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The main challenges for manufacturing companies in implementing and utilizing configurators

Katrin Kristjansdottir, Sara Shafiee, Lars Hvam, Cipriano Forza, Niels Henrik Mortensen

Abstract. Companies providing customized products increasingly apply configurators in supporting sales and design activities, thus improving lead-times, quality, cost, benefits perceived by customers, and customer satisfaction. While configurator advantages have been substantially investigated, the challenges of implementing and utilizing configurators have less often been considered. By reviewing relevant literature, the present study first categorizes the main challenges faced by manufacturing companies when implementing and utilizing configurators. Six main categories of challenges are identified: (1) IT-related, (2) product modeling, (3) organizational, (4) resource constraints, (5) product-related, and (6) knowledge acquisition. Second, through a survey, the importance of those categories of challenges is assessed, and the specific challenges within each of those categories are highlighted. Finally, it is investigated whether the importance of the main categories of challenges varies according to a number of potential context variables. The results of the survey, which studies manufacturing companies that use configurators in providing customized products, offer new insights into the importance of these categories of challenges. The findings contribute to the research on manufacturing companies' utilization of configurators and will raise awareness of the main challenges associated with their implementation and use.

Keywords: *information technology, configurators, mass customization, challenges, explorative survey*

1. Introduction

In today's business environment, customers increasingly demand customized products with short delivery times, adequate quality, and competitive prices [1, 2]. As one means of responding to those demands, mass customization strategies have attracted increased interest from both practitioners and researchers. Mass customization refers to an organization's ability to provide customized products and services that fulfil each customer's idiosyncratic needs without considerable trade-offs in cost, delivery time, and quality [3–5]. An important factor in achieving this ability are configurators, which are information systems that support the specifications of the product configuration as well as the creation and management of configuration knowledge [6]. Configurators can support interaction with customers directly or through a salesperson, thus presenting the offered products, collecting customer requests, and producing quotations [2, 7]. Configurators can also support the translation of commercial product specifications into product documentation needed to produce the required product variant (e.g., a bill of material and production sequence) [2, 7]. Some configurators support both commercial and technical processes while others support one or the other [2].

The benefits of configurators in supporting commercial and technical processes have been deepened by academic literature [2, 7–24]. The use of configurators is notable in this: it reduces lead times [8–10, 19], improves the quality of product specifications [7, 10–12] and products [13, 14], improves costing accuracy and product profitability [20], preserves product knowledge [7, 16], reduces routine work [2], improves the certainty of delivery [7, 10, 17, 19], augments the product-related and experience-related benefits perceived by customers [21–24], and increases customer satisfaction [7, 10, 18]. However, the challenges companies face in implementing and using configurators have not been addressed to the same extent as the benefits derived from the use of configurators, given the tendency in the literature to highlight successful uses [25]. A number of projects involving the adoption of configurators do fail [2, 25]; in such cases, diminishing benefits derived from company resources and innovation efforts. Further, even companies that have managed to implement and utilize configurators have faced, and are still facing, various challenges. The empirical studies of these challenges are mainly based on case studies [6, 7, 10, 14, 20, 26–29] and are based on surveys only to a limited extent [30–32]. Though some limited indications of the importance of the described challenges are given in some studies [10, 20, 25, 26, 30–32], a direct comparison of the importance of different challenges has not yet been provided.

The limited understanding of challenges and, more importantly, the importance of the challenges in implementing and utilizing configurators restricts the help that managers can find based on

research results in reducing the difficulties their companies encounter in exploiting configurators. To move further in this direction, it is necessary to continue to explore for unknown challenges and—even more importantly, given the status of knowledge on this issue—to explore the relative importance of known and unknown challenges. The knowledge that can be gained through this kind of investigation will provide precious insights for the future development of theories on the mechanisms that prevent or mitigate the negative effects of the challenges under consideration. The present study aims to bridge this research gap by addressing the following research questions (RQs).

> **RQ 1:** What are *the main categories of challenges* faced by manufacturing companies when implementing and utilizing configurators?
>
> **RQ 2:** What is the *level of importance of each category* of challenges faced by manufacturing companies when implementing and utilizing configurators?
>
> **RQ 3:** Which *specific challenges within each category* do manufacturing companies face when implementing and utilizing configurators?

We address these RQs by means of an exploratory survey designed based on what knowledge is already established in the relevant literature. To comply with the exploratory nature of the research, we have used open questions answered through phone interviews. To comply with the necessity of comparing the relative importance of the challenges already known, we used closed questions sent by email.

The remainder of the paper is structured as follows. Section 2 presents the relevant literature base. Section 3 explains the research method, and Section 4 presents the results of the research. Finally, Section 5 discusses those results in relation to the RQs and the existing literature and presents the conclusions of the study.

2. Literature review

As this paper considers the challenges of implementing and utilizing configurators rather than the algorithms or technologies used to make those configurators more powerful, the literature review reported on hereafter focuses on managerial rather than technological challenges. The considered publications are presented by combining chronological order and the groups of researchers involved. In this way, the reader can get a rough description of the evolution of the discussion on the challenges under consideration.

When reporting the configurator case of Digital Equipment Corporation in 1989, Barker et al. [14] described strategic/business challenges, technical challenges, and human

resource/organizational challenges. *Strategic/business challenges* relate to cross-functional business needs that are traced to the implementation of configurators for enhancement of business processes, requiring support from top management. The identified *technical challenges* include underdeveloped commercial configuration software with limited functionality; application challenges in aligning the system with frequent product updates and launches of new products; scope expansion of the system; and the size and complexity of the configurators. The managerial issues implied by these technical challenges include the development of an explicit understanding of the software architecture, time-consuming training of new configuration experts, and prioritization of configurator maintenance without limiting the development of supporting tools for the configurators. Finally, *resource/organizational challenges* concern the awareness of key players and roles requiring organizational changes.

Tiihonen et al. [30], in 1996, published a study based on a survey of 10 Finnish industrial companies (answer rate 5.6%) to assess the "state of the practice" in product configuration. The deeply studied companies have not yet implemented configurators, but almost all of them were planning to do so at the time of the study. They identified the following five problems areas in product configuration: the economic importance of product configuration, the product configuration task, product configuration processes, long-term management of product knowledge and configurations, and interfaces with other systems and processes. By focusing on knowledge-based systems that can be used to model configuration knowledge, the authors identified the following issues: configuration knowledge (which is often not systematically documented), configurators' ability to support parametric components, geometry, and product configuration (e.g., to generate 2D and 3D drawings of parametric instances), customer requirements at different levels of abstraction, the level of automatic operations (where it is not always desirable to automate the complete process), long-term management of configurators' models, semi-configurable products, and finally, market areas that the configurator should support.

In another paper published in 1998, Tiihonen et al. [31] went deeper into the main challenges of long-term configurator projects by using the same 10 Finnish industrial companies analyzed in the previous study [30]. The authors underscored that long-term management of product knowledge is a challenge: difficulties in maintaining the configuration models have been the cause of configurator project failure. After a successful introduction of a configurator, it is meaningful to encourage its use by the entire sales force (i.e., those who sell configured products) and integrate it into retailers' IT systems. This wide adoption improves the front-end processes of a company system-wide. If

retailers, however, are unwilling to acquire or use a configurator, integrating automatic and manual configuration processes is a challenge.

Ariano and Dagnino's [26] 1996 study related to a furniture manufacturing company in which a primary challenge was that too few employees understood the structure of the configurator. This caused difficulties when the only employee who fully understood the structure left the company. Additionally, when the main sponsor of the projects left, the company failed to further develop the system because of a lack of support and resistance to changing established work practices. The company lacked the expert knowledge needed to expand the system and was unwilling to allocate the required resources despite the known benefits. An overall lack of commitment from the company was, therefore, the main challenge in relation to the implementation of the configurator.

In 2000, Felfernig et al. [33] found that the complexity of configurator software development requires highly technical expert knowledge and that the knowledge base must be adapted continuously because of changing components and configuration constraints. Additionally, the development and maintenance time for configurators is strictly limited as the configurators need to be aligned with product developments and companies' offerings. To overcome these difficulties, a Unified Modeling Language (UML) is proposed as an approach to provide more formal descriptions of application domains. The approach is evaluated both in private telephone switching systems and in the automotive industry.

Also in 2000, Aldanondo et al. [34] described two kinds of expertise needed to develop a configurator: industrial expertise and configuration expertise. This knowledge is especially required in companies providing highly customized products, such as furniture, electronics cards, and power stations. The authors reported, however, that it was too time-consuming to train people to become experts in both areas. People with industrial knowledge do not usually develop the configurators, and industry knowledge is often distributed among various employees, making it difficult to develop a comprehensive understanding of both areas (i.e., configuration and product expertise). Furthermore, other challenges included representing the underlying structure of the configurators' models and finding a logical way to ask the customers questions in the configuration process.

Forza and Salvador [10], in 2002, identified product modeling as the main challenge of configurators' implementation and use in a small manufacturing company that made mold-bases for plastics molding and punching-bases for metal sheet punching. High product variety resulted in a complex product model, especially when there was heavy interdependency among product characteristics. Difficulties in constructing the product model could cause project delays, and

challenges in documenting the product model arose after the configurator was implemented. Delays were also caused by not relieving the people responsible for setting up the configurator from their daily activities at the company. They should have been committed full-time to the implementation of the product model.

In another study in 2002, Forza and Salvador [7] described the main challenges of implementing a configurator in a small manufacturing company that designed, produced, and sold small- and medium-power voltage transformers personal role changes, inter-function collaboration, workload, and software personalization. Personal role changes occur as the system takes over routine tasks, a takeover that some employees considered a threat to their positions, and difficulties in inter-function collaboration within the company made it more difficult to build the product model. Because of the considerable time required to build the product model and the consequent increase in workloads, the company did not implement the most complex products into the configurator. Software personalization was considered challenging because the commercial configurator was unable to meet the company's specific needs.

In 2006, Forza et al. [27] studied a machinery company that produced small, medium, and large electric motors and alternators. Based on their findings, the authors explained that, for highly complex products involving a very large solution space that is difficult to pre-define, it might not be economically feasible to implement a configurator—not only because the cost of implementation was greater than the benefits but also because the amount of time and effort involved increased the burden to be overcome.

Forza and Salvador [2], in a 2007 analytical study, combined the results of anecdotal cases, case studies, and exploratory surveys and identified the following project killers for configurators: changes in employees' roles and responsibilities, reduced freedom of action, conflicts between the front and back offices regarding the requirements of the configurator, excessive workload, unreasonable architecture of the product families, and excessive software customization.

In 2003, Ardissono et al. [35] identified the main challenges experienced with configurators as increased complexity of products and services offered, which resulted in increased complexity of the systems, making it difficult for the end-user to utilize the system due to a lack of technical knowledge. They also mentioned the companies' dependency on retrieving information from the suppliers of the customized products because knowledge representations were not shared across companies.

Heiskala et al. [28], in 2005, investigated challenges related to configurators in service companies. Heiskala et al. [28] first identified from literature the following main challenges for configurators in manufacturing companies: rapid update and maintenance requirements, knowledge acquisition, knowledge testing, maintenance requiring configuration and product experts, high dependency on configuration experts, and specification errors arising from misunderstandings. Subsequently, they studied two service companies and found out that the identified challenges affected those companies too.

In 2007, Heiskala et al. [6] described challenges related to configurators by reviewing the literature on how configurators affected the operations and business of companies pursuing mass customization with configurable products. Their discussion is divided into customer and supplier viewpoints. The supplier viewpoint is further divided into issues concerning the business (e.g., major changes might be required that can be difficult to achieve; the introduction of the configurator can be both costly and time-consuming), organization (e.g., employees' role changes can cause resistance; cooperation is required within the companies), specification processes (e.g., understanding the customer needs, fixed interaction with customers, difficult-to-modify created configurations), long-term management of configuration knowledge (e.g., fast updating, growing configuration models and complexity, various expertise required), and development and initial introduction of the configurators (e.g., knowledge acquisition, knowledge systemization and formalization, integration to other IT systems, user-interface).

In 2006, Hvam et al. [29] described challenges related to knowledge acquisition and product modeling in configuration projects for complex products as well as communication difficulties between domain and configuration experts. They also reported the challenges of implementing a configurator in an investigated engineering company, including resistance to using the configurator because of previous unsuccessful implementations of other IT systems.

Petersen [36] found, in 2007, that the main challenges in implementing configurators in engineering companies concern product characteristics, customer requirements, and lengthy project timespans. In relation to product characteristics, where the complexity of products offered by engineering companies is high, product families may not be clearly defined. As customer requirements can be both diverse and highly specific, the configurator must be able to support products that have not previously been defined in the system.

To explain why configuration projects dealing with complex products and multiple users do not deliver the expected results or are even abandoned, in 2012, Haug et al. [25] noted two major

difficulties. First, if the configurator project is more expensive than anticipated, companies may abandon the implementation to prevent further losses before a prototype is fully developed. Second, the company may refuse to accept the configurator because of its insufficient capability to support sales and engineering processes. Finally, Haug et al. [25] mentioned the need for sufficient accuracy and allocation of maintenance resources to preserve alignment with the company's offerings.

In 2017, Shafiee et al. [37] described the main challenges for a configurator project based on a large international company providing catalysts and process plant technology in terms of documentation and communication with domain experts. The significant time and effort needed to maintain the documentation of the configurator model results in both insufficient time spent on documentation and a lack of validation by domain experts that can, in turn, lead to errors in the configurator.

In a 2017 study analyzing the impact of a configurator on the accuracy of cost calculations and, consequently, on product profitability, Myrodia et al. [20] identified three challenges faced by a small company that manufactures pre-made structural elements for buildings and provides installation services. Those challenges were as follows: a lack of proper testing before launching the configurator, failure to support the entire product portfolio, and employee resistance to changes in their work routines.

In 2016, Zhang and Helo [32] conducted a survey to analyze changes in companies' business activities and also to identify difficulties and potential barriers to designing, developing, and using configurators. The survey analyzed 61 companies (answer rate 20%) in the computer, telecommunication systems, and industrial machinery industries. The respondents were mainly IT managers or managers with sales IT responsibilities. The survey was conducted in collaboration with the EMpanel Online consulting company. Their findings showed that continuous product evolution is the challenge mentioned by most respondents. Other challenges frequently mentioned included a lack of IT system designers and developers, unclear customer requirements, and employees' concern about losing their work.

The challenges indicated in the reviewed studies fall into six main categories: IT-related, product modeling, organizational, resource constraints, product-related, and knowledge acquisition. While the literature also describes other challenges, this categorization, as reported in Table 1, encompasses the most commonly reported challenges.

Table 1. Categories of challenges related to implementation and utilization of configurators

The main categories of challenges	*Nature of challenges within the category*	*Main contributions*
1. IT-related	All technical challenges related to IT systems (e.g., software personalization, design of a user interface, scope expansion, interaction with software suppliers, and functionalities)	[2, 6, 7, 14, 26, 30, 31, 33–35]
2. Product modeling	Challenges related to formalizing the product knowledge and model to be embedded in the configurator	[6, 7, 10, 25, 28–31, 33, 34, 36–38]
4. Organizational	Lack of support from management, resistance to change, allocation of resources	[2, 6, 7, 14, 20, 25, 26, 29, 31, 32]
3. Resource constraints	Lack of personnel to model the configurator and gather and provide information, and dependency on resources	[2, 14, 25, 26, 28, 32, 34]
5. Product-related	Challenges in the product range, commonly described as complexity of product structure and continuous change in products	[2, 6, 7, 10, 14, 27–33, 35, 36]
6. Knowledge acquisition	Difficulties in knowledge-gathering and availability of information in development and maintenance phases	[6, 28–35]

While previous studies [2, 6, 7, 10, 14, 25–38] have identified several challenges for configurators' implementation and use, their relative importance remains largely unknown. This knowledge limitation relates not only to the categories of challenges reported in Table 1, but also—and to a greater extent—the specific challenges included in each category. Furthermore, the specific challenges in several publications are simply mentioned and not clearly defined, exemplified, and contextualized. For both practitioners and academics, it would be useful to know which challenges have the greatest impact. This would help to focus managerial attention and research efforts on the more important challenges, supporting strategic prioritization of investment to address these challenges.

The fact that empirical studies on challenges are based mainly on case studies [6, 7, 10, 14, 20, 26–29, 37, 38] and, to a limited extent, on surveys [30–32] and that our knowledge of the relative importance of challenges is very limited [10, 20, 25, 26, 30–32] suggests that we still need exploratory research into the relative importance of the main categories of challenges. Even if it is merely exploratory, this research should specify clearly the contexts in which the various challenges

appear and should also provide a detailed description of the challenges to prepare for well-grounded, extensive studies.

3. Research method

Coherently with the RQs of the present study and the current knowledge of challenges companies face when implementing and utilizing configurators, exploratory survey research design is selected to help us become more familiar with the studied phenomenon and to provide the foundation for future descriptive or explanatory survey research [39, 40]. To get a deeper understanding of the challenges and the context in which they take place, we administered the survey using a combination of emailed questionnaires and telephone interviews. The sample used in this study included 22 manufacturing companies that were producing and selling customized products and utilizing configurators to support their commercial or technical processes. This sample allows us to explore the main challenges faced by experienced adopters in implementing and utilizing configurators. Accordingly, with the exploratory nature of the study, more effort is devoted to ensuring the depth of the data, and less effort is devoted to enlarging sample size. Small sample sizes are justifiable for exploratory research [41, 42]. The following sections provide further details on sampling, questionnaire design, data collection, and data analysis.

3.1 Sample

The Danish Association for Product Modeling was used to identify companies that fulfilled the selection criteria for the study. Eligible companies were required to manufacture customized products and to have established experience using configurators. This would allow for analysis of the challenges of both implementing and utilizing configurators. Brainstorming sessions (e.g., with consultancies, vendors of configurators, and other collaborators) were conducted to identify additional companies of relevance. During the interviews, respondents from sampled companies were also asked to list other companies that might fulfil the selection criteria. Thus, we identified another couple of companies to be contacted for participation in the study. In total, 26 companies were contacted; of those, 22 answered (a response rate of 85%). Further attempts at telephone contact with the remaining four companies were not successful. These four companies have staff sizes of 500, 2,000, 13,000, and 21,000 employees. Two of them make customized plants and system solutions while the other two produce customized machines and components.

The resulting sample comprises 22 manufacturing companies of various sizes. The sampled organizations range from small companies (i.e., 20 employees) to very large companies (i.e., 15,000

employees), with larger companies being present in larger numbers in the study. Of the companies in the sample, 81.81% have 450 or more employees, and 90.91% have more than 100 employees.

All companies in the resulting sample produce and offer physical products. The main products offered by the surveyed companies are plants, machines, system solutions, and components. *Plants* include, for example, processing material for food and heating supplies. A plant consists of several machines, their interfaces, and surrounding constructions. *Machines* include, for example, machines supporting the agricultural, printing, building, and shipping industries. A machine consists of several components/modules and their interfaces. *Systems solutions* include complete solutions for the building industry, electronic systems, ventilation systems, and climate control systems, among others. Finally, *components* include mechanical, hydraulic, control board, building, and heating system components, among others.

Each company in the sample earns the greatest part of its revenues from one of the above-mentioned products offerings. Thirteen companies (59.09%) offer more than one of these products. Two companies (9.09%) generate the most significant part of their revenues from plants, and in total, four companies (18.18%) get some part of their revenues from selling plants. Six companies (27.27%) get the most significant part of their revenues from systems solutions, and in total, 10 companies (45.45%) get some part of their revenues from systems solutions. Five companies (22.73%) get the most significant part of their revenues from machines, and in total, seven companies (31.82%) get some part of their revenues from machines. Nine companies (40.91%) get a significant part of their revenues from components, and 17 companies (77.27%) get some part of their revenues from components. None of the sample companies gets the largest share of their revenues from products outside of these four main product groups.

In adherence with the sample selection criteria, all sampled companies offer customized products. More specifically, 13 (59.09%) of the companies get over 60.00% of their sales revenues from customized products. This high incidence of customized products is not surprising, given the products offered and the fact that all the sampled companies operate in the business-to-business (B2B) markets.

The use of configurators in each company of the sample is significant, though it varies considerably across companies. Eleven (50.00%) companies get over 60% of their revenues from products supported by configurators while seven companies (31.82%) receive less than 20.00% of their revenues from products supported by configurators. The companies' reasons for not supporting their complete product range with configurators include excessive product complexity,

inadequate sales volumes, newly introduced products not yet added to the configurator, and product families without customization.

All companies in the sample have considerable experience in using configurators and can, therefore, inform researchers of the challenges of both implementing and utilizing configurators. The companies' experience using configurators ranges from a minimum of three years to a maximum of 25 years. Seventeen (77.27%) of the companies have seven years' or longer experience utilizing configurators.

The sampled companies differ considerably in the number of configurators they use, up to a maximum of 20. All of the sample companies have at least one configurator in operation, 12 (54.55%) have two or more configurators in use, and six (27.27%) have five or more configurators in use. In counting the number of configurators in use, we consider a configurator as having a separate knowledge base, irrespective of the software platform used. Two different knowledge bases (each of which includes knowledge of a single product family) built on the same software platform, therefore, counts as two configurators. A product family supported with both commercial and technical configurators can be counted as either one or two. If the commercial and technical configurators are built on the same knowledge bases (i.e., the knowledge of the technical configurator is added to the commercial one), this counts as one configurator. However, when the commercial and the technical configurators are built upon separate knowledge bases (i.e., the commercial and the technical configurators can be defined as separated standalone systems), they count as two configurators.

3.2 Respondents

One person from each company was responsible for answering the survey, based on the respondent familiarity with the configurators and irrespective of the formal role at the company; top-level management might not possess the required in-depth knowledge of configurators. It is notable that those responsible for managing configurators occupy different positions within the organizational structure of participating companies. The respondents' positions at their respective companies included the following (the number of companies are indicated in parentheses): business process manager (1), consultant (1), design support manager (1), group manager (1), information officer manager (1), manager of customization and specialized equipment (1), manager of the drawing department (1), mechanical engineer (1), customer support and master planner (1), product data manager (2), product manager (1), production technician (1), project manager (2), sales technician

(1), sales manager (1), strategic development (1), system developer (1), system manager (1), and technical director (2).

3.3 Questionnaire

A first version of the questionnaire was developed based on the literature review, using a brainstorming approach to specify the main constructs. The study was designed to explore—both qualitatively and quantitatively—the importance and the nature of the main challenges. For the purposes of this research, respondents were asked the following questions:[1]

1. What are the three greatest challenges your company has faced or is facing when implementing and utilizing the configurator?

2. On a five-point scale, ranging from one (not important) to five (very important), please rate the importance of the following types of challenges your company has faced or is facing when implementing and utilizing configurators:
   - IT-related challenges
   - Product modeling
   - Organizational challenges
   - Resource constraints
   - Product-related challenges
   - Knowledge acquisition

The first question was designed to capture the nature of the challenges and to encourage respondents to describe, in their own words, the main challenges their companies had encountered in relation to implementing and utilizing configurators. The aims were (1) to identify additional categories of challenges that had not been described in the literature and (2) to gain further insights into the main categories of challenges already addressed in the literature (i.e., RQs 1 and 3). The second question was designed to quantify the importance of the main categories of challenges described in the literature to allow for direct comparison (i.e., RQ 2).

To validate the questionnaire, three pilot interviews in differing industrial configuration settings were conducted. The pilot interviews focused on (1) testing the relevance of the questions and instruments to ensure that the questions made sense, formulations were accurate, and assumptions were explicit, and (2) discussing companies' configuration practices to identify additional topics of relevance for the questionnaire. Following the pilot interviews, small amendments were made to the questionnaire, including changes in wording for improved clarity.

[1] Additional questions have been asked to characterize the company context.

3.4 Data collection

To begin, the questionnaires were emailed to respondents, along with a description of the study's purpose, interview procedure, and follow-up notification. Appointments were made for telephone interviews, which were conducted as a walkthrough of the questionnaire. During the interview, the researcher made notes of the respondent's answers. Each interview lasted 40–90 minutes, depending on the complexity of the configuration setting and the respondent's particular situation. This time allowed the interviewer to build positive rapport with the interviewees, hopefully leading to more specific—and, we think, also more reliable—information. Immediately after the interviews, the completed questionnaires were emailed to respondents for verification while the interviews were fresh in their minds, and a few respondents used the opportunity to modify their answers.

The interview process enabled clarification and elaboration of responses to ensure correct and consistent interpretation of the questions and to ensure that the interviewer gained a complete understanding of the companies' settings. Most respondents listed three or four challenges, five companies mentioned only one challenge as their primary difficulty, and one company listed five challenges. When needed, respondents were asked to elaborate on the challenges to provide us with a deeper understanding of the difficulties in question, and we made notes of their answers.

3.5 Data cleaning and analysis

Once data had been collected, responses to the questionnaire and interviews were entered into a database. Subsequently, the responses were cross-checked for data entry errors and analyzed.

Answers to the open questions were coded and grouped into the main categories identified based on the literature; to prevent any bias, the interview data were coded and analyzed by a person other than the interviewer. Grouping of responses was discussed among the authors to check consistency, and the data were cleaned to ensure their reliability. In one case, an inconsistency was found between the qualitative data (i.e., data gathered through the open questions) and quantitative data (i.e., data gathered through closed questions); the discrepancy was corrected after further investigation. In one other case, where the company reported only one challenge, the reported challenge was assigned to multiple categories because the content of the answer touched on each of the categories. In a few cases, an individual answer was broken down into two separate challenges since it addressed multiple challenges. In other cases, individual answers were collapsed into the same challenge because the respondent was describing different aspects of the same challenge. At the end of this process, from the open questions, 15 (68.18%) of the companies had three

challenges, three (13.64%) companies had two challenges, and four (18.18%) companies had one challenge.

Subsequently, overall consistency across qualitative and quantitative data was checked to ensure that the challenges mentioned or omitted in the qualitative part (i.e., where we asked for the three greatest challenges) were assigned a coherent importance in the quantitative part (i.e., where we asked for the level of importance of each category of challenges). Appendix 1 reports some of the details from this analysis. The consistency checks confirmed the following:

- In the quantitative part, companies assigned higher importance to a challenge category for which they identified a corresponding challenge in the qualitative part than did companies that did not identify such a challenge.
- None of the companies that expressed a challenge in the qualitative part rated the category that included such a challenge as unimportant in the quantitative part.
- Companies that made no mention (in the qualitative part) of any challenge belonging to a certain category also did not assign very high importance to that category.

In one exception, a company rated resource constraint challenges as highly important without mentioning any challenge related to this category in the qualitative part. Specifically, this company rated IT-related, product-related, and knowledge acquisition challenges as highly important, product modeling as very important, and organizational challenges as important. By further analyzing the data retrieved from this company, resource constraint emerged as the underlying challenge. The lack of resources intensified IT-related, product-related, and organizational challenges.

Descriptive statistics are used to present the findings of the study. All the reported percentages in the results section refer to the same number of companies (N = 22), with no missing data in the dataset. The fact that, in the open question, some companies provided less than three challenges does not mean that data is missing since our intention is to find the most important challenges. For that purpose, even the absence of important challenges is admissible. If a company, when answering the open question, points out one or two challenges only, it means that, for this company, there are only one or two important challenges. Our objective is not to provide an exhaustive list of challenges but to point out the most important challenges.

4. Results

This section presents the results of the performed analyses. Section 4.1 reports the results of the analysis of the qualitative data while Section 4.2 presents the results of the analysis of the quantitative data.

4.1 Identified challenges in implementing and using configurators

The results presented in this section aim to assess the main challenges that manufacturing companies encounter when implementing and utilizing configurators, thus (1) indicating whether the categories derived from the literature are among the main categories (and whether additional categories are identified [RQ 1]) and (2) highlighting and describing specific challenges within each of the derived categories (RQ 3). Table 2 details the percentages of companies that referred to the different main categories of challenges identified based on the literature.

Table 2. Number of companies reporting challenges belonging to the main categories of challenges

The main categories of challenges	*Number of companies*	*Percentage of companies*
IT-related	8	36.36%
Product modeling	9	40.91%
Organizational	15	68.18%
Resource constraints	5	22.73%
Product-related	5	22.73%
Knowledge acquisition	13	59.09%

Based on the answers from the company respondents, we concluded that no additional categories were required. The following sections describe the individual categories of challenges, based on the respondents' answers, in more detail.

4.1.1 IT-related challenges

The reported IT challenges are grouped into two subcategories related to (1) software development and (2) system design to achieve user-friendliness.

With regard to *software development*, two of the respondents explained that the technical aspects of developing and implementing a web-based configurator had presented a major difficulty; two other respondents reported difficulties in integrating the configurators with other IT systems at their companies. One respondent also referred to challenges in exchanging information across different configurators. Operating the database and developing customized functionalities caused problems for some respondents.

Designing *user-friendly* configurators was also considered challenging. One respondent reported that salespersons' desire to use the configurator was proportional to its user-friendliness. The same respondent added that the sales configurator was launched and tested to achieve user-friendliness and was later expanded to include the technical configurator. Another respondent reported that the

complexity of technical requirements and the product range had made it difficult to incorporate all of the right product combinations in the configurator and, thus, compromised the configurator's user-friendliness.

4.1.2 Product modeling

The reported product modeling challenges can be grouped into three subcategories: (1) complexity due to lack of overview of product range, (2) correctness of specifications generated by the configurator according to the product model, and (3) lack of knowledge related to product modeling.

Regarding *complexity due to lack of overview*, respondents highlighted problems caused for users by the complexity of the configurator. Two respondents noted that the lack of a product overview made it difficult to formalize in a logical way the questions asked in the configuration processes, another respondent referred to difficulties in maintaining an overview, and another said that it was difficult to ensure the configurator's ease of use with increasing complexity.

The *correctness of specifications* generated by configurators depends on the underlying product model. One respondent reported a constant need to test whether parts were properly configured, owing to a lack of product modeling and validation. Another respondent stated that, in addition to ensuring that the configurator could generate bills-of-materials (BOMs) in the configuration process, it was also important to verify that the individual parts or components fit together and that instructions were provided for setting up the individual parts or components. A product model that does not accurately represent the different relationships in the product structure hinders the correctness of configurations and outputs.

Regarding *unfamiliarity with product modeling*, one respondent reported challenges in establishing knowledge and acquiring information about how configurators work and how to build the underlying product model.

4.1.3 *Organizational challenges*

Organizational challenges refer to (1) a lack of support from management, (2) resistance to using the configurator, and (3) disagreements about the scope of the configurator.

Two respondents reported a *lack of support from management* and a lack of backup in addressing change management challenges. As implementation of a configurator is usually cross-functional and affects multiple stakeholders, increased support from management promotes project success. This support can ensure that key activities are prioritized and that resources are assigned to the project. As one respondent explained, key people at the company have the necessary knowledge to

develop and validate the system. To secure access to this professional knowledge, management must prioritize configurator projects. One respondent said that the configuration team found it difficult to keep current with product development because the team was usually the last to know about new products. Finally, one respondent referred to a lack of documentation, and another to a lack of ongoing training and documentation, as organizational challenges in which resources and central activities are not prioritized by management.

One respondent mentioned the challenge posed by *resistance to using the system*, emphasizing the difficulty of changing employees' habits so they could adapt to use of the configurator as part of a new work procedure. Another respondent stated that this resistance might stem from employees' reluctance to abandon the comfort of the old system (e.g., employees who were used to working alone experienced difficulties in adjusting to a system that required them to work on the same things with more customer focus). Increased standardization of products and processes was also mentioned as a source of organizational resistance. One respondent explained that the configurator marked a move toward a more standardized and structured sales process, limiting individual freedom and shifting the focus from prices to customer value creation. In addition, one respondent explained that sales representatives used the configurator only in special cases while continuing to use the old system in other cases, indicating that sales representatives were not committed to the new procedure, even in cases that could be handled by the configurator. As well as this internal resistance, four respondents reported difficulties in convincing their sales agents or customers to use the configurator despite offers of training and discounts for using the systems in the sales process.

Disagreement about configurator scope was also reported as a major organizational challenge. One respondent mentioned that all products need to be supported by the configurator if salespersons were to recognize the system's usefulness. When only some products are supported by the configurator, there is a limitation to the extent that the configurator can be used. If some products are out of the scope of the configurator, salespersons are forced to use the old process, thus reducing their acceptance of the configurator. Finally, two respondents noted a challenge in agreeing on the configurator's content and boundaries. According to companies, not all products were included in the configurator because that would result in great complexity. It follows that, in supporting configuration for a greater variety of products, the system can compromise user-friendliness.

4.1.4 Resource constraints

The main challenges related to resource constraints were described in terms of (1) lack of resources and (2) vulnerability if key personnel leave.

With regard to challenges related to *lack of resources* in configuration projects, two respondents highlighted the lack of resources for the configuration team and the release of resources from the business (e.g., product experts). Another respondent explained this in terms of capacity planning difficulties. Yet another said that a lack of resources meant that not all products were included in the configurator, thus increasing resistance to using the system (as explained in Section 4.1.3).

In terms of *vulnerability if key personnel leave,* one respondent indicated that a lack of resources made it difficult for anyone other than key personnel to gain an overview of the configurator and the knowledge embedded in the system. Confining access to all the valuable knowledge to a small number of employees puts the company at risk if these key personnel leave. It can be difficult for another person to become familiar with the system because this requires knowledge about both the companies' products and the configuration software.

4.1.5 Product-related challenges

The main challenges related to the products were described in terms of (1) complexity of product structures and (2) continuous change in product offerings.

One respondent explained that, as *complex products* entail more options, rules, and dependencies, they require improved decision-making and more complex configurators. In this sense, managing complexity is a challenge. Another respondent emphasized that proceeding with the configurator requires a high level of standardization of the product range. This corresponds to how configurators require components or modules to be defined with constraints that determine how different parts and components can be combined. Another respondent explained these challenges in relation to the generation of BOMs, in which individual parts and components are fitted together and setup instructions are generated.

With respect to challenges related to product range and *continuous changes in product offerings*, one respondent pointed out that configurators must be capable of rapid updating to align with offered products. Another respondent expressed the view that configurators must stay updated to ensure that they are aligned with the company's products. The configuration team, therefore, needs to be at the forefront of new product development.

4.1.6 Knowledge acquisition

The main challenges relating to knowledge acquisition were characterized as (1) difficulties in acquiring the correct knowledge, (2) a lack of knowledge needed to meet users' and customers' needs, and (3) failure to communicate knowledge in the maintenance phase.

The process of *acquiring correct product knowledge* was considered critical in ensuring configurator quality. One of the interviewees explained this in terms of the need to transfer specifications to the configurator without misinterpreting or losing knowledge. Other problems arose regarding the requirement that specifications should be as accurate as possible, so all users have the same starting point. Another respondent explained that incomplete product definitions made it difficult to keep track of products and their variants. A respondent from a company specializing in engineered solutions for individual customers referred to challenges resulting from an inadequate product program structure, which made it difficult to capture the required knowledge and expand the configurator. Similarly, another respondent noted challenges in relation to parameters of each variant requested by the customer and another described a lack of knowledge of how different parts can be combined as being a key challenge. Finally, it was observed that organizations had different approaches to validate the correctness of the configurators. While some organizations validated the correctness of the gathered information when making the product model before developing the configurator, other organizations went through an extensive testing phase to eliminate errors after developing the configurator, and finally, other organizations relied on feedback after launching the system.

Another challenge related to knowledge acquisition was expressed in terms of *understanding customers' and users' needs* to ensure that these could be fulfilled in the configuration process. As configurators are commonly used to guide sales processes, it is critical to gather sufficient information to capture users' and customers' needs. As in the case of organizational challenges, if the system lacks the necessary scope to address users' needs, resistance to the use of the system is likely to increase. This was also expressed as a problem of knowledge acquisition; one respondent noted that the configurator could not meet all salespersons' needs and all product variants because of a lack of knowledge. Another challenge expressed by respondents in two companies was the difficulty of acquiring knowledge of the customers' needs to be reflected in the configurator setup.

Issues related to *knowledge acquisition in the maintenance phase* were also considered a challenge. This challenge relates to increasing difficulties, as time passes from the development of the configurator, to recall or acquire the underlying reasons for certain logic within the configurator (e.g., why certain selections are not allowed). This difficulty makes it more challenging to troubleshoot the configurator in the maintenance phase. Two other respondents stated that new options were not being updated in the configurator because product knowledge was not being

communicated in the maintenance phase. Finally, it was seen as challenging that new products had to be approved each time because of a lack of validation and information from product experts.

4.1.7 Summary of the main challenges identified within each category of challenges

In Table 3, the specific challenges within each of the main categories of challenges are synthesized based on the previous descriptions of the specific answers given by the companies' respondents. For each of the categories, two or three challenges are highlighted, providing an answer to RQ 3.

Table 3. Specific challenges per main category—derived through open questions on three main challenges per company.

Main categories of challenges	*Specific challenges within each category of challenges*	*Companies (%)*	*Companies (%)*
IT-related	Software development	27.27%	36.36%
	Systems design for user-friendliness	9.09%	
Product modeling	Complexity due to lack of overview of product range	22.73%	40.91%
	Correctness of specifications generated by the configurator according to product model	13.64%	
	Lack of knowledge related to product modeling	4.55%	
Organizational	Lack of support from top management	27.27%	68.18%
	Resistance to using the configurator	36.36%	
	Disagreements about the scope of the configurator	13.64%	
Resource constraints	Lack of resources	18.18%	22.73%
	Vulnerability if key personnel leave	4.55%	
Product-related	Complexity of product structures	13.64%	22.73%
	Continuous change in product offerings	9.09%	
Knowledge acquisition	Difficulties in acquiring the correct knowledge	27.27%	59.09%
	Lack of the requisite knowledge to meet users' and customers' needs	13.64%	
	Failure to communicate knowledge in the maintenance phase	18.18%	

4.2 Importance of the main reported categories of challenges

The second part of the research focuses on assessing the importance of the categories of challenges encountered when implementing and managing configurators (RQ 2). Table 4 sets out the main categories of challenges in terms of their importance as measured on a five-point scale, ranging from one (not important) to five (very high importance). In Table 4, ratings of four and five are

aggregated to signal *primary importance*, and ratings of two and three are aggregated to signal *secondary importance*. Furthermore, Table 4 recalls the percentage of companies related to a given category in the qualitative part of the study (see also Tables 2 and 3), when informants were asked to list the three most important challenges faced by their company in implementing and utilizing configurators.

Table 4. The importance of the main categories of challenges—combining the qualitative and quantitave analyses

Categories of challenges	**Qualitative results**	**Quantitative results**					**Overall importance**
	Percentage of companies referring to the category	**Not important**	**Secondary importance**		**Primary Importance**		
		Not important	*Very low importance*	*Low importance*	*High importance*	*Very high importance*	
		[1]	*[2]*	*[3]*	*[4]*	*[5]*	
Organizational	68.18%	**13.64%**	**36.36%**		**50.00%**		**Very high**
			13.64%	22.73%	36.36%	13.64%	
Knowledge acquisition	59.09%	**18.18%**	**31.82%**		**50.00%**		**High**
			18.18%	13.64%	36.36%	13.64%	
Product modeling	40.91%	**9.09%**	**40.91%**		**50.00%**		**Medium high**
			22.73%	18.18%	36.36%	13.64%	
Resource constraints	22.73%	**18.18%**	**36.36%**		**45.45%**		**Medium low**
			13.64%	22.73%	31.82%	13.64%	
IT-related	36.36%	**9.09%**	**54.55%**		**36.36%**		**Low**
			31.82%	22.73%	18.18%	18.18%	
Product-related	22.73%	**22.73%**	**50.00%**		**27.27%**		**Very low**
			31.82%	18.18%	18.18%	9.09%	

Each category of challenges was recognized as important in the closed questions by at least 17 (77.27%) of the companies. The levels of importance, however, differed across categories. To provide an overall assessment of the importance of each category of challenges hereafter, we complement the information gathered by the closed questions with the information gathered by the open questions.

Three categories have been recognized as being of primary importance by 11 (50.00%) of the companies: organizational, knowledge acquisition, and product modeling. Surprisingly, the number of companies that rate them as being of very high importance is the same (three, or 13.64%) as those that rate them as highly important eight (36.36%). Organizational challenges were not only the highest in the quantitative part (i.e. 11 [50.00%] rated them with primary importance) but also,

by far, the highest in the qualitative part (i.e., 15 [68.18%] of the companies mentioned a challenge in that category among the three main challenges). Thus, we ranked organizational challenges as very high in overall importance. The results for the knowledge acquisition category are slightly higher than those of product modeling in the quantitative part but much lower in the qualitative part. Thus, we ranked knowledge acquisition as being of high overall importance and product modeling being of medium overall importance. Notably, these two categories address related issues.

The other three categories (i.e., resource constraints, IT-related, product-related) are of secondary importance. The product-related challenges category results are by far the lowest among these three categories in both the qualitative and quantitative parts. The results for the resource constraints and IT-related categories are close, but almost half (i.e., 10 [45.45%]) of the companies rated the resource constraint category as being of primary importance while the IT-related category was rated as being of primary importance by only one-third (36.36%) of companies. The overall importance rating of the resource constraint category, therefore, is medium-low while the overall rating of the IT-related category is low.

4.3 Exploring contingencies

The importance of the main categories of challenges varies considerably across companies as the figures in Table 4 suggest. This variation could limit the usefulness of the presented results for practitioners. To reduce this limitation, we used the Kruskal-Wallis test to explore whether companies with different values in a potential contingent variable present significant differences in the importance of the main categories of challenges. Each of the variables used to describe the sample (Section 3.1) was considered as a potential contingent variable. For each contingent variable, the companies were divided into groups of two, three, and four. To build those groups, we used different thresholds. We retained the groupings that showed more significant differences. The results reported in Table 5 should allow practitioners to recognize whether their specific situation in each of the nine potential contingency variables significantly changes the importance of the identified main categories of challenges.

The importance of the organizational challenge category presents some variations regarding the *size of the company*. The 10 largest companies (which have between 600 and 15,000 employees each) present a higher degree of organizational challenge (median = 4) than the 12 smaller companies (which have between 20 and 500 employees each [median = 3]). This difference is statistically significant at the conventional (10%) level according to the Kruskal-Wallis test ($p = 0.071$). At a more detailed level of challenges, the smaller companies suffer more from higher

software development challenges (five [41.67%] companies) and complexity due to a lack of an overview of the product range (four [33.33%] companies) than the larger companies, among which each one of these challenges was mentioned by one (10.00%) company only.

There are some weak signs that the *number of years of using PCS* could be associated with the differing importance of organizational challenges. The 10 companies that have used configurators for shorter period (three to nine years) rate organizational challenges as being more important than the 12 companies that have used configurators for longer time (10–25 years). In fact, the median values are respectively equal to four and three, but this difference does not result in statistical significance at conventional levels when using the Kruskal-Wallis test ($p = 0.183$). However, looking at the qualitative answers, eight (80.00%) of the companies that have used configurators for a shorter period mentioned an organizational challenge (two companies expressed two organizational challenges each) while seven (58.33%) of the companies that have been using configurators for a longer period did the same. In detail, it emerges that six (60.00%) of the companies in the former group suffer from resistance to the use of configurators versus only two (16.7%) in the latter group.

The *number of configurators* is an important contingent variable for the product-related challenges category and shows some weak signs of being relevant for the knowledge acquisition challenges category also. The four companies that have only two configurators present product-related challenges (median = 1) that are lower than the 10 companies that have only one PCS (median = 2.5), which, in turn, is lower than the eight companies that have more than two PCS (median = 3). The same situation (median = 2, 3, and 4, respectively) holds for the knowledge acquisition challenge category. However, while these differences are statistically significant, according to the Kruskal-Wallis test, for the product-related challenge category ($p = 0.049$), they are not significant for the knowledge acquisition challenge category ($p = 0.224$). Looking at the single challenges, it emerges, regarding the product-related challenge category, that the complexity of product structures is mentioned only by companies with one configurator while only companies with more than two configurators mention continuous change in product offerings. Regarding the knowledge acquisition challenge category, the difficulties in acquiring the correct knowledge decrease as one moves from a group with one configurator to a group with two or more configurators while the challenge regarding the failure to communicate knowledge in the maintenance phase increases.

The *degree of customization* offered seems to be a very important contingency factor. This is observable by splitting the companies into three groups: six companies with a low degree of customization (i.e., companies for which 1–40% of their revenues come from customized products), seven companies with a medium degree of customization (41–80%), and nine companies with a high degree of customization (81–100%). Based on this grouping, we observed differences in knowledge acquisition, product modelling, and product-related challenge categories, even though the differences were only statistically significant at a 10% level for the first two categories ($p = 0.036$, 0.057, and 0.165). For each one of these three categories of challenges, the lowest median value was placed in the group with a medium degree of customization (median = 2, 2, and 2, respectively) while the highest median value was in the group with the highest degree of customization (median = 4, 4, and 3, respectively). (Note that, for the product modelling category, the median value for high and medium degrees of customization is equal.) Furthermore, seven (77.78%) of the companies in the "high degree of customization" group (two companies expressed two organizational challenges) and six (85.71%) of the companies in the "medium degree of customization" group expressed organizational challenges as being among the three most important challenges while only two (33.33%) of the companies in the "low degree of customization" group did so.

The *degree of configuration* offered does not show significant associations with any challenge category. However, by splitting companies into three groups (10 companies with a low degree of configuration [i.e., companies for which 1–40% of their revenues comes from products supported by the configurators]; four companies with a medium degree of configuration (41–80%); and eight companies with high degrees of configuration (81–100%)) indications in the importance of organizational challenges was found. Eight (80.00%) of the companies with low degrees of configuration mention organizational challenges among the three main challenges that they faced (two companies expressed two organizational challenges each) while three (75.00%) of the companies with medium degrees of configuration and four (50.00%) of the groups with high degrees of configuration did so.

The *company offering* seems to be an important contingency factor. More specifically:

- The four companies that get some part of their revenues from selling **plants** seems to experience more knowledge acquisition and product-related challenges (median = 4 and 3.5, respectively) compared to the other companies (median = 3 and 2, respectively), but this difference is not statistically significant ($p = 0.159$ and 0.204, respectively).

- The 10 companies that offer **systems solutions** (for four of the companies, this product constitutes 1–40% of their turnover, and for the other six, it constitutes 41–100% of their revenues) suffer more than others from product modelling challenges (median = 4 versus 2.5; p = 0.004). At the level of a single challenge, they suffer more from continuous change in product offerings, difficulties in acquiring the correct knowledge, and the correctness of specifications generated by the configurator according to product model.
- The seven companies that offer **machines** (for one of them, this product constitutes 1–20% of its turnover, and for the other six, it constitutes 21–60% of their revenues) present higher values than the other 15 companies for which the selling of machines has a null incidence on turnover as regards the IT-related (median = 4 versus 3; p = 0.02), organizational (median = 4 versus 3; p = 0.058), and—even if not statistically significant at the conventional 10% level—knowledge acquisition (median = 4 versus 3; p = 0.135) challenge categories.
- The nine companies that get more than 40% of their revenues from selling **components**, when compared with the 13 companies that present this share at lower values (the value was even null for five companies) show lower values as regards knowledge acquisition (median = 2 versus 4; p = 0.053) and product modelling (median = 3 versus 4; p = 0.057) challenge categories and, even if not statistically significant at conventional levels, for organizational (median = 3 versus 4; p = 0.147) and IT-related (median = 2 versus 3; p = 0.243) challenge categories.

Overall, the figures reported in Table 5 suggest that the contingencies shown by the analysis do not invalidate the results of the overall importance of the main challenge categories reported in Table 4 (which correspond to the orders of rows in Table 5). First, even though, in a number of cases, the importance of a challenge category is lower in certain contexts, in only two cases (1.59%) out of 126 (i.e., for the 21 contingency groups analyzed for the six main categories of challenges) did the main challenge category results turn out to be almost unimportant (median = 1.5), and in only one case (0.79%) were the results unimportant (median = 1). Noticeably, these three cases involved the smallest contingency groups (N = 4). It indicates that the considered main categories of challenges remained important in 97.62% of the contingent groups considered. Second, the categories are underscored (in each subgroup with respect to the overall order provided in Table 4) of three or four positions, respectively, in six (4.76%) and seven (5.76%) of the 126 cases. No categories have been underscored by more than five positions in any contingency group. In 64 (50.79%) of cases, the position remained the same. This indicates that the order provided in Table 4 is, to a certain extent, robust and does not too

frequently underestimate the importance of each category of challenges in comparison with the importance of the other categories of challenges. Third, the overall importance of challenges (obtained as the average of the various challenge categories) is significantly ($p = 0.009$) higher (median = 4) in companies with a high degree of customization, followed by companies with a low degree of customization (median = 3), and, finally, companies with a medium degree of customization (median = 2). Companies getting over 40% of their revenues from components, in contrast to the other companies, experience overall challenges to a lesser extent (median = 2 versus 4, $p = 0.001$), and companies selling machines also experience challenges relating to the configurators to a greater extent (median = 4 versus 3, $p = 0.000$). Therefore, the effect of the contingencies seems to be more relevant in terms of global challenges than for the relative importance of each category of challenge.

Table 5. How the importance (median) of challenges varies according to potential contingency variables*

Main categories of challenges	*Median*	*Mean*	*Std. dev.*	*Size*		*Years using PCS*		*No. of PCS*			*Degree of customization*			*Degree of configuration*			*Product offerings*							
																	Plants		*Sys. solut.*		*Machines*		*Components*	
				≤ 500 *N = 12*	*≥ 600* *N = 10*	*3–9* *N = 10*	*10–25* *N = 12*	*1* *N = 10*	*2* *N = 4*	*4–20* *N = 8*	*1–40% (low)* *N = 6*	*41–80% (medium)* *N = 7*	*81–100% (high)* *N = 9*	*1–40% (low)* *N = 10*	*41–80% (medium)* *N = 4*	*81–100% (high)* *N = 8*	*0%* *N = 18*	*1–100%* *N = 4*	*0%* *N = 12*	*1–100%* *N = 10*	*0%* *N = 15*	*1–100%* *N = 7*	*0–40%* *N = 13*	*41–100%* *N = 9*
Organizational	3.5	3.23	1.24	3	4	4	3	3	3.5	4	3	3	4	3.5	3.5	3.5	3.5	4	4	3	3	4	4	3
				p = 0.071		p = 0.183					p = 0.199										p = 0.058		p = 0.147	
Knowledge acquisition	3.5	3.09	1.35	3	4	3.5	3.5	3	2	4	3.5	2	4	4	1.5	3.5	3	4	3.5	3.5	3	4	4	2
								p = 0.224			p = 0.036						p = 0.159				p = 0.135		p = 0.053	
Product modeling	3.5	3.23	1.20	3	4	3.5	3.5	3	4	4	4	2	4	3.5	3.5	3.5	3.5	3	2.5	4	3	4	4	3
											p = 0.057								p = 0.004				p = 0.057	
Resource constraints	3	3.09	1.31	3	4	3.5	3	3	4	3.5	3.5	3	3	3.5	2.5	3.5	3.5	3	3	3.5	3	4	3	3
				p = 0.186																	p = 0.294			
IT-related	3	3.05	1.26	3	2.5	3	2	3	2.5	2.5	2.5	3	3	2.5	3.5	3.5	3	2.5	3	3	2	4	3	2
																					p = 0.02		p = 0.243	
Product-related	2	2.59	1.27	2.5	2	2.5	2	2.5	1	3	2.5	2	3	2.5	1.5	2.5	2	3.5	2	2.5	2	3	3	2
								p = 0.049			p = 0.165						p = 0.204						p = 0.033	
Overall challenge	3	3.05	1.29	3	3.5	3	3	3	3	4	3	2	4	3	2	3	3	3	3	4	3	4	4	2
				0.100		0.435		0.361			0.009			0.735			0.268		0.326		0.001		0.000	
Number of categories with median importance below 2				0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Number of categories underscored with 3(4) positions				1(1)	1(0)	0(0)	0(0)	1(1)	1(0)	0(0)	0(0)	1(1)	0(0)	0(1)	0(1)	0(0)	1(0)	0(0)	0(0)	0(1)	0(0)	0(0)	0(0)	0(1)

* To facilitate the reading of the table, values of $p \geq 0.3$ are only reported for the overall challenges.

5. Discussion and conclusion

The present study explores the hidden side of product configurators—namely, the challenges companies face in implementing and utilizing them. While the benefits from using the configurators have received considerable attention from the research community over prior decades [e.g., 7, 10–18], the issue of challenges has received much more limited attention [25]. The findings of the present article complement existing studies that mention the challenges of implementing and utilizing configurators [2, 6, 7, 10, 14, 25–38] by strengthening and detailing our knowledge about what these challenges are and by providing the first insights into a comparison of importance across the main categories of challenges.

5.1. The main categories of challenges: identification

The present study identified, through a literature review, the following six main categories of challenges: (1) IT-related, (2) product modeling, (3) organizational, (4) resource constraints, (5) product-related, and (6) knowledge acquisition. The qualitative part of the study showed that all these categories are important and that no additional categories are required (see Tables 2 and 3). The quantitative part of the study reinforced this conclusion, showing that each category was important in at least 17 (77.27%) of companies (see Table 4).

The proposed categorization of the main challenges of implementing and utilizing configurators shows the ability, to some extent, to parsimoniously address the categories of the main challenges. The fact that (as shown in Appendix 1) the challenges expressed by managers openly and without verbal constraints correspond (once grouped according to the proposed categories) with the data that emerges when the managers are asked the importance of each of these categories means that the categories have some potential to synthetically gather data on the main challenges of implementing and utilizing configurators. The fact that respondents did not have difficulty interpreting the meaning of the various categories and that they differentiated the importance between the various categories provides evidence that this categorization may be useful to communicate with practitioners. So, this categorization constitutes a new ad hoc proposal that advances the work initiated by Barker and O'Connor [14], Tiihonen et al. [30], and Heiskala et al. [6], which presented the various challenges from specific perspectives.

5.2 The main categories of challenges: level of importance

This study considered the level of importance of the categories representing the main challenges of implementing and utilizing configurators by combining quantitative and qualitative data to provide an overall indication of the importance of each category of challenges (see Table 4). The study also investigated potential contingent effects, namely, company size, years of using configurators, number of configurators in use, customization degree, configuration degree, and product offerings (see Table 5). Table 6 summarizes all of these results and compares them with related studies.

Table 6. The importance of the main categories of challenges—comparison of results with related studies

Main categories of challenges	*Overall importance*	*Contingency variables*	*Number of articles (and articles) mentioning a challenge in the category*	*Number of articles (and articles) considered important challenges in the category*
1. Organizational	Very high	Company size	10	4
		Product offerings (machines)	[2, 6, 7, 14, 20, 25, 26, 29, 31, 32]	[20, 25, 26, 32]
2. Knowledge acquisition	High	Degree of customization	9	3
		Product offerings (components)	[6, 28–35]	[30–32]
3. Product modeling	Medium high	Degree of customization	13	2
		Product offerings (system solutions, components)	[6, 7, 10, 25, 28–31, 33, 34, 36–38]	[10]
4. Resource constraints	Medium low	Company size	7	2
			[2, 14, 25, 26, 28, 32, 34]	[10, 32]
5. IT-related	Low	Product offerings (machines)	10	1
			[2, 6, 7, 14, 26, 30, 31, 33–35]	[32]
6. Product-related	Very low	Number of configurators	14	0
		Product offerings (components)	[2, 6, 7, 10, 14, 27–33, 35, 36]	None

Our results show that all categories are important, though at different levels. While organizational, knowledge acquisition, and product modeling are challenging categories of primary importance, resource constraints, IT-related, and product-related challenges are of secondary importance, and the product-related category is of very low importance.

However, we found that most categories of main challenges might vary levels of importance in different contexts. *Organizational challenges* are more important in larger companies (≥ 600 employees) and in companies that produce machines. *Knowledge acquisition* and *product modelling challenges* are of primary importance at low and high degrees of customization as well as when 60% or more of revenues come from plants, machines, or system solutions. The results also show

that these three categories (i.e., organizational challenges, knowledge acquisition, and product modelling) become less important when the companies get over 40% of their revenues from components. *Product modelling challenges* are the most important category in companies that offer system solutions. Furthermore, *product-related challenges'* results are more important when there are more than two configurators and in companies getting 40% or less of their revenues from selling components (i.e., with 60% or more of revenues coming from plants, machines, system solutions, or other sources). Finally, *IT-related challenges* are of high importance in companies that sell machines and of very low importance in companies that sell other products. However, the identified contingency variables influence the importance of the overall challenge categories while not making the various categories unimportant or seriously undermining the importance of the various challenge categories.

Previous research has identified many challenges in relation to implementing and utilizing configurators. However, the attention paid to the various categories from the research community does not always correspond to the categories' relative importance as has emerged from the present study. The most frequently mentioned category in the literature (i.e., product-related challenges) is of secondary importance while the organizational and knowledge acquisition challenges—rated of primary importance—are not as often addressed. Since all of these categories of challenges are important, we can simply conclude that future research should devote more attention to organizational and knowledge acquisition challenges. Furthermore, future research should more carefully consider resource constraints (the least frequently mentioned challenge in the literature) since challenges in that category can influence or interact with other challenges and, thus, are not immediately detectable.

Very limited insight has been provided by previous research on the level of importance of the various challenges. Notwithstanding this fact, we can use the number of articles considering to be important at least one challenge of a given category as a rough proxy of the importance recognized by previous studies of that category of challenges. Interestingly, the order of importance of the various categories resulting from this rough proxy coincides with the order identified by our study. Our results show some differences, however, from those reported in the only other study [29] that provides some quantitative data. Though the results are not fully comparable (i.e., the questions asked in [29] are different from the ones in this study), it seems that, for Zhang and Helo [29], resource constraints, IT-related, and product-related results are more important than they were in our study. In particular, Zhang and Helo [29] report that most companies (75%) agreed that

continuous evolution of products is a challenge to continuously applying the product configurator. It could be that the inclusion in their sample of computer and telecommunication systems companies make the product-related challenges more relevant than they were for the companies analyzed in this study.

5.3 Structuring challenges: the importance of categories and subcategories of challenges

Finally, this study sought more in-depth knowledge about the specific challenges within each of the categories faced by manufacturing companies when implementing and utilizing configurators. This study has detailed each of the main categories by identifying subcategories and provides a description of each subcategory (Section 4.1).

Previous studies [6, 7, 14, 30, 32] list the main challenges, and some of them [6, 14, 30] also articulate some sub-challenges. In particular, Heiskala et al. [6] provide a multilevel description of challenges, but their description is organized to pursue the wider objective of reviewing the literature on how configurators affect the operations and business of companies pursuing mass customization with configurable products. The present paper moves further towards a categorization and subcategorization focused on important challenges. The subcategorization proposed here is grounded on the empirical data gathered through the explorative survey. Each of the main categories of challenges is described in more detail by two or three subcategories. Table 7 shows this categorization and also reports the level of importance of categories of challenges (as evident from both our quantitative and qualitative analyses) and the level of importance of subcategories of challenges (as evident from our qualitative analysis). Table 7 also reports the articles in which the specific challenges have been considered and studies that have indicated the importance of the different challenges.

Table 7. The subcategories of the main challenges and their importance—comparison with related studies

Main categories of challenges	*Overall importance*	*Specific (subcategory) challenge within each category of challenges*	*Importance (% of companies reporting the challenge)*	*Number of articles (and articles) mentioning the challenge*	*Number of articles (and articles) that consider the challenge important*
Organizational	Very high	Resistance to using the configurator	Highest (36.36%)	8 [2, 6, 7, 20, 25, 29, 31, 32]	3 [20, 25, 32]
		Lack of support from top management	Among highest (27.27%)	3 [6, 14, 26]	2 [25, 32]

		Disagreements about the scope of the configurator	Low (13.64%)	2 [2, 7]	0 None
Knowledge acquisition	High	Difficulties in acquiring the correct knowledge	Among highest (27.27%)	8 [6, 28–30, 32–35]	3 [30–32]
		Failure to communicate knowledge in the maintenance phase	Medium (18.18%)	4 [6, 28, 30, 31]	0 None
		Lack of requisite knowledge to meet users' and customers' needs	Low (13.64%)	4 [6, 30, 32, 34]	1 [32]
Product modeling	Medium	Complexity due to lack of overview of product range	High (22.73%)	12 [2, 6, 7, 10, 29–31, 33, 34, 36–38]	2 [7]
		Correctness of specifications generated by the configurator according to product model	Low (13.64%)	4 [6, 25, 28, 37]	0 None
		Lack of knowledge related to product modeling	Low (4.55%)	0 [Found no reference]	0 None
IT-related	Medium	Software development	Among highest (27.27%)	9 [2, 6, 7, 14, 26, 28, 30, 31, 33]	1 [32]
		Systems designed for user-friendliness	Low (9.09%)	4 [6, 14, 34, 35]	1 [32]
Resource constraints	Low	Lack of resources	Medium (18.18%)	9 [2, 10, 25, 26, 32]	2 [10, 32]
		Vulnerability if key personnel leave	Low (4.55%)	4 [6, 14, 26, 28]	0 None
Product-related	Low	Complexity of product structures	Low (13.64%)	8 [2, 6, 7, 10, 27, 29, 35, 36]	0 None
		Continuous change in product offerings	Low (9.09%)	7 [6, 14, 28, 30–33]	1 [32]

The results reported in Table 7 give preliminary indications of the importance of the subcategories based on the numbers of companies reporting the specific challenges, as illustrated in the fourth column. Obviously, stronger results need a quantitative analysis as was done for the categories of the main challenges (Section 4.2). The numbers of companies reporting a specific sub-challenge range from one company (4.55%) to eight (36.36%) companies.

As expected, most of the subcategories of challenges that were most frequently mentioned by the respondents (i.e., in answers to the question about the three most important challenges) belong to challenge categories of primary importance. Resistance to use of the configurator was expressed by eight (36.36%) companies and lack of support from top management by six (27.27%) companies that belong to the organizational category. Difficulty in acquiring the correct knowledge was expressed by six (27.27%) companies that belong to the knowledge acquisition category. Complexity due to lack of overview of the product range was expressed by five (22.73%) companies that belong to the product modeling category. One of the most frequently mentioned subcategories, however, is software development, which is mentioned by six (27.27%) companies and belongs to the IT-related category—of secondary importance.

Further, by considering articles mentioning the different sub-challenges, we see that the challenges most frequently mentioned in the literature are not necessarily those most often mentioned by the company's respondents as being among the three most important. More specifically, three publications mention a lack of support from top management as a challenge while six (27.27%) of the companies report this specific challenge as one of the three main challenges. This is quite surprising, given the recognized relevance of top management support in implementing and using information systems [e.g., 43–45]. Additionally, while product complexity is mentioned by eight publications, only three (13.64%) companies recognize it among their three top challenges. We have a very similar situation for continuous change in product offerings and, to a lesser extent, for vulnerability if key personnel leave. The companies in our sample (skewed towards large companies operating with complex products in B2B markets) are less affected than others by these challenges due to their size and their long experience in managing the evolution of complex products.

Interestingly, the challenge subcategories that are most frequently mentioned in literature as important are also those most often mentioned by the company's respondents as being among the three most important. Therefore, there is an emerging picture that tells researchers that, in analyzing challenges, there is a degree of importance that should be considered. It is not the same to ask whether, or to state that, a challenge exists, is important, or is of primary importance. Furthermore, the context of the companies (company size, degree of customization, product offerings, and number of configurators) seems to have some influence on the importance of the main challenges. Our results, derived from a joint investigation of the importance of categories and subcategories,

move the research a step further toward the understanding of the structure of challenges affecting the implementation and use of configurators.

5.4 Research limitation and further studies

The present exploratory study analyzed 22 manufacturing companies by using an emailed questionnaire (with closed questions) and phone interviews (with open questions) to gather high-quality data and attain a good understanding of the context. This is the first quantitative study that specifically asked informants to quantify the importance of different challenge categories concerning implementation and utilization of configurators. It is also the first study to explore several potential contingencies that may affect the importance of challenges. Its sample size, nevertheless, limits the generalizability of its results.

The provided categorization of main challenges, the list of challenges for each category, the importance and the relative importance of each category of challenges, and the effect of the considered possible contingencies are all findings of the present research that should be tested in larger samples and in samples that include other types of companies (e.g., consumer goods, services, and SMEs). The present exploratory research provides a detailed and organized description of facts, thus strengthening the bases for subsequent ad hoc explanatory research. In transforming our results in research hypotheses, future research should identify theoretical frameworks that explain why it is logical to expect certain challenges. The information processing view, which has been successfully used in other mass customization issues [46], could be one theoretical lens used to explain some results, such as why the offering of simpler products (> 40% components) is associated with lower overall challenges. The consideration of configurator projects as knowledge management projects [47] could explain why certain challenges are expected and indicate how to overcome these challenges. Given the importance of organizational challenges, future research could take advantage of recent results in mass customization studies, which recognized that external environmental factors (e.g., demand dynamism) play a fundamental role in the strategic decisions (e.g., degree of product customization) a company intends to make, which in turn influence the organizational design choices (e.g., training and development of people for mass customization) [48–50].

Even though our investigation provided several new insights into the relevant challenges, other exploration efforts should be performed. Contingency variables have been collected to carefully describe the sample using aspects that are known to be important for configurators. A study that specifically aims to identify all main contingency factors should search for additional potentially

influential context factors, such as aspects of culture or whether companies have used some preliminary configuration tools (e.g., those implemented in Excel) prior to the implementation of the configurators.

Furthermore, in the present study, we calculated the overall challenge as the sum of the various challenge categories. If we had asked the respondents directly, we could have also used an alternative way to assess the importance of the challenges. That is their (eventually joint) contribution to the overall challenge.

The present study focuses on the challenges of implementing and utilizing configurators by studying companies that are using configurators. Companies that abandoned their configurators (either in development or after launching the system) have not been specifically addressed. Studying challenges that have led to the abandonment of configurators' projects would surely be interesting and valuable for both the research community and practitioners.

Finally, we focused our attention on identifying challenges and their importance. Challenges, once identified, need to be dealt with. More research should, therefore, be devoted to eliminating or reducing the impact of the important challenges. This includes more formalized procedures and methods to address the individual challenges (e.g., in terms of change management, knowledge acquisition, and product modeling) specifically aimed at configuration projects.

5.5 Implications for researchers and practitioners

This study provides novel insights for researchers and practitioners by analyzing the main challenges manufacturing customizers face when implementing and utilizing configurators. This new insight has implications for both research and practice.

Having structured challenges in categories and subcategories allows the design of research on a high level (categories) and on a detailed level (subcategories) of analysis. The results obtained at different levels can be compared, thus facilitating the building on the results of other studies. This facilitation is important, given the need to investigate different settings to assess generalizability and to explore possible contingency factors. Knowing the relative importance of the various categories and subcategories of challenges in specific kinds of companies not only sets a clear reference point for future studies but also indicates more valuable directions on which to start to develop tools, support, and approaches to face the considered challenges successfully.

The results of the study provide practitioners with a short list of main categories of challenges that are further structured into subcategories, each of which is described using various short examples. This structured and exemplified list of challenges may help managers to identify

potential challenges. Furthermore, the information provided concerning the relative importance of these challenges in a sample and the analyses of several potential contingency factors allow them to understand whether or not their contexts are similar to those of one of the companies in the sample. In the end, practitioners can derive indications regarding the most important challenges and strategically focus their attention to address them.

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Appendix 1: Consistency of the data

We checked the overall consistency of the data gathered through open and closed questions. To perform this check, we used the figures shown in Table 1. For each category, columns 2–6 show the percentage of companies that (in the closed question) assigned a given level of importance to that category and that indicated (in the open question) a challenge belonging to that category. Columns 7–11 show the percentage of companies that (in the closed question) assigned a given level of importance to that category and that did not indicate (in the open question) a challenge as belonging to that category.

Table 1. Consistency check of the data sets—overall comparison between the data acquired through the closed and the open questions

	Companies indicating a challenge					**Companies <u>not</u> indicating a challenge**				
	None	**Low**		**High**		**None**	**Low**		**High**	
	None	*Very low*	*Low*	*High*	*Very high*	*None*	*Very low*	*Low*	*High*	*Very high*
IT challenges	**0%**	**13.64%**		**22.73%**		**9.09%**	**40.91%**		**13.64%**	
	0.00%	0.00%	13.64%	4.55%	18.18%	9.09%	31.82%	9.09%	13.64%	0.00%
Product modeling	**0.00%**	**9.09%**		**31.82%**		**9.09%**	**31.82%**		**18.18%**	
	0.00%	9.09%	0.00%	18.18%	13.64%	9.09%	13.64%	18.18%	18.18%	0.00%
Organizational challenges	**0.00%**	**22.73%**		**45.45%**		**13.64%**	**13.64%**		**4.55%**	
	0.00%	9.09%	13.64%	31.82%	13.64%	13.64%	4.55%	9.09%	4.55%	0.00%
Resource constraints	**0.00%**	**0.00%**		**22.73%**		**18.18%**	**36.36%**		**22.73%**	
	0.00%	0.00%	0.00%	13.64%	9.09%	18.18%	13.64%	22.73%	18.18%	4.55%
Product-related challenges	**0.00%**	**4.55%**		**18.18%**		**22.73%**	**45.45%**		**9.09%**	
	0.00%	0.00%	4.55%	9.09%	9.09%	23.73%	31.82%	13.64%	9.09%	0.00%
Knowledge acquisition challenges	**0.00%**	**18.18%**		**40.91%**		**18.18%**	**13.64%**		**9.09%**	
	0.00%	9.09%	9.09%	27.27%	13.64%	18.18%	9.09%	4.55%	9.09%	0.00%