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Framing business cases for the success of product configuration system projects

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ABSTRACT

Product configuration systems (PCSs) are peculiar IT applications used for efficient product customization. Unfortunately, PCS implementation involves many challenges. A well-defined business case (BC) could increase PCS project success. However, the literature does not provide specific guidance for building BCs for PCS projects. The proposed BC framework for PCS projects was developed based on literature and professional expertise, and tested in three PCS projects at two engineer-to-order (ETO) companies. Figures of benefits, costs, ROIs, scenario examples, sensitivity analyses, risk analyses, and key information about application experiences were reported. The framework test shows that it is viable and helps overcome PCS challenges.

1. Introduction

An increasing number of companies across sectors and countries are offering a wide variety and customization of products (Forza and Salvador, 2006; Jimeno-Morenilla et al., 2021). In such contexts, product configuration systems (PCSs) facilitate selling and order-fulfillment processes (Felfernig et al., 2014) by using information about product features, product structure, production processes, costs, and prices (Forza and Salvador, 2006). It is therefore not surprising that among the digitalization opportunities of Industry 4.0 (Jimeno-Morenilla et al., 2021; Cisneros-Cabrera et al., 2021; Ramírez-Durán et al., 2021; Battistello et al., 2021), PCSs represent an essential building block for organizations that offer a wide variety of products, and researchers have identified PCSs as a fundamental lever for successful mass customization (Forza and Salvador, 2006; Sandrin, 2017). Furthermore, PCSs can bring substantial benefits to companies that offer product customization, such as shorter lead times for specification and quotation processes (Forza and Salvador, 2002; Trentin et al., 2011; Mueller et al., 2022), fewer errors (Forza and Salvador, 2002; Trentin et al., 2012), increased ability to meet customers' requirements regarding product functionality (Forza and Salvador, 2002; Forza and Salvador, 2002), use of fewer resources (Forza and Salvador, 2006), less routine work, and improved on-time deliveries (Haug et al., 2019; Shafiee et al., 2020). A PCS assists customers in the search process (Forza and Salvador, 2006) and enhances the perceived benefits of both the mass-customization experience (Trentin et al., 2014) and mass-customized products (Sandrin, 2017; Sandrin et al., 2017).

Although PCSs have clear advantages, their implementation remains costly (Haug et al., 2019) with considerable chances of failure (Haug et al., 2019), because companies must overcome various challenges to implement and utilize PCSs (Kristjansdottir et al., 2018). For example, the development of a PCS often requires highly complex technical or commercial knowledge, which can be difficult for domain experts to communicate to configuration experts (Shafiee et al., 2018). Furthermore, the corresponding knowledge base has to be adapted continuously in response to changing components and configuration constraints (Shafiee, 2017). The difficulty of acquiring and modeling the required technical or commercial knowledge depends on whether it is available in a clear and formal form (Rasmussen et al., 2021; Shafiee et al., 2021), which in turn may be contingent on company size (Forza and Salvador,

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2002), product complexity (Rasmussen et al., 2021; Shafiee et al., 2021), degree of product customization (Sandrin, 2016), or other factors, such as knowledge management and the scoping process (Shafiee et al., 2020; Shafiee et al., 2018). Besides complexity, a major cause of failure in such projects concerns planning-related problems because of an unclear scope (Shafiee et al., 2018). The documentation of PCSs is often not maintained after the systems become operational because the documentation process is time-consuming (Shafiee et al., 2017). The challenges of managing technical and commercial knowledge in the implementation of a PCS may significantly increase the cost and time needed to develop a PCS and maintain its effectiveness.

One of the substantial solutions to limiting a PCS project's cost and risk of failure is developing a well-structured PCS business case (BC) that considers the challenges peculiar to PCS projects (Haug et al., 2019; Kristjansdottir et al., 2018). A BC is concerned primarily with the question of what an organization stands to gain from a given investment. A BC establishes a rationale for investment in the project in terms of costs, risks, and benefits (Gambles, 2009) while PCS projects go through planning, development, implementation, and maintenance phases. Typically, BCs are part of the planning phase, because their purpose is to guide the project in an effective way (Remenyi and Remenyi, 2009). A BC framework can enable companies to improve the BCs on PCS projects and reduce the complexity of the projects by limiting their scope to stakeholders' requirements, evaluating the current company's processes, and assessing future scenarios considering risks and financial returns.

For information technology (IT) projects in general, various BC frameworks are available (Gambles, 2009; Nielsen and Persson, 2017; Berghout and Tan, 2013). Regarding BCs for PCS projects, researchers have addressed topics such as stakeholder analysis (Zhang, 2014) and the evaluation of AS-IS and TO-BE configuration processes (Felfernig et al., 2014; Zhang, 2014). However, no systematic BC frameworks for configuration projects have been developed. This represents an important gap in the literature because the challenges of PCS projects are different, at least in part, from those of other IT projects. These challenges in PCSs make the initial analysis and cost estimation of investments difficult, and the configuration team could miss the information to estimate the adequate resources and time.

To address the above-mentioned gap, which has important practical implications, this paper proposes a framework that identifies the necessary elements of a BC for a PCS project, the activities that must be performed to develop this BC, and the supporting tools for each of these activities. First, the BC elements are drawn from extant BC frameworks designed for IT projects and from practitioners' experiences; as PCS projects are special cases of IT projects, indications of BC for PCS and similar knowledge-based systems are limited, while there are sound BC frameworks for IT projects. The proposed BC elements are BC objectives, benefit appraisal, consolidation, stakeholder analysis, technological requirements, project planning and governance, cost appraisal, and risk assessment elements. Second, the activities for developing a BC are drawn from the PCS literature, given the availability of specific indications for PCS. These activities are benefit analysis, stakeholder analysis, process analysis, scenario making, and gap analysis, and scenario evaluation, including cost-benefit analysis, sensitivity analysis, and risk analysis. Third, the supporting tools are drawn from the PCS literature and the IT projects literature. The suggested tools include interview and workshop sessions, use-case diagrams, MosCoW rule, AS-IS and TO-BE process flowcharts, return on investment (ROI), and ROI sensitivity analysis graphical tool. The proposed framework was tested in three case projects at two different companies.

The rest of the paper is structured as follows. Section 2 reviews and discusses the relevant literature. Based on the literature review, Section 3 develops a BC framework for PCS projects, Section 4 outlines the method for assessing the framework, and Section 5 discusses the results of the empirical studies. Sections 6 and 7 bring the paper to a close with a discussion and a presentation of the study's conclusions, respectively.

2. Literature review

A BC is "a recommendation to decision makers to take a particular course of action for the organization" (Gambles, 2009, p.1) – for example, an investment in a project – that is "supported by an analysis of its benefits, costs, and risks compared to the realistic alternatives, with an explanation of how it can best be implemented" (Gambles, 2009, p.1). A BC includes the underlying rationale for why a company should accept and progress with a project that promises to yield a suitably significant return, thus justifying the investment (Carroll and Shabana, 2010). A BC takes a multi-lens view of a business opportunity in order to assess its results (e.g., by considering not only economic concerns but also corporate strategy, stakeholders and their views, and the use of technology) (Remenyi and Remenyi, 2009). Moreover, BCs offer multiple advantages, such as better control of the implementation of the chosen initiative (Gambles, 2009) and consensus building among various stakeholders (Remenyi and Remenyi, 2009).

A well done BC is recognized as highly important for company projects and, in particular, for IT projects, which can fail to achieve their goals or stay within deadlines and budgets (Berghout and Tan, 2013). It has been shown that investing time in identifying the benefits, expectations, financial needs, and risks of an IT project can minimize the chances of failure and maximize those of success (Whittaker, 1999). Accordingly, BCs favor the success of IT investments by empowering organizations to undertake informed decisions regarding IT projects, monitor the progress of projects, and evaluate project outcomes (Berghout and Tan, 2013; Remenyi, 2012; Ward et al., 2008). Whittaker (1999) found, in a survey on a sample of Canada's public and private sector organizations, that the three most common reasons for IT project failure are poor project planning, a weak BC, and a lack of top management involvement and support. A comprehensive BC framework can improve BCs thus favoring the success of IT projects (Berghout and Tan, 2013). Multiple BC frameworks have been proposed to guide the development of BC for IT projects (Berghout and Tan, 2013).

In the next subsections, the literature is reviewed to present what is available to develop BCs for PCS projects, which are a very special class of IT projects. Section 2.1 presents what the current PCS literature provides for PCS planning, highlighting the lack of indication for BC development. Section 2.2 identifies the BC frameworks developed for IT projects in general (Berghout and Tan, 2013) and highlights the importance and characteristics of BC development processes and the related supporting tools. Section 2.3 identifies the differences between IT projects in general and PCS projects. These differences motivate the need for BC frameworks tailored to PCS projects. It presents specific requirements and tools for PCS-specific BCs and the current lack of suitable frameworks.

2.1. Business cases for PCS projects

Despite the importance of PCS project planning, PCS literature provides limited guidance for identifying the elements of a BC for a PCS project, although it considers some BC-related concerns. More specifically, the PCS literature has outlined various activities that should be performed before launching a PCS project, and it has developed tools to support these activities, although it generally does not connect these activities to a global scheme. What follows is a discussion of the PCS planning activities identified by PCS research.

Benefit analysis is essential for PCS projects because it determines the requirements of the project and clarifies the project scope (Shafiee et al., 2014; Hvam et al., 2008). The project objectives support knowledge management and the identification of relevant stakeholders (Forza and Salvador, 2002; Felfernig et al., 2014). Some goals (e.g., higher quality, lower resource, and time consumption) are suitable for all PCS projects (Ardissono et al., 2003), whereas others are suited only to specific projects (e.g., empowering sales offices).

Stakeholder analysis examines users' expectations and requirements

Table 1
Representative PCS publications and provided hints for activities required to develop BC in PCS projects.

Articles	Benefit analysis	Stakeholder analysis	Process analysis	Cost & risk analysis
(Ardissono et al., 2003)	✓			
(Mortensen et al., 2008)	✓			
(Heiskala et al., 2007)	✓			
(Forza and Salvador, 2006; Forza and Salvador, 2002)	✓	✓	✓	✓
(Hvam et al., 2008)	✓	✓	✓	✓
(Shafiee et al., 2014)	✓	✓	✓	
(Felfernig et al., 2014)	✓	✓		
(Kristjansdottir et al., 2018)	✓			✓

for the system, which tend to expand as PCS projects become more successful and popular among users (Barker et al., 1989). Stakeholder analysis is typically described as one of the most difficult components of PCS-project planning because stakeholders vary considerably and have different levels of expertise (Forza and Salvador, 2002). Furthermore, the existing literature has offered limited suggestions regarding available tools or methods for communicating among stakeholders, while identifying and analyzing their requirements before starting a project enables time- and resource-saving decisions (Felfernig et al., 2014; Shafiee et al., 2014).

Process analysis for PCSs is a major activity to perform before initiating a PCS project because it typically involves analyzing the current sales and engineering processes and redesigning them to increase efficiency with the help of a PCS (Forza and Salvador, 2006). Future scenarios could include IT architecture and IT requirements if needed. A gap analysis is then conducted to assess the performance of the current process and set goals for the target performance. Furthermore, gap analysis can show how the different scenarios contribute to the target performance (Shafiee et al., 2014; Hvam et al., 2008).

Cost and risk analyses are required to compare different scenarios in PCS projects. The literature has conducted cost estimations to evaluate the savings from PCS (Kristjansdottir et al., 2018). The literature has also advised on different possibilities in PCS project implementation that led to different costs, benefits, and risks, thus making sensitivity analysis of PCS projects' ROI highly recommendable. A list of the risks of PCS projects was provided by Hvam et al. (2008) and Forza and Salvador (2006).

Table 1 summarizes the information discussed in the present section and depicts what is provided by representative PCS publications (and provided hints for activities) useful for developing BC for PCS projects. Notably, only the research by Forza and Salvador (2006, 2002) and Hvam et al. (2008) covered all the activities. They also added the objectives of the various activities, deliverables, and supporting tools. Forza and Salvador (2006, 2002) focused more on organizational aspects and proposed a process that progressively increases the level of detail (preliminary analysis, macroanalysis, microanalysis, system design, implementation planning, system implementation, and launch). Hvam et al. (2008) devoted more attention to supporting tools and proposed a more linear process. However, neither Forza and Salvador (2006, 2002) nor Hvam et al.(2008) considered BCs, and they did not link their work to the BC literature or provide information about the financial returns of a PCS, which is an essential aspect of a BC for a PCS.

2.2. Business cases for IT projects

Given the lack of BC examples in PCS literature, we could search for support in BCs for projects that are similar to those of PCS, such as knowledge-based systems. Unfortunately, only two articles, dealing respectively with conducting feasibility studies for knowledge-based systems (Kingston, 2004) and justifying investment in the knowledge-based systems (Oldham et al., 1997), include aspects for the creation of a BC for such systems. These two papers are based mainly on practical experience and are somewhat disconnected from the literature on BC frameworks for IT projects. Although these articles provide useful examples and practical suggestions for the development of specific BCs for knowledge-based systems, they provide limited indications of the BC elements and of the supporting tools. Given these limitations in PCS and knowledge-based systems literature regarding BC development, it is convenient to broaden our focus, thus also considering the literature on BCs for IT projects in general. In fact, PCS projects are IT-based projects, although they are characterized by substantial differences, and the literature on BCs for IT projects has developed structured BC frameworks that identify BC elements (Berghout and Tan, 2013).

The various BC frameworks for IT projects have certain elements in common, even though such elements sometimes appear under different names. In a thorough review of the literature on BCs for IT projects, Berghout and Tan (Berghout and Tan, 2013) identified and described BC elements and reported the percentage of reviewed articles that considered each BC element (BC objectives, 41.4%; benefits appraisal, 58.6%; consolidation, 27.6%; technological requirements, 41.4%; supplier options, 17.2%; project planning and governance, 24.1%; cost appraisal, 27.6%; risk assessment, 27.6%; stakeholders, 51.7%).

Although a BC for an IT project is presented as a document, its development is a process (Nielsen and Persson, 2017; Remenyi, 2012; Ward et al., 2008) that serves multiple objectives (Ward et al., 2008). It serves not only as a basis for informed decision-making regarding whether to invest in a proposed project but also as a means of eliciting the commitment of stakeholders, the lack of which is "perhaps the single most important reason why IT projects fail" (Remenyi, 2012, p.27). The way in which this process is performed affects the achievement of these objectives (Nielsen and Persson, 2017; Remenyi, 2012). This process may take weeks or even months and may cost the organization a nontrivial amount of money (Remenyi and Remenyi, 2009; Ward et al., 2008).

Tools that support the various activities of the BC-development process can lower the required effort and guide the company toward a better BC and more informed decisions (Ward et al., 2008). Because differences in the BC-development processes impact the success of IT projects, a BC framework for IT projects will be more effective if it includes guidelines not only for BC elements but also for BC-development activities. This is the case not only because the completed BC will be better but also because the BC-development process will transform the organization and its stakeholders into supporters of the project.

2.3. Comparing IT and PCS projects

There are several differences between PCS and non-PCS IT projects, considering that the PCS literature has underlined the importance of performing certain activities before embarking on a PCS project (Forza and Salvador, 2006; Hvam et al., 2008). Differences between PCS and IT projects have recently been discussed by Shafiee et al. (2018) to investigate how to scope configuration projects and manage the knowledge they require. Hereafter, the main differences highlighted by Shafiee et al. (2018) are summarized and complemented.

The first difference relates to knowledge complexity and the extension of the scope in PCS projects due to the large and complex knowledge bases, which is an issue for several knowledge-based systems (Kingston, 2004). For example, to model medical equipment, a knowledge engineer in a medical equipment company needs to learn various domain aspects from experts. Hence, product modeling is a tedious task in PCS projects and relies heavily on the complex management of different knowledge. Although IT projects have different natures, they usually require less extensive product knowledge (Shafiee et al., 2018).

The second difference relates to the details of the communication level for configuration projects compared to IT projects, as the required knowledge is very specialized product knowledge that lies beyond the configuration team's expertise. Whereas the knowledge required for IT projects typically does not necessarily need to be communicated, updated, and validated continually (Shafiee et al., 2020), the configuration team[1] for a PCS project needs to communicate with the domain experts[2] regularly to validate both the essential and extended product knowledge (Forza and Salvador, 2002), as happened for many knowledge-based systems (Kingston, 2004; Oldham et al., 1997).

Third, in PCS projects, there is a need for specific comprehensive documentation and maintenance of the product's detailed knowledge in non-IT language and explicit to all organizations. By contrast, documentation in IT projects is normally summarized explanations of codes for another IT expert and not necessarily all the detailed complicated knowledge for the whole organization (Shafiee, 2017). This characteristic of PCS projects is also present in knowledge-based systems, where special attention is paid to the way knowledge is formalized, documented, and maintained (Kingston, 2004; Oldham et al., 1997).

Fourth, PCS projects exhibit a high level of integration with other IT systems (Felfernig et al., 2014) to connect the PCS to other databases, calculation systems, drawing software, etc. Integration of PCS with other IT systems processes necessitates IT development, testing, and collaboration across teams (Shafiee et al., 2021), because of the complexity of knowledge involved, the range of stakeholders, special system requirements, specific risks, and varying cost estimations (Hvam et al., 2008).

Fifth, PCS projects normally need less effort for software programming, as PCS projects often fall into one of the following two cases (Shafiee et al., 2018). First, most companies use one of the software applications available on the market that supports the development and updating of PCS. These applications provide a software environment for inserting the product models, rules, and constraints, and eventually design the final user interface in a more user-friendly way, without programming from scratch. Second, some companies develop their own PCSs by creating a common platform for the development and updating of the various PCSs dedicated to different sets of product families (Kristjansdottir et al., 2018). Hence, in this second case, for each PCS project, the company does not need to develop PCSs from scratch. To clarify, each PCS project is very solid in terms of IT architecture, and because of the available platform, each project is modified based on specific pre-determined standards (Shafiee et al., 2017). Conversely, for non-PCS IT projects, because the nature of the systems is different, the architecture, user interface, and standards may even need to be defined and developed from scratch (Shafiee, 2017).

PCS projects are very heterogeneous, with peculiarities that depend on specific business contexts. While PCS systems may support sale processes, engineering processes, or both, they may or may not include price and cost information, and the automation level may be different for commercial and technical parts of a PCS, for different product families, or for different commercial channels (Forza and Salvador, 2006). Unfortunately, there are different mass-customization strategies that deeply influence the organizational design (Sandrin, 2016), thus including PCS systems. The functionalities required for a PCS system, as well as its integration with the rest of the information system, depend on the mass-customization strategy pursued (Forza and Salvador, 2006). As a result, the design of the PCS sociotechnical system is an extremely complex and context-dependent task that involves several stakeholders belonging to different functions and, eventually, different organizations (Forza and Salvador, 2006).

In summary, configuration projects differ from other IT projects. Owing to the complex nature of knowledge and scope, continuous communication, validation, documentation, and maintenance, and the quantity of required integrations in configuration projects, the BC frameworks for generic IT projects fail to pay enough attention to the peculiar aspects of PCS projects. Hence, the BC framework for IT projects should be enhanced and tailored to PCS projects. In particular, more attention and more specific support should be given to the steps, outputs and processes of extensive stakeholder and comprehensive AS-IS and TO-BE analyses, gap analysis, and sensitivity.

3. Proposed framework

The foregoing literature review shows that the potential challenges of PCS projects and the consequent risk of failure underscore the need to develop good BCs for such projects. Unfortunately, the literature provides limited support as PCS projects are not considered in BC literature while the peculiarities of PCS projects call for controlling the applicability of existing BC frameworks to PCS projects or, even better, developing PCS-specific BC frameworks. Consequently, there is a need and an opportunity to develop a PCS-specific BC framework by considering not only BC elements but also activities required to develop a BC and tools that can facilitate these activities. This section describes the proposed framework and how it was developed. Specifically, Section 3.1 presents the method for developing the proposed framework, and Sections 3.2–3.6 present this framework in detail.

3.1. Framework development

We developed the proposed framework using (1) extant literature, (2) analytical thinking, and (3) interactions with an industrial partner.

First, we considered (1) BC elements identified by the literature on BCs for IT projects, (2) activities to be performed before launching a PCS project, and related objectives, deliverables, and supporting tools, as suggested by the PCS literature, and (3) guidance on the BC project process provided by practitioners' publications.

Second, we performed a thorough analysis of the various aspects of BC (BC elements, BC development activities, and supporting tools). Dissecting the problem allows for focused and deep analyses. Some of the researchers involved in this analysis have 20 years of experience working with industrial partners on a variety of PCS projects. The extensive experience of the researchers deepened the analysis and made the framework more comprehensive.

Third, an industrial partner was involved in the framework development. This partner is an engineer-to-order (ETO) manufacturing company, and the partner team that participated in the framework development has experienced both successes and failures in PCS projects. The researchers at the case company observed and studied the different PCS projects undertaken by the company over the last five years. This provided the researchers with the ability to act as internal and external observers (Hollway and Jefferson, 2000). An iterative development method that blended the activities of developer and user, and creator and player was used. This method involved a cyclical process of prototyping, analyzing, and refining work in progress. Hence, over the course of six months, the framework was iteratively discussed, outlined, validated, and redesigned by members of the partner company's research group until the team was satisfied with the framework.

3.2. Framework overview

Although the proposed framework is based on currently available BC frameworks for generic IT projects, it differs slightly from them. More specifically, although it might be possible to modify the available BC frameworks designed for IT projects, IT, and PCS projects exhibit important differences, as mentioned in Section 2.3. Generally, the PCS's IT architecture and software platform are chosen when the company decides to adopt the PCS (Hvam et al., 2008), and reconsidering them for each subsequent PCS project is not necessary. Hence, the IT platform and

[1] The team working on configuration projects (i.e., configuration team) include knowledge engineers, modelers, developers, and project managers.

[2] These experts provide domain knowledge of the process of performing the task and the data content, as well as quality assurance and verification support.

Table 2
Proposed BC framework for PCS projects and available tools for each BC activity in IT and PCS projects.

The proposed framework for developing a BC for a PCS project				Available supporting tools	
Set of activities		**Description of the activities**	**Contributed BC element****	**Suggested by generic IT-project literature**	**Suggested by PCS-project literature**
1. Benefit analysis		Provide a condensed overview of the BC. Identify the objectives of the project, such as its overall costs and benefits.	BC objectives	No specific tool	Interview and workshop sessions and alignment of overall strategies (Forza and Salvador, 2006; Felfernig et al., 2014; Ardissono et al., 2003; Barker et al., 1989)
		Estimate an overall review and understanding of the issues and solutions. Assess the project at a high level of abstraction. Align overall strategies and prioritize the projects.	Benefit appraisal		
2. Stakeholder analysis*		Conduct an overview of the project and its BC. Establish alignment with the stakeholders and their requirements.	Consolidation	Unified modeling language tools, including use-case diagrams and MoSCoW rules (Kruchten, 2007; Bittner, 2002)	Use-case diagrams to define the requirements and the MosCoW rule to prioritize them (Hvam et al., 2008; Mortensen et al., 2008; Friedrich et al., 2014)
		Analyze, group, and prioritize the stakeholder requirements.	Stakeholder analysis		
3. Process analysis, scenario making, and gap analysis		Analyze the technical requirements. Illustrate AS-IS and TO-BE processes. Identify different scenarios to meet the requirements.	Technological requirements	Process flowcharts, gap analysis (White, 2004)	AS-IS and TO-BE flowcharts to demonstrate current and possible future scenarios, and gap analysis to compare the current and future situations in terms of lead time, quality, resources, and sales (Hvam et al., 2008; Felfernig et al., 2014). A preliminary not too detailed draft of product variant master to visualize product space variability and configuration (Hvam et al., 2008)
		Assess the time and milestones for the selected scenario. Perform gap analysis to compare the current and future situations in terms of lead time, quality, resources, and sales.	Project planning & governance		
4. Scenario evaluation	***Cost-benefit analysis***	Calculate and demonstrate the profitability of the project based on various factors (licenses, development, maintenance, and training) and then the saved man-hours after the project launch.	Cost appraisal	Return on investment (ROI) (Pisello, 2003)	ROI to calculate and demonstrate the profitability of PCS projects (Shafiee, 2017; Kristjansdottir et al., 2018)
	Sensitivity analysis*	Check the cost-benefit analysis and measure the uncertainty or changes in different parameters to increase the accuracy of the cost-benefit analysis (sensitivity analysis conducted for the accuracy of cost analysis).	Cost appraisal	Sensitivity analysis of cost estimation (Renkema, 2000)	Sensitivity analyses (Hvam et al., 2008) results summarized in time-dependent ROI lines showing ROIs for different scenarios and different levels of conservativeness in estimates
	Risk analysis	Prepare the checklists to list all the probabilities regarding different threats for the projects, including the change management threats and the risks related to the loose of resources.	Risk assessment	Formulas, analytical frameworks, checklists, process models, and risk-response strategies (Johnson et al., 2001; Boehm, 1991)	Checklists of all the probabilities regarding different threats for the projects (Hvam et al., 2008)

*The stakeholder analysis is conducted at an earlier stage in PCS projects (compared to non-PCS IT projects) in order to identify stakeholder requirements before performing the process and gap analysis.
** Typically, hardware and software suppliers are not included because for many PCS projects hardware and software components are fixed once and are not changed for several years.
***We add this activity to check the cost-benefit estimations in order to consider the risks of estimations in different scenarios.

general architecture are reviewed and decided on only once every few years, and the infrastructures are chosen while the PCS investments are in place. Therefore, based on the existing literature, discussions, and validations during framework development, we merged IT requirements with scenario making, and process and gap analyses. A sensitivity analysis (Hvam et al., 2008) is also included in response to academic and industry reports on inaccurate cost estimations in PCS projects.

Consequently, in the proposed framework, the activities for building a BC for a PCS project are as follows: (1) benefit analysis, (2) stakeholder analysis, (3) process analysis, scenario making and gap analysis, and (4) scenario evaluation (subdivided into cost-benefit analysis, sensitivity analysis, and risk analysis). These activities are explained in Table 2, together with the supporting tools identified in the literature review. The first column of the table presents the proposed activities of the BC framework, the second explains each activity, and the third column describes the connection of the proposed framework to the IT project's BC framework and how different activities in this framework contribute to BC elements in IT projects. In the last two columns of Table 2, we identify the available supporting tools for the activities of PCS and non-PCS IT projects.

To keep the proposed framework simple, these activities are described at a certain abstraction level in Table 2, while they are presented in a more specific way in Subsections 3.3–3.6. More concrete examples are provided with Case application 1 and the cross-case analysis in Section 5. The actual application cases have shown that these activities in the proposed framework were capable of representing the several specific PCS activities that had to be performed to develop BCs. These activities can be performed following an incremental approach, that is, a fast and rough analysis of the possible redesign of the configuration process, benefits, costs, and risks, followed by a fine-grained and precise analysis. This approach can increase the number of people involved in the process of analysis, understanding, and commitment to the project. Obviously, this approach is more suitable for situations in which the understanding of and commitment to the configuration project is relatively weak or in which knowledge elicitation and management are challenging. The converse holds for highly structured organizations, well-established PCSs and unchallenging knowledge elicitation. Thus, it is more suitable to execute these activities in an almost sequential manner, with none or minimal iterations.

3.3. Benefit analysis

The literature has emphasized the various benefits of using PCSs in different organizational settings. The most common benefits are reduced lead times, reduced resource consumption, higher quality of specifications, higher independence from domain experts, better decision-making in the early phases of sales, accurate, and error-free quotations, less rework, and higher customer satisfaction (Forza and Salvador, 2006; Trentin et al., 2012; Hvam et al., 2008; Ardissono et al., 2003; Barker et al., 1989).

Determining the benefits helps to align the project goals with the company's current strategy and difficulties, such as, saving time and resources in the quotation process and/or in the design of the activities during the ordering process, to be more competitive against leading competitors. Identifying goals and desired benefits is vital because it will guide subsequent sets of activities. So, listing the benefits in this step aligns the project with the overall goal and visions of the company before any future investment.

In this activity, all quantifiable and unquantifiable benefits will be listed. Some benefits, such as independence from domain experts, are hardly quantifiable in economic terms. However, this is not a problem because in a BC the final suggestion for taking or not taking an investment also considers unquantifiable aspects.

3.4. Stakeholder analysis

Identifying the main requirements of the stakeholders (domain experts, knowledge engineers, IT specialists, final users, and managers) clarifies the goal of the project. Researchers have conducted stakeholder analyses for IT (Bittner, 2002; Ebert, 1997) and PCS projects (Hvam et al., 2008; Mortensen et al., 2008; Friedrich et al., 2014). For IT projects, requirements can be divided into two types: functional and nonfunctional. A nonfunctional requirement involves not what the software will do, but how the software will do it (Ebert, 1997), and a functional requirement specifies each of the functions a system must be capable of performing (Ebert, 1997). For PCS projects, the definition of requirements is complicated by the difficulty of eliciting the knowledge intertwined with the changing scope of the project, the distance between various stakeholders, and the need to continuously update the knowledge included in the PCS.

In this activity, it is important to consider all the requirements from the various stakeholders and to effectively communicate these requirements among stakeholders for a shared understanding (overcoming differences in terminology relating to variety, configuration, and customization) and to agree on which requirements to satisfy based on priority. Examples of stakeholders' requirements are PCS outputs that would be presented to and used by engineers, salesmen, and customers (e.g., price and cost calculation, bill of materials, production cycles, and CAD documents), types of integration with other IT systems (e.g., ERP, CRM, PDM, and CAD), features of the user interface (e.g., user interface layout, graphs, and visual representation of the product). The various stakeholders present their ideas about which product families to include in the PCS, which parts of the configuration process to automate (e.g., sales configuration and/or the technical configuration processes), and which experts' knowledge to include in the PCS. Some of these ideas are accepted or discarded immediately, while others undergo deeper scrutiny in subsequent activities.

The demand for better communication of requirements among the different PCS stakeholders in the planning phase has led to the employment of use-case diagrams and the MoSCoW rule to illustrate and prioritize requirements (Shafiee et al., 2018; Shafiee et al., 2014; Hvam et al., 2008). Use-case diagrams illustrate the requirements and define the actors involved in the project (Kruchten, 2007; El-attar, 2019). The main elements of a use-case diagram (El-attar, 2019) are the system considered, the actors, the use cases, and their connections. For example, a PCS may have a salesman as an actor, and the generation of quotations in different languages as a use case. In this example, a connection between an actor and a use case becomes the action of the salesman in generating the quotation in three different languages (Ebert, 1997). The MoSCoW rule (Shafiee et al., 2018; Friedrich et al., 2014) helps to clarify the importance of the various requirements—that is, Must have (Mo), Should have (S), Could have (Co), and Want to have (W).

3.5. Process analysis, scenario making, and gap analysis

An analysis of a company's configuration process can be conducted to obtain an overview of the most important activities and their sequences and connections, and to list the persons responsible for the different activities, information flows, and processes' inputs and outputs (Hvam et al., 2008). Understanding current processes is fundamental for designing future processes performed through PCS.

Multiple tools are available for this purpose, such as graphical processes modeling notations to represent workflow patterns (White, 2004). Gap analysis is recommended for comparing operational performance with target goals (Hvam et al., 2008). Once the gap is identified, different scenarios can be generated to demonstrate how a PCS can be used to achieve the targeted performance (Hvam et al., 2008).

In these activities, a detailed consideration and accurate understanding of the project complexity in terms of what to insert in the PCS is required to generate and subsequently evaluate different scenarios in a sound manner. Documents already used by the company to manage the configuration process, interviews with key people, and preliminary and synthetic drafts of the product variant master (i.e., a tree representation of a product family structure) (Hvam et al., 2008) are used to identify, for example, the product families, the width of the product space of each product family, the number of rules and constraints to be inserted in the PCS, the knowledge models to include (e.g., sales models, technical models, production cycles, cost, and pricing models), what to automate, etc.

3.6. Scenario evaluation

The last set of framework activities evaluates the proposed scenarios based on the following analyses (Shafiee et al., 2014; Hvam et al., 2008): Cost-benefit analysis, Sensitivity analysis, Risk analysis. Studies of the complexity and unforeseen costs of PCS projects have indicated that the rough estimations involved in cost and risk analysis for BCs are a challenge that requires further investigation (Shafiee et al., 2014).

3.6.1. Cost-benefit analysis

PCS financial-benefits. Previous studies have shown that using a PCS results in *reduced man-hours and lead time for generating product specifications* (Forza and Salvador, 2002; Ardissono et al., 2003; Barker et al., 1989). Even though this is the most commonly mentioned and quantified benefit, the literature has not determined the extent to which reduced man-hours and lead time result in direct cost savings. Most research has used case studies to demonstrate the man-hours saved due to using PCS in a company (e.g., Forza and Salvador, 2002).

Previous research has also shown that *increased sales* can be achieved as salespeople are able to better respond to customers because PCSs improve their responsiveness and efficacy (Heiskala et al., 2007). Even though increased sales have been mentioned as a PCS benefit, this benefit remains largely unaddressed by extant research. Nonetheless, this impact should be considered when calculating the benefits (Kristjansdottir et al., 2018).

Benefits may vary from case to case, depending on the situation of the company and the scope of the PCS. It is worth remembering that the different kinds of benefits should, in the end, be transformed into monetary benefits to be included in the calculation of ROI. For this purpose, we propose to group all benefits into the following three classes:

a) Man-hour savings evaluated at the different hourly costs of the human resources involved. In this category, we find, for example, salesmen, and technician man-hours used for the definitions of product specifications, in tendering, and in generating the engineering and production product documentation.
b) Increased sales and avoided, reduced, or lost sales evaluated at their contribution margins. Many benefits derived from the use of PCS, such as shorter lead time to generate quotations, more professional quotations, better communication of product value, better customer customization experience, greater punctuality in delivery, better conformance to customer requirements, and better post-sales service, can be included in this category for economic quantification purposes.
c) Reduced non-quality costs. Examples of these costs are reduced penalties for delays because of mistakes in product configurations, and cost opportunities due to underestimation of product costs and product value during the quotation process. In several cases, these costs are not considered either because they are not important or because they are very difficult to estimate.

PCS costs. Few studies have addressed the cost factors of PCSs. Forza and Salvador (2002) mentioned that a large investment in terms of man-hours may be needed to implement a PCS. Hvam (2006) reported that the cost of developing and implementing a PCS for a large engineering company is approximately USD 1 million, with yearly operating costs of USD 100,000 (Kristjansdottir et al., 2018). Costs of PCSs were discussed and include software licenses (the cost of buying the software and annual licenses) and internal and external man-hours for modeling, programming, and implementing the PCS. The costs consist partly of the initial costs of creating the PCS and partly of the annual operation and maintenance costs (Pisello, 2003). However, there are still some hidden costs, such as the time needed for people to learn and use the system, but these hidden costs can be measured as man-hours. When calculating the costs and benefits of the PCS and, subsequently, the ROI, the period for which the calculation is done needs to be determined. The period could be anywhere from 2 to 10 years, and the period chosen will strongly influence the ROI calculated. The literature provides different examples of the period for the calculation (Barker et al., 1989). We have settled on five years as the most commonly used period of time for both case companies to estimate the BC (Kristjansdottir et al., 2018).

Return on investment in PCS. In many surveys on IT investment strategies, IT managers have indicated that ROI is the preferred analysis method (Pisello, 2003). Traditional cost-benefit (ROI) analyses focus on quantified monetary benefits, thereby excluding the potential strategic impact of the investments from the analysis (Pisello, 2003). Clearly, many IT projects are implemented for strategic reasons, such as business agility, some of which are difficult, if not impossible, to quantify (Pisello, 2003).

The financial benefits of PCS projects should be clear from the beginning, and cost evaluation is important when creating BCs. Cost-benefit analysis is used to compare the expected costs and benefits for different scenarios and the results from a variety of actions (Haddix et al., 2003). The ROI, which is commonly used as a cost-benefit ratio, is a performance measure for evaluating the efficiency of investments (Phillips, 2012) and it has been used to determine the profitability of PCS projects (Kristjansdottir et al., 2018). The ROI is calculated as shown in Eq. (1) (Pisello, 2003; Phillips, 2012). In the ROI formula, the investment costs are subtracted from the total benefits to produce net benefits, which are then divided by the investment costs.

$$\mathrm{ROI} = \frac{\text{Total benefits} - \text{Cost of investment}}{\text{Cost of investment}}$$

or

$$\mathrm{ROI} = \text{Cumulative net benefit} \,/\, \text{Total costs} \tag{1}$$

Detailed calculations of ROI in PCS projects and an overview of the publications on the role of ROI in the PCS literature have been compiled by Kristjansdottir et al. (2018). However, they (Kristjansdottir et al., 2018) focused on the ex-post calculation of the ROI of an already implemented PCS project. In this study, we need to decipher how to calculate ROI ex-ante in a few different contexts. An actual example of this is presented in Section 5.3. Benefits and costs that are often quantified in PCS projects are presented in Subsections "PCS financial-benefits" and "PCS costs." Finally, the further inspiration of potential benefits, including those not commonly economically quantified are presented in Subsection 3.3.

3.6.2. Sensitivity analysis

Sensitivity analysis measures the uncertainty or changes in various parameters and increases the accuracy of the cost-benefit analysis. Sensitivity analysis calculates the certainty that can be apportioned to various sources of uncertainty in its output (Renkema, 2000; Saltelli, 2002) and shows how a function (e.g., ROI) varies depending on the variations of parameters affected by uncertainty (Pannell, 1997). In this study, sensitivity analysis is mainly used to improve cost estimations and calculate uncertainties in ROI. Hence, sensitivity analysis helped us establish a lower and upper bound for the calculated ROI.

Essentially, an ROI estimate depends on the scenario employed (e.g., full technical and commercial automation versus technical automation only), on how conservative the estimates of the costs and benefits are (e.g., sales could be estimated to increase 10% due to PCS but a more conservative estimation could be 5% while a more optimistic estimation could be 20%), and on the time span considered (e.g., longer periods distribute the initial investment over a longer period but increases the chances of having greater costs of knowledge maintenance). To appreciate all the factors that greatly influence ROI estimates, a sensitivity analysis should be performed. The high number of different ROI values to be considered makes cognitively complex the overall understanding of the sensitivity analysis results; this is a common problem of sensitivity analyses for which Pannell (1997) indicated several possible solutions. To simplify this task, it is advisable to use a graphical time-phased comparison of ROI estimates using different ROI lines for the different scenarios and different levels of conservativeness in estimates as a supporting tool.

3.6.3. Risk analysis

Generally, IT project risk analysis aims at improving the chances of achieving a successful project outcome and/or avoiding project failure by identifying, analyzing, and managing risk factors (Boehm, 1991). During the project's lifetime, whenever a risk appears, the odds should be weighed against the BC to determine whether the benefits still fall within the expected time and cost constraints.

In the context of using PCS, a scenario's risks can be divided into risks associated with (1) developing a PCS (knowledge management, system ownership, modeling issues, and complicated systems), (2) risks associated with deploying and using a PCS (lack of training, inadequate testing, and lack of motivation for users), and (3) maintenance and further development of a PCS (neglecting documentation, lack of commitment for further developments, and out-of-date systems) (Hvam et al., 2008). Regarding the first point, evaluations of the complexity of PCSs can be used to support risk assessment. In this context, Brown et al. (2007) categorized PCS complexity into three major components: (1) execution, (2) parameter, and (3) memory complexities. Execution complexity covers those involved in performing actions that make up the configuration procedure, and memory complexity refers to the number of parameters the system manager must remember. Finally, organizational challenges are the most commonly experienced risk in PCS projects.

As mentioned above, Brown et al.'s (2007) categorization of PCS complexity can support risk assessment relating to PCS development. In this study, parameter complexity is the most important because it measures the complexity of providing configuration data to the computer system during PCS development.

4. Research method for framework assessment

4.1. Method setting

To test the developed framework, a case-application approach was used. The framework's actual practical performance can be demonstrated by applying it to several real cases. Therefore, we applied our framework to case companies. Case-based research seeks to find logical connections among observed events, relying on the knowledge of how systems, organizations, and individuals work and helps in understanding the "how" and "why" of observed connections (Yin, 2003; Voss et al., 2002). However, because applying a framework not only requires a company's availability but also requires considerable time and resources in the organization, we were able to apply the frameworks to only three projects in two different companies. Studying a limited number of case applications allowed us to conduct a detailed assessment of how the framework works and investigate potential challenges in its application.

When conducting case-based research, attention should be given to data and observer triangulations (Yin, 2003). In this study, a few researchers were involved in the observation and feedback processes. The researchers' outsider perspectives minimized subjective interpretation (Van de Ven, 2015).

Table 3
Background information of the case companies.

Companies	Company A		Company B
Products	Catalyst and chemical technology		Construction industry
Number of employees	3000		20,000
PCS projects	Project 1 (Case 1)	Project 2 (Case 2)	Project 3 (Case 3)
Estimated timeframe for development (months)	24	6	12
Estimated complexity of the project ([number of attributes] / [number of constraints in the PCS])	Great ([~2220] / [~1300])	Medium ([~1370] / [~950])	Medium/Great ([~2050] / [~1150])
No. of employees involved	10	4	6
No. of workshops	6	3	4
No. of feedback meetings	15	4	4

4.2. Case selection

The proposed framework was tested in two ETO companies, with the configuration projects as the unit of analysis. The first company (Company A) specializes in the production of heterogeneous catalysts and the design of process plants. The second company (Company B) specializes in the construction industry. The case companies have certain important characteristics in common, including the following: (1) they were in the process of implementing PCSs to support their sales and engineering processes, (2) they were facing challenges in defining the BCs and analyzing different factors before the project's initiation and were consequently interested in using our framework, (3) they have global operations, and (4) their products are highly engineered and complex. The two latter commonalities are important because complexity may be an essential contingent factor for PCS projects (Kristjansdottir et al., 2018). Both case companies were also the participants in the survey for this study. Company A tested the proposed framework on two projects, and Company B tested it on one project.

4.3. Framework assessment

Each of the three research teams (one for each case application) included two researchers and two or more experts from the configuration team in each participating company (Table 3). Workshops were conducted to introduce all stakeholders to the proposed framework and tools for the individual activities. Finally, feedback meetings were held in the form of semi-structured interviews to collect knowledge about the team's satisfaction with the new framework. Each meeting lasted 30 min and included members of the configuration teams, ranging from project managers and developers to end users and top managers.

Because the study sought rich information, open-ended interviews (Yin, 2003) are used to collect background data. This interview technique offered respondents the freedom to add comments and opinions (Hollway and Jefferson, 2000). However, some questions used a Likert-type scale (*strongly disagree*, *disagree*, *neutral*, *agree*, *strongly agree*) to enable numerical comparisons. The aim of the interview questions was to assess the overall benefits and challenges associated with the framework's performance. As discussed in Section 4.2, all the PCS cases deal with challenges. Hence, during this assessment, we evaluated the effect of implementing a BC framework on overcoming or decreasing these challenges (Kristjansdottir et al., 2018). The results illustrate the influence of using the proposed BC framework compared to previous situations without any BC framework, even though some aspects of the BCs were considered.

Table 4
Benefit and stakeholder analyses.

Projects	Project goals, stakeholder identifications, and stakeholder requirements
Case 1	*Goals:* Empower the sales offices around the world and generate proposals more quickly to increase the hit rate and increase sales. *Main stakeholders:* Configuration-group manager and engineers from the sales and process-design departments, including cost estimators, process engineers, and mechanical engineers. *Main requirements:* Two integrations with the simulation and computer-aided design (CAD) tools used in the company, thus supporting the full automation of the configuration process. The requirements were communicated through use-case diagrams and prioritized according to the MoSCoW rule (see Appendix).

5. Framework application: selected evidences and cross-case comparisons

This section reports and compares the application test results for the proposed framework in the three projects described above. Because of space limitations, for each activity, we provide application details (which are useful both as illustrations of the method and as evidence of the application) for only one case. Evidence for all cases is available on request.

5.1. Benefit and stakeholder analysis

Interviews with domain experts revealed that, before using our BC framework in the case companies, unstructured meetings with the main stakeholders were held to determine the goals of PCS projects. However, the various stakeholders' requirements were not sufficiently stated before starting the projects: some requirements were ignored because of limited and ineffective communication among the different stakeholders, such as requests for outputs, user interfaces, and additional IT automation. This situation changed with the application of our proposed BC framework, in which use-case diagrams and the MoSCoW rule were used to prioritize the requirements of the PCS projects. The resulting goals differed across cases because they reflected the companies' current operational challenges. Table 4 lists the main results of this activity for Case 1.

Awareness of project goals and the importance of stakeholder requirements before starting the project proved helpful for the project team. The observed advantages of using the tools for the benefit and stakeholder analyses were as follows: (1) improved understanding of the stakeholders' requirements for the system, (2) visualization of the stakeholders' needs, which established a common understanding, reduced the time needed for meeting with experts as a result of clear goal setting in the first step, and improved communication and task delegation, consequently reducing the expenditure on time and resources.

The stakeholders reported that the main obstacle in these sets of activities was unfamiliarity with the introduced tools. They also reported that significant amount of time was needed to change the current method of working, and that substantial time and resources were required for workshop preparations. In Company A, it was initially difficult for the team members to employ and recognize the purpose of the use-case diagrams because of difficulties of habit changes and inabilities to see the value of illustration tools. However, the workshops proved to be helpful because they provided step-by-step training for the configuration team and domain experts. In contrast, Company B refused to incorporate use-case diagrams because the involved managers considered it time-consuming and preferred to use MoSCoW rules when communicating among the various stakeholders. The configuration team realized the benefits of this activity from discussions with different stakeholders regarding how to prioritize the requirements.

Table 5
Example of gap analysis.

	Current	Target	Gap
Lead time	168 h (1 week)	0.5 h	167.5 h
Mistakes in offers	5%	1%	4%
Resource consumption	Two full-time salespersons	No salespersons	Two salespersons
Product offers	25/month	30/month	5/month

Table 6
Process analysis, scenario making, and gap analysis.

Projects	Current situation and proposed scenarios
Case 1	The *current situation* is complex and wastes time by spreading responsibilities across departments. To design the future processes supported by PCS, *two scenarios* were generated. In Scenario 1, the system is used as an improved user interface, the main aim of which is to empower sales offices around the world. In Scenario 2, the system includes all the integration required to generate accurate proposals and process-drawing templates in a more efficient manner. Gap analyses demonstrate how each scenario contributes to the targeted goals.

Table 7
Cost-benefit analysis in five years.

		Scenario 1	**Scenario 2**
Case 1	Investment cost: software and development hours (including training and implementation)	327,785	395,335
	Annual costs: software and maintenance hours	72,000	75,000
	Total project investment (EUR)	399,785	470,335
	Five-year benefits from increased sales (increased sales revenues - costs of additional goods sold)	1007,862	1068,468
	Five-year benefits from saved man-hours	189,569	191,256
	Total project benefits (EUR)	1197,431	1259,724
	ROI in 5 years	199.5%	167.8%

5.2. Process analysis, scenario making, and gap analysis

As proposed by the framework, process mapping and gap analysis were performed. Table 5 reports the main metrics used in Case 1 to describe the current situation, the future scenario, and the gap between the two.

From the results, a shared understanding of how the current processes provide learning points for the stakeholders emerges. In particular, in Case 1 (see Table 6), which involved several departments, the team gained in-depth understanding of the current process. This allowed them to anticipate all the integrations required for future processes. In all cases, the team noticed excessive redesign loops that resulted from an insufficient flow of information in the processes' various steps. Furthermore, the gap analysis provided an effective overview of the companies' future states. Training sessions were prepared to ensure that employees knew how to use the new methods; however, stakeholders considered this a time-consuming process. Furthermore, the learning points derived from the analysis of the current process (such as the clarification of tasks) and from defining possible future scenarios were reported to be very effective. In all cases, the project teams found that the gap analysis was a beneficial and easy-to-use tool that demonstrated how different scenarios contributed to the goals.

5.3. Scenario evaluation

5.3.1. Cost-benefit analysis

Once identified, the various scenarios underwent a cost-benefit

Table 8
Sensitivity analysis (five-year span).

All figures (except %) are €		Lower bound	Most likely	Upper bound	Lower bound	Most likely	Upper bound
Case 1	Scenario	**Scenario 1**			**Scenario 2**		
	Saved man-hours	170,612	189,569	208,000	172,000	191,256	216,119
	Benefits from increased sales	600,000	1007,862	1200,000	700,000	1068,468	1300,000
	Sum	770,612	1197,431	1408,000	872,000	1259,724	1516,119
	ROI	92.7%	199.5%	252.1%	85.3%	167.8%	222.3%

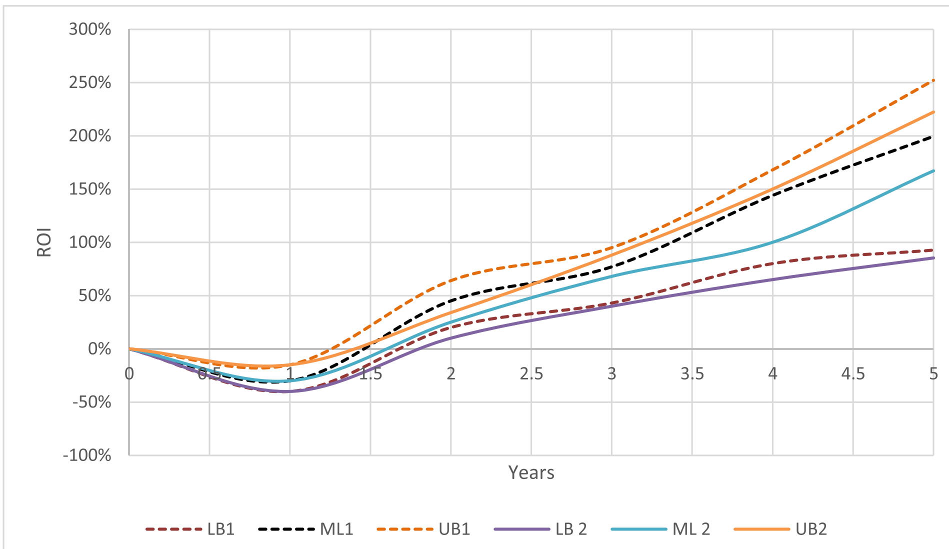

Fig. 1. Sensitivity analysis (UB: upper bound, LB: lower bound, and ML: most likely for Scenarios 1 and 2).

analysis. Table 7 presents the main results of this analysis for Case 1. The five-years ROIs obtained from this analysis for the various scenarios were 199.5% and 167.8% for Case 1, 251.7% and 248.3% for Case 2, and, finally, 298.9% and 265.5% for Case 3.

The principal result of this activity for each PCS project has been the estimation of its ROI over a five-year period. Benefits have been calculated based on increased sales and saved man-hours; the exclusion of other potential benefits that are difficult to estimate allowed for more conservative economic assessments. The benefit derived from increased sales has been calculated as the difference between increased sales and increased direct costs. The total project investment is calculated as the project cost, which includes the development, implementation, and yearly running costs, such as licenses and maintenance activities. The main challenge in this activity was quantifying future savings, which attracted a great deal of interest from the stakeholders.

5.3.2. *Sensitivity analysis*

A sensitivity analysis was conducted to determine the effects that changes in PCS implementation or the benefits and savings would have on ROI. If many factors exhibit uncertainty, sensitivity analysis can warn managers of possible changes in the project's profitability. The calculations (see Case 1 results in Table 8) are based on company experts' expectations that, by using the PCS, the company sells more or less products with more or less adequate pricing, and saves more or less man-hours. The five-years ROI lowest bound and highest bound obtained from this analysis were respectively 85.3% and 252.1% for Case 1, 173.6% and 318% for Case 2, and, finally, 226% and 307% for Case 3.

Sensitivity analysis has been confirmed as a critical aspect of PCS project management because it increases the credibility of the anticipated savings and cost-benefit analysis. To fully appreciate the results of the sensitivity analysis, the lower bound, most likely, and upper bound of ROI for different scenarios are reported on the same graph, which as on the x-axis the different time spans are used to calculate the ROIs. Fig. 1 reports the graphical results for sensitivity analysis for Case 1, which proved to be highly effective for discussion among managers.

Table 9
Risk analysis.

Projects		Different scenarios and embedded risks
Case 1	Scenario 1	Enormous risk of system avoidance. Another risk concerns proper documentation and validation, because the system tends to be large and complex.
	Scenario 2	Same risk factors as Scenario 1 but at a lower scale, because the delivered system is more accurate, more reliable, and fully automated and integrated with all other systems. Additional risks concern the IT process, which could be challenging and time-consuming, and the need for resources (i.e., business experts) to test the system.

5.3.3. *Risk analysis*

As noted above, the categorization of PCS complexity can support the assessment of PCS development risks. Parameter complexity is the most important indicator because it measures the complexity involved in knowledge elicitation and insertion into PCS models. When a project has a high degree of complexity, the risks of development, resource access, avoidance, and documentation are typically higher. The cases considered are of great, medium, and medium/great complexity. Table 9 presents the results of the PCS implementation risk analysis for each of the defined scenarios for Case 1.

According to PCS literature, the risk of users' system avoidance highlights the need to employ skillful managers to change employees' mindsets. In the three cases, the solution was to involve the main users in the project from the beginning to create a feeling of ownership and commitment. Another risk relates to the calculations and trust in their

Table 10
Company participants' evaluation of the BC framework.

The proposed BC framework for PCS initiatives	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The proposed BC framework helps to define stakeholder requirements more precisely.				2c	1a, 1b, 2a, 3a, 3b
The proposed BC framework is useful in providing additional insight into scoping and planning PCS projects.				1b, 2a, 2c	1a, 3a, 3b
The proposed BC framework helps to prioritize the projects and reduce the risk of failure.				1a	1b, 2a, 2c, 3a, 3b
The proposed BC framework is useful in comparing different scenarios of a future specification process.				1a, 1b, 3a	2a, 2c, 3b
The proposed BC framework can improve our previous way of working regarding efficiency and accuracy.				2a, 3a, 3b	1a, 1b, 2c
It will be realistic for an industrial company to use the proposed BC framework.				2c	1a, 1b, 2a, 3a, 3b
It will require little effort to learn and understand the proposed BC framework.				2a, 3b	1a, 1b, 2c, 3a

accuracy and reliability. The solution was to present visualizations of all the data and formulas in the PCS to the domain experts and to involve them in the system testing. In all cases, risk checklists were prepared based on the literature and experiences of working with PCS. To reduce the risk of avoidance, change-management strategies regarding project acceptance after releasing the PCS were evaluated.

Risk analysis was appreciated and helped stakeholders make final choices. In Case 1, Scenario 2 was accepted by the stakeholders. In Case 2, Scenario 2 was accepted; however, both scenarios have almost the same risks and ROI. In Case 3, Scenario 1 was accepted because it had a higher ROI and less associated risk, and it was also extendable in the future. The cross-case comparisons show that the framework affected the companies differently, which may have resulted from the different cultures of Companies A and B. Company A took the risk of experimenting with new tools and techniques, and the employees reported that many benefits and challenges resulted from employing them. Company B's management board achieved efficiency by keeping up with routine work while making minor changes. By contrast, Company A's management board aimed to improve the current workflow of PCS projects by accepting the changes and modifications recommended by the researchers.

6. Discussion

The proposed framework was tested on three configuration projects in two ETO companies. The PCS projects were engineering projects in which vast, complicated products had to be configured. In this section, we discuss the framework evaluation and its relationship with the current literature.

6.1. Evaluation of the framework by company participants

The BC framework helped the companies address the main difficulties of building BCs for PCS projects. Using the framework also affected the methods of working in the case companies. The scope of the PCS projects, for example, was determined and kept limited, whereas before using the framework, this scope was continuously expanded. The PCS project scope supported the configuration team in measuring project risks, thus reducing the difficulties associated with calculating costs in different scenarios. Consequently, the companies established a standard approach for prioritizing their PCS projects and a reduction in the time and resources needed for scoping them.

The configuration teams involved in using the framework expressed a willingness to continue using the proposed framework in future PCS projects to save time and resources. Moreover, the companies' domain experts appreciated their inclusion in the work of identifying stakeholder requirements. These results indicate both the effectiveness of the framework and its positive influence on the people engaged in the configuration project.

The main obstacle to the configuration teams' use of the framework was their lack of familiarity with the suggested tools. The introduction of the tools in workshops significantly reduced their resistance to the framework. Using the framework and related supporting tools did not introduce additional burdens or costs, and the training for configuration engineers and domain experts was carried out in a short amount of time (two to three days, on average).

Once the BC had been prepared, the researchers collected evaluations of two members from each project team, including the project manager and another team member. The evaluations of these six company users regarding the framework's applicability were concordant, as shown in Table 10, in which the numbers represent the case and the letters represent the informant role (a = project manager, b = developer, c = business analyst). Please note that none of the evaluators manifested disagreement (*strongly disagree* or *disagree*) or neutrality (*neither agree* nor *disagree*).

In interpreting the results reported in Table 10, it should be noted that both companies are experienced in managing PCS projects (5 years for Company 1 and 7 years for Company 2) and were using a kind of BC for PCS projects (Company 1 in the last 2 years before the present study performed some of the activities needed for a BC, including cost, resource, and process analysis; Company 2 performed process analysis only). In terms of tools, before the present study, they both used process analysis (AS-IS and TO-BE flow charts) and cost-benefit analysis to estimate the ROI of the PCS projects. Therefore, when the interviewed PCS team members declared improvements in stakeholder requirement definitions, PCS project scoping and planning, risk of failure reductions and working method enhancements, these PCS team members were comparing the use of the proposed framework with a situation where the PCS project planning was not negligible.

In summary, the interviewees indicated that the BC framework facilitates the scoping and planning of PCS projects. They maintained that this framework is a straightforward and easy method of assessing the situation of projects at a high level of abstraction, with little effort needed for training and changes. Therefore, they recognized that the BC framework with the proposed tools and indications for activities is effective.

Table 11
Effects of using the BC framework (the number of stars indicates the intensity of the challenge category, as reported by Kristjansdottir et al. (2018)).

Main categories of challenges	*Specific (subcategory) challenge*	*Importance of specific challenge*	*Use of the BC framework facilitates the overcoming of PCS projects' challenges*	
			How much does the framework help?	*How the framework helps*
Organisational * ** *	Resistance to using the PCS	Highest	4	AS4: Risk analysis raises the awareness of system avoidance.
	Lack of support from top management	Among highest	4	AS4: While evaluating the scenarios and risks, top management will become committed to the project.
	Disagreements about the scope of the PCS	Low	4	AS1,2: Stakeholder requirements are analysed, and through discussions and confrontation, the project will be scoped.
Knowledge acquisition * **	Difficulties in acquiring the correct knowledge	Among highest	5	AS1,2,3,4: Defining the project objectives and expectations sheds light on the knowledge and resources required to acquire knowledge. Consequent better planning of knowledge acquisition and better scoping reduce the difficulty of knowledge acquisition. Defining and evaluating future scenarios helps to measure the benefits and risks in order to solve the knowledge-acquisition challenges.
	Failure to communicate knowledge in the maintenance phase	Medium	3	NA. We did not observe anything regarding this aspect.
	Lack of requisite knowledge to meet users' and customers' needs	Low	5	AS1,2: Defining the project objectives helps to define customer expectations. AS3: To analyse the configuration process and products, more detailed knowledge and relevant resources are gathered.
Product modeling * *	Complexity due to lack of overview of the product range	High	4	AS3,4: Analysing the processes and products and defining the scenarios will result in a better overview of products and processes and will require discussions about standardization and complexity reduction in both the product and process range.
	Correctness of specifications generated by the PCS according to product model	Low	4	AS1,2,3,4: Defining the project objectives and the exact requirements of stakeholders before cementing the PCS projects, as well as defining the current and future configuration processes, will result in correct and exact product/process specifications and a well-defined product model. The BC does not include any steps for testing the correctness of knowledge, as it belongs to the development phase.
	Lack of knowledge related to product modeling	Low	4	AS3,4: The details of the acquired knowledge will be gathered in the subsequent steps of the project. However, analysing the process and product knowledge at the beginning of the project in a BC requires gathering the essential knowledge to build the product model and listing the details of the relevant sources and resources for these data.
IT related * *	Software development	Among highest	4	AS2,3: Defining the expectation from PCS, determining the functional and non-functional requirements, and establishing an overview of the product structure helped to solve some of the development challenges, such as modeling the product elements with the relevant connections.
	Systems designed for user friendliness	Low	4	AS2,4: Defining the requirements and analysing future scenarios lead to having an overview while designing the user interface. However, the user-interface design belongs to the detailed planning and development phase.
Resource constraint *	Lack of resources	Medium	5	AS2,4: The defined requirements, potential future scenarios, calculating the effort time and investment implications, and risk analysis will help to determine the needed resources before cementing the project.
	Vulnerability if key personnel leave	Low	5	AS4: Implementing risk analysis, the backup plans can be defined to help with different potential challenges, including missing key personnel.
Product related *	The complexity of product structures	Low	5	AS2,3,4: Gathering the knowledge and analysing the process help to reduce the complexity and improve the understanding of the project's structure before initiating the project.
	Continuous change in product offerings	Low	5	AS4: In scenario evaluation, the factors related to updating and maintenance are considered.

AS=activities' set

6.2. *Effects of using the proposed framework on the challenges of PCS projects*

The case applications show that the framework is useful in overcoming some of the challenges of PCS projects. The main challenges of PCS projects and their importance, as assessed by Kristjansdottir et al. (2018), are reported in the first three columns of Table 11, and the last two columns present the BC framework's specific contribution to overcoming these challenges. The fourth column presents the degree of this contribution (1 = *null*, 2 = *very small*, 3 = *small*, 4 = *big*, 5 = *very big*). In the fifth column, AS stands for "activity set." Table 11, therefore, explains how applying the proposed framework overcomes specific challenges. Notably, the report in the last two columns emerged from direct observations, interviews, and talks involving the case companies and subsequent reflections on the underlying reasons for what was observed.

There is additional evidence of positive effects derived from the use of the proposed framework. This is because three years after the first use of the framework, it is still used in the two companies that participated in this study.

6.3. *Contributions to research*

This study is the first to investigate and provide actual detailed examples of creating BCs for PCS projects. It contributes both to the literature on IT investments and PCS. To the first literature (Nielsen and Persson, 2017; Berghout and Tan, 2013), for the first time, it adds the consideration of an IT application with peculiar characteristics: the PCS. Into the PCS literature, it strengthens PCS planning with the guide of a BC framework. The proposed framework includes not only specific BC elements (Berghout and Tan, 2013) but also specific activities and related supporting tools for BC development; activities and tools that can highly influence an IT project (Remenyi and Remenyi, 2009; Remenyi, 2012). By tailoring the body of knowledge on BCs for IT investments to the case of PCSs, this paper establishes a link between the literature on PCS implementation and the literature on BCs for IT investments, two research streams that have been developed independently.

Another contribution relates to the use of BCs to overcome problems associated with PCS implementation. Previous PCS literature has shown that PCS projects face specific challenges that can hinder their successful implementation (Kristjansdottir et al., 2018), although with limited effort in developing specific countermeasures (e.g., Shafiee et al., 2020). The proposed framework, as shown in Table 11, can facilitate the overcoming of PCS challenges, thus motivating managers to adopt it.

Previous research has reported that PCSs offer substantial benefits; however, the ROI of PCS projects has been scarcely investigated. An exception is a recent article (Kristjansdottir et al., 2018) reporting the profitability of a PCS project in a specific case, unfortunately without any risk analysis, being done once the project was ended. The present paper provides ROI figures under different scenarios thus showing the variability in PCS projects' expected ROI. It also notifies managers and researchers that this variability is high and depends on the considered time horizon (see Fig. 1).

6.4. Threats to research robustness and adopted countermeasures

This research was challenged by threats to its robustness; consequently, we applied various countermeasures. The first relates to the possibility that interview terms are not interpreted in the same way by interviewees and interviewers (Yin, 2003; Runeson and Höst, 2009). The workshops conducted for each project reduced this possibility by enhancing a common in-depth understanding among the project members, including the researchers. Moreover, we avoided misinterpretation and enhanced result trustworthiness using triangulation (Runeson and Höst, 2009), which was realized through multiple observers and a combination of different data sources and data collection methods, such as the use of multiple interviews, direct observation, and documents made during each project.

The second concern relates to the evaluation of the BC framework (its usefulness and its contribution to overcoming PCS challenges), which might be affected by spurious factors (Yin, 2003; Voss et al., 2002; Runeson and Höst, 2009). For example, the responses to the interviews for BC evaluation might reflect respondents' biased opinions rather than an honest report of the framework performance. On the one hand, the multiple interactions between researchers and the case companies ensured that the framework was correctly applied in the three projects; on the other hand, triangulation techniques allowed for the comparison of different evaluations of the same project. Moreover, the interviewees were those who did the project using the framework. Table 11 provides reasons behind the framework effects in overcoming specific PCS challenges, thus improving the trustworthiness of these results. In addition, using multiple cases allowed us to detect a similar pattern of effects, thus increasing the robustness of the findings.

The third concern relates to the generalization of the research findings (Yin, 2003; Voss et al., 2002; Runeson and Höst, 2009). Although the findings of this study are based on multiple projects in two companies, they are drawn from organizations with certain characteristics (Section 4.2). However, it is very likely that the obtained results can also help companies that aim to invest in PCS but are operating in other contexts. For example, the evidence of how the framework helps in overcoming PCS projects' challenges may give useful insights to companies facing similar needs and similar challenges.

7. Conclusions

The literature on PCSs has suggested that several analyses need to be performed before starting a PCS project (e.g., Forza and Salvador, 2002; Hvam et al., 2008). However, this literature has not integrated the various analyses to recommend practitioners a specific BC framework for PCS. This gap is highly relevant for practice since BCs are known to play vital roles in avoiding or at least limiting failures in IT projects (e.g., Remenyi, 2012), and failures also occur in PCS projects due to numerous challenges (e.g., Kristjansdottir et al., 2018). To help managers developing BC for IT projects, several frameworks have been proposed (e.g., Berghout and Tan, 2013). Unfortunately, the peculiarities of PCS projects (e.g., Shafiee et al., 2018) call for assessing the viability of existing BC frameworks or even better for developing PCS-specific BC frameworks. The present study proposes a framework that includes not only the BC elements but also the process to be followed for BC preparation because it has been recognized by the practitioner literature on BCs for IT (e.g., Remenyi, 2012) that this process has a great impact on the success of IT projects. To guide the development of a BC for a PCS project, the proposed framework also identifies tools that speed up and improve the quality of the BC activities. The framework and supporting tools are intended to help practitioners focus on and prioritize the goals and specific requirements of stakeholders, analyze the current configuration process, design future configuration processes, and evaluate possible scenarios based on cost-benefit, sensitivity, and risk analyses.

The proposed BC framework was assessed in three PCS projects at two ETO companies. Those who used the framework expressed a willingness to continue using it, and the case companies still use it. Using three application cases allowed us to assess—in-depth, in detail, and in real-world contexts—the proposed framework's effectiveness. However, we were able to apply the framework to only a limited number of projects and companies, and this limits the generalizability of our results. The ability of the framework to cope with highly engineered, complex PCS projects in ETO companies indicates that it could also be used in PCS projects of less complexity. However, the effectiveness of such a structured framework in less complex PCS projects remains untested and constitutes a limitation of the present study. Further testing of the suggested framework in other contexts is required.

Previous research in the rare cases that investigated ROIs of PCS projects did not perform risk and sensitivity analyses. The case applications of the present article showed that the estimated ROI and risks may vary widely for a given project depending on the assumptions of the estimators (Section 5.3). The proposed framework helps companies balance ROI with associated risks. The figures reported for the three studied cases may be useful for managers as points of comparison. However, the present study has some limitations in this aspect. Further studies of the ROI and risks expected for different PCS projects in different types of industries and for different applications would support the development of BCs for PCS projects and the related managers' decision processes.

Finally, we observed that the use of the proposed framework mitigates the main challenges of PCS projects identified by Kristjansdottir et al. (2018). We have provided some explanations for this effect. It results not only from the more precise calculation and trade-off of ROI and risks but also from the involvement of the stakeholders, thus reducing resistance to change and guaranteeing management support during project implementation. This result of direct observation, interviews, and talks followed by analytical reasoning, to the best of our knowledge, constitutes the first consideration in the academic literature on the contribution of BCs to facing PCS challenges. This is also an essential result for practice because it helps companies address the challenges of PCS implementation. It would be worthwhile for future research to further investigate the relationship between BCs and PCS challenges to provide deeper explanations and perform ad-hoc tests moving from the first insights we provided.

CRediT authorship contribution statement

Sara Shafiee: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing –

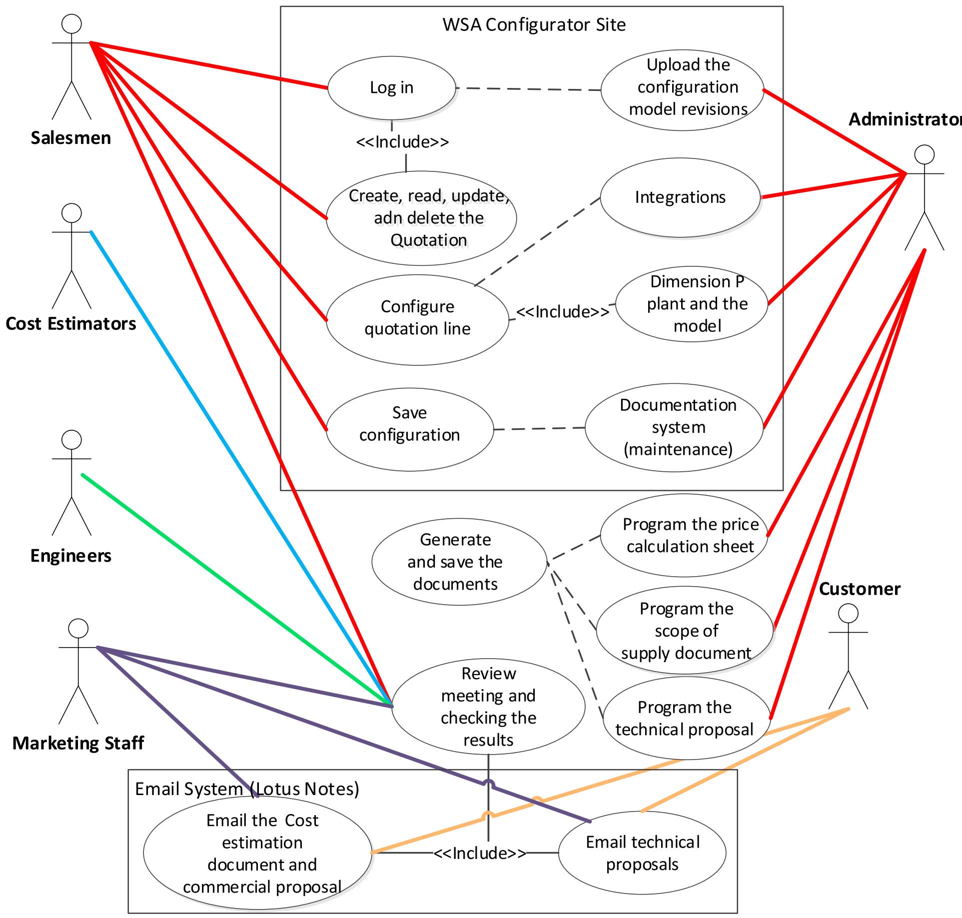

Fig. A1. Example of a use-case diagram (Case 1).

Table A1
Stakeholder-requirement prioritization by MoSCoW rule (Case 1).

List of requests	Must have	Should have	Could have	Want to have
Combining document snippets into full technical or commercial proposals (salespeople and cost estimators)		✓		
Loading data from the PCS into tables in both technical and commercial PCS (sales, cost estimators, and marketing group)			✓	
Price calculation, bills of material and scope of supply (all stakeholders)	✓			
Having colors for different components in user interface				✓

review & editing, Visualization, Supervision, Project administration and management. **Enrico Sandrin:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Cipriano Forza:** Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Katrin Kristjansdottir:** Investigation. **Anders Haug:** Writing – original draft. **Lars Hvam:** Methodology, Investigation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

There is an attachment at the end of manuscript.

Appendix

See Appendix Fig. A1 and Table A1 here.

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