Chapter 8
From ETO to Mass Customization: A Two-Horizon ETO Enabling Process

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8.1 Introduction

Engineer to order (ETO) is referred to a manufacturing strategy for highly customized products which are required to be designed and engineered in detail, based on the customer's order specifications [1–3]. On the one hand, highly specialized customer requirements pose various challenges in such systems, such as difficulties in accurate estimation of lead time and delivery dates, late changes and expensive reworks, poor product quality, and material waste [2]. On the other hand, globalization, margin shrink, increased competition, and dramatic technological advances raise crucial issues concerning the ETO firms to retain a competitive edge [2, 4, 5].

Mass customization (MC) is defined as "customer co-design process of products and services, which meets the needs of each individual customer with regard to certain product features. All operations of customization are performed within a fixed solution space, characterized by stable but still flexible and responsive processes" [6]. Solution space (SS) refers to the possible permutations of design parameters in order to fulfill future customer needs [7]. Salvador et al. introduce solution space development as a basic competence for MC firms [8].

MC, which aims at producing customized goods and services to satisfy individual needs of the customers [9], has several similarities with the ETO environment. Along the same lines, tackling a combination of ETO and MC settings, as a hybrid strategy toward ETO firms, is likely to provide room for improvement. As a consequence, a transition toward MC calls for fresh approaches and effective mechanisms to smooth this process and, in turn, to achieve superior results of formulating such a hybrid strategy.

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Interestingly, empirical evidences show a paradigm shift for ETO companies to formulate innovative strategies in order to employ MC in the ETO systems [10]. Past studies in the context of ETO environment have not entirely addressed the interplay between MC and ETO settings. Although at the strategic level, ETO-MC has been articulated by Haug as a hybrid strategy for ETO firms which gathers MC and ETO characteristics together, aiming at optimizing the internal processes [10]. However, the impact of solution space management in such setting, both in the short- and long-term outlook, needs further investigation.

Thus, this paper is outlined as follows. Having examined the extant literature on the solution space allows us to establish a conceptual framework to deal with the ETO-MC setting. Then, we would empirically examine our proposition through the context of three Swiss ETO companies. Finally, we underline the investigated success practices that are likely to enhance effective management of customization processes.

8.2 Solution Space Definition, Research Gap, and Questions

The aim of the following section is to provide a definition of "solution space" in pursuit of the ETO-MC settings and in turn to frame the research questions of this study.

8.2.1 The Solution Space

The definition of the solution space is a fundamental issue concerning the ETO-MC companies. Typically, Pine defines the solution space as a hyperplane shaped by all the possible permutation of the predefined design parameters [11]. This definition mainly derives from the idea of configurators, implemented in the mass customization environment.

The basic idea of the ETO systems is that the customer order decoupling point is prior to the engineering phase [12]. Therefore, it is not always a priori reason to reduce and enumerate the possible design parameters.

The spread of the configurators and the success of mass customizers have made complicated the definition of solution space. Henceforward, we divide the solution space into two classes: standard solution space (SSS) and nonstandard solution space (NSSS).

To define the SSS, we follow the definition of Hadzic that defines a product through a mathematical definition of three objects: variables, domain for the variables, and formulae [13]. The standard product belongs to this domain. It is worth emphasizing that, as long as the variables can be defined by a continuous domain, the SSS can be infinite accordingly. The standard products can be managed by the company as make-to-order (MTO) products [14]. This definition can be suitable for the commercial offer for the mass customizer, whereas in the ETO-MC context, the customer needs to choose over a wider set of variables and attributes compared to the one offered as standard products [10].

Similarly, it is necessary to define NSSS. A nonstandard product, which belongs to the NSSS, is the outcome of the violation of variables, domains of the variables, or formulae. The NSSS encompasses the hypothetic domain of technically feasible solution requested by the customer. This domain is infinite by definition. The sum of SSS and NSSS defines the solution space.

The advanced ETO companies are capable of representing their standard space by utilizing the configurators. The advantages pertaining to the implementation of the configurator are out of the scope of this study, although they have been entirely articulated in past studies [14–18]. Notice that a technical, computer-aided configurator is just the representation of the SSS and an efficient but costly implementation strategy. Nonetheless, firms that do not invest in a configurator are capable of shaping their standard offers through standard processes. This projection of a standard product at the operational level can be defined as "standard space of action."

8.2.2 Gap and Research Questions

Past studies adequately address the issues relating to companies switching processes from mass production to mass customization. For those companies, therefore, the solution space is standard. To date, the studies related to the transition from ETO to MC are mainly focused on the technological aspects [10]. However, the characteristics of the ETO-MC companies need further investigation. Their typical solution space can gather some additional relevant information from the clients within their operational processes. In particular, the design management of the nonstandard products is a significant process. The information and knowledge which are generated in the process of developing tailored solutions can lead to a modification of the SSS [19]. To date, the dynamics of this emerging challenge and the evolution of the solution space have not entirely explored. Therefore, this study aims at addressing the following research questions.

RQ.1: *How can the evolution of the SSS be described in an ETO-MC setting*?

RQ.2: *How can an ETO-MC setting operatively deal with the modifications of the SSS*, *in order to gain a sustainable competitive advantage*?

The first research question defines the base framework for ETO-MC companies and their solution space evolution of the order-specific engineering and its developed knowledge. The second research question underlines the operational management of this evolution. Two types of enabling processes are represented, with different levels of planning.

8.2.3 Methodology

This study is based on an extended literature review and multiple case studies. Firstly, the topics related to mass customization, ETO, knowledge, and information management have been considered.

Secondly, a series of interviews were conducted with the engineering managers and product line managers of three ETO companies in order to understand the real effectiveness of the research agenda. After a cross analysis, the resultant topic has been narrowed and defined. For the following 2 years, the authors and three Swiss leading companies closely collaborated together in order to address the identified issues. All of the practices and the tools presented below were identified, selected or developed, and implemented in the selected companies.

8.3 The ETO Enabling Process

The hybrid business model has some issues to be addressed. Firstly, the interaction between standard and nonstandard products is a specification of the ETO-MC environment. Secondly, the operational management and updating the solution space are the other major issues in such setting. A proxy of the competitive value of a firm in the ETO-MC sector can be identified pertaining to the success rate of the winning tenders. In a pure ETO sector, this value is less than 30 %, and, therefore, fast and cost-efficient processes are essential attributes in the engineering phase [20]. In this ETO-MC extension, the management of order-specific engineering with regard to the modules and subsystems of the final product is a crucial task. The relationship between knowledge and information reuse and successful performances is relevant to the ETO environment [21], and the focus of this study is on inclusion of relevant knowledge into their standard space of action.

In order to confront this challenge, two complementary processes are represented. The ETO enabling process and the effective practices related to the implementation process are represented by Schönsleben [14] and Duchi et al. [5]. This study extends the primary model that presents every nonstandard product as a triggering mechanism of exchanging know-how in the ETO value chain.

The extension includes two classes named "short-term ETO enabling process" and "long-term ETO enabling process." The former relates to the operational management of the specification fulfillment for the nonstandard products. The latter refers to the creation of a sustainable competitive advantage. Moreover, there is a cross-interaction between these two dynamics that will be further investigated.

8.3.1 Short-Term ETO Enabling Process

To have an in-depth understanding of the short-term ETO enabling process, it is necessary to deal with the order-specific engineering (Fig. 8.1).

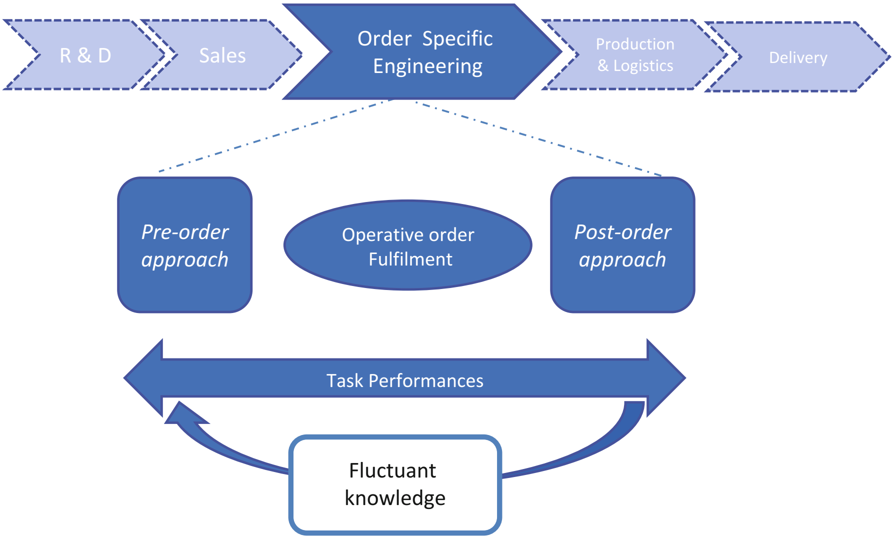

Fig. 8.1 Order-specific engineering

The order-specific engineering is a process activated by those requests that are submitted by the customers and requires the direct engineer work to develop a tailored product. Furthermore, this process is divided into the three sequential phases, such as preorder approach, operative order fulfillment, and post-order approach. The focus of this study will be on the design phase, and the other relevant aspects, e.g., cost estimation and pricing, are out of the scope of this study [22].

The first stage of the short-term (ST) ETO enabling process is the approach to tackle the development of a new required technical solution. It can include the correct receipt of the specification, the analysis (cost and design feasibility), the study of the issues, the communication with other functions, and the research of the previously created similar solutions.

The operative order fulfillment phase refers to the creation of the specific solution, the production of the new technical drafts, the selection of the right subcomponents, and the comprehensive assessment of the solution feasibility.

The last stage of ST ETO enabling process is the post-order process, which includes the communication of the created solution, the intra- and intercompany idea sharing, and the completion of the project. The efficient and effective capabilities to successfully carrying out these three phases will eventually lead to shorter lead times, cost reduction, and improvements in the quality of the offers [22].

Considering the company processes as a dynamic nature, it seems reasonable to assume that several issues have been already addressed out of the SSS boundaries. These processes are likely to lead to the creation of both explicit and implicit knowledge. Theoretically, the bodies of information and knowledge inside of the company are continuously changing and expanding [21]. It represents that the firm's and employee's capabilities have been developed during the past problem-solving issues, as well as all the past produced documentation. We coin this as "fluctuant knowledge." This knowledge represents the key enabler for the short-term ETO enabling process.

The ST ETO enabling process starts from the firm's awareness of the potential impact of this order-specific engineering process on the competitiveness outcomes. It aims at determining the process of acquisition, assimilation, transformation, and exploitation with regard to the order-specific engineering. Moreover, it establishes a framework to follow the actors in every phase [23]. Therefore, the ST ETO enabling process affects the operational level. It is worth mentioning that not only does this process focus on the reuse of the previously created knowledge but also it affects all the sharing, elaborating, and solution-renewing processes. Effective ETO-MC firms are able to implement a series of organizational and IT-based practices in order to determine the ST ETO enabling process.

8.3.2 Long-Term ETO Enabling Process

The generation of a sustainable competitive advantage is considered as a main goal of the knowledge management systems [24, 25]. This issue relates to the ETO-MC companies, and, therefore, the long-term ETO enabling process will operationally address it.

The main risks and the challenges of the knowledge management in such firms are linked to the owners of the knowledge, the so-called knowledge workers [26]. The knowledge is tied up to the human experiences and interactions [27]. In the previously discussed knowledge generation environment (order-specific engineering), human resources play a relevant key role. The tasks are performed to fulfill the delivery of a product belonging to the NSSS, and therefore they request a not automatable outcome. With the ST enabling process, the solutions are rationally stored, but their impact on the process performances will retain to the individuals.

ETO-MC settings can institutionalize the existing information and knowledge [28] toward the standard space of action, as a reliable basis to gain competitive advantage. The possibilities of standardization and formally institutionalization are the main drivers that lead the firms to compete with this hybrid business model.

The long-term ETO enabling process primarily gives the awareness of the long-term potential improvements inside of the firms in pursuit of fluctuant knowledge.

Needless to say, the whole created knowledge is not necessarily embodied in the standard space of action. The modifications call for different processes and IT tools. The improvement of the latter is a topic discussed by several scholars [29–31]. In the ETO-MC context, the concretization of these changes is visible through the solution space. Simply put, the solution space performs with the functionality of a knowledge repository. For instance, in reshaping of the SSS, some product variants are considered as MTO by the company. This means that the associated knowledge, belonging to the fluctuant knowledge, needs to be embodied in a relatively structured way. This argument raises a serious challenge since the nature of the fluctuant knowledge consists both tacit and explicit knowledge, and it is argued that the tacit knowledge cannot be easily incorporated in the IT systems [32, 33]. However, the knowledge which is subject of institutionalization is mainly related to the product knowledge and is less likely to be defined as a tacit knowledge [28].

The trade-off between the inclusion and exclusion of the information is loosely related to the trade-off between cost and benefit [10].

It is noteworthy that the renewal of the offer in terms of eliminating the obsoleted commercial portfolios that are not requested by the market anymore is a fundamental task. Therefore, not only the SSS will be increased in terms of its dimension but also it will be changed into different shapes.

The long-term ETO enabling process concretizes itself in the IT tools and in the organizational practices that lead the company to capture the relevant information inside the standard space of action. The reshaped commercial offer, represented in the SSS, is therefore the reflection of the new organizational and IT systems in order to have an accurate understanding and forecast of the market needs. Some successful cases are represented in the Sect. 8.4.

8.3.3 Interaction Between Short- and Long-Term ETO Enabling Process

The interaction between the short- and long-term ETO enabling process is outlined as follows. It is argued that these two processes should be seen as complementary.

Figure 8.2 illustrates the interaction between these two processes and the impact on the SSS and NSSS. A generic customer could either ask for a standard product, so this product belongs to the SSS and will be dealt with by the company as an MTO product, or ask for a product which belongs to the NSSS. The performances of the process of creating an NSSS are primarily connected to the effectiveness of the ST ETO enabling process, in which on the one hand defines and creates the fluctuant knowledge and on the other hand allows an effective knowledge retrieval. The companies attempt to fulfill the requests which are outside of the SSS. As a consequence, the available fluctuant knowledge will be further advanced. At a certain point when the fluctuant knowledge has more consistent patterns, it is likely to trigger the long-term ETO enabling process. Thus, this stimulates capturing such expertise, awareness, information, and newly created solutions into the SSS. As a consequence, the solution space is likely to be reshaped. This is in light of the fact that some information is added and some information is deleted accordingly. A relevant issue concerns with the definition of the relationship between these two processes.

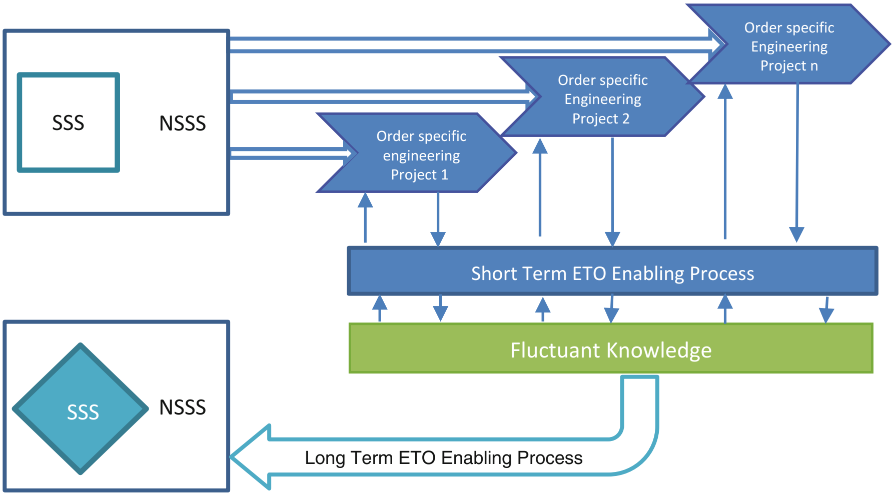

Fig. 8.2 The interaction between the short- and long-term ETO enabling processes

Firstly, it is believed that the LT ETO enabling process is less likely to operate without replication of the ST ETO enabling process. The LT ETO enabling process is triggered by the fluctuant knowledge, and its creation is connected to the effectiveness of the ST enabling process. Therefore, the more a firm is capable of developing the tools and practices to structure this knowledge, the more effective it can acquire relevant knowledge and information to eventually improve changes in the SSS.

Secondly, we believe that the ST ETO enabling process can be implemented without the existence of the LT ETO enabling process. However, this is an unsustainable approach which leads the firms toward inevitable loss of relevant knowledge and in turn degrades competitiveness.

8.4 Implementations

This chapter provides an overview of some practical implementations of the ST and LT ETO enabling processes. The practices employed by the three companies are classified according to two features: one of them relates to the temporal horizon of the enabling process, and the other examines whether the actors involved in the practice are internal or external in accordance with the boundary of the firm.

The first category distinguishes between practices contributing either to the ST or LT ETO enabling process. This distinction is useful to realize whether a practice is part of a firm's set routines or it has been triggered during the SSS renewal process. It is worth to emphasize that the same practice can be useful for both the enabling processes, although with diverse purposes and approaches.

The second category deals with the practices as *internal* that is implemented and operatively managed by internal actors and *external* that actors out of the boundary of the firm are expected to perform. According to external actors, we take the entire value chain into consideration; suppliers and customers are two notable instances. The subsidiaries that actively operate at the engineering phase are considered as internal actors in this study [9]. The motivation of the introduction of this distinction is that the relationship between the firm and the external actors is peculiar in ETO context, because every order fulfillment presents some unique dimensions.

8.4.1 The Companies

Table 8.1 represents the characteristics of the three case study companies relevant to this study.

8.4.2 Successful Implementations

8.4.2.1 Company A

Company A has developed the *naming convention*, a language protocol to univocally define product components and subsystems. Information that is related to the component variance and configuration is contained in the naming codification, and unnecessary searches in product data management are avoided. Substantial benefits arise from time savings and cost reductions that spread both internally and externally. For instance, in the case of strategic relationships with suppliers, this practice is useful to avoid recycles and to facilitate quick exchange of structured information. This practice therefore belongs to the ST enabling process and the actors are both internal and external.

A second practice is the *documentation sharing platform*. Company A has managed to create a single point of sharing and communication with the customers and the suppliers. Such IT tool enables company A to define the most convenient channel of communication for each document exchanged. Furthermore, it plays a vital role in capitalizing past documents exchanged in order to facilitate and speed up the information retrieving process. This practice is classified in the ST enabling process and with both internal and external actors.

Component information manager is the third practice that can drastically reduce the order-specific engineering lead time by leveraging past developed solutions. This tool helps the engineers in handling both technical- and process-related information. The database can be easily accessed through the web-based interface, and, by filling in some basic parameters, it could give back a past solution already developed with similar features.

Table 8.1 Case study companies

Company	A	B	C
Industry	Industrial steam turbines	Elevators	Concrete mixing and mineral processing plants
Product	Extremely diverse, ad hoc technologies for different customers	Slightly diverse, high degree of commonality among the product families	Highly diverse, different core technologies
Market (units/year)	Less than 50	More than 1000	300–500
Supporting IT systems/tools	Sales configurator	Design configurator	Design configurator
Company engineering knowledge	Engineering knowledge is based on the expertise on advanced precision engineering	The company B has to face with critical issues related to the use of the meta-knowledge. The European site retains most of the advanced technologies and know-how	The company relies on a deep and strong base of engineering meta-knowledge
Organizational practices	Engineer project is separated into subtasks, each of them refers to a specific component development that belongs to NSSS	One of the highest levels of efficiency among the main competitors in dealing with engineer tasks, thanks to the deployment of both a technical and a commercial configurator	Considerable system's complexity does not allow the firm to achieve high level of standardization in the short run
ETO enabling process	Profit margin increases with more customized tools	The high volume of specifications customized per year allows to identify communalities in the customer's requests and also to feed the company's SSS	The ETO enabling process shows several improvement margins due to the high-customized products
Maturity level	Low	High	Low

Although it is mostly used during the phase of pre-order approach, it has a relevant impact on the post-order approach, as every new drawing needs to be uploaded in order to update the meta-knowledge tool. It belongs to the ST ETO enabling process practices, with internal actors.

8.4.2.2 Company B

The *SE-AE process* is a process between the sales engineers and the application engineers. The sales engineers are responsible for the commercial offer of the standard products. They prepare a tender with the support of a technical configurator. Every time an order-specific engineering is required, the sales engineer calls for the assistance of the application engineer who develops a tailored solution as a feedback. An interesting attribute of the process is that the list of variable violations is automatically provided to AE toward an extension of the configurator, which resulted in reducing the error rates and their associate loops. The impact of this internal practice is relevant mostly on the ST ETO enabling process. This tool is also an enabler for the LT ETO enabling process because the electronically provided data contributes to the creation of the *fluctuant information*.

The *AE-PLM process* is between the *application engineers* and the *product line manager*. The product line managers are responsible for the commercial offers. Every 6 months, these two functions are called to evaluate the future commercial offer of the firm, reshaping the SSS. The value of this process is both on the creating and unlearning solutions. This practice belongs to the LT ETO enabling process with internal actors.

The former practices are supported by the data gathered toward the *Frequently Asked Request* (*FAR*) *Tool*. This IT tool handles the fluctuant knowledge created during the order-specific engineering. It allows the application engineers to evaluate the nonstandard task required by customers. It is possible to find some pattern and evaluate the most frequently violation of parameters (frequently in terms of range). This tool is the core of LT ETO enabling process that allows the company to gather relevant information from the non-SSS and evaluates its introduction into the standard boundaries. Furthermore, the internal actors are involved in this process.

8.4.2.3 Company C

The first practice that has been implemented in company C is *issue manager*. Whenever a problem is being reported during the life cycle of a product, it will be communicated to the engineering department, and the designs will be fixed accordingly. This mechanism aims at avoiding recycles and waste of resources. Functioning like a knowledge-based repository, on the one hand, it stimulates the possibility of increasing the level of efficiency of the product development phase and on the other hand represents a long-term arrangement in light of expanding the company's

Table 8.2 Summary and categorization of success practices

Success implementation	Company	Temporal horizon of the ETO enabling process	Range of action
Naming convention	A	Short term	Internal/external
Documentation sharing platform	A	Short term	Internal/external
Component information manager	A	Short term	Internal
AE-PLM process	B	Long term	Internal
SE-AE process	B	Short/long term	Internal
FAR tool	B	Long term	Internal
Issue manager	C	Long term	Internal
Sharing platform	C	Short/long term	Internal

meta-knowledge. This practice belongs thus to the long-term ETO enabling process with internal actors.

Serving different markets, the company C represents three different engineering locations spread out in different countries that often have to solve similar engineering tasks. The *sharing platform* has been developed in order to avoid repetition of engineer tasks. It is an IT tool that allows different functions to share information in a fast and structured way. The centralization of information represents not only a mean to save time and costs, but it mainly enables the transformation of special requests into valuable knowledge for the organization. This practice supports both the short- and long-term enabling process, and just internal actors are involved during this process.

In the following table, the success practices are summarized and categorized (Table 8.2).

8.5 Conclusions

Mass customization as a business reality and ETO setting as a manufacturing environment for highly customized products are making a customization-efficiency trade-off from different perspectives. Furthermore, they are facing serious challenges in pursuit of the hybrid strategy of ETO-MC. One of the challenges is linked to the definition of the commercial offer. ETO-MC companies decide for the rationalization of a batch of products (the ones represented in the SSS), but at the same time, they allow customers to customize them in several dimensions. This strategic decision needs to be sustained by an operative and continuous approach. A conceptual framework for the evolution of the SS has been presented in this study, based on the information and knowledge management in the design phase. The proposed conceptual framework not only suits the companies that can afford the investment in configurators but also the ones that can deal with standard offers with less advanced tools.

Several companies are likely to develop such framework and, in turn, to take it as a reliable basis for an understanding and rationalization of their internal processes. Furthermore, some practical cases have been presented that allow for having an in-depth understanding about the practical implementation. This study attempts to posit the research gap into the real ETO-MC environment. Therefore, we confronted the real challenges that our case study companies were facing with, and, indeed, we introduced and promoted success practices, leading to a more efficient ST enabling process and a sustainable readaptation of the solution space in the long term.

This study presents some limitations. The first one is driven by the different core competences and market of each ETO Company. Consequently, it is essential to strongly consider the relevance of the sector and the context of the firm to the identified success practices. We were not able thus to define generic operative practices. The second limitation relates to the focus of this study, which mostly deals with the engineering phase. It is necessary to examine related aspects of the downstream phases in the ETO value chain. The third limitation is concerned with the impact of the maturity of the company. This dimension is likely to affect the development of the SSS and the company's suitability for some practices instead of others.

The primary goal of this study is to define the different engineering capabilities that are essential for the sustainable development of the SSS. This suggests directions for future research. In concrete terms, it is essential to draw a meaningful distinction between diverse ETO settings in terms of, for instance, the degree of engineering complexity and customization. This is likely to lead to a deep understanding of the information and knowledge management requirements for the short- and long-term ETO enabling processes.

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