be that the scope is unrealistic or creates more work than the company can invest in the project, as described by Kristjansdottir et al. (2018). For example, if the scope sets too lofty goals, standardizing the product and creating configuration rules can require more resources than planned. This was reported for the existing PC in company 2, where the PC's requirements generated more work for engineering than they could complete within the time limits.

There is process uncertainty involved in the sales process for ETO products; additionally, staff involvement from several departments is required, contributing to complex information flow (Hicks, McGovern, & Earl, 2000). In both case studies, the process of designing the product for quotation was not standardized and varied from product to product. When determining the scope, a future sales process scenario is sketched, establishing new processes, information flow, and new tasks, changing the personal roles, and defining new procedures. This can be difficult when the processes used earlier differ and the change affects several departments, not only sales. In case study 2, it was highlighted that the PC's requirements must reflect that the PC should help the sales personnel configure a product, but also take into account the engineering needs and technical constraints. The same challenge was also reported in a company in the case study by Cannas et al. (2020). Finally, when the PC solution space is unclear, it is difficult to know what tasks need to be executed manually for each order; thus, it is difficult to define standard processes.

Defining PC solution space

In light of the findings from the case studies, it can be said that when aiming for partial configuration, the PC solution space can be thought of not only as of the variants that the PC can produce. It also means which parts are specified and the level of detail at which the product is specified using a PC. Thus, some parts and details of the design, meaning components, systems, component or system details, are included in the PC solution space and some excluded. Therefore, defining PC solution space for a sales configurator for ETO products can be divided into two tasks: (1) determining the product variants to include, and (2) determining the design parts and the level of detail of the products to include.

The first task is challenging because companies often have an unclear product range or blurred lines between variants. Thus, the company does not have a good overview of their products and what they offer customers. This was seen in case study 2, where the product design had very few product standardizations and was largely designed from scratch each time. Also, it may be necessary to keep some products out of the PC solution space and maintain a sales process independent of the PC, as was necessary in both case studies for some functionality. It will likely be important to clearly define what products and functionalities are excluded to avoid confusion around whether the PC can be used when a potential customer establishes contact.

Determining the design parts to include in the PC solution space was challenging in both case studies. It was found that this could not be done without defining or planning to define standardizations and configuration rules. This shows that parts of the product design included in the PC solution space have to be changed, which is challenging because solutions must be engineered for these parts in anticipation of what customers will require. Ideally, the PC should determine as much of the product as possible to produce a high-level design and quotation of as high quality as possible. Due to the wide product variety, low demand per product variety, and a high degree of customization for each customer order, this becomes increasingly challenging for ETO products. This was seen in case study 1, where the engineers struggled with defining PC solution space and had to consult sales personnel and supervisors. They could not foresee what design parts could be engineered in anticipation of customer orders, and the sales personnel and supervisors could not offer much more insight. The result was a relatively sparse PC solution space, which left most of the design to manual engineering. Cannas et al. (2020) report the same challenge but do not relate it to the ETO characteristics, as done here. A related challenge is that it can be hard to understand what can be achieved using configuration rules. It was challenging for the company representatives in both case studies to understand which parts of the product really needed manual engineering or if they could be determined using configuration rules. It was hard to see how much freedom for customization would be kept if determining the product using configuration rules. It can also be challenging to understand how much work will be needed to formulate these rules. Suppose the time and resources needed to formulate configuration rules to include a design part are very high. In that case, it might not be profitable to include it because the cost might be higher than the gains of determining this part in the configurator, which was also mentioned by Forza and Salvador (2006). In case study 2, this was seen when the engineering department representative informed that formulating rules which would ensure that the product would not break under the specified loads would be very hard to formulate because of how many design details the rules would have to take into account. This could have been included, but it was hard to understand whether it would be worth the time and resources required to do so.

Since defining the PC solution space requires standardization efforts for ETO products, this activity is closely connected to the business strategy because of the effect on all departments. As company 1 pointed out: By standardizing products, procurement can become more efficient across projects by reducing component variant variety, facilitating larger orders. Thus, the standardization choices should not be taken in isolation from the rest of the company, increasing the challenge of making PC solution space decisions. These connections have not been explicitly described in the literature as far as the literature review showed. The underlying reasons for this challenge seem to be that the decisions need to be grounded in a thorough understanding of the impact this will have on what the company can offer, what kind of changes the customers will accept, and how this will affect sales. It was indicated through the case studies that choosing the most favorable standardizations was difficult. A risk of standardizing is losing the flexibility of meeting customer requirements (Willner, Gosling, & Schönsleben, 2016; Haug, Ladeby, & Edwards, 2009). Since a high degree of customization is important for competitive advantage for manufacturers of ETO products, parts of the product have to be outside the PC solution space. Additionally, company 2 highlighted the importance of manually engineering to keep a close and unique relationship with customers.

Another challenge related to defining the PC solution space is that product modeling of ETO products is difficult, which is also reported in the configurator literature (Cannas et al., 2020; Kristjansdottir, Shafiee, & Hvam, 2016). Two aspects contribute to this. Firstly, as was seen in both case studies, it was challenging to model the product and understand the dependencies between parts because of the complex and integral product structure.

In case study 1, the engineers often pointed out that some special customer specifications would require a particular product design or that a given component's design would affect other component's design. Secondly, low product standardization where many details are order specific and not shared between variants contributes to this challenge. Also, companies may have an unclear product range or blurred lines between variants, which, as mentioned, were the case for company 2.

Develop configurator logic
As a result of the high degree of customization and order specific engineering, it is common that few engineering standardizations have been formalized for ETO products (Cannas et al., 2020; Willner, Gosling, & Schönsleben, 2016). This was seen in both case studies and presents a challenge when developing configurator logic. As found in case study 1, the engineers struggled with coming up with configuration rules that could be used to determine the design of different components. This also caused the PC decision flow to change. These findings illustrate the challenges of formulating configuration rules. A reason for this challenge is that the configuration rules are used to define the product in the PC while ensuring flexibility to offer a high degree of customization and enabling the generation of many different configurations. Thus, the configuration rules must be very complex to be able to generate products of many variants, of high complexity, and designs without errors. As found in case 2, their existing PC had configuration rules that allowed for the generation of infeasible products, lowering the PC's usefulness. This illustrates how hard it can be to formulate these rules. A company also has to consider whether the resources put into creating configuration rules are justified by the saved engineering work later. Moreover, contradicting requirements from the stakeholders was seen as a challenge in case study 2. The sales department representative wanted as many configuration rules as possible to help the sales personnel define as much of the product as possible. In contrast, the technical manager said some of them would be too complicated and thus infeasible.

Since there is such a wide product variety, a high degree of customization, and large amounts of order specific engineering, it can be challenging to define a fixed order in which each part of the product design can be determined. Process uncertainty also contributes to this challenge, meaning that the design process does not follow the same steps for every customer order nor between the people performing the design. Therefore, it is challenging to establish the PC's decision flow because it needs a defined order in which the design parts are defined. Often, this order is different from the order the engineers configure the product. In both cases, this was seen where the design process was quite "ad-hoc" for each customer order, and there was no standard way of reusing old designs. The challenges related to the configurator logic for ETO products provided here were not found during the literature review. A likely cause of this is the relationship between literature and academia as described in Section 2.2.7, as neither companies nor software vendors want to provide information regarding this.

6.2 The learnings of developing PCs for ETO products

This section continues the cross-case analysis and discusses the learnings of how the challenges of developing PCs for ETO products may be addressed to lay the basis for meeting objective 3. The discussion is based on the learnings from the case studies and the reviewed literature.

A common cause of the difficulties encountered in the case studies is the uncertainties and unknowns of the project, making each of the activities challenging. To remedy this, it was found that parallel execution of activities and short iterations were helpful. This facilitated better decision making in each activity by using the information and insight from the other activities. In case study 1, the parallel execution of each activity enabled information sharing. It was found that demonstrating the prototype at the end of the project enabled the managers to get insight into what product and component variants can be included and how they can be designed using the PC if configuration rules are formalized. In case study 2, a more agile approach was taken based on the two findings from case study 1. In the literature review, it was found that agile development with short iterations can adapt to changing environments and handle complexity, but using agile approaches in PC projects is barely investigated (Shafiee, Wautelet, et al., 2020; Paetsch, Eberlein, & Maurer, 2003). Haug, Shafiee, and Hvam (2019a) also suggest that the different phases in a PC project can be carried out iteratively but do not elaborate on how it should be done. Case study 2 had two short iterations (1 week each) where knowledge acquisition, scoping, defining solution space, and logic development was executed. At the end of each iteration, the PC solution space, scope, and logic were demonstrated. The researchers saw that the agile approach was helpful by rapidly displaying tangible outputs to stakeholders, informing them to enable rapid feedback and decision-making, and agreement across stakeholders. It increased the understanding of the PC potential. The demonstrated outputs incrementally grew and were continuously aligned with the company representatives' wishes in the next iteration. Short iterations facilitated making better decisions in each activity by using the information and insight from the other activities, which is also reported by Shafiee, Wautelet, et al. (2020). Thus, it seems that an agile approach may be suited to handle the complexity and uncertainty in the PC project.

Based on the arguments of short iterations, it can also be said that the order of the early activities, such as scoping and defining PC solution space (including product analysis and modeling), may be performed with some overlap and in the order that seems logical in the specific case. If the company already has a good overview of the products and has many standards formalized, the scoping can be done directly. If not, product family and variant analysis should be performed to obtain a better overview and provide the scoping activity with suggestions for focus products, which is also suggested in the CPM procedure by Hvam, Mortensen, and Riis (2008). It should be noted that in case 2, it worked well to spend relatively low amounts of time on the product variant and family analysis before logic development and programming were started. This illustrates that short iterations can be helpful. Following is a discussion on how the challenges related to each specific activity may be addressed.

Knowledge acquisition

The PVM and the top-down approach was applied in both case studies based on the state-of-the-art to support the knowledge acquisition activity. They are used to model products and break them down into components and sub-components, effectively organizing product information (Shafiee, Piroozfar, et al., 2020; Hvam, Mortensen, & Riis, 2008). The top-down approach facilitated structured information gathering, and the PVM organized the product information during the project. However, they did not address the communication challenges in either of the case studies. In case study 2, the researcher used the dependency flowchart (see Figure 9, further explained under logic development below) initially for understanding the flow of how the product was currently being configured. This proved to be a beneficial tool and facilitated better communication between the company and the researchers. The communication in case study 2 was easier, even though the product is categorized as more complex than the product in case study 2. The dependency flowchart also enabled the technical case representatives to confirm if the researchers correctly understood the dependencies and point out inaccuracies and errors.

The researcher defined a list of useful information used for both PC solution space and defining product logic after case study 1. This was used in case study 2 to structure and guide the knowledge acquisition and focus on the relevant product knowledge. This proved to be very useful and reduced unnecessary information gathering (the information that was not needed for the PC solution space, scope, or logic) compared to case study 1. Due to differences in products and processes, the list was expanded with more useful information. The researchers saw that the list was particularly useful in the project's first iteration to aid product modeling and developing configurator logic. The PVM was also useful for understanding what standards and dependencies were lacking and what information was needed. This helped the researchers ask the right questions and can be used to overcome the challenges of knowledge acquisition, as the configurator literature suggests (Shafiee, Hvam, & Bonev, 2014; Hvam, Mortensen, & Riis, 2008)

Scoping

The scoping activities are quite well defined in the configurator literature (Haug, Shafiee, & Hvam, 2019a; Shafiee, Kristjansdottir, Hvam, & Forza, 2018; Shafiee, Hvam, & Bonev, 2014; Hvam, Mortensen, & Riis, 2008; Forza & Salvador, 2006) and the researchers based the scoping activity in the case studies on the framework proposed by Shafiee, Hvam, and Bonev (2014). In both cases, it was beneficial to define the scope in rough outlines and at a high abstraction level early in the project and gradually add more detail to the scope as more insight became available. Case study 1 showed that it was easier to define the scope when the other activities had started, as the PC solution space became more defined and the logic formulated. Findings from case study 2 showed that short iterations made it easier to clarify several aspects of the scope, such as inputs, outputs, and user interfaces, by rapidly developing a PC solution space and PC logic draft and presenting this to the case representatives. This study argues that short iterations are a good way of conducting the development to overcome the scoping challenge related to the uncertainty of the PC solution space and the ETO product characteristics, supported by Shafiee, Wautelet, et al. (2020). Short iterations provide a more structured approach compared to executing the activities in parallel. At the end of each iteration, demonstrations allow making adjustments rapidly to align the scope with the different activities' outputs.

Several sources in literature note that relevant stakeholders must be identified and involved in the scoping process (Haug, Shafiee, & Hvam, 2019a; Shafiee, Hvam, & Bonev, 2014). The case study findings support this, as the scoping activity was much easier in case study 2, where more departments and decision-makers were present. Haug, Shafiee, and Hvam

(2019a) also warns against involving too many stakeholders. However, as there were few company representatives involved in each case study, this was not an issue, and the case studies do not have a foundation for supporting or opposing this. Then, one can assume that stakeholder involvement should be handled carefully, ensuring that all important stakeholders are included, but avoiding including too made representatives from each department. By having representatives from all the affected departments involved, it can be easier to set realistic PC requirements and define the future specification process.

Defining PC solution space
To overcome challenges related to selecting product variants, it is important to get a good overview of the products and understand which of them share underlying architecture. As shown in case study 1, when products share architecture and main components, it is easier to include them in the PC solution space. This is also noted in the literature, such as by Forza and Salvador (2006), (Haug, Ladeby, & Edwards, 2009) and Haug, Hvam, and Mortensen (2013).

Including products that share architecture also alleviates the second task's challenge regarding understanding what parts of the product can be defined using configuration rules. The same rules necessary to include a product may apply for products with similar architecture, thus increasing the benefit of formulating the rules while not increasing the resources needed to do so, as seen in case study 1. This challenge can also be alleviated by understanding how much flexibility the company gives up by including a part of the design in the PC solution space and weighing this against the effort needed to standardize and formulate the configuration rules. The dependency flowchart was also found helpful to identify parts of the design that should be included the prototype solution space, by showing the most critical parts. The dependency flowchart is discussed in under developing configurator logic.

To handle the challenges of defining the PC solution space, it can be learned from the case studies that it is important to include personnel from different departments such as sales and engineering. Additionally, decision-makers should be included as the PC solution space considerations can affect the company widely. Including stakeholders is not a revolutionary insight for project management and has been remarked by several researchers regarding PC development (Haug, Shafiee, & Hvam, 2019a). However, defining the PC solution space also means changing the product design itself. This can affect what the company can offer, making it especially important to include stakeholders in this activity. Including people from several departments can make it easier to understand what parts can be engineered in anticipation of customer requests, as it will be easier when insights from both the sales department and engineering department can be used for these decisions. It is also important to include decision-makers in this activity because the company business strategy should drive PC solution space decisions because it can greatly impact what products the company can offer, the flexibility for customization, and order specific engineering. This can be seen when comparing the case studies. In case study 1, only engineers were present, so it was hard to make decisions regarding the PC solution space. In case study 2, decision-makers were present, making it much easier to define the PC solution space. The researcher's interpretation was that they had more insight into the business strategy and had the mandate to decide how the product can be offered. It can also be helpful to include decision-makers because they may want to reevaluate what they want the company to offer when understanding the potential of a PC, thus aligning the business strategy and the IT capabilities (Silvius, 2007; Brown & Blackmon, 2005). This was seen in case study 1, where the decision-makers saw the opportunities of a PC in the concluding presentation and subsequently started discussing how the products can be changed to benefit from the potential of a PC.

Additionally, taking advantage of the information and insights from the other activities can help decide what design parts to include. For example, the configurator logic shows how the PC can automatically determine the product design using user input and configuration rules. This gives new insights into how products can be designed using the PC and thus a better understanding of what parts can be included while still retaining the ability to provide a high degree of customization. This was seen in case study 2, where the company representatives understood better what could be included after a preliminary configurator logic was presented.

Both case studies showed that it was helpful to use the top-down approach and the PVM for modeling and analysis. This is also frequently reported in the configurator literature (Kudsk, Hvam, et al., 2013; Mortensen, Hvam, & Haug, 2010; Hvam, Mortensen, & Riis, 2008). However, combining it with an agile approach has not been addressed according to Shafiee, Wautelet, et al. (2020) but was beneficial in case study 2 showing that it is possible and can be useful.

Logic development

The first challenge that is addressed is the challenge of formulating configuration rules. The company needs to consider the time and resources required to formalize the configuration rules. As the findings show, making these considerations were easier with people from several departments and with decision-makers, as they could each contribute different knowledge relevant for each of these considerations. If it requires too much engineering effort, the company should reconsider the PC solution space and consider leaving it for manual engineering. Cannas et al. (2020) also suggest redesigning the product if it is not possible to formulate configuration rules.

In contrast to the framework proposed by Shafiee, Hvam, and Bonev (2014), the discussions regarding the PC's decision flow in the PC were done in this activity and not in scoping activity in case study 2. As necessary information and insight to define this was scarce in early stages, this made it easier to define decision flow, compared to case study 1. Case study 2 showed that using a flowchart of product dependencies can address the challenge of defining the PC decision flow. A similar approach was not found during the literature review. However, the use of flowcharts for process modeling is well known (Monk & Wagner, 2012). The dependency flowchart consists of customer specifications, the product's main components, and the dependencies between them. The parts in the flowchart depicted first, or high up-stream, are directly impacted by the customer specifications or have many other parts dependant on them. This is illustrated in Figure 9, where component 1 would typically be decided first in the PC. For example, in case study 2, the flowchart showed that the product variant could be decided first because it was upstream of the other design parts and components. This order of defining the design was not formalized in the company originally. From case study 2, it was also found that the flowchart should depict the entire product, not only the PC solution space, as it facilities decisions of inclusion of parts and part variants. Comparing the cases, developing the

PC's decision flow was much harder in case study 1, where a dependency flowchart was not used.

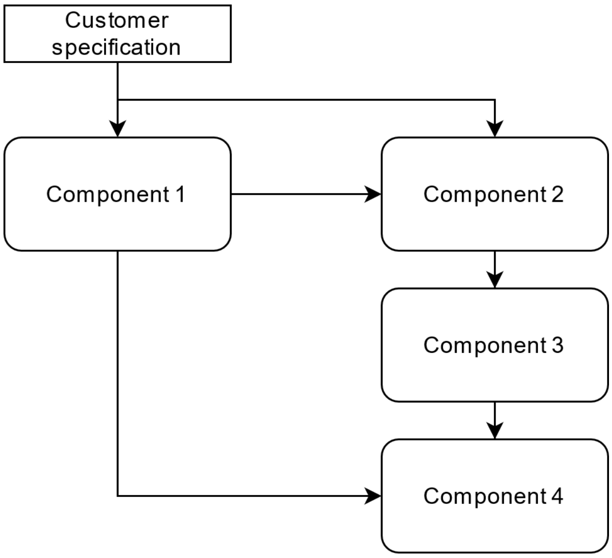

Figure 9: Example of the flowchart of product dependencies

6.3 Limitations

This section discusses the limitations of the study. As presented in the methodology chapter, case research presents several limitations. Moreover, Voss, Tsikriktsis, and Frohlich (2002) highlights the importance to pay attention to validity in case research, which is discussed in relation to the research performed in this study.

Construct validity refers to "what extent the operational measures that are studied really represent what the researcher has in mind and what is investigated according to the research questions" Runeson and Höst (2009, p. 23). There are threats to the construct validity of this study. First, the research aimed to provide more knowledge about the development of PCs for ETO products. The unit of analysis was thus the project itself in the case studies. However, neither of the development projects was equivalent to a full-scale development project. Only a prototype and conceptual prototype were developed, and the goals were not implementation but exploration and demonstration of potential. Thus, the researchers could not see the effect of the development approaches in an entire project cycle. This may reduce the construct validity of the results, and it is hard to assess the findings' applicability to a full-scale PC development project. Conceivably, some of the findings may be specific to small-scale development. Additionally, as only two development projects were conducted, the results are vulnerable to features specific to them which are not normally present in development projects. This is hard to detect because of the lack of case descriptions of development for ETO products to compare with.

Internal validity is of concern when causal relations are examined (Runeson & Höst, 2009; Voss, Tsikriktsis, & Frohlich, 2002). Comparing findings from two case studies and the literature, the researchers increased the data's internal validity to make inferences. It permitted the researchers to detect similar patterns to provide recommendations for future development projects. The researchers used factual data related to PCs challenges and development approaches and qualitative data from an interview and direct observation and participating in the development projects. However, research bias has to be addressed as the researchers were directly involved and participated in the case studies. Thus, the results may be skewed by the researchers' own expectations and biases. Also, the researchers' role as configurator designers may contribute to challenges that would not occur if the research was conducted by configurator experts with more extensive experience with PCs.

External validity is concerned with knowing whether a study's findings are generalizable beyond the immediate study. For case studies, the issue relates directly to the discussion of analytic generalization (Yin, 2014). Analytic generalization compares the results of a case study to a previously developed theory. The generalization in this study takes the form of the recommendations presented in the next chapter. They are posed at a conceptual level higher than that of the specific cases to apply to other situations (Yin, 2014). The projects had several differences providing a foundation for analytical generalization. Thus, it can be justified that the findings are applicable for similar projects and companies with similar characteristics as the case companies. Moreover, the case studies were carried out sequentially, allowing case study 2 to apply learnings from case study 1. As the findings illustrated, case study 2 encountered fewer challenges than case study 1, implying that case study 2 benefited from the learnings and. This strengthens the validity of the findings. The products in focus in the projects close to the complex quadrant (following the archetypes of ETO (Willner et al., 2015)), but none of the products are of the most complex types of ETO products, such as ships or oil platforms, nor are they close to the repeatable type where higher volumes are common. Therefore, the findings may have limited applicability for these types of products. However, this may be of little importance in regards to the most complex of products as it may be that a PC is not feasible or desirable for these as automation possibilities are so limited, as described in Section 2.1.3. For less complex products of higher volumes, the findings may not be directly transferable but may still have some relevance, as many of the same characteristics of ETO products still apply. Challenges of developing PCs for such products can possibly be handled similarly as for the products in focus in this study.

Moreover, this study applies a qualitative method, which is considered an effective methodology for an in-depth understanding of phenomena due to the direct observation in the natural setting. However, the findings from this method can be challenging to generalize (Miles & Huberman, 1994). Although the research has been designed to promote the study's validity, the population studied cannot be as large as the ones addressed by quantitative studies.

6.4 Reflections on the research process

There were some obstacles during the research process. Because of the COVID-19 restrictions, the first case study was delayed approximately one month, reducing the time available for both case studies. Additionally, the researchers had originally planned to visit the companies to conduct most of the knowledge acquisition and product modeling in collaboration with company representatives. This was not possible because of the restrictions, and all communications had to be conducted via video conferences. This limited how much the company representatives could participate in the product modeling, and they were reduced to primarily providing information. This made information gathering and product modeling take more time. Because of the time restrictions and these obstacles, the scope of case study two had to be reduced. Fortunately, the company representatives from both companies were very helpful in providing information during meetings and through e-mail, which helped overcome this obstacle.

Another obstacle to the research process was that the main supervisor was unavailable on sick leave during the last two and a half months of the research time. This made guidance from supervisors and discussions of the research limited for a part of the project. Fortunately, the secondary supervisor took over most of the responsibilities and provided guidance in the last period of the research.

Working with the companies gave interesting insights into how engineering company's work. Also, it provided different and engaging ways of working, contrasting the academic work conducted during this study and over the course of the master's program.

Working together on this study provided opportunities for discussions and working together to solve problems. This was very helpful and aided in finding which direction the research should go. It also made it possible to achieve more as the workload was split, permitting doing more work during the case studies and achieving more during the study in general. The researchers are satisfied with the cooperation.

7 Recommendations

Based on the cross-case analysis of the learnings in Section 6.2, a set of recommendations is developed to supplement the existing development approaches for PCs in the configurator literature. The recommendations are mainly aimed at development projects for sales configurators for ETO products. The goal of the recommendations is to contribute to overcoming the challenges of developing PCs for ETO products. By proposing the following recommendations, objective 3 is met, and a contribution to knowledge in the field of PCs for ETO products is made.

First, recommendations for the development approach, and participants in the project are given before recommendations for each main activity; knowledge acquisition, scoping, defining solution space, developing configurator logic. Figure 10 illustrates how the development approach supports the main activities and places the contribution in the context of a PC development and implementation project.

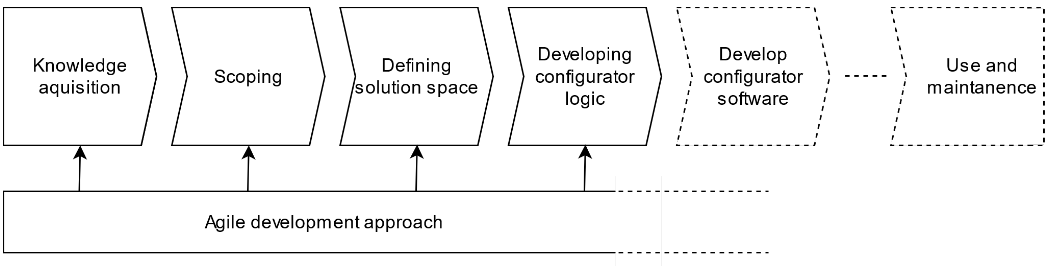

Figure 10: The activities of development supported by an agile approach

Agile development approach
An agile development approach is recommended, using a development plan with short iterations with a duration of 1-3 weeks. Each iteration should include the four main activities described in the following sections. It is not recommended to put off traditionally late activities such as developing configurator logic and programming since short iterations help address issues emerging from previous activities promptly. The order in which the activities are carried out in each iteration is not stipulated, but the following suggestions are provided. The activities can be done in the presented order, but product family and variant analysis and the scoping may be performed simultaneously or in reverse order. Additionally, when the product variant and family analysis get sufficiently detailed, and rules and dependencies are identified and formulated, the logic development may start. These two activities may overlap in this way, the last step starting at the end of the previous one. If the company already has a good overview of the products and has many dependencies and standards formalized, the scoping may be done directly. If not, a rapid product family and variant analysis should be performed before scoping.

The aim of each iteration should be to define each of the outputs (PC scope, PC solution space, configurator logic) more precisely and correctly. For example, the first iteration should produce a rough draft of the PC scope and be further developed in the subsequent iterations. This information can then used in the later activities but are not static and should be updated in later iterations using new information and insight gained from each activity. Suggested tools are the PVM and dependency flow chart. At the end of each iteration, the outputs should be demonstrated for the entire project team.

Before development, the company should identify all relevant stakeholders that should be a part of the project team. Stakeholders include representatives from the different departments affected by a PC to ensure that the project aligns with their needs and requirements. Additionally, different stakeholders are needed to contribute knowledge when conducting the activities. Decision-makers concerned with product design and business strategy should be included to ensure that the project is aligned with the company's overall strategy. PC solution space decisions should consider the company market and overall business strategy, including standardization, and decision-makers may reevaluate the strategies and target market segment as the PC development displays new potentials.

Knowledge acquisition
The knowledge acquisition activity aims to collect the right information and knowledge to scope, define solution space, and develop logic. It is recommended to structure the information using the PVM and follow the top-down approach. However, as information is needed for the other activities, knowledge acquisition may be beneficial to carry out in parallel with the other activities. The first iterations may need to put greater effort into this activity, while the later iterations may not require new information, only refinement of the other activities.

The following information is recommended to obtain in the early iterations, in addition to information about product structure and parts. The information listed below helps with sketching the PC solution space, logic, and scope in the first iterations and is further described in the following sections.

- What the customer usually specifies in a request for quotation, including functionalities and component variants
- All input that is required to fully specify a product for quotation
- Use cases (application area) that are expected to have a high demand
- Product functionalities that are expected to have a high demand
- Components and equipment where the different variants or design choices affect the price of the final product significantly
- Components and equipment where the different variants or design choices affect the lead time of the final product significantly
- Design areas (can be components or systems or sets of these) that affect the most other design areas
- The logical sequence of specifying a product; that is what needs to be decided first, then second, etc.
- Common errors from the specification of the product caused by wrong or missing information from sales personnel
- The rules, dependencies, and constraints governing the design that is already defined for the product(s)

Scoping
The PC scope should include the following; for more details, see Shafiee, Hvam, and Bonev (2014):

- Aims and purpose of PC
- Requirements and functionality
- Current and future sales process
- Structure of the PC
  - Inputs and outputs
  - Integrations with other systems
- Important products and product features

For this activity, decision-makers should express what the company wants to gain from implementing a PC. However, care should be taken to include just enough people to have relevant stakeholders represented but not more. The scope should be defined in rough outlines and at a high abstraction level in the early iterations. Later iterations should more rigorously define the scope by using the experience and learnings from the other activities.

Defining solution space
This activity aims to identify what product families and variants should be included in the solution space, what parts of the product design, and what level of detail should be included in the PC solution space. Product families and variants should first be analyzed before the architecture is described and broken down into main components and systems. For each iteration, the PC solution space should be better defined and revised if needed. It is recommended to use the top-down approach and thus evaluate the products' higher levels (main components) for inclusion in the PC solution space in the first iteration. In the subsequent iterations, more detailed levels of the product structure are evaluated.

It is recommended to include product families, variants, and functionalities expected to have high demand. Additionally, families and variants with largely shared architecture are good candidates, as the rules and dependencies governing their design are likely related. This means that many of the configuration rules required for one family or variant may be applied to many or all, making logic development easier. Moreover, parts of the design necessary to give the customer an offer (what is included depends on the company and their business processes), such as parts that significantly affect the product's price, should be included. It is important to identify whether there currently exist no or few configuration rules for these parts. If these parts are to be included in the PC solution space, standard component variants and/or configuration rules must be defined, which may require much engineering effort. Otherwise, they have to be manually engineered for each quotation. When determining whether to formalize and include the design parts in the PC solution space, several factors should be considered, including:

- The time and resources required to define standard product and component variants and formalize configuration rules to generate the design.

- The impact it will have on the company's flexibility to offer new and innovative solutions.
- How often the specific design part needs complex engineering to define.
- If it is necessary to define this design part in the sales process.

When defining the PC solution space, it is recommended to use the PVM and a dependency flowchart to visualize the product and the dependencies. The flowchart shows the most critical parts that should be included in the PC solution space. These parts are shown first or high up in the map and stream of dependencies because they are directly impacted by the customer specifications or have many other parts dependant on them. An example of such a flowchart is shown in figure 9, where at least component 1 should be included in the PC solution space.

Logic development
This activity aims to determine the decision flow in the PC and formulate the configuration rules. It is recommended to use the dependency flowchart to help determine the decision flow in the PC. The flowchart represents the movement or flow of how the product within the PC solution space is determined. The needed configuration rules should be determined based on the PC solution space.

8 Conclusion

This chapter summarises the findings of the study and presents the conclusions by addressing the three research objectives. Following is the study's contribution, before suggestions for further research are presented.

PCs can bring potential value to companies, such as shorter lead times for generating quotations and the use of fewer resources. The case studies reported expected benefits such as a lead time reduction in sales up to 60%, free capacity from technical experts, and an increase in the number of quotations produced and products sold. Unfortunately, PC development projects are different from other software development projects, mostly because of the comprehensive product knowledge. Companies have developed PCs for ETO companies successfully, but also, many projects fail. Developing PCs for ETO products presents unique challenges. However, these are less investigated in the literature. The following research objectives were developed to guide the research into an increased understanding of the challenges involved and how they can be overcome. The activities of the study and the findings are presented according to the objectives.

8.1 Research objectives

Objective 1: Explore state-of-the-art and challenges of product configurators for ETO products.

The state-of-the-art and the challenges found in the literature review are presented in Chapter 2, and the most important points are summarized in Section 2.3. There are documented cases of PCs for ETO products, but most focus on the potential benefits of PCs, and few details the development approach used and the challenges encountered. Partial configuration differentiates the development of PCs for ETO products from other products, and several studies suggest that it is necessary for companies with ETO products. However, little attention is given to the consequences this has for the company and the development process of PCs.

Little research is devoted to the specific challenges for ETO products. The challenges from the few studies found include communication difficulties between experts, unnecessary information gathering, and unrealistic or unclear scope. Additionally, the ETO product may require redesign. These challenges are caused by the ETO characteristics.

Five main activities were derived from the configurator literature; configurator scoping, product analyses, product modeling, configurator logic development, and configurator software development. The literature also suggests the use of the PVM and the top-down-approach for product modeling and analysis. Recent studies have focused on agile development approaches, which are more adaptive than traditional approaches and may handle complexity in projects better. The studies have shown promising results, but more research is needed.

The literature review concluded that there is a need for more investigation of the challenges and more knowledge of partial configuration and agile development approaches for PCs.

Objective 2: Explore challenges that occur during the development of PCs for ETO products

Two case studies were conducted to explore the challenges of developing PCs for ETO products. In each, a development project of a PC prototype was conducted and (removed).

A cross-case analysis of the case findings related to the challenges is presented and discussed in Section 6.1. The challenges are structured according to the four main activities in both case studies; knowledge acquisition, scoping, solution space development, and logic development. A majority of the challenges are related to partial configuration, which creates uncertainty across all activities because the solution space is challenging to determine. Defining solution space requires defining standardizations and configuration rules, which should be done considering the business strategy, increasing the challenge of making PC solution space decisions. A related challenge is that it can be difficult to understand what can be achieved using configuration rules and whether it is worth the time and resources required to define them.

Some of these challenges are not reported in the literature, and new and different aspects of known challenges are shown. The discussion was also centered around the consequences of the ETO product characteristics and thus provided a better understanding of the challenges and contributes to filling the literature gap.

Objective 3: Provide recommendations for developing PCs for ETO products

Findings from the case studies include learnings of how the challenges may be overcome and are presented in Sections (removed) and (removed). A cross-case analysis of the learnings continuing the cross-analysis on challenges is presented and discussed in Section 6.2.

The learnings are structured according to the same four activities in Section 6.1. It was concluded that an agile approach with short iterations shows promising results for addressing the challenges. At the end of each iteration, demonstrations allow for rapid feedback and frequent changes, which are suitable for the uncertainty involved in a PC project for ETO products. Moreover, the case studies also found it beneficial to apply the PVM and the top-down approach presented in the literature but also found that a flowchart showing the product dependencies may be helpful. The involvement of different stakeholders is also discussed, and having decision-makers involved in the development is important to align the development with the business strategy. It may also be prudent to reevaluate the business strategy as the potential of a PC becomes more visible throughout the project. The discussion in 6.1 is formulated into a set of recommendations that are presented in Chapter 7. The recommendations address the literature gap of the development of PCs for ETO products and are aimed at helping companies overcome the challenges of developing PCs for ETO products.

8.2 Contribution

This study's main contribution is an increased understanding of the challenges of developing PCs for ETO products and how they may be overcome. First, the study has gathered and synthesized existing research on PCs for ETO products. Second, it increases the understanding of the challenges by presenting empirical observations from a multiple case study on the development of PCs for ETO products.This also allows the researchers to improve the description of partial configuration and so extend the existing knowledge. Third, the research supplements existing development approaches by presenting a set of recommendations that companies can employ to face the challenges ETO products bring. Finally, the researchers have adopted an agile development approach for PC development, which is, to the researchers' knowledge, limited in the configurator literature. Thus, this study extends previous research on an agile development approach for PC development.

The new insight into challenges, partial configuration, an agile development approach may be useful, for example, for further development of methods and techniques to support PC projects. The study should be particularly valuable for practitioners, as the case descriptions and recommendations may help with the development of PCs.

8.3 Further research

The limitations of this research were discussed in Section 6.3 and should be used to guide further research. The decision to conduct this study using small-scale development projects allowed the researchers to control numerous activities. However, it limits the research's generalizability to real development projects because the projects conducted were not full-scale development projects of PCs. Future research should engage in more in-depth study of full-scale development projects with complete development cycles. Additionally, only two projects have been analyzed where only one product type was involved in each of them. Although the two case companies were different, they operate and are based in the same country and some of the same industries. This may not have allowed the researchers to detect potential contingencies due to the specific context, which could have affected the development and the challenges encountered. Future research should be performed in different research settings, with more products with more different characteristics. Also, with larger numbers of, and more different companies. Moreover, the study did not discuss the relative importance of the each of the explored challenges, and future research may want to address this. Since the researchers were deeply involved in the projects, their biases may have affected the results. Future studies should be conducted where the researchers are not directly involved in the development and only observe the development to avoid this. The research is subject to the limitations of qualitative methods. Therefore, future studies are invited to address this research topic by applying quantitative methods to obtain a statistical validation of the findings and increase their generalizability. Finally, the usefulness of the proposed recommendations are not verified, and future research should test and evaluate the practical usefulness of the recommendations. The recommendations may also be tested in other manufacturing environments and for engineering configurators.

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Appendix

A Design automation maturity model (Willner, Gosling, & Schönsleben, 2016)

	Level 1 – Ultimate Freedom –	Level 2 – Product Standardization –	Level 3 – Automation of Tendering –	Level 4 – Automation of Order Execution –	Level 5 – Full Automation –
Strategies	• Open solution space; customer is free in defining order specifications • No performance management: budget and schedule are not tracked and often exceeded	• Definition of product lines; creation of product structures; product modularization • Distinction between standard, configurable and special components • Basic performance management: budget and schedule are manually tracked	• Implementation of commercial product structures in sales configurators → formalization of solution space • Advanced performance management: budget and schedule are tracked; deviations are monitored	• Implementation of technical product structures in engineering configurators → formalization of solution space • Superior performance management: Budget and schedule are tracked; deviations are monitored and used to define improvement measures	• Fixed solution space that is regularly adjusted to customer needs • Performance measurement used for continuous improvements
Processes	• Ad-hoc processes, occasionally chaotic	• Nascent processes; no clear distinction between processes for standard, configurable and special components • Replication of processes across locations	• Process 1 (standard & configurable components): Tendering guided by sales configurators; automated generation of tender documents (semi-automation) • Process 2 (special components): roughly defined process	• Process 1: Order execution process guided by engineering configurators; automated generation of purchase orders & drawings • Process 2: meta-process for special components	• Fully defined and coordinated processes
Systems	• No IT systems for tendering and order execution exist • Data is collected randomly	• Product structures are stored in various IT applications (e.g. PDM systems, ERP and spreadsheet applications) • Structured, but manual data collection	• Sales configurators are used • Configurators support standardized and automated data collection within tendering	• Engineering configurators and order-specific engineering databases are used • Interfaces between configurators and CAD systems are set up • Configurators support standardized and automated data collection within order-execution; data used for product optimizations	• Fully integrated IT systems for tendering and order execution in place • Rigorous and automated data collection and analysis
People	• No clear roles and responsibilities • Success depends on individual effort and heroics	• Development of skills on the individual level	• Formation of groups and specialization (split up between people who define the MTO process, who execute the MTO process and people who improvise the ETO)	• Routines for standard & configurable components (first plan, then execute); automatic execution • Routinized improvisation for special components (simultaneous planning and execution)	• Clearly defined roles and responsibilities • Success depends on collective effort and comprehensive integration of tasks and roles
					MTO

Figure 11: Design automation maturity model (Willner, Gosling, & Schönsleben, 2016)

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