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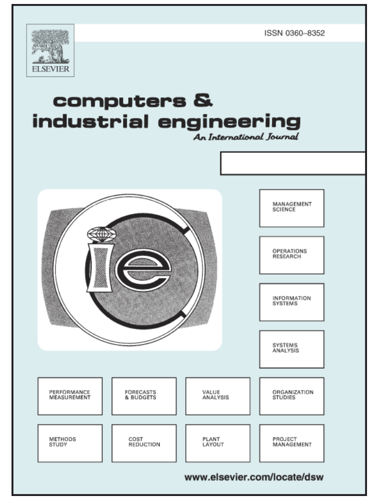

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A framework for multistage product configuration systems: Analysing costs and benefits

Abstract
Product configuration systems (PCSs) have been successful applications of artificial intelligence principles in engineer-to-order (ETO) companies in recent decades. Such applications mainly focus on quotation or production processes rather than multiple business processes. However, in some cases, there could be a benefit of applying multistage PCSs, that is, PCSs that can support several business processes. To investigate the conditions required for the beneficial application of multistage PCSs, this study examines the costs and the benefits associated with this approach. This is done by outlining a

framework that defines multistage configuration, hereunder the identification of costs and benefits, as well as the strategies for implementing the approach. The framework is tested through a case study of an ETO company, which provides empirical evidence of the feasibility and the potential benefits of multistage configuration projects. Specifically, the case study shows that investments are modest when moving from a single-stage configurator strategy to a multistage strategy, while demonstrating significant benefits. This paper thereby provides two novel contributions: (1) a definition of multistage configuration, hereunder two strategies for its implementation and (2) empirical evidence that identifies costs and benefits of multistage product configuration, thereby, supporting its feasibility.

Keywords: Product configuration system; Multistage product configuration; Engineer-to-order; Mass customization; Process improvement

Paper type: Research paper

1. Introduction

One of the major challenges for engineer-to-order (ETO) companies is the systematic management of product specifications throughout order handling (Colledani, Terkaj, Tolio, & Tomasella, 2008). In ETO companies, product designs are typically specified at a high level of abstraction in the sales phase. After the order is accepted, a detailed design is performed in the engineering phase. This workflow often includes specification changes in late project phases that have consequences for the project output. This challenge introduces the need for a structured approach to creating new designs and changes to product specifications. In response to this, companies adopt strategies, such as mass customisation (Pine, 1993; Yao & Xu, 2018), product platforms (Meyer & Lehnerd, 1997) and product modularisation (Ulrich, 1995; Ulrich & Eppinger, 2007), in order to reuse product designs, specifications, modules and parts.

In addition to these strategies, companies have started to implement product configuration systems (PCSs) in their sales phases to improve specification processes by selling standardised products. PCSs are considered successful applications of artificial intelligence principles (Dou, Lin, Nan, & Lei, 2018; Haug, Hvam, & Mortensen, 2011; Hvam, Mortensen, & Riis, 2008; Mittal & Frayman, 1989). PCSs support product specification activities by allowing users to combine predefined components and modules while enforcing constraints on such combinations (i.e., knowledge-based configuration) (Felfernig, Friedrich, & Jannach, 2000; Mittal & Frayman, 1989). Most configuration research is limited to single-process configurators, that is, sales configuration systems to create fast and precise quotations (Hvam et al., 2008). Sales configurators have gained popularity due to their substantial benefits for the companies, such as shorter lead times for generating quotations (Haug et al., 2011; Hvam, Haug, Mortensen, & Thuesen, 2013; Hvam & Ladeby, 2007; Trentin, Perin, & Forza, 2011), fewer errors (Forza & Salvador, 2002a, 2002b), the increased ability to meet customers' requirements regarding product functionality (Forza & Salvador, 2002a, 2002b), the use of fewer resources, optimised product designs (Gronalt, Posset, & Benna, 2007; Trentin, Perin, & Forza, 2012), less routine work and improved on-time delivery (Liu, Shah, & Schroeder, 2006; Squire, Readman, Brown, & Bessant, 2004). PCSs are widely used in a broad range of industries supporting ETO solutions, including construction (Kudsk, Hvam, & Thuesen, 2013), process plants (Orsvärn & Bennick, 2014) and the electronics industry (Hvam et al., 2008).

Unfortunately, companies face various challenges in developing and using PCSs (Kristjansdottir, Shafiee, Hvam, Forza, & Mortensen, 2018; Shafiee, 2017). Among the most important are the knowledge acquisition and product modelling required for complex products and the communication difficulties between domain and configuration experts (Shafiee, Kristjansdottir, Hvam, & Forza, 2018). The third challenge involves PCS documentation, which is often not maintained after PCSs become operational because the process is too time-consuming (Haug & Hvam, 2007; Shafiee, Hvam, Haug, Dam, & Kristjansdottir, 2017). These and other challenges increase the risk of PCS project failure (Haug, Shafiee, & Hvam, 2019a; Kristjansdottir, Shafiee, Hvam, Forza, et al., 2018). Good management of the PCS development process is required to avoid this failure (Shafiee, Hvam, & Bonev, 2014). Moreover, these challenges are highlighted in the case of ETO companies due to incomplete specifications at the point of sale, schedule correct lead times, delivery of products at a competitive cost (Konijnendijk, 1994) and compliance with regulatory constraints and IT-system integrations (Foehr, Gepp, & Vollmar, 2015).

However, ETO companies cannot rely entirely on standard solutions based on a modular strategy but need to make engineering changes (compared with the configuration that was initially sold) as the project progresses (Johnsen & Hvam, 2018). Hence, ETO companies need to keep track of both product and process changes between the product that was initially sold to the customer using a PCS and the item that was specified, produced and delivered (Shafiee et al., 2017). A consequence of the lack of documentation is that the costs associated with customer-specific changes in projects – and therefore, how to predict profitability throughout project execution – are not always clear to ETO companies.

Studies have cited numerous examples of ETO companies that have adopted advanced sales configurators (Christensen & Brunoe, 2018; Haug et al., 2011; Haug, Shafiee, & Hvam, 2019b; Kristjansdottir, Shafiee, & Hvam, 2016; Orsvärn & Bennick, 2014; Petersen, 2007). Furthermore, several articles have explored the application of PCSs to support ETO processes (Christensen & Brunoe, 2018; Kristianto, Helo, & Jiao, 2015; Zeng, Tseng & Lu (2006); Petersen, 2008) and discussed how to integrate PCSs with customer relationship management (CRM), product data management (PDM) and enterprise resource planning (ERP) systems (Forza & Salvador, 2007, 2008; Myrodia, Randrup, & Hvam, 2019). However, such literature does not describe the application of PCSs to support the whole order-handling process in an ETO setting.

To address the above-mentioned gap that has important practical implications, in this paper, we propose a framework that combines a number of important insights from the literature on PCS single-stage implementation. Moreover, we demonstrate the gained benefits in an integrative framework, using a case study that supports the successful management of a multistage PCS project, thus contributing to the PCS literature on increasing the benefits gained from PCS projects. We ask the following research question:

What are the costs and the benefits of multistage product configuration?

By addressing this question, the present paper answers the calls for more research on how to extend PCSs across different processes and user groups (Cao & Hall, 2019; Forza & Salvador, 2007; Shafiee et al., 2018). This involves two main contributions. First, the paper proposes and defines the concept of “multistage configuration”, hereunder strategies for the implementation of this approach. Although existing research has discussed the use of PSCs in different phases (e.g., Forza and Salvador, 2007; Haug et al., 2010b; Shafiee et al., 2018), concrete strategies have yet to be defined. By doing so, this paper extends existing research on implementation of PCSs in ETO companies. Second, the paper provides empirical evidence that supports the feasibility of the proposed multistage configuration strategy. Specifically, the paper investigates the costs and benefits associated with the prosed strategy, as compared to a traditional approach. The paper, thereby, also extends research on the effects of PCSs (e.g., Haug et al., 2019b; Hvam et al., 2013; Heiskala et al., 2007). For practitioners, this study provides insights which may help companies choose more efficient approaches to the implementation of PCSs.

The remainder of the paper is structured as follows. We first present a literature review, based on which we clarify the concept of multistage configuration and discuss the associated costs and benefits, as well as strategies. Next, to investigate the framework, we conduct a case study of an ETO company in which a multistage PCS was developed. Finally, we discuss the results of the case study and draw our conclusions.

2. Theoretical Background

2.1 Engineer-to-order companies

As there is no generally agreed definition of ETO companies in the literature (Gosling & Naim, 2009), it is widely concurred that the customer order decoupling point (CODP) can be used to define an ETO strategy relative to other strategies, such as make-to-order (MTO), assemble-to-order (ATO), configure-to-order (CTO) and make-to-stock (MTS) (Gosling & Naim, 2009; Haug, Ladeby, & Edwards, 2009; Wikner & Rudberg, 2005). The ETO strategy differs from others by having to perform engineering for each order instead of before stocking products (Rudberg, 2004). Four archetypes of ETO companies have been introduced (Willner, Powell, Gerschberger, & Schönsleben, 2016), defined by engineering complexity and number of units sold: complex ETO, basic ETO, repeatable ETO and non-competitive ETO. Similar to Johnsen and Hvam's (2018) argument, we contend that an ETO company does not necessarily fall under a single engineering dimension but can provide products with elements from CTO, MTO and ETO at the same time.

In ETO companies, products are manufactured to meet specific customer needs by carrying out unique engineering or significant customisation; all activities in the manufacturing value chain are initiated by the customer order (Olhager, 2003; Kang et al., 2017; Murray, Agard & Barajas 2018; Afrouzy, Nasseri & Mahdavi 2016). The customer order influences design, engineering, procurement, fabrication, final assembly and shipment (Olhager, 2003). ETO companies find it especially challenging to control the influence of customers since ETO customer requirements commonly change during the sales–delivery process (Little, Rollins, Peck, & Porter, 2000), and the requirements might not be fully specified in sales (Pandit & Zhu, 2007). As a result, the order-handling process in ETO companies has numerous challenges. These include receiving incomplete customer specifications at the point of sale, setting correct lead times, delivering products at a competitive cost (Konijnendijk, 1994) and complying with regulatory constraints and IT-system integrations (Foehr et al., 2015). The main cause of ETO challenges is inefficient or ineffective information sharing (Pandit & Zhu, 2007).

2.2 Use of product configuration systems

In the industrial 4.0 era, product life cycles become shorter, competition increases, and customers makes more demands (Dou, Huang, Nan & Liu 2020; Pacaux-Lemoine, Trentesaux, Rey & Millot 2017). To address such challenges, an increasing number of companies use PCSs. Typically, PCSs are applied in the sales process. Sales configurators are PCSs specifically designed to support sales and create fast and precise quotations (Hvam et al., 2008). Sales configurators have gained popularity due to their ability to help control the product assortment and encourage sales to offer standard solutions (Forza & Salvador, 2002a). Sales configurators are used in manufacturing companies to support front-end sales and back-end technical specifications (Forza & Salvador, 2007) and to create a bill of materials (BOM).

A BOM describes a product unambiguously in a tree structure, with the components needed to manufacture a product (Garwood, 1993). A BOM is shared by all departments in an organisation (production, design and manufacturing engineering, sales, management control, after sales, etc.). It is made for operational purposes (to define the list of components to be assembled), for planning (to anticipate component procurement needs) and for commercial needs (to guide customer choice and prepare sales forecasts) (Chatras, Giard, & Sali, 2016). A BOM is represented differently at various stages of the order-fulfilment process, and its variations include procurement, design, process, manufacturing and sales BOM (Zhou & Cao, 2018).

However, ETO companies cannot rely entirely on standard solutions based on a modular strategy but need to engineer and change the product that was initially sold as the project progresses (Johnsen & Hvam, 2018). Multiple cases of PCSs used in ETO companies are reported in the literature. However, the cases are usually focused on either sales configuration or engineering configuration as two separate configurations (Haug et al., 2019a; Hvam et al., 2013; Tiihonen, Soininen, Männistö, & Sulonen, 1998). Multilevel configuration systems are introduced to allow a complex ETO company to handle non-configurable components and gradually specify the BOM as the project progresses (Petersen, 2008). System-level configuration with the so-called *white spots* supports continuous specification of the BOM as the project evolves (Kristianto et al., 2015). However, there is no available empirical in-depth case study on how a PCS can be applied to support multiple stages of the order-fulfilment process by updating product specifications, cost and time estimates in a project-based ETO company.

In the case of a project-based ETO company where product specifications often change after sales, interaction between the knowledge from sales and engineering is desirable. Therefore, ETO companies might still benefit from interaction between sales and engineering (Forza & Salvador, 2007).

Recent research has investigated the alignment of sales models and technical models with the introduction of configuration lifecycle management (CLM) (Configit & Batchelor, 2013; Myrodia et al., 2019), which generally stresses the need for the alignment of various IT systems, such as product lifecycle management (PLM), CRM and ERP, with configuration systems at the core. Despite the simple concept of a single source of data, the alignment between sales configuration and production configuration is challenging in practice (Aldanondo, Vareilles, & Djefel, 2010; Zhang, Vareilles, & Aldanondo, 2013). In this study, we explore a case company that used a common application to realise control of product specifications, time estimates and cost control at multiple stages of the order-fulfilment process.

2.3 Costs and benefits of product configuration systems

Companies have started to use PCSs in various phases of the order process in order to gain more control of the product specifications (Forza & Salvador, 2002b; Forza & Salvador, 2007). PCSs support product customisation by defining how predefined entities (physical or non-physical) and their properties (fixed or variable) can be combined (Hvam et al., 2008). Haug, Shafiee, and Hvam (2019b) have identified two types of benefits of product configuration projects: resource use reduction (i.e., cost reduction) and sales performance increase (i.e., revenue increase). The resource-related benefits are the result of automating specification work that was previously carried out by domain experts. These involve aspects such as "less time needed for quote creation, less time needed to create bills of materials and less effort needed for communication between sales staff and engineers" (Haug et al., 2019b). The sales-related benefits concern the development of abilities to produce quotes faster, improved customer communication and improved quote accuracy. The benefits described in the literature include the following:

- improved cost calculation accuracy (Myrodia, Kristjansdottir, & Hvam, 2017; Rasmussen, Hvam, & Mortensen, 2017; Yu & Skovgaard, 1998),
- improved product specification quality (Forza & Salvador, 2002a; Forza, Trentin, & Salvador, 2006; Haug et al., 2011; Heatley, Agarwal, & Tanniru, 1995; Heiskala, Paloheimo, & Tiihonen, 2005; Hvam et al., 2013; Hvam, Malis, Hansen, & Riis, 2004; Hvam et al., 2008; Sviokla, 1990; Trentin et al., 2012; Yu & Skovgaard, 1998),
- improved manufacturing specification quality (Haug et al., 2011),
- increased product standardisation and measurement (Huang, Simpson, & Pine, 2005; Hvam et al., 2013; Meyer & Lehnerd, 1997),
- reduced man-hours in the specification processes (Aldanondo, Rougé, & Véron, 2000; Ardissono et al., 2003; Barker, O'Connor, Bachant, & Soloway, 1989; Forza & Salvador, 2002a; Forza et al., 2006; Haug et al., 2011; Heatley et al., 1995; Heiskala, Tihonen, Paloheimo, & Soininen, 2007; Heiskalaet al., 2005; Hvam, 2006a, 2006b; Hvam et al., 2013, 2004; Petersen, 2007; Sviokla, 1990; Tiihonen, Soininen, Männistö, & Sulonen, 1996),
- increased profitability of customer orders (Haug et al., 2019b; Kristjansdottir, Shafiee, Hvam, Bonev, & Myrodia, 2018; Myrodia et al., 2017) and
- increased product quality (Yu & Skovgaard, 1998).

Regarding the general costs of PCSs, Haug et al. (2019b) have identified four types, as shown in **Fig. 1.** The four types of cost are derived from the distinction between prelaunch and operating costs and between material and human resource costs.

Fig. 1. Cost types in product configuration projects (Haug et al., 2019b)

	Material costs	Human resource costs
Prelaunch costs	▪ Configurator software purchase ▪ Other software purchases ▪ Computers ▪ Etc.	▪ Product redesign ▪ Configurator development ▪ Initial user training ▪ Etc.
Operating costs	▪ Configurator software licenses ▪ Other software licenses ▪ Computer replacements ▪ Etc.	▪ Product model maintenance ▪ Configurator maintenance ▪ Ongoing user training ▪ Etc.

2.4 Multistage product configuration systems

Using different search strings, literature searches in Scopus-indexed papers do not reveal prior studies on the application of PCSs to cover the order-fulfilment process from sales to execution in order to update product specifications in an ETO company. It should be noted that the literature provides a few case studies in which product configurators have supported multiple order-fulfilment stages, for example, sales and engineering (Myrodia, Randrup, & Hvam, 2018; Shafiee, 2018). However, these studies neither outline different strategies for engaging in multistage configuration nor clarify the costs and the benefits of using multistage configuration compared with a single-stage product configuration. To address this literature gap, in the next section, we outline a framework that is later tested in a case study.

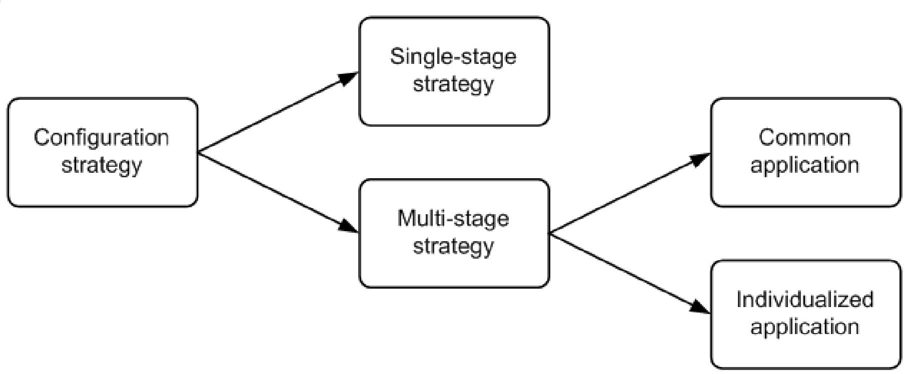
3. A Multistage Product Configuration Framework

In this paper, we use the term "multistage configuration" to describe a strategy where a PCS supports several stages of the order-fulfilment process (e.g., quotation, initial design, detailed design, production and delivery or installation processes). As discussed in literature study, previous studies of PCSs do not discuss multistage configuration as compared to a single-stage product configuration, hereunder clarification of costs, benefits and challenges associated with the use of multistage configuration. This paper addresses this gap in the literature in two steps. First, in this section, we present some assumptions on the differences between single- and multi-stage configurators. In the subsequent sections, these assumptions are tested through a case study.

First, two archetypical multistage product configuration strategies may be defined: (1) single-stage configurators, and (2) multistage configurators. A single-stage configurator supports only one process, such as sales, initial design, or detailed design. Thus, if to support several of such process stages with the single-stage configurator strategy, a separate configurator would be applied in each phase. In the multistage configurator strategy, on the other hand, the same configurator is used during several process stages.

Fig. 2 illustrates different strategies regarding multistage configuration. First, we propose a distinction between single-stage and multistage configuration. Second, under multistage configuration, we distinguish between common application and individualised application. The common application strategy describes an approach where different groups use the same interfaces and knowledge model. The individualised application strategy describes an approach where different groups use different interfaces and knowledge models, respectively. These are discussed further in the following sections.

Fig. 2. Configuration stage strategies.



We suggest that the costs associated with the development of PCSs (as shown in **Fig. 3)**, on average, would be lower when developing a multistage PCS than several separate PCSs for one stage each, since knowledge models and interfaces can be reused across stages, as opposed to the case of implementing separate PCSs. Specifically, the arguments for the decreasing prelaunch costs at Stage 2 and later are as follows: (1) There are only limited additional costs of more hardware and software. (2) Much of the configurator development from the previous stage can be reused. Regarding the operating costs, from Stage 2 onward, there are (1) only limited additional licensing costs and (2) synergy effects with regard to configurator maintenance and documentation. These assumptions are examined in the case study presented later in this paper.

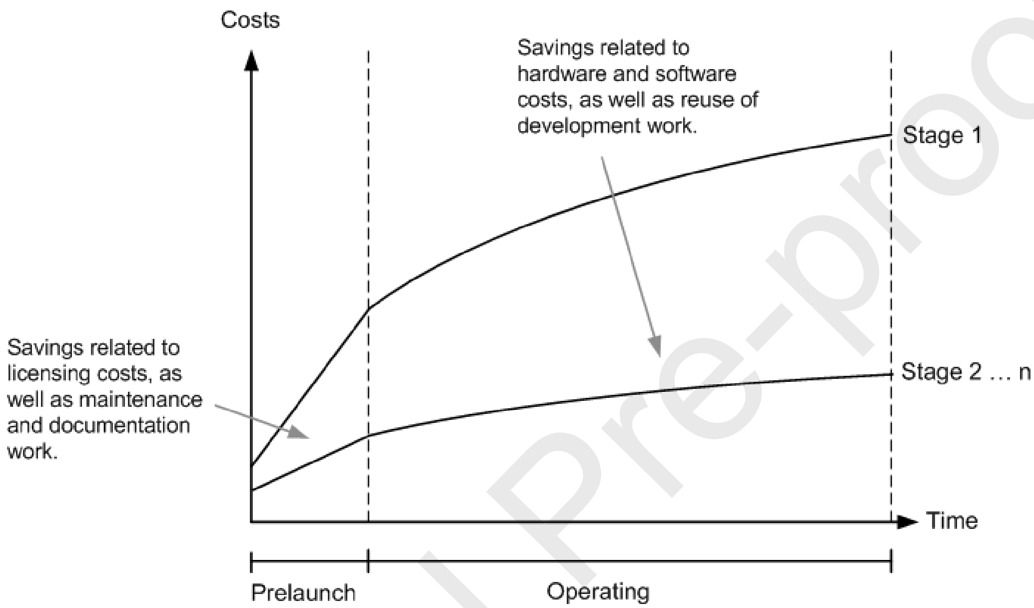


Fig. 3. The costs of multistage configuration.

The two overall types of benefits of product configuration identified by Haug et al. (2019b) – (1) the resource use reduction (i.e., cost reduction) and (2) the sales performance increase (i.e., revenue increase) – may be increased by the use of multistage PCSs. Specifically, multistage configuration benefits from the increased formalisation and coherence of the work in order-fulfilment costs, which can provide resource reductions at additional stages, as well as increased sales performance benefits related to better customer communication and product quality. In other words, extending a PCS beyond the sales phase could increase sales PCS-related benefits gained as a consequence of the product specification steps being carried out in one system.

By distinguishing between individualised and common applications of PCSs, we can define two archetypical multistage product configuration strategies, as illustrated in **Fig. 4.** As seen in **Fig. 4**, in the individualised application strategy, different user groups associated with various disciplines (e.g., sales, initial design and detailed design) are presented with different user interfaces, which draw on various parts of the PCS knowledge base, albeit with significant overlaps. In the common application strategy, different user groups are simply presented with the same interface; thus, they are presented with some fields that should not be filled out at the first stages.

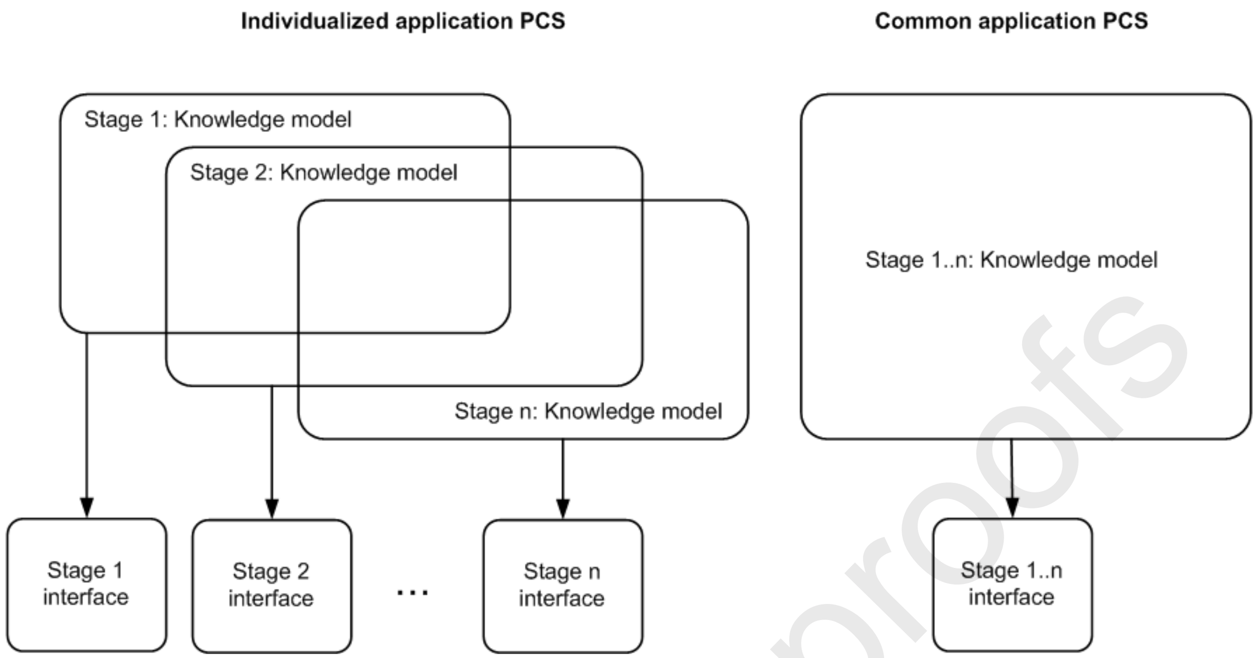


Fig. 4. Multistage product configuration strategies.

The choice between the two multistage product configuration strategies concerns a trade-off between higher development and maintenance costs in the individualised application scenario as a consequence of having to manage several knowledge models (Haug, 2010a, 2010b). In contrast, the common application scenario entails a greater need for user expertise in order to know which field to address at a particular stage, while not being confused by fields that are not associated with the particular stage. Thus, this could involve a longer development time and the need for training and support of PCS users. Not offering adequate training and support poses the risk of users' inputs in fields that they are supposed to ignore. Furthermore, if opting for this scenario, the common application PCS must be sufficiently comprehensive to support the requirements of multiple business groups.

In summary, the benefit of the "common application PCS" strategy is that it has lower development and maintenance costs as compared to the "individualised application PCS" strategy. However, if the different business groups have much different needs, their access to a range of fields that are not relevant for them could cause confusion, leading to errors or inability to carry out tasks. Thus, in cases in which the needs of business groups are different, and this gives raise to too much confusion, the "individualised application PCS" strategy should be chosen. These types of scenarios are further investigated in the subsequent case study.

4. Research Method

4.1 Research aim

The above literature review showed that former studies have not addressed the application of PCSs to support the whole order-handling process in an ETO setting, i.e., on multi-stage configuration.

Moreover, it is not all clear what will be the gained benefits of such an integrative framework. Thus, in this study, we use a case study to investigate multistage configuration, thus contributing to the PCS literature on the benefits from PCS projects.

These considerations are the basis for this study's main research question: *What are the costs and the benefits of multistage product configuration?* We will use the current literature on the concept of multistage configuration to extend the knowledge about the utilisation of PCSs by introducing our framework. In addition, we will discuss the case study and the associated costs and benefits, as well strategies. Next, we discuss the results of the case study including the gained benefits and challenges.

4.2 The case study method

A case study was conducted to explore the framework presented in the previous section. An explorative single-case study was used because it allowed a phenomenon to be examined in its natural setting, addressing the questions of "how" and "what" (Karlsson, 2016; Meredith, 1998). The single-case study design allowed the research team to investigate the possibilities of using a common application PCS to support a multistage configuration strategy in a project based medium-sized enterprise delivering ETO products.

The research team had access to the company for one year and nine months and worked in close collaboration with the company to conduct an in-depth analysis (**Fig. 5**). The time span of the research allowed an in-depth understanding of the company processes, as well as the observation of behavioural changes over time as the project evolved and created an impact. The researchers observed the changes in meetings, informal chats and co-development workshops while investigating the cost benefits for the company, as well as conducting semi-structured interviews with selected employees and administering questionnaires to them.

4.3 The company

The case company was selected due to managerial support in providing complete access to information and testing the proposed case application, as well as the availability of a pre-existing single-stage configurator that was planned to be extended to support multiple stages. The case company also agreed to share all costs and data from both the pre-existing configurator and the multistage configurator. The downside of the single-case study design is the reduced generalisability (Karlsson, 2016), which can be mitigated by repeating the research in other case companies (Eisenhardt, 1991); however, it was not always possible to access multiple case companies due to resource constraints. Reliability was improved by using triangulation with the available data sources (Karlsson, 2016). To increase construct validity, three forms of triangulation were implemented: observer, data (source) and methodological triangulation (Runeson & Höst, 2008).

4.4 Timeline of research activities

Fig. 5 depicts a chronological sequence of the research activities undertaken in this study. The single-stage configuration approach was used for seven years prior to this research project, indicating the case company's extensive experience in product configuration. The development of the configurator to support multistage configuration took nine months. The multistage strategy was in operation for one year before the evaluation of the solution presented in this study.

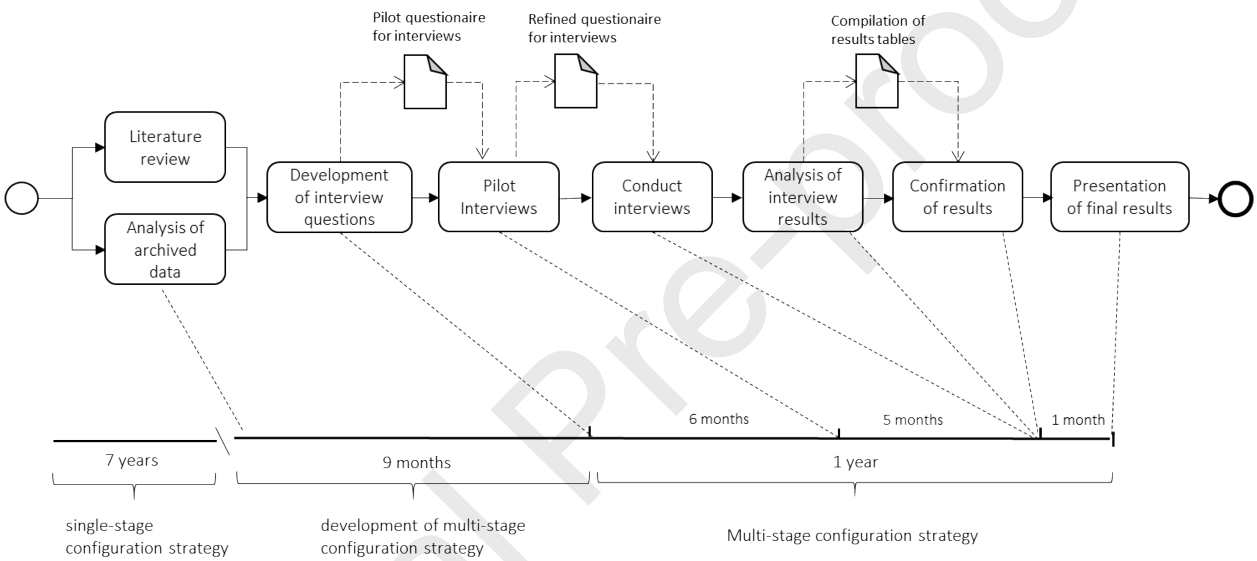


Fig. 5. Mixed methodology and time plan of the study.

The research project was initiated with an analysis of archived data and a literature review conducted in parallel. The literature on costs and benefits under a single-stage configuration strategy was reviewed to transfer learnings to a multistage strategy. The purpose of the analysis of archived data was to obtain knowledge about the development costs of the configuration system that served as the foundation for the multistage extension. These activities were performed for nine months, along with the development of the multistage configuration solution.

Subsequently, the following processes were performed sequentially.

1. *Development of interview questions*. The structure of the questions for the semi-structured interview was based on the benefits of implementing configurators. In accordance with the research objectives, the interviews were designed to systematically compare the benefits gained from a multistage configurator with those from a single-stage configurator with respect to PCS benefits. The semi-structured interview process involved experienced researchers, experienced PCS project stakeholders and management representatives.

2. *Pilot interviews.* The identified questions based on the literature were tested in pilot interviews with a relevant employee with sufficient experience to assess the clarity of the questions and their relevance to the multistage solution.

3. *Refinement of interviews.* Based on the pilot interviews, the number of questions was reduced from 14 to 10. Questions were removed if they could not be answered sufficiently based on the current knowledge of the company or if they were irrelevant to the multistage system. The excluded items related to the difference between single-stage and multistage configurators included the following: "The time from customer request to quote has increased", "Sales have increased", "Resources needed to create quotes have decreased" and "Lead time to deliver product has decreased".

4. *Conducting the interviews.* The interviews were conducted separately with four employees from the management team. They all completed the questionnaire and participated in a short conversation about the questions and the results.

5. *Confirmation of results.* The results were compiled, and selected answers were presented to selected interviewees to confirm the results and elaborate on potential reasons.

6. *Presentation of final results.* Based on the final remarks of the interviewees, the results were edited for the last time before being presented in this paper.

4. 5 Data collection

4.5.1. Archived data

In case studies, documents play an explicit role in data collection (Yin, 2003). In the present study, the collected documents were related to (1) the *documentation of the configuration project development and product details* and (2) the *time spent on different tasks related to configuration development based on calendar entries and time tracking*. In this research, these documents have been used as literal recordings of past events to assess the development costs. We reviewed all of these documents before starting with other empirical investigations to gain further insights into the company, the culture and the specification processes.

4.5.2. Interviews

These interview questions were developed based on a literature review of benefits gained through single-stage configuration. The aspects identified in the literature were evaluated by the interviewees using a 5-point Likert scale to compare the impact of a multistage configuration strategy to a single-stage strategy. Each participant answered ten different questions in the first interview using the Likert scale and open questions to add insights, explanations and comments. The interviews were recorded, typewritten and analysed, following the prescriptions suggested by (K. Eisenhardt, 1989; Yin, 2003). The questions were followed by an open-ended discussion of the questions. Due to the open-ended format, there was sufficient freedom for the interviewees to add extra comments. This open-ended interview technique (Yin, 2003) facilitated the collection of background data and consequently enhanced the richness of this study. The qualitative results are presented in **Table 4**.

4.5.2.1. Interview team and the interviewed stakeholders

The interview questions were prepared by a team consisted of one specialist in construction modularization, one specialist in PCS, and one specialist in both domains and conducted by the specialist in PCS. For this research, four employees were selected to be interviewed based on the following criteria: they must have (1) *different backgrounds and responsibilities, representing knowledge of multiple stages of the company*; (2) *years of experience in the company at the management level*; (3) *a direct impression of the multistage configuration system's impact on the business;* and *(4) been present during the sales PCS performance and witnessed the transition from a single-stage to a multistage PCS. The differences among the selected interviewees included (1) They had different backgrounds and a different number of years of experience with PCSs; hence, they had different perspectives, expectations and concerns; (2) They had different roles in the PCS team, ranging from user of the system, user of outputs generated from the PCS, project manager and domain expert; hence, they could share their varying perspectives, and the study can report different challenges form different perspectives.* A summary of the selected employees and their experiences is shown in **Table 1.**

Table 1

The interviewees' background information

Position	**Company director**	**Financial director**	**Sales director**	**Production director**
Years in current position	3	2	8	3
Years of relevant experience	10	5	10	4
Current role	Responsible for setting strategies and goals, prioritising resources	Responsible for financial planning, record keeping and financial reporting	Manages a team of salespeople; responsible for sales and configuration development	Responsible for quality, planning and installation of products

4.5.2.2. Interview questionnaire and process

The interviews aimed to understand and verify the retrieved archived data, as well as to obtain additional information on costs, benefits and challenges. The interview questions were developed based on a literature review of the benefits gained through a single-stage configuration. The interview guide questions were followed by open-ended discussions. The open-ended format allowed the interviewees sufficient freedom to provide extra comments or opinions. This open-ended interview technique (Yin, 2003) facilitated the collection of background data and consequently enhanced the richness of this study. The interview process was semi-structured (Runeson and Höst, 2008). The aspects identified in the literature were evaluated by the interviewees using a 5-point Likert scale (ranging from strongly agree to strongly disagree) to compare the impact of a multistage configuration strategy with that of a single-stage strategy. Each participant answered ten different questions in the first interview using the Likert scale and open questions to add insights, explanations and comments. The questions were asked in a way that gave the respondents the freedom to add comments or opinions to the scale (Jefferson and Hollway, 2000). For each interview, a researcher reported the interview responses in a text file and returned the file to the respondent to check and confirm the interview content.

4.5.2.3. The interplay of interviews and data analysis

Once the questionnaire was set up, the data collection and analysis began as proceeded through the following steps:

1. An initial analysis of the documents from the case study was performed including the statuses of the project; the requirements for the development of a common multistage application; and cost of implementing the multistage PCS for balconies. This is reported in section 5.1--5.4;
2. The interviews were performed with the individuals who had the most comprehensive knowledge about the impact of the system using the questionnaire set up by the research team. The interviews and complementary data sources were studied a numeric expression of the employees' assessment of the impact of the multistage configuration strategy compared with the single-stage strategy. This is reported in section 5.5;
3. Final discussions and conclusions were drawn. They are presented in section 6.

4.5.2. Data triangulation

As mentioned earlier, in our case study, we focused on investigating the feasibility of the multistage configuration system approach outlined by the proposed framework. Thus, our analyses of the collected data focused on identifying the costs, benefits and challenges of this approach by finding the parts of the interview transcripts that concerned these topics. To ensure validity, data triangulation (Denzin, 2006) was carried out in the form of cross-checks of the information received from different interviewees, as well as the retrieved archived data. In cases of disagreement, the interviewees were contacted again to understand the reasons for such differences in perceptions until such issues had been resolved. Investigator triangulation (Denzin, 2006) was carried out by having two researchers analyse the interview transcripts and compare their conclusions.

4.6 Data analysis

Data analysis was performed in parallel with data collection. Qualitative data were structured into tables in order to obtain the best possible overview and each project was subjected to a preliminary analysis as a stand-alone entity. First of all, we analysed the Initial PCS order-fulfilment process used by the company which consisted of four major phases; the results were then demonstrated in figure 7. Two of the researchers independently went through all the documents and collected the data relevant for understanding the case. Second, the aim of the multistage configuration and the overall process is shown in Figure 8. Third, we analysed the three identified capabilities needed in the common multistage application of a PCS and drawn the figures 9 and 10. Fourth, the interview results were analysed by examining to retrieve the cost of developing the multistage PCS, and the additional cost of including further phases by extending the single-stage approach as shown in Table 3. Moreover, Likert-scale ratings were used to evaluate the employees' assessment of the impact of the multistage configuration strategy compared with the single-stage strategy (Table 4). Finally, to further explain the evaluations provided by the interviewees, especially the associated challenges, we provided a set of sample statements derived from open questions. For the sake of readability, the results are summarised/illustrated in Table 5.

5. Case Study Results

To explore the proposed framework, we conducted a case study of a company where a multistage PCS was developed and implemented. It was a medium-sized company that sold, planned and installed balconies on existing buildings. The company operated in a market where customisation was necessary in order to satisfy the requirements from customers and local authorities. Consequently, all products had to meet particular needs, such as specific dimensions, architectural appeal and structural strength, to fit the existing buildings. The company handled the process of designing and specifying the products, obtaining approval from the authorities, ordering balconies from a manufacturer and installing them.

All products had to undergo engineering calculations after the orders were received. The company could thereby be classified as a repeatable ETO in the construction category with yearly production and mounting of thousands of balconies (Willner et al., 2016). The company offered products and installation procedures based on a predefined structure, consisting of modules that could be mixed and matched to create customised solutions, as illustrated in **Fig. 6.** This involved specifying a large number of product and installation attributes; a selection of the most important attributes is listed in **Table 2**. Since the attributes could be mixed and matched, a large variety of products was also offered by the company. The complete configurator consisted of over 4000 unique attributes and more than 1500 constraints and supported 2 x 10^94 different solutions. According to Shafiee et al. (2017), this can be classified as a configuration system with high complexity.

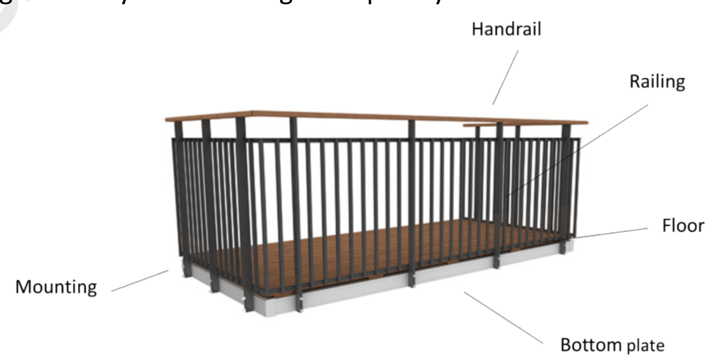


Fig. 6. Predefined balcony structure.

Table 2
Examples of attributes that can be customised on a balcony offered by the company

Attribute	No. of variants	Values
Balcony bottom plate	10	Custom measure
Railing	180	Custom measure
Door	100	Custom measure
Window	10	Custom measure
Floor	4	Custom measure
Balcony-to-building mounting	22	Custom measure and custom static calculations
Rail-to-balcony bottom-plate mounting	3	Kinds
Water overflow principle	3	Kinds
Colour variants for all the above parts	10 -> infinity	10 standard colours, infinite colours on request
Procedures related to installation	~ 125	Specific tasks, including numerous subtasks

5.1 Initial PCS order-fulfilment process

The process used by the company consisted of four major phases: (1) sales, (2) initial design specification, (3) detailed design specification and (4) installation on site. **Fig. 7** depicts the original specification process, where a single-stage configurator provided product specifications in the form of a BOM and cost and time estimates in the sales phase. In later phases, specification changes were documented in other systems. The process included obtaining initial design approval from local authorities. The detailed specification phase included static calculations and specifications of exact drawings, which required another approval from local authorities. Based on the detailed project, the products were ordered from a supplier, and on-site production was initiated and completed.

In Phase 1, the salespeople would generate an offer based on customer wishes and the sales configurator. When the customer and the salespeople agreed on the product variant and price, they would sign a contract based on the PCS calculations. When the salespeople handed over the contract, the PCS would no longer be updated. The consequence was that the project controller would only have the specifications of the BOM and cost and time estimates from the point of sale. The initial and the detailed design phases usually introduced changes to product designs, and the project changes were handled in various systems, such as electronic document and record management systems, text documents, spreadsheets and pdf files on shared drives. When the project was completed, the products would be ordered from suppliers and installed by the company on site.

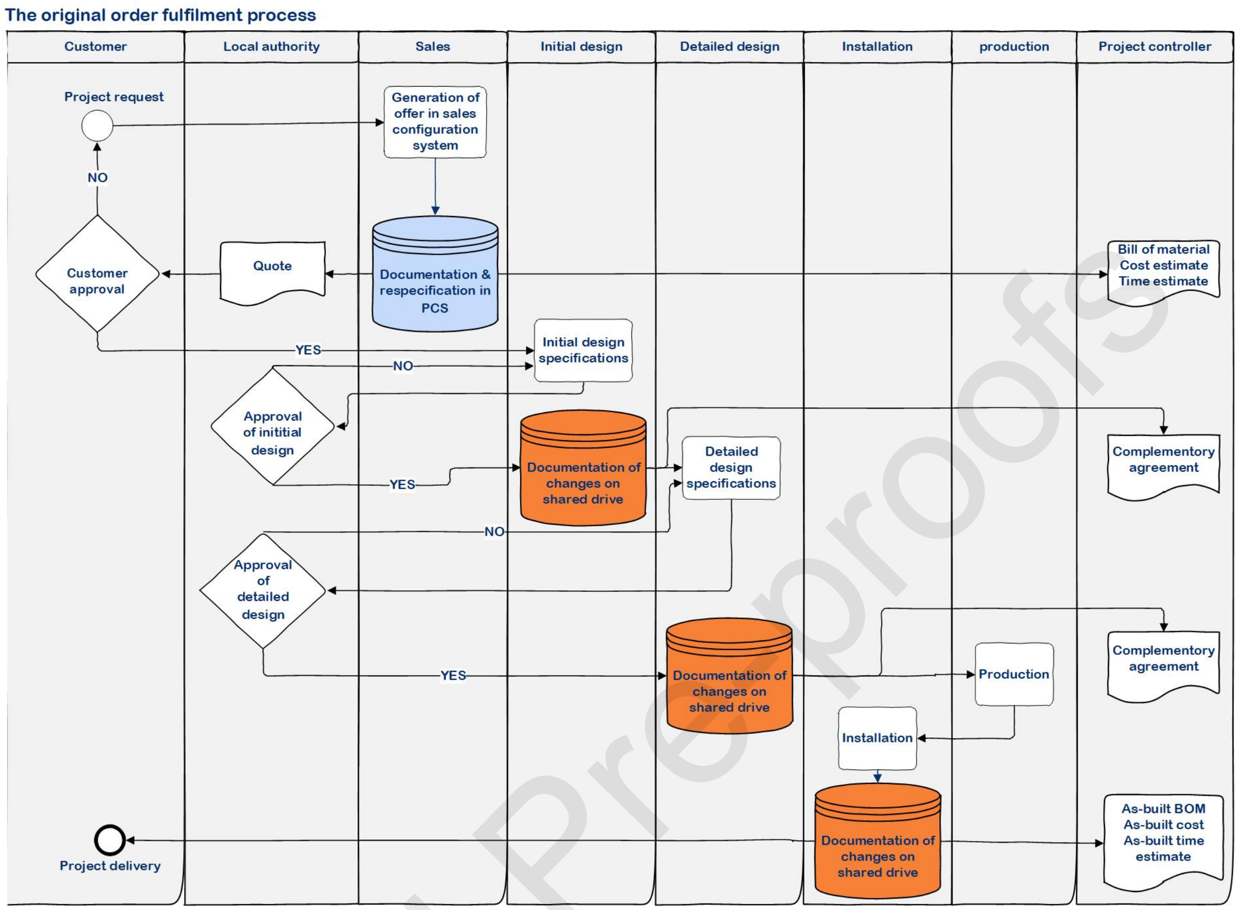


Fig. 7. Original order-fulfilment process.

This company experienced many product specification changes between the point of contract and production, as reported in the ETO literature (Foehr et al., 2015; Konijnendijk, 1994). After the analysis of the case company, the original order specification introduced three major challenges: (1) The product specification changes in subsequent phases typically had an impact on product specifications, including BOM specifications, cost estimates and time estimates. These changes were stored in multiple IT systems for the product manufacturers and salary calculations. These changes were not necessarily documented in a systematic way that allowed other employees to track the changes and the progress. This was a source of frustration as the details stored in different systems could deviate, making the employees question the correctness of the data. (2) The changes made outside the sales configurator no longer had to comply with the product configurator. The effect was that changes could be made that did not favour the preferred solutions in terms of cost agreements with suppliers. This resulted in higher costs due to extra engineering hours. (3) The dynamic effects in the configurator were no longer taken into account. Therefore, if a solution was changed in the detailed design material, the change in material costs would be registered but not necessarily be reflected in the time estimates and the cost estimates that would automatically be performed by the configuration system. To gain more control of the order-fulfilment process and the associated changes in cost and time estimates, the company expanded the existing PCS to support the order-fulfilment process by adopting the common application multistage configuration approach, as presented in this paper.

5.2 Order-fulfilment process supported by a comprehensive, integrated PCS solution

The company extended the single-stage PCS to a multistage configurator to support all phases of the order-handling process. The aim of the multistage configuration process is shown in **Fig. 8**. The overall process was the same – however, it was changed in the sense that changes in product specifications were updated throughout the order-fulfilment process and recalculated based on the multistage PCS updating the BOM and cost and time estimates in all phases. Specifically, phase 1 was handled in the same way as in the original process, while Phases 2–4 were handled in the multistage configuration process. In other words, previously, the PCS only supported the sales process, while now it supports initial design and detailed design as well. The two latter phases have the same purpose and outputs as before, the only difference being is that they now are supported by the PCS.

The goal of the process change was to update the configurator at multiple stages consistently according to project changes, as opposed to only use it in the sales phase. The applied solution for this had to be feasible, preferable and in accordance with the product knowledge at all times. This setup allowed the company to track specification changes related to the BOM, cost estimates and time estimates throughout the project order handling.

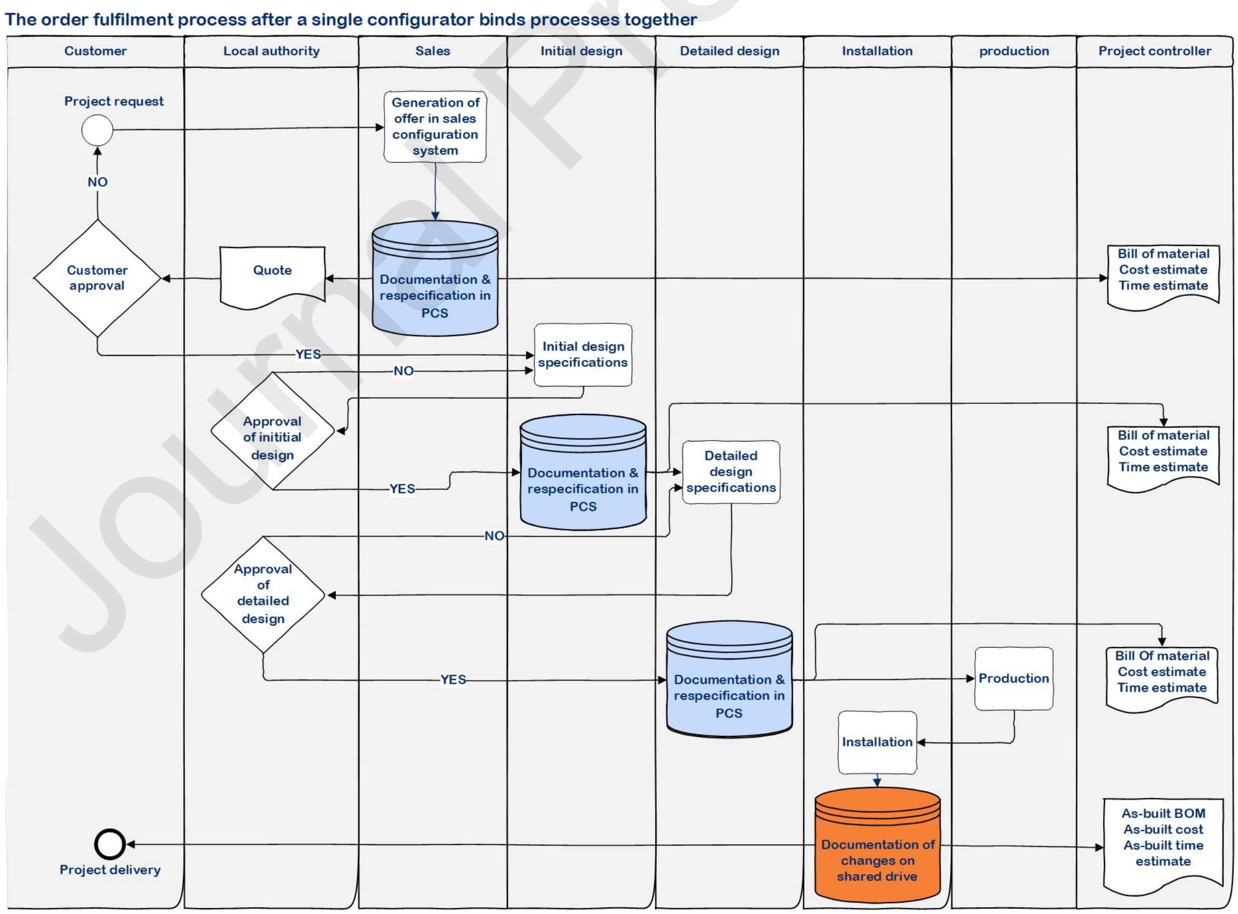


Fig. 8. The new multistage configuration order-handling process.

5.3 Configuration system requirements for the development of a common multistage application

The company identified three capabilities needed in the common multistage application of a PCS: (1) a well-structured, comprehensive PCS model covering product specification needs in all phases, (2) the ability to handle off-standard specifications and (3) revision control and traceability of changes in the project as it moves through Phases 1–4. The company employed the following three development initiatives to address the identified capabilities:

1. Evaluation of PCS comprehensiveness. The company evaluated the comprehensiveness of the PCS model and identified some minor changes and missing configuration choices that had to be added to support later specification phases. The overall structure of the products and of the process knowledge stored in the configuration system was found to be identical to the structure in all order-handling phases. This made it possible for the company to expand the knowledge model and adopt the common application approach to multistage configuration, as presented in Section 3.

The most significant change involved the task of aligning the naming convention of the parts between all departments and systems so that everyone could understand and use the output of the configurator. An illustration of a product model with an increased detail level as the project evolved is shown in **Fig. 9**, which was drawn using the product variant master (PVM) notation (Harlou, 2008) (in this context, showing part of the structure and part of the attributes). As illustrated, the PCS evolves throughout the order-fulfilment process, where attributes are continuously changed and updated as more knowledge is gathered or changed in the project.

2. PCS handling of non-standard products. The company introduced the configurator's ability to handle "non-standard" parts and products by allowing "special solutions". The special solutions were associated with a custom cost that was manually entered and a description for future reference. This cost was calculated manually based on the experience with similar projects or retrieved from external suppliers. The special fields were integrated into the BOM, costing and time data.

3. Introduction of revision system. The company developed a revision system that indicated phase changes so that a list of all configuration revisions was easily accessible on a project basis. This is illustrated in **Fig. 10**, where each row represents a revision of a complete configured project. The right-most column represents the process stage; different icons represent draft, contract and legally binding states of the configuration.

This revision system enabled the company to trace how costs and specifications changed in different phases of the project. The revision tool included the unique ID of the responsible employee who created the revision, an automatically generated revision number, a change date, a field for a customised project title, estimated overall costs and a process state. The company formalised the process states as "offer", "contract", "initial design", "initial design (approved)", "detailed design" and "detailed design (approved)". Every change in the configuration was assigned its state, and a copy was made. During the legally binding process steps, the configuration was "frozen" to illustrate the importance of that exact configuration. For example, the contract phase included the legally binding price signed by the customer, and the exact design that was approved in the design phase locked some configurations, so they were no longer changeable. The goal was to ensure traceability, responsibility and data quality.

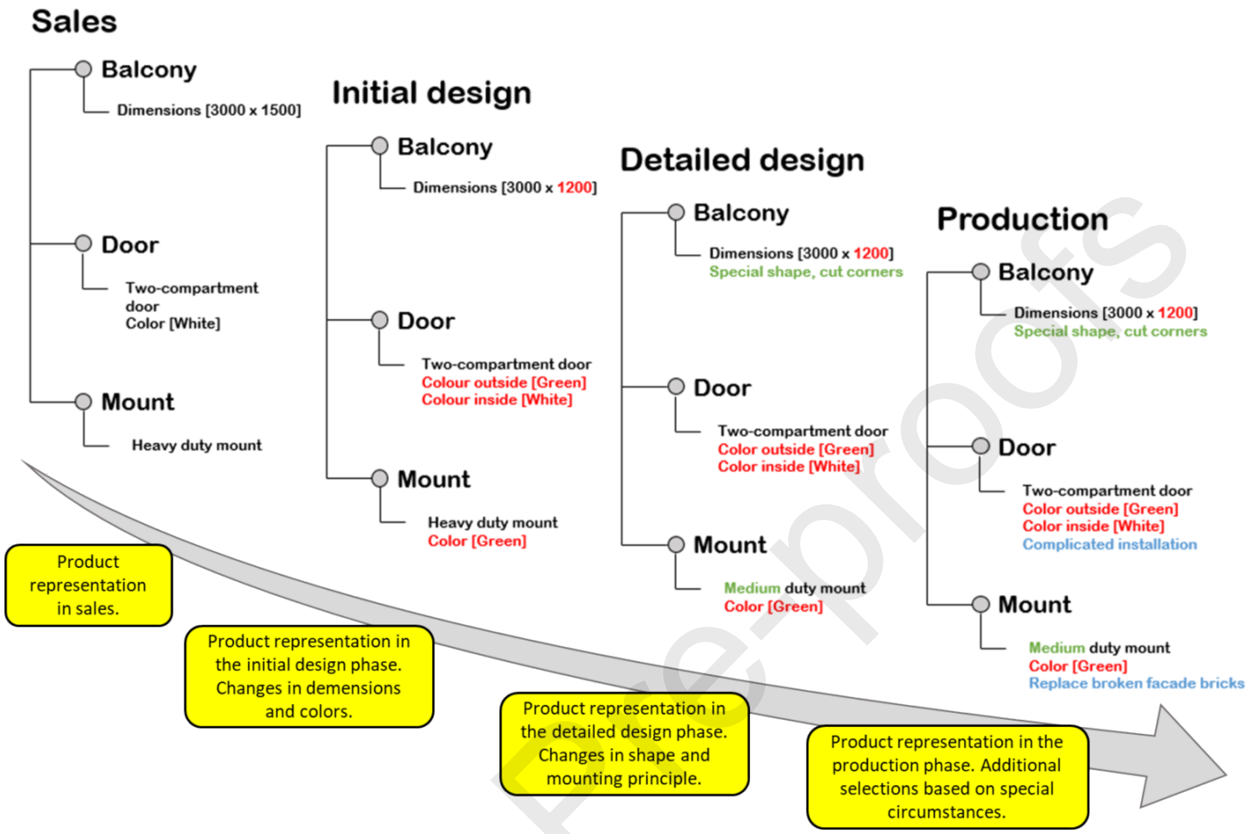
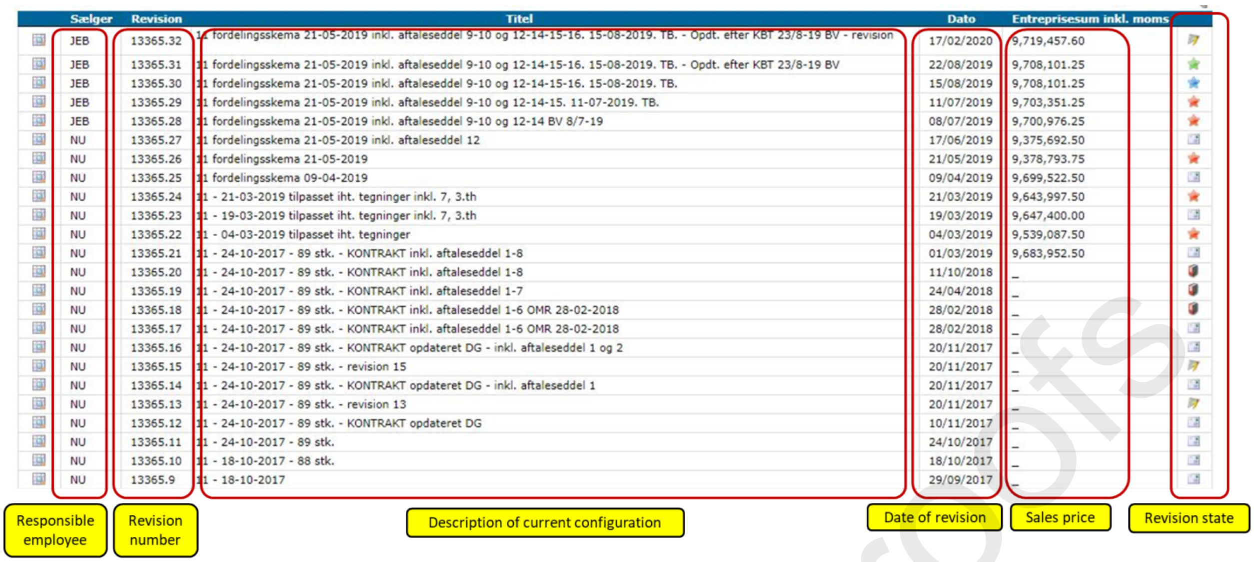


Fig. 9. Evolution of product specifications.



	Sælger	Revision	Titel	Dato	Entreprisesum inkl. moms	
	JEB	13365.32	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 9-10 og 12-14-15-16. 15-08-2019. TB. - Opdt. efter KBT 23/8-19 BV - revision	17/02/2020	9,719,457.60	
	JEB	13365.31	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 9-10 og 12-14-15-16. 15-08-2019. TB. - Opdt. efter KBT 23/8-19 BV	22/08/2019	9,708,101.25	
	JEB	13365.30	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 9-10 og 12-14-15-16. 15-08-2019. TB.	15/08/2019	9,708,101.25	
	JEB	13365.29	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 9-10 og 12-14-15. 11-07-2019. TB.	11/07/2019	9,703,351.25	
	JEB	13365.28	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 9-10 og 12-14 BV 8/7-19	08/07/2019	9,700,976.25	
	NU	13365.27	11 fordelingsskema 21-05-2019 inkl. aftaleseddel 12	17/06/2019	9,375,692.50	
	NU	13365.26	11 fordelingsskema 21-05-2019	21/05/2019	9,378,793.75	
	NU	13365.25	11 fordelingsskema 09-04-2019	09/04/2019	9,699,522.50	
	NU	13365.24	11 - 21-03-2019 tilpasset iht. tegninger inkl. 7, 3.th	21/03/2019	9,643,997.50	
	NU	13365.23	11 - 19-03-2019 tilpasset iht. tegninger inkl. 7, 3.th	19/03/2019	9,647,400.00	
	NU	13365.22	11 - 04-03-2019 tilpasset iht. tegninger	04/03/2019	9,539,087.50	
	NU	13365.21	11 - 24-10-2017 - 89 stk. - KONTRAKT inkl. aftaleseddel 1-8	01/03/2019	9,683,952.50	
	NU	13365.20	11 - 24-10-2017 - 89 stk. - KONTRAKT inkl. aftaleseddel 1-8	11/10/2018	_	
	NU	13365.19	11 - 24-10-2017 - 89 stk. - KONTRAKT inkl. aftaleseddel 1-7	24/04/2018	_	
	NU	13365.18	11 - 24-10-2017 - 89 stk. - KONTRAKT inkl. aftaleseddel 1-6 OMR 28-02-2018	28/02/2018	_	
	NU	13365.17	11 - 24-10-2017 - 89 stk. - KONTRAKT inkl. aftaleseddel 1-6 OMR 28-02-2018	28/02/2018	_	
	NU	13365.16	11 - 24-10-2017 - 89 stk. - KONTRAKT opdateret DG - inkl. aftaleseddel 1 og 2	20/11/2017	_	
	NU	13365.15	11 - 24-10-2017 - 89 stk. - revision 15	20/11/2017	_	
	NU	13365.14	11 - 24-10-2017 - 89 stk. - KONTRAKT opdateret DG - inkl. aftaleseddel 1	20/11/2017	_	
	NU	13365.13	11 - 24-10-2017 - 89 stk. - revision 13	20/11/2017	_	
	NU	13365.12	11 - 24-10-2017 - 89 stk. - KONTRAKT opdateret DG	10/11/2017	_	
	NU	13365.11	11 - 24-10-2017 - 89 stk.	24/10/2017	_	
	NU	13365.10	11 - 18-10-2017 - 88 stk.	18/10/2017	_	
	NU	13365.9	11 - 18-10-2017	29/09/2017	_	

Fig. 10 Revision list of the multistage configuration progress of a single project.

Finally, **Fig. 11** shows one of the user interfaces of the PCS (in Danish). In the Figure, to the left, it is shown which users insert or edit which information. As seen, the fields "AltanType" (balcony type) and "ProductSerie" (product series) are filled out by a salesperson and not subsequently revised. On the other hand, fields such as "Bredde" (width) and "Dybde" (depth) may later be modified in the initial design and detailed design phase by construction architects and engineers.

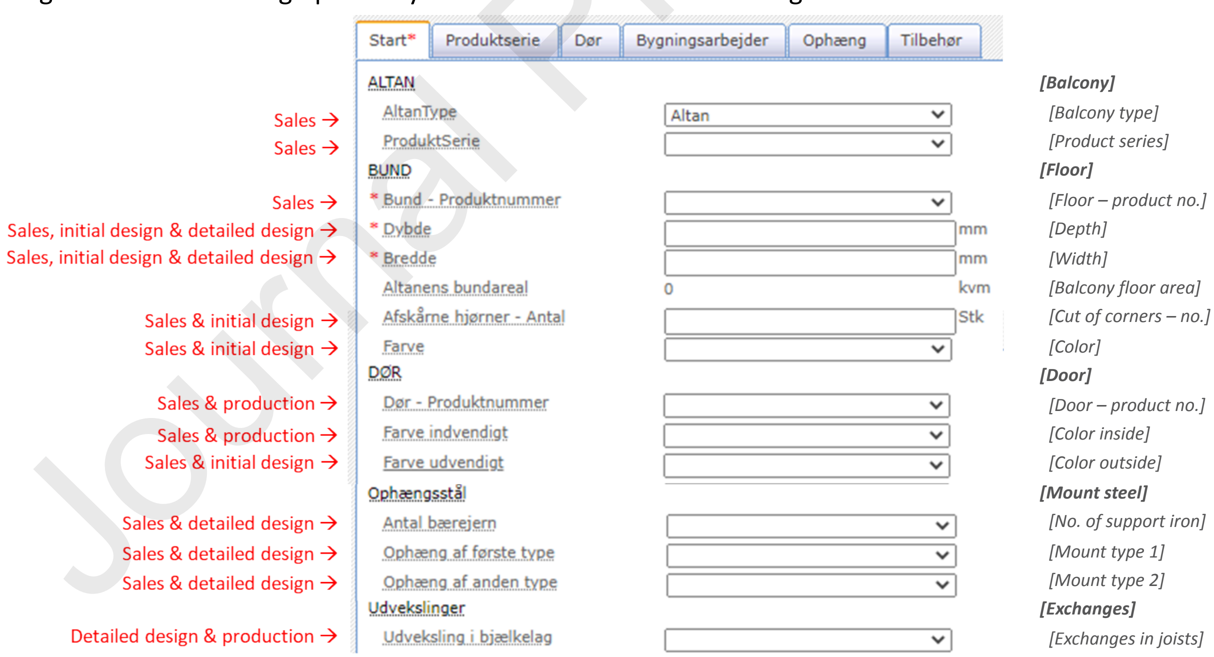


Fig. 11. Screenshot from the system showing fields used by different users.

5.4 Cost of implementing the multistage PCS for balconies

The cost of developing the multistage PCS was retrieved from the four interviewees and organised as defined by Haug et al. (2019b). The additional costs of extending the configurator beyond the sales phase are shown in **Table 3**. As presented in the theoretical model for multistage configuration, the additional cost of including further phases by extending the single-stage approach is low compared with the initial investments.

Seven years before the start of this study, the first version of the single-stage configuration system was developed to support balcony configurations. The configuration system was modernised to a second-generation PCS before the implementation of the multistage configurator. The costs in this study represent the development of the second-generation PCS to reflect modern technology and current costs. However, the experience gained by the company during prior projects might have eased the transition from single-stage to multistage configuration. The costs represent investments in a customised configuration system that included the development of several unrelated specialised features, including dynamic interaction between different product configurators and support of multiple currencies and languages. Therefore, some of the hardware and software investments were not strictly necessary to obtain the benefits presented in this paper.

The prelaunch costs related to multistage support were modest in terms of hardware and software investments, which were limited to the development of support for non-standard products and a revision system. The additional prelaunch costs of the multistage configuration were related to the PCS development time and domain expert time. A significant amount of effort was dedicated to testing and adjusting the common application configuration model to ensure that correct specifications were generated by the PCS.

The operational costs of the multistage configurator had no noticeable increase compared with those of the single-stage configurator. The software costs did not increase since the company had chosen a vendor that allowed unlimited users of the configuration system without an increase in licensing costs. To adress the challenge of teaching all employees how to use a complex product configurator, the company assigned experienced configuration users to update projects. Due to the close resemblance between the multistage and the single-stage systems, the training was very modest. The added level of detail and instructions on how to use the common application were explained in emails and via informal knowledge sharing among colleagues.

Table 3

Costs of developing a multistage product configuration system for balconies

		Sales configurator project (18 months)	**Additional costs of including initial design (3 months)**	**Additional costs of including detailed design (3 months)**	**Additional costs of including installation (3 months)**
Prelaunch	Hardware and software investments	300.000 €	5.600 € (+1,9%)		
	Developer time for development of PCS	42.750 € (950 h)	6.660 € (148 h +16%)	3.105 € (69 h +7%)	3.555 € (79 h +8%)

	Domain expert time for development of PCS	8.325 € (185 h)	2.655 € (59 h +32%)	1.710 € (38 h +21%)	2.160 € (48 h +26%)
	PCS training	2.035 € (55 h)	Almost no additional training required		
Annual operation	Licences for PCS software	3.300 €	No additional operational costs		
	Service agreement for external PCS support	5.900 €	No additional operational costs		
	Maintenance of product model	6.660 € (148 h)	315 € (7 h +5%)	315 € (7 h +5%)	675 € (15 h +10%)
	Training of salespeople	3.256 € (88 h)	Almost no additional training required		
Total costs					
Prelaunch (including training)		353.110 €	11.182 €	6.682 €	7.582 €
Annual operation		19.116 €	315 €	315 €	675 €

5.5 Benefits of implementing a multistage product configuration system for balconies

As mentioned previously, four key employees were interviewed to assess the costs and the benefits of implementing a multistage PCS in the order-fulfilment process. The employees were selected from the project leaders and the responsible employees to gather a qualified evaluation of the impact.

The main results obtained from the interviews regarding the benefits are summarised in **Table 4**, which contains a numeric expression of the employees' assessment of the impact of the multistage configuration strategy compared with the single-stage strategy. The effects of using and extending the PCS beyond the sales stage were rated on a Likert scale, as follows: strongly disagree (1), disagree (2), undecided (3), agree (4) and strongly agree (5). The benefits of the three additional stages are described in a single evaluation as these were difficult to assign to particular stages but should be viewed in combination.

As shown in the last column of **Table 4**, we calculated the mean values of the answers. The mean value provides a good evaluation of the overall rating of different statements.

Table 4

Impact of multistage compared to single-stage configurator strategy

	Evaluation of benefits of moving from single-stage to multistage PCS	Company director	Financial director	Sales director	Production director	Mean value
1	Accuracy of cost calculations has increased	5	4	5	NA*	4.66
2	Accuracy of the BOMs has increased	5	NA*	5	4	4.66

3	Accuracy of the salary calculations has increased	5	4	5	5	4.75
4	Accuracy of project time estimation has increased	5	NA*	5	4	4.66
5	More products are specified and ordered within standard measures	NA*	4	5	4	4.33
6	Time required to identify project information has decreased	NA*	NA*	5	4	4.5
7	More projects can be handled by the same or fewer number of employees	5	4	5	4	4.5
8	Projects have become more profitable	NA**	4	5	NA*	4.5
9	Quality of the finished products has improved	5	NA*	NA*	4	4.5
10	Multistage product configuration provides a competitive advantage	5	4	3	5	4.25

* Not answered because the question was out of their expertise area
** Not answered because the interviewees neither agreed nor disagreed with the statement

Table 4 shows that for all the benefit categories, the multistage configurator provides better support to the company. Additionally, the mean value of the benefit ratings for the multistage configurator compared with the single-stage configurator is higher than 4.33 out of 5. As a multistage configurator covers different disciplines, the interviewees could not answer all questions since the impact was expected to be broad and not possible for every employee to know. Hence, the production director may know more about the finished product quality than sales. Most notable are the answers to questions 5, 8 and 10 (**Table 4**). Statement 5, “More products are specified and ordered within standard measures”, was difficult to assess, so the interviewees settled on a conservative estimate that favoured their impression of better compliance with standards. The sales director and the financial director agreed with Statement 8, “Projects have become more profitable”, while the company director was not sure that the multistage configurator was the reason for it. The interviewees generally agreed with Statement 10, “Multistage product configuration provides a competitive advantage”, except the sales director, who did not think that customers cared about the internal process when selecting a supplier.

To further explain the evaluations provided by the interviewees, **Table 5** presents a set of sample statements. As shown, the company director understood the project from a high-level perspective and found that the implementation process was long, but the results were worth the wait. The financial director and the production director both elaborated on the increased salary calculation accuracy, which resulted in better planning and resource allocation. The sales director stressed the new process of recalculation with the multistage configurator as a huge gain in the internal processes, noting the decreased likelihood of mistakes.

Table 5

Main interview results obtained from the semi-structured open questions in the balcony company

Interviewee	**Statement**
Company director	“It was a long process to get the multistage configuration to work, but now that it works, it increases the quality of the project execution in terms of both efficiency and accuracy.”
Financial director	“It is my impression that the configurator accuracy has improved after we started to update the configurator in initial design and detailed design phases. Before the implementation, there [were] significant differences between calculated salary cost and realised salary cost, but after the configurator is visible for anyone, the costs have been renegotiated to fit.”

	"Overall, the configurator output is very important for my ability to make correct financial reporting on projects. When a project is in the detailed design phase, my impression on the ongoing projects right now is that it will deviate in the range of ± 1,5% on the contribution margin."
Sales director	"The ability to update and use the configurator in project order handling is a huge gain internally and makes sure that the quotes are precise and the sold projects comply with product standards."
	"Before, only a subset of projects was recalculated throughout order fulfilment (approximately 45%). Thanks to the multistage configurator, 100% of projects are recalculated, and [it] provides a more accurate picture of costs due to a more detailed configuration model."
Production director	"The most significant change in the production is that the salary calculations are now more precise."

6. Discussion and Conclusions

6.1 Summary

To address the lack of knowledge about multistage configurators and the costs and the benefits related to such implementations, as discussed in the product configuration literature, in this paper, we have developed a theoretical framework to describe multistage configuration strategies. This has been done by relating the multistage configuration framework to the costs and the benefits reported in the single-stage configuration literature. As the existing literature does not delve into details about the different approaches to implementing multistage configurators, as well as the associated costs and benefits, the framework and the supporting case study represent novel contributions that are of value for both research and practice.

To investigate the usefulness of the framework, a case study has been conducted in a company that has adopted a multistage configuration strategy from a single-stage system. The company had already used a single-stage configurator for seven years and therefore represents an enterprise experienced in product configuration. This project-based company delivers customised and engineered solutions with similar characteristics. Therefore, the repeatability of products and projects, relatively low product complexity and similar product specifications are considered enablers for gaining benefits from the multistage configuration strategy. Companies such as this are referred to as basic and repeatable ETOs (Willner et al., 2016), which we consider ideal candidates for adopting our presented approach. The key capabilities needed to adopt a common application multistage strategy have been identified as follows: (1) a well-structured comprehensive PCS model covering product specification needs in all phases, (2) the ability to handle off-standard specifications and (3) revision control and traceability of changes in the project as it moves through the specification phases. Furthermore, the costs of developing the multistage configuration system have been compared with the benefits reported by key employees. The benefits have been assessed using questionnaires and semi-structured interviews with four key employees. The benefits of the multistage configurator compared with the single-stage configurator include improved specification quality, better compliance with the standardisation strategy, reduced resource consumption in specification processes and increased overall benefits resulting from configuration.

The results obtained from the interviews and the cost–benefit analysis indicate that investments could be modest when moving from a single-stage configurator strategy to a multistage strategy. The reasons for this are the slight increase in the investments in software licences, hardware, and so forth, and the minimal additional training needed for employees. In this context, development is found to be the most expensive part of the expansion of the knowledge base. The interviews indicate that the multistage strategy supports the company better than the previously applied single-stage strategy. The reported benefits align with those described in the PCS literature.

6.2 Implications for research

Overall, the present research answers the calls for more research on how to extend PCSs across different process and user groups (Cao & Hall, 2019; Forza & Salvador, 2007; Shafiee et al., 2018). This involves two main contributions. First, the paper proposes and defines the concept of "multistage configuration". This involves the identification of two archetypical strategies to implement multistage configuration. Existing research has discussed the use of PSCs in different phases (e.g., Forza and Salvador, 2007; Haug et al., 2010b; Shafiee et al., 2018), but there has been a gap in literature with regard to concrete strategies for the implementation of multistage configuration. Second, the paper provides empirical evidence that supports the feasibility of a multistage configuration strategy. Besides demonstrating the usefulness of the proposed framework, these findings contributes with new insights into the costs and benefits associated with PCSs, as well as the cost-reduction potential of multistage configuration. The study also identified a number of benefits of multistage configuration, hereunder improved specification quality (Haug, Hvam, & Mortensen, 2013; Haug et al., 2019b), and an increase in costing accuracy (Myrodia et al., 2017). Thus, the present study also extends existing research on the effects of PCSs (e.g., Haug et al., 2019b; Hvam et al., 2013; Heiskala et al., 2007).

With regard to the first contribution, the literature includes many studies on ETO companies that have adopted advanced sales configurators (e.g., Christensen & Brunoe, 2018; Haug et al., 2011; Haug et al., 2019b; Kristjansdottir et al., 2016; Orsvärn & Bennick, 2014; Petersen, 2007). The literature has also explored the application of PCSs to support ETO processes (Christensen & Brunoe, 2018; Kristianto et al., 2015; L Zeng, 2015; Petersen, 2008), as well as discussed how to integrate PCSs with CRM, PDM and ERP systems (Forza & Salvador, 2008; Forza & Salvador, 2007; Myrodia et al., 2019). Nonetheless, our literature search could not identify publications that describe the application of PCSs to support the whole order-handling process in an ETO setting. Thus, in this paper, we extend such research by developing a framework for multistage configuration and by clarifying the costs and the benefits associated with such a strategy.

With regard to the second contribution, we demonstrate the feasibility of developing a multistage PCS through a case study. This study suggests that the proposed framework could help companies establish their PCS projects' objectives, analyse the requirements, involve stakeholders, reduce resistance, manage the changes and guarantee managerial support during multistage PCS project development and implementation. Compliance with standard solutions has increased due to the configurator's guidance regarding the selection of feasible and preferred solutions. Resource consumption is reported to be further reduced compared with the consumption by a single-stage configurator. The overall benefits at a higher level can be difficult to measure objectively, but the interviewees agree that the projects are more profitable, overall product quality has increased, and the multistage configuration offers a competitive advantage.

To summarise, in this paper, we combine a number of important insights from the literature on PCS single-stage implementation into an integrative framework that supports the successful management of multistage PCS projects. Specifically, our paper provides a novel framework that defines multistage configuration and presents a case study that identifies a number of benefits associated with this approach. Furthermore, our study shows that in some cases, the benefits of transitioning from single-stage to multistage configuration far exceed the additional costs. In the studied case, the explanation was that the additional stages required only relatively modest extensions of the initial sales configurator, since individualised application design for different user groups could be avoided. Instead, the additional stages included in the PCS mainly concerned extending the sales PCS.

6.3 Limitations and future research

This research is based on a single exploratory study, which introduces some limitations. First, the company size may be an enabler that allows the firm to merge everything in a common application; it is unknown how this concept would work in larger companies. Furthermore, in the studied case, the PCS users are all rather familiar with the construction of the products. In contrast, in cases where users have less understanding of the products, it may be more difficult to implement the type of multistage PCS described in the case. Second, the discussed approach is a common application using a multistage configurator with a single knowledge model. The individualised application approach has not been tested in this research; thus, the costs and the benefits presented in this study may not provide a fair comparison. More research is needed to gain insights into the individualised application approach. Third, the timeframe of the research has its limitation. As the project lead time in the case company is usually between one and two years, it has not been possible for us to conduct a detailed analysis of the financial impacts. Future studies could investigate the long-term impacts of multistage configuration in relation to costs and benefits.

More research is also needed to explore the various strategies for multistage configuration presented in this paper. As our case study has only addressed one of the two types of applications of a multistage approach, the other type requires further research. However, as demonstrated in this paper, our framework for multistage configuration will be useful in organising such future studies.

6.4 Implications for practice

Other companies may use the proposed framework and the lessons learned from the case study to support their decisions about whether or not to adopt a multistage configuration strategy. The relevance of this approach essentially comes down to an assessment of the costs and the risks associated with the expansion of PCSs across multiple stages in comparison to the potential benefits. In this context, the identified cost and benefit dimensions described in this paper may constitute the basis of this evaluation. The multistage configurator provides better support for the company, with a higher number of benefits gained compared with the single-stage configurator.

Based on the results of the interviews and the cost–benefit analysis, the investment in a multistage PCS or the extension of a single-stage PCS (in case of a pre-existing PCS in the company) is recommended for practitioners and managers in other ETO companies. The case study also provides a good understanding of the situation in the case company and of different levels of development. Other practitioners can compare their cases with the presented one and evaluate the situation to estimate the investment and the benefits.

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Title

The costs and benefits of multistage product configuration systems: A framework and case study

Highlights

- Product configuration systems are typically used to support single processes
- A framework for supporting multiple processes (stages) is proposed
- Two strategies for multistage product configuration systems are defined
- A case study supports the proposed framework
- The case shows multistage configuration systems can be profitable

Rasmussen, J. B.: Conceptualization, Methodology, Investigation, Writing and Editing **Haug. A.**: Conceptualization, Writing- Reviewing and Editing. **Schafiee, S**: Methodology, Writing- Reviewing and Editing ***Hvam, L.**:* Reviewing and Editing **Mortensen, N.H.**: Reviewing and Editing.: **Myrodia, A:** Methodology, Investigation