DTU Library

Identifying profitable reference architectures in an engineer-to-order context

Løkkegaard, Martin; Bertram, Christian Alexander; Mortensen, Niels Henrik; Hvam, Lars; Haug, Anders

Published in:
International Journal of Production Research

Link to article, DOI:
10.1080/00207543.2022.2036850

Publication date:
2023

Document Version
Early version, also known as pre-print

Identifying Profitable Reference Architectures in an Engineer-to-Order Context

Companies operating with an engineer-to-order (ETO) strategy are often challenged with generating the desired profit as a consequence of product volumes and high levels of product customisation. Profit margins are seen to vary greatly from project to project, which may partly be explained by a lack of references to guide design decisions. Specifically, new product offerings are often based on reuse of design knowledge, which is often not efficiently utilised, as the knowledge transfer and reuse across projects are unstructured, incomplete, or not providing a suitable reference for design specification. To address this issue, this paper presents a method for identifying reference architectures under the consideration of profitability. The method was developed by combining and extending known methods within the fields of product architecture and complexity cost estimation to cover part of the ETO domain. The method was tested in two companies, one producing industrial spray drying plants and the other providing solutions for the production of confectionary products. The findings suggest that a limited understanding of "preferred solutions" existed in the two case companies, and applying the suggested method to identifying reference architectures could potentially support a more profitable project execution.

Keywords: Product Design; Engineer to Order; Cost Analysis; Reference Architecture; Complexity Cost

Introduction

Some engineer-to-order (ETO) companies design and manufacture highly customised industrial systems, such as power supply systems, chemical plants, food processing plants, HVAC (heating, ventilation, and air conditioning) systems, industrial machinery, ships, and aircrafts. These kinds of systems are typically complex in nature, as they include a high number of components and subsystems with many interactions across these systems (Foehr, Gepp and Vollmar, 2015). Based on the average number of units sold per year and the average engineering hours per unit, Willner et al. (2016a) classified four archetypes of ETO: basic ETO, complex ETO, repeatable ETO, and non-competitive ETO. The basic and complex ETO archetypes are classified by a low number of annual units sold and varying engineering efforts per project; these are the two archetypes in focus in this paper. A low number of annual projects often results in a low-order repetition rate and a project-by-project approach. This challenges the definition of design references and the ability to reuse design information (Silventoinen et al., 2014). Thus, we use the term "ETO" in the remainder of the paper to refer to these two archetypes.

Within the ETO scope described above, customers are typically highly involved in the product specification phase (Hicks, McGovern and Earl, 2000; Hobday, 2000; McGovern and Hicks, 2006; Hicks and McGovern, 2009; Dixit et al., 2019). This, however, concerns only the early parts of the project, as design freeze usually occurs in the quotation or tender phase (Hvam, Mortensen and Riis, 2008). As it can be difficult to clarify all requirements up front, these early specifications are often of varying quality (Foehr, Gepp, and Vollmar, 2015; Haug, Shafiee, and Hvam, 2019b). Combined with technical risk and cost estimations, pricing consequently comes with a high degree of uncertainty—making it difficult to achieve the desired profit in some ETO projects, (Mortensen et al., 2010; Gepp, Foehr, and Vollmar, 2016; Johnsen and Hvam, 2018). This is especially difficult if operating under a fixed price contract. As shown in the study by Hvam, Mortensen, and Riis (2008), contribution ratios of ETO projects can vary greatly, and where some projects generate profit, others generate a loss—ultimately reducing the yearly earnings. Several factors play a role in this challenge; for instance, many ETO companies operate with a cost-based pricing strategy, where unexpected cost added during project execution quickly results in reduced project profitability (Hooshmand, Köhler and Korff-Krumm, 2016). Examples of this include unexpected needs for changes that lead to extra time spent on engineering and production/assembly hours, unexpected costs related to commissioning, and non-conformance costs, etc. (Rahim and Baksh, 2003; Haug, Ladeby, and Edwards, 2009; Johnsson, 2013; Gepp, Foehr, and Vollmar, 2016; Kristjansdottir et al., 2017). A competitive market that focuses on short lead times and competitors pressuring price levels further adds to the challenge of executing profitable projects in an ETO context (Hooshmand, Köhler, and Korff-Krumm, 2016; Johnsen, Kristjansdottir, and Hvam, 2017).

To stay competitive, companies are required to be efficient in their project execution processes and to be able to handle the uncertainty inherent in their projects. This requires extensive design knowledge, in which context ETO companies often rely heavily on experienced and highly skilled domain experts and former project documentation, such as drawings, specifications, and budgets, to provide a design reference (Grabenstetter and Usher, 2014; Hooshmand, Köhler, and Korff-Krumm, 2016). Even if the required knowledge exists within the companies, it might be difficult to access due to resource constraints or to access it at the time needed (Elgh and Sunnersjö, 2003)Beyond this, it can be difficult to fully understand the technical consequences of product customisations, which have not yet been designed (Martin and Ishii, 1996; Johnsson, 2013; Christensen and Brunoe, 2018).

This paper aims to address the challenges described above, as well as the gap in the existing literature on the application of a profitability perspective as a guiding factor for the selection and definition of suitable design references in an ETO context. To this end, we suggest a method that includes an analysis of product attributes and profitability of historical projects to identify reference architectures in the form of a set of principle solutions for the ETO products in focus. Specifically, reference architectures describe a reuse approach that aims to capture design knowledge from profitable projects and apply it as a blueprint for future projects (Böhm et al., 2021). In the proposed method for identifying profitable reference architectures, historical project data were used to determine the boundaries of the existing solution space and to identify preferred designs for matching sets of key product attributes. To assess profitability, a complexity cost perspective was used (Hansen, Mortensen and Hvam, 2012). Specifically, in an ETO context, the loosely defined solution space and high level of customisation of product offerings can have large effects on the so-called complexity cost (Schleich, Schaffer and Scavarda, 2003; Parry and Graves, 2008; Hvam et al., 2020). The suggested method was applied in two ETO companies, and the results indicated that defining and matching reference architectures with a set of customer requirements can support these types of ETO companies in improving the profitability of their projects.

Research method

Background of the study

Industrial insights obtained through engagement with ETO companies initiated our interest in supporting profitable project execution in an ETO context. Reviewing the existing literature, a gap was identified in supporting ETO companies in defining design references based on historic project profitability. Methodology related to product architecture modelling was used as a basis for capturing such product knowledge and establishing references for design. Specifically, understanding how to capture design knowledge in a reference architecture relied on an interface diagram as a tool for structural and functional product architecture modelling (Bruun, Mortensen and Harlou, 2014), and Harlou's (2006) product family master plan (PFMP) formed the basis for capturing knowledge across product and organisational domains.

The concept of market segmentation and the definition of the optimal number of architectures in a product program (Meyer and Lehnerd, 1997) was our inspiration for systematically identifying some architectures to optimally cover a solution space. Lastly, the concept of complexity cost (Hansen et al., 2012; Hvam et al., 2020) was used as the basis for assessing the profitability of historic ETO projects. The theory is primarily known from the make-to-stock (MTS) industry, where several studies over the past decades have shown how the concept of product architectures has been used to capture, document, and apply design knowledge (Karl Ulrich, 1995; Fixson, 2005; Magnusson and Lakemond, 2017). This is often observed regarding to product standardisation, rationalisation, and modularisation (Jiao and Tseng, 2000). The concepts have also gained attention in the context of products that are delivered based on a project-orientated ETO approach (Haug, Ladeby and Edwards, 2009).

Methodology

To develop and test a method for identifying profitable reference architectures in an ETO context, an action research approach (Lewin, 1946; Reason and Bradbury, 2001; Coughlan and Coghlan, 2002) was employed. Action research is a methodology introduced by Kurt Lewin (1946), which is characterised by focusing both on producing new knowledge and changing the context in which the phenomenon is studied. Thus, in action research, the researcher has two roles: being a participant in a change process and an observer reporting from the study. As stated by Reason and Bradbury (2001, p. 1), "[Action research] seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people and more generally the flourishing of individual persons and their communities".

The argument for choosing an action research approach was that it is particularly well suited for studies focusing on complex social processes, as it allows researchers to introduce changes in processes while being able to directly observe the effects of these changes (Baskerville, 1999). In the present study, the research approach allowed the researchers to test and refine the method for identifying profitable reference architectures.

Case context

As mentioned previously, the focus of this study is on basic and complex ETO archetypes. On this basis, two case companies were selected as representatives for the situation with a low-order repetition rate and a history of delivering unique yet relatively similar products within a known solution space. Regarding the archetypes of ETO by Willner et al. (2016a) case company represented the basic ETO archetype (Company A) and the other represented the complex ETO archetype (Company B). The studies were carried out as part of two research projects at the Technical University of Denmark over a period of 2 years from 2018 to 2020.

Company A was a manufacturer of industrial solutions for the production of confectionary articles. The company had a yearly turnover of approximately EUR 85 million and 400 employees in 2019. The product programme covered different branches, and the majority of the yearly turnover was generated by selling complete plants for continuous production with a capacity ranging from a few hundred kg/h to several ton/h. The company produced 10–30 complete plants per year with an average engineering effort per project just below 2000 engineering hours.

Company B was a manufacturer of processing plants for the handling of liquid and the production of powders. This study focused on a sub-division of the company employing

600–800 employees, supplying plants for drying condensed milk into powder particles ready for further processing. The company produced 5–15 plants per year, with an average engineering effort above 2000 engineering hours per project.

Data collection and analysis

As a first step, historical project data were collected. This included data on the delivery processes, product specifications, financial performance, and cost factors. The information was combined from internal data management systems into a single database from which correlations could be assessed. A total of 51 historical ETO projects, focused on delivery of complete processing plants executed over a period of 5 years, created the basis for the analysis. Based on this, profitability was analysed in relation to product attributes and complexity cost factors.

The proposed method is mainly analytical rather than statistical; thus, mathematical modelling was not used in the analysis of project data. Instead, reference architectures were reviewed and further developed through data visualisation sessions and workshops with key stakeholders. This approach addressed the challenge of identifying performance, cost-driving product attributes, and related complexity cost factors without qualitative input from key stakeholders, that is, project and sales managers. In total, 15 workshops were held in Company A and 13 in Company B, divided into four categories, as shown in Table 1. The role of the researchers during the workshops was to actively facilitate the presentation of data and to support discussions while taking notes of significant events.

Table 1: Overview of workshops

TOPIC	PARTICIPANTS	NUMBER OF WORKSHOPS COMPANY A	NUMBER OF WORKSHOPS COMPANY A	AVG. DURATION IN HOURS

DATA COLLECTION, APPROACH AND ANALYSIS	Management Specialists	3	5	2
DISCUSSION OF FINDINGS	Management	4	4	1
STRATEGY LINKED TO REFERENCE ARCHITECTURES	Management	3	2	2
DEFINITION AND REVIEW OF REFERENCE ARCHITECTURES	Specialists and sales managers	5	2	3

Literature review

This section discusses relevant literature on design knowledge management in an ETO context, ETO product architecture, and methods for assessment of ETO project profitability.

Design knowledge management in an ETO context

In an ETO context with low-order repetition, a recurring need often exists to find new yet relatively similar solutions to satisfy customer requirements. Specifically, a significant impact on product development efficiency is achievable by improving the capabilities to reuse existing design knowledge (Brière-Côté, Rivest and Desrochers, 2010). In an ETO context, such existing design knowledge can be utilised for the application of rule-based parametric models to accommodate knowledge-based engineering and the configuration of predefined modules, handled in some kind of product configuration system (PCS) (Elgh et al., 2018).

The use of parametric product models allows the customisation of designs based on a set of rules and constraints. Generally, changing a feature of a model updates all related features. Parametric modelling is an efficient way of storing design knowledge in an ETO context and can improve the reuse of knowledge across different project (Jensen, Lidelöw and Olofsson, 2015). Parametric models can be implemented in PCSs, which allow the configuration of custom products based on predefined product modules

(Hvam, Mortensen and Riis, 2008; Custódio et al., 2018). A level of design standardisation is required to configure products, and the approach can fall short when extensive product customisation is needed (Haug, Shafiee and Hvam, 2019a). This challenge can be observed both in the early quotation phase and when customisations are needed later in the ETO design and delivery process. However, several studies have shown that ETO companies can benefit from managing design knowledge using PCSs (Shafiee, Hvam, and Bonev, 2014; Kristjansdottir et al., 2017).

To support the improved utilisation of existing design knowledge, some frameworks have been developed. One of the most well-known such frameworks is the MOKA framework introduced by Stokes (2001). This framework includes a methodology and tools aimed at developing knowledge-based engineering applications. MOKA applies formal and informal models, that is, functional, structural, and behavioural product models, to support design automation. The framework provides general support for capturing design and engineering knowledge related to product design across domains. Another relevant framework was developed by Elgh (2014), which is a task-oriented approach to enable traceability of design rationale in relation to automated engineer-to-order systems. The approach focuses on the documentation and knowledge management of systems supporting the design and manufacture of customised products. A third framework is the adaptive generic product structure (AGPS), developed by Brière-Côté, Rivest, and Desrochers (2010), based on the Generic Bill-of-Material (GBOM) (Hegge and Wortmann, 1991). This approach focuses on improving the reuse of product information in the sales–delivery process in an ETO context. A fourth framework is the design platform (DP), which was developed by André et al. (2017). This framework describes a model for ETO-based companies to leverage the benefits of product platform design. In the DP, some generic product items within the ETO solution space are identified for use as references for future designs. Yet another framework is model-based system engineering (MBSE), which is a general approach to managing design knowledge (INCOSE, 2015). It applies some product models to represent the system of interest. The framework suggests mapping requirements to three structural product levels: functional, logical, and physical. MBSE have also been used to capture and manage design knowledge in the ETO context (Elgh, 2014; Hooshmand, Köhler, and Korff-Krumm, 2015).

A common feature across the described frameworks is the use of structural and functional representations of the ETO products. The approaches themselves are mainly technical and only, on a conceptual level, address the question of which design knowledge to actually document. However, limited support was found to explicitly support cost and profitability aspects as a guiding factor for defining which design knowledge to prioritise when defining references for design within an ETO context.

ETO product architecture

As described above, ETO products can be represented by applying structural and functional viewpoints, despite the uniqueness of the individual products (Shafiee, Hvam and Kristjansdottir, 2015). In this context, to provide an overview of functional and structural properties, product solution spaces are often represented by the hierarchal compositions of elements (Brière-Côté, Rivest, and Desrochers, 2010). Of these, a limited number of high-level product attributes are typically the main drivers for product performance, as well as the costs (Hooshmand, Köhler, and Korff-Krumm, 2016). This could, for example, be the capacity of a production plant, which dictates the size of the plant and equipment needed, or the complexity of the production tasks, which dictates the need for different types of equipment.

Some central definitions for understanding product architectures were provided by Ulrich (1995), who defined a product architecture as (1) the arrangement of functional elements, (2) the mapping of functional elements to physical components, and (3) the specification of interfaces among interacting physical components. Structural properties mainly focus on the geometrical aspects of the product, whereas functional aspects are mainly focused on the flow of information, material, and energy across the technical system. With a basis in this kind of understanding of product architecture, Bruun, Mortensen, and Harlou (2014) presented the interface diagram as a comprehensive and visual representation of the product architecture, capturing structural and functional elements and interfaces across the system. Describing ETO products using such techniques allows for the analysis of ETO product architectures and improved reuse of existing design knowledge.

Project profitability in an ETO context

As indicated above, for ETO projects, the ability to capitalise on existing design knowledge is a key factor in profitability (Elgh et al., 2018). Specifically, if project costs can be reduced while not changing revenue, the profitability of projects is increased. Given this paper's focus on improved utilisation of design knowledge, it is this type of profitability increase that is of interest. Achieving such cost reductions, however, is not an easy task (Hvam et al., 2020).

As mentioned previously, cost estimation in an ETO context often comes with a high degree of uncertainty (Kingsman and De Souza, 1997). Furthermore, offering a wide range of products introduces costs that go beyond material costs, labour costs, and engineering hours (Hansen et al., 2012). In an ETO context, the loosely defined solution space and high level of customisation of product offerings can quickly increase the so-called complexity cost (Schleich, Schaffer and Scavarda, 2003; Parry and Graves, 2008; Hvam et al., 2020). This could, for example, be the need for R&D resources, documentation, flexible manufacturing capabilities, an extensive and responsive supply chain, or training of service technicians to enable adequate service regardless of variations of the individual products. Orfi, Terpenny, and Sahin-Sariisik (2011) divided cost-driving complexity into five dimensions—structural, functional, design, production, and variety—and linked these to associated cost elements. They concluded that product complexity is an essential driver of cost along the product life cycle.

Assessment of complexity cost is used as the basis for product programme rationalisation in an MTS context (Hvam et al., 2020) and consensus in existing literature seems to be that product complexity across the different dimensions significantly influences cost. The main application of complexity cost as a means for product programme rationalisation is to cut away unprofitable product variance (Hvam et al., 2020), which can be difficult in an ETO context, as product variants that have not yet been designed are difficult to cut away. However, it is possible to identify designs that historically have performed well in terms of profitability when considering complexity cost. Only when we consider these factors across the life cycle of the ETO product can we potentially identify suitable reference architectures to support profitable project execution in an ETO context.

Literature discussion

The review of existing literature indicates that several tools and methods exist for capturing and managing design knowledge in an ETO context, including documentation and application of design knowledge for sets of customer requirements and documentation of structural and functional aspects of the ETO products. The methods and tools can all provide suitable support for the reuse of design knowledge within an ETO solution space. However, limited support exists for defining which design knowledge is the most essential to document and manage, and a gap exists regarding applying a profitability perspective to support the selection of suitable design references within an ETO solution space.

To address these gaps in the literature, this study suggests utilising the concept of reference architectures. Specifically, the term reference architecture is used in the software domain to describe a generalised template solution, that is, a way to encapsulate knowledge about system design within a specific domain (Nakagawa, Oliveira Antonino and Becker, 2011). This includes business rules, architecture styles, best practices, domain terminology, etc. However, no consolidated understanding of a reference architecture exists, but it is generally agreed to be at a high level of abstraction (Angelov, Grefen and Greefhorst, 2012). Reference architectures are also used within the domain of technical systems, defining unified terminology, standards, the structure and responsibilities of system components, etc. (Van Brussel et al., 1998). In the suggested approach, the term reference architecture is used to describe the derived principal solutions for profitable project execution within an ETO solution space. Specifically, the term seems to be well suited to cover ETO products that are not fully specified, and to capture design principles that have been balanced under consideration of cost-driving complexity.

The studies on the two companies, presented in the subsequent section, investigated the assumption that the use of reference architectures can support companies in identifying the design knowledge that is the most essential to document and manage to increase the profitability of their projects.

Identifying profitable reference architectures in an ETO context

Addressing the observed industrial challenges and the gap in the existing knowledge base, this section presents the suggested method, which was tested and refined through action research studies on the two companies. The method combines elements found in the existing literature to support ETO companies in identifying profitable reference architectures within their existing solution space.

The method includes three steps: (1) scoping and collection of historical project data, (2) assessing correlations between main product attributes, cost, and profitability, and (3) identifying profitable areas within the existing solution space and matching reference architectures. Each step will be presented in the following sections and will be illustrated through the projects conducted at the two companies.

Step 1: Defining the scope and collecting the project data

The first step is the selection of projects to include in the analysis and the identification of the project data to collect. To limit the effort required for data collection, it is advisable to focus on a limited number of product families within the existing ETO solution space. The authors suggest selecting the product families that constitute the majority of the yearly revenue over the last 5 years. A large variety of projects can exist in an ETO company, for example, projects focused on upgrades of existing assets, service, and maintenance projects, etc. However, as the focus of this approach was to identify profitable design references for future ETO products, the projects were aimed at the development of new ETO products.

We divided the project data collection into three categories: *project information, product attributes, and cost elements*. Within each category, some quantifiable data points exist. *Project information* describes general information about the project, that is, customer, country of delivery, date of delivery, product structure/layout, specific product configuration, sales price, etc. The data in this category allow filtering the delivered products to identify if they match the selected scope and, finally, to backtrack which product designs have performed well in terms of profitability. *Product attributes* describe the main variable product features, such as capacity and size (an extensive list of product attributes is provided by Hubka and Eder (1988)). *Cost elements* describe the main cost drivers across the product life cycle, for example, costs of sales order administration, warranties, setting up production, inventories, and handling in distribution centres. According to Hvam et al. (2020), significant cost drivers can be identified by taking a basis in lists of cost drivers found in the literature (e.g. Closs et al., 2008; Jacobs and Swink, 2011; Myrodia and Hvam, 2015) to support the identification of relevant cost drivers, on which basis cost distributions the product families can be elaborated.

Data availability can be an issue, as it is typically scattered across several systems, drawings, documents, etc. As the suggested approach is based on data-driven decision making, we suggest spending the effort to extract all relevant information and convert it into data that can be processed. An essential element is to create a holistic overview of cost distribution across the life cycle of the products, which ensures the optimal basis for further analysis. Available and collected data in the two cases are presented in Table 2. In each of the two cases, data were available through the corporate IT systems, and it was possible to calculate or extract from available project information and resources.

Table 2: Data categories and available case data

DATA CATEGORIES	DATA POINTS	CASE COMPANY A	CASE COMPANY B
PROJECT INFORMATION	Customers	X	X
	Country/region of delivery	X	X

	Delivery date	X	X
	Layout of plant	X	X
	Sales price	X	X
	Discount rate	X	
	Profit margin	X	X
	Profit margin adjustments		X
	Budgets	X	X
	Product family/architecture	X	X
PRODUCT	Production volume	X	X
ATTRIBUTES	Production mix	X	X
	Number of tasks in process plant	X	
	Production flow	X	X
	Size of plant	X	
	Sizes of product to be produced	X	X
COST	Material cost	X	X
ELEMENTS	Labour cost	X	X
	Nonconformance cost	X	
	Shipping cost	X	
	Cost of design	X	
	Cost of installation	X	X
	Cost of commissioning		X
	Warranty cost	X	

Other data categories might be relevant to include depending on context, and it is difficult to present a thorough compilation of data points that will suit any case. However, based on our experience, study of existing literature (Orfi, Terpenny, and Sahin-Sariisik, 2011; Shafiee, Hvam, and Kristjansdottir, 2015), and findings from the present studies, Table 1 represents a fairly generic collection of relevant project attributes and cost factors to include in analysing historical ETO project delivery.

Step 2: Identify main product attributes and their correlation with cost and contribution margin ratio

This step covers the identification of the main product attributes and their correlations with cost and contribution margin. To do this, each of these product attributes is plotted against both the cost and contribution margin ratio (CMR) to create an overview. This can be used as a basis for discussing links between products and project profitability. The CMR is expressed as a percentage defining the relative difference between the sales price of a project and the variable cost factors. The cost used in this analysis is the sum of the collected variable cost factors across the life cycle.

Through the process of data collection and interactions with key stakeholders in Company A, the main product attributes were, in this case, identified as:

- **Production volume**: The maximum capacity in terms of kg/h
- **Number of tasks**: Total number of value-adding processes in the plant
- **Production mix**: The number of different products to be produced in the plant.
- **Production technologies**: The technologies used for different products to be produced; this indicates how homogeneous the products are.

Figure 1 shows how these product attributes were plotted against CMR and cost. The data were generalised to avoid disclosing confidential information from the two cases. Thus, the axes on the graphs indicate, on a scale from low to high, how variations in, for example, CMR correlated with changes in production volume.

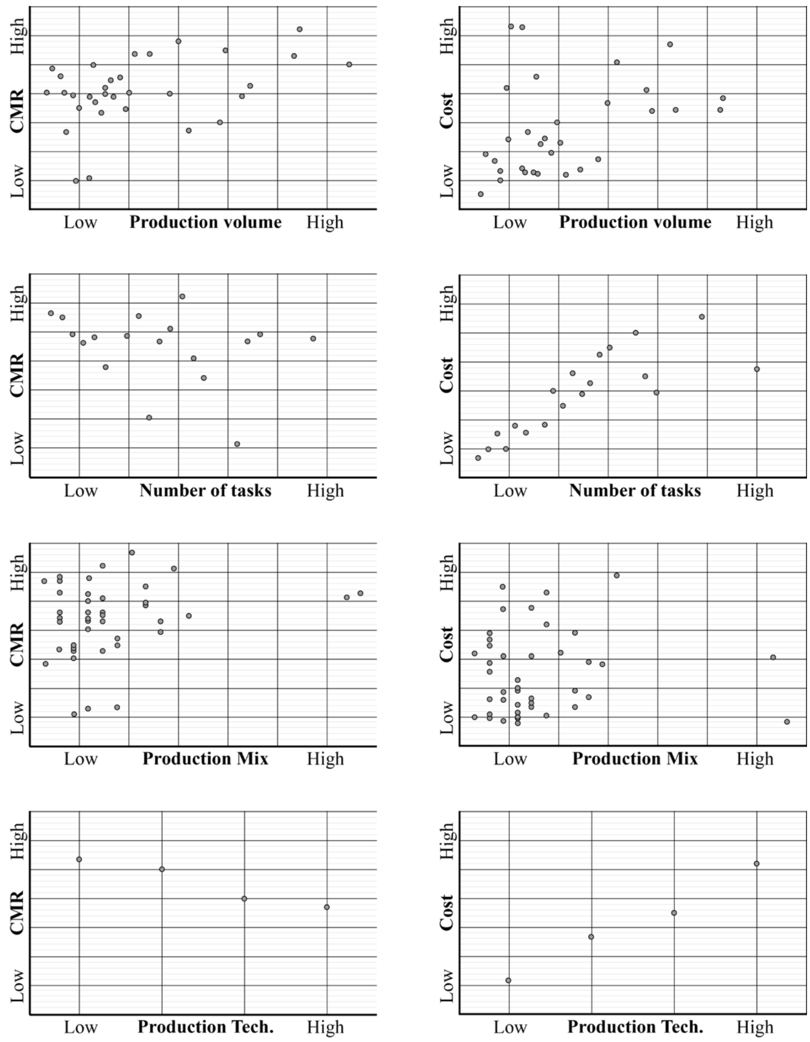

Figure 1: Cost and CMR plotted against main product attributes for Company A

The top left plot of Figure 1 indicates how an increase in production volume influences the CMR of a series of projects. The top right plot indicates how the same change in production volume influences the sum of variable cost factors for the same series of projects. Vertically the plots illustrate how variations of the main product attributes historically have affected the CMR and project cost. Regarding the number of tasks, a linear correlation existed when considering an increase in the number of tasks and the sum of variable cost. By contrast, it is less clear how CMR changed when the number of tasks in the plant increased. This could indicate that the company was able to perform cost-based pricing fairly accurately when it related to the number of tasks in the process plant.

Similar to Company A, it was possible to identify the following as the main product attributes in Company B:

- **Production volume**: The maximum capacity of the plant in kg/hour across all production scenarios.
- **Number of tasks**: Number of key functional components in the plant
- **Production range**: Number of different products to be produced in the plant.
- **Production mix**: Expressed as an index of the homogeneity of the produced products.
- **Production flow**: The number of interactions across value-adding processes.

Figure 2 shows how the five attributes correlate with CMR and cost (including the available cost elements in Table 1).

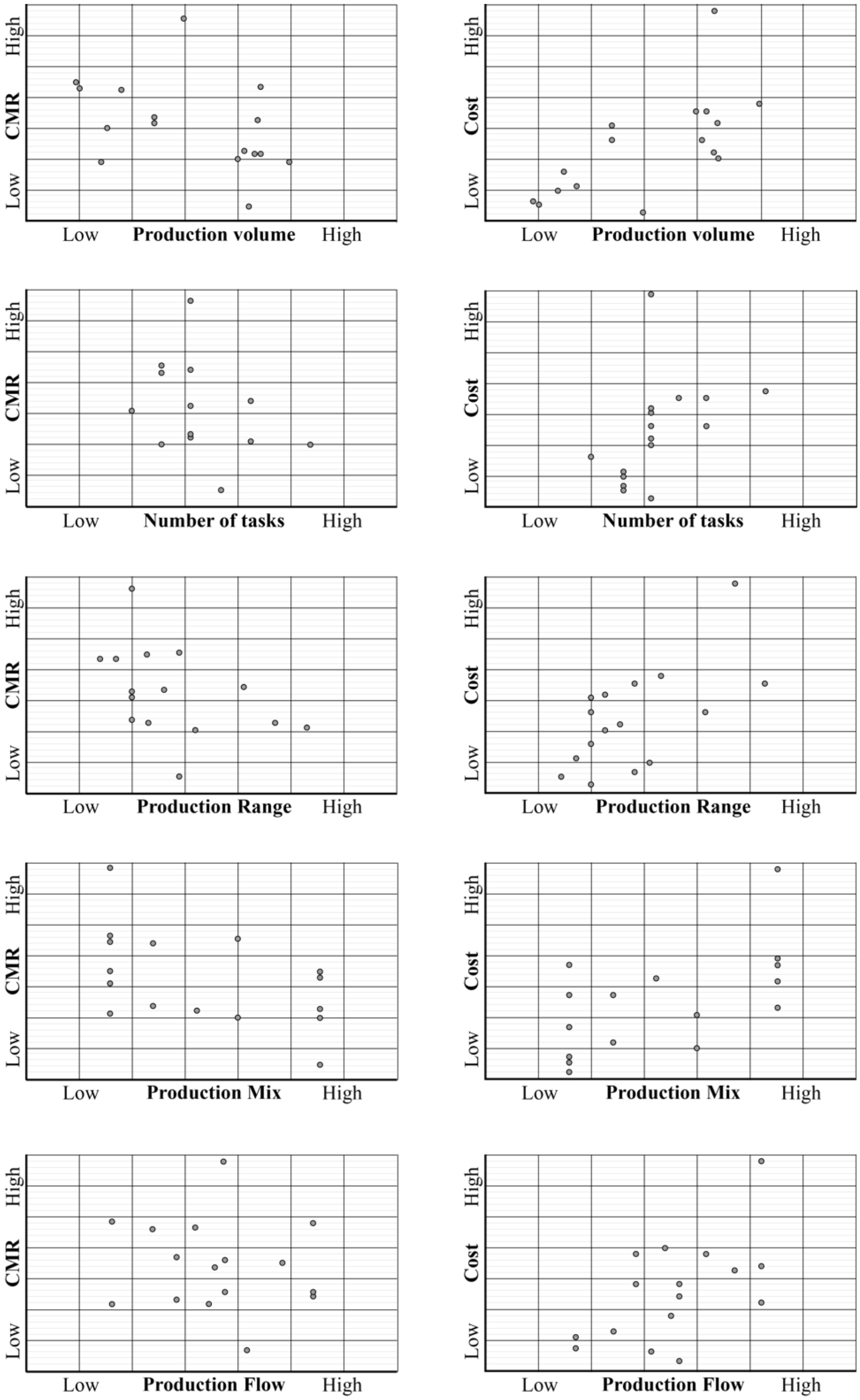

Figure 2: Cost and contribution margin ratio plotted against main product attributes for Company A

As mentioned in the research approach, no mathematical modelling was applied in the identification of the main product attributes or in assessing correlations between parameters. Instead, based on the data visualisation, workshops with key stakeholders were held to discuss and identify these key correlations. One reason for this approach is that historical project data can only indicate what happened during the project to a certain extent. Other, and undocumented, factors can have had an impact on aspects such as cost and profit, for instance, decisions of strategic sales where low earnings are expected. The combination of data visualisation and review with key stakeholders is believed to be a strong and valid approach for identifying key correlations between product attributes and the profitability of historically delivered projects.

The statements from the executive managers during the workshops focused on the challenges of identifying the optimal product strategy within the existing solution space. As one top manager stated, "We have to know the corner flags of our product programme and know where to focus", emphasising the challenges of understanding the product solution space and determining where to focus sales efforts. Another manager described the challenge of determining the boundaries of the product programme in terms of key product attributes: "We have to define the boundaries for our products in terms of size, capacity, and so on". Lastly, a member of the board in one of the case companies pointed to the challenge of ensuring adequate internal technical know-how though the statement: "Our knowledge is the same or less than previously, while our product programme has grown. This gives us significant technical challenges". In summary, these comments illustrate the challenge of being in control of a large and growing ETO solution space and the importance of being able to identify and define optimal solutions within it.

Step 3: Map solution space and identify profitable reference architectures

In the final step, the ETO solution space is visualised from the perspective of the most significant product attributes when considering their costs and CMR. Specifically, this was done by producing a list of attributes together with their CMR and cost information, from which the attributes that were most significant were chosen. This process narrowed the number of product attributes to allow for a simple representation of the existing solution space by plotting two product attributes against each other.

In Company A, *production volume* and the *number of tasks* were identified as the main drivers of cost and profitability across the life cycle of the ETO products. In Company B, the main drivers were *production volume* and *production mix*. Combining this with information about product families allowed us to visualise how different designs had performed against each other. As ETO projects are often quoted based on an expected contribution margin ratio (Mortensen et al., 2010) and this level varies from case to case, the authors suggest identifying the benchmark for when a project is considered successful or not. By comparing whether the realised CMR equals or is higher than the forecasted/benchmarked CMR enables us to indicate where profitable projects have historically existed within the solution space. The visualisation is then used to identify profitable reference architectures within the ETO solution space.

Figure 3 shows how the solution space of Company A was visualised. The two main product attributes are displayed as indices, and the product families within the scope are represented by spanning a polygon based on the maximum and minimum on the two axes.

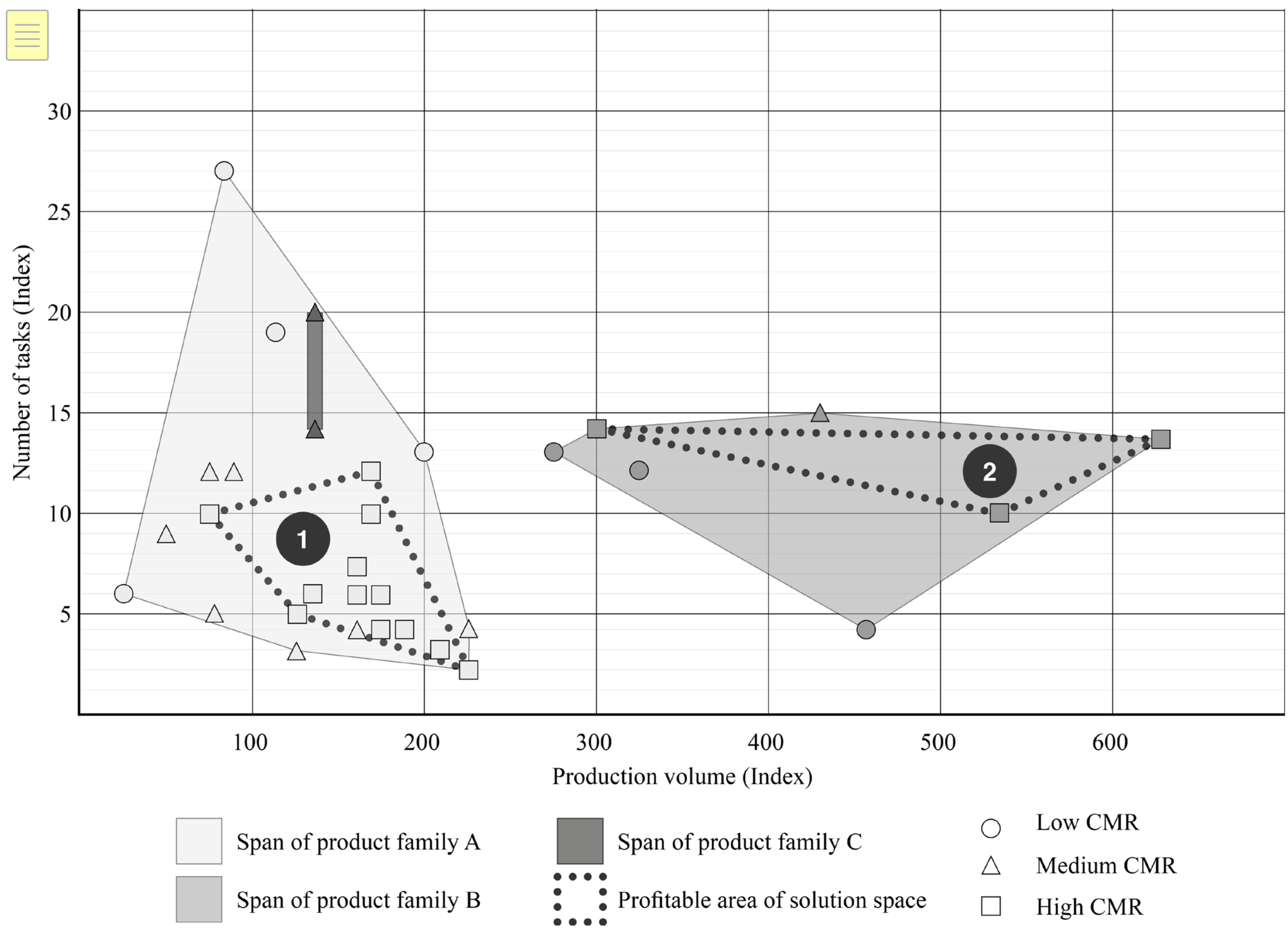

Figure 3: Visualisation of the existing solution space for Company A and indication of profitable reference architectures.

Three different product families were included in the scope. Within areas 1 and 2, we found projects in which the realised CMR was equal to or higher than the forecasted CMR. Outside areas 1 and 2 were projects that historically had not been able to generate the desired profit.

Similarly, the analysis for Company B included three product families. Each of them differed in the design of a key functional system and structural architectures. The solution space is visualised in Figure 4. The two areas 1 and 2 indicate the historically profitable areas within the existing solution space.

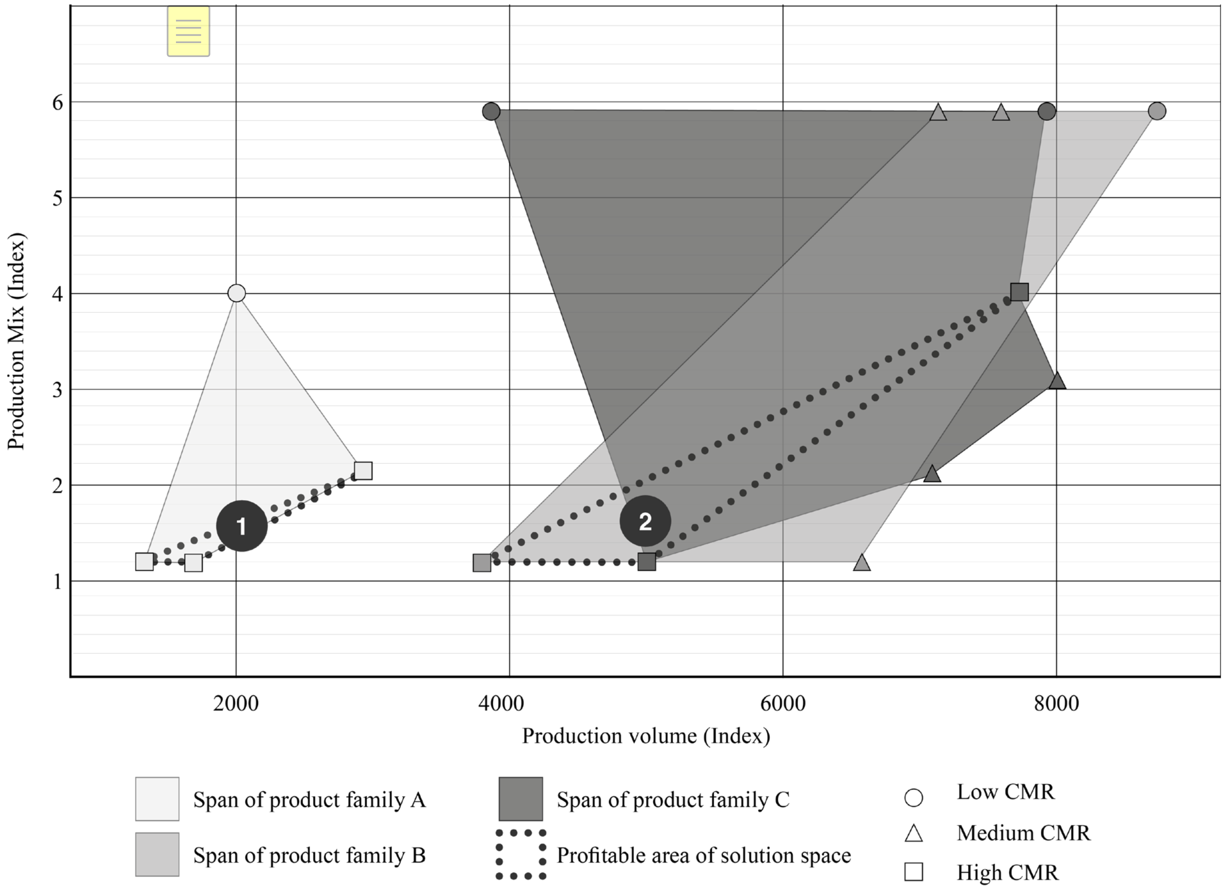

Figure 4: Visualisation of the existing solution space for Company B and indication of profitable reference architectures.

Figures 3 and 4 indicate that profitable areas existed within the existing solution spaces of the two companies. The observations suggest that when receiving new orders, the specifications can be matched against these attributes to identify the preferred solution, which most likely will turn out profitable—the reference. Table 2 provides an overview of the identified reference architectures in the two cases.

Table 1: Identification of reference architectures

	COMPANY A	COMPANY B
AREA 1	Product family A is under the following constraints considered a suitable reference	Product family A is under the following constraints considered a suitable reference

	for profitable project execution: Capacity range of [80–220], with a maximum number of tasks to be performed of 11.	for profitable project execution: Capacity range [0–2000], with a production mix up to 2.
AREA 2	Product family B is under the following constraints considered a suitable reference for profitable project execution: capacity range of [300–650], with the number of tasks to be performed in the plant between [10-14].	Product family B is under the following constraints considered a suitable reference for profitable project execution: capacity range of [4300–7200] and a production mix up to 4.

As the purpose of this approach is to identify the profitable reference architectures within an existing ETO solution space, we do not go further into detail of how to practically describe the architectures. Documentation of how to design products within the relevant product families already existed in the two case companies; however, as the ETO solution space by nature is arbitrary, the suggested approach supports ETO companies in consolidating and describing references for design under some limitations, thus improving the likelihood of achieving the desired CMR.

Discussion

In this paper, a three-step method for identifying profitable reference architectures in an ETO context was developed and tested in two industry cases. In the analysis of the existing body of knowledge, several methods and tools were found to support the definition, documentation, and application of functional and structural references for design in an ETO context. However, a gap exists in explicitly supporting the identification of design references under the consideration of historical project profitability. The presented method addresses this gap and builds on existing concepts to support decision makers in including profitability as a parameter when defining references for future designs.

Defining design references for tomorrow's projects based on insights from historical projects has both benefits and limitations. It is generally a reactive approach, and for ETO companies with no problems of controlling costs and achieving the forecasted profit margins, this might not provide much value. However, many ETO companies are challenged to deliver solutions that are on the edge or just outside their capabilities, such as increasing capacity or functionality beyond what have previously been designed. Without a clear reference for when such inquiries are within or outside of known competences, it is difficult for managers to assess uncertainty and predict whether a project will be attractive in terms of potential profit. As shown in the two cases, it is possible to identify areas within the ETO solution space where project profitability is higher than in other areas. This may appear logical, but if the companies are not aware of what defines these profitable parts of the solution space, they have little chance of leveraging them. Thus, it is useful to identify reference architectures within an ETO solution space based on a historical analysis of profitability.

The discussion above should not be understood as suggesting that ETO companies should never step outside the boundaries of the reference architectures, but it thus clearly indicates when it is the case and extra risk or cost should be expected. The need to step outside these concern situations in which customer demands call for novel solutions not captured by the existing reference architecture, as well as when new technologies promise quality, cost, or time improvements. If such projects are initiated and they offer improvements that could be of relevance in later projects, the reference architecture should be updated to include these solutions.

The discussion of when to update the reference architecture relates to the difficult trade-off between being reactive and being innovative in an ETO context. Do we risk killing all innovations by defining clear references for design? The answer is not straight forward. As mentioned, the idea with the suggested design method is not to restrict the solution space but to highlight optimal design references when considering profitability. However, as expressed by one of the executive managers in one of the case companies, as soon as the design references are clearly defined and documented, there is a high chance that we will see our sales activities centred around these designs. If this is the case, we risk limiting the natural evolution of the solution space within an ETO context with the risk of compromising competitiveness in the long run. However, if the alternative is to sell unprofitable solutions, this might be a rational approach. If companies are not in control of their core product offerings, success in other parts of the solution space can be difficult to achieve. Thus, consolidation of design references for the core product programme is considered an essential enabler of profitable project execution in an ETO context.

A central limitation of the suggested approach concerns considerations related to market development and future product requirements. Thus, future research activities should address the challenge of systematically including these parameters in the analysis. Furthermore, a number of non-functional project parameters, such as the composition of the project team, sourcing strategy, and production planning, could be relevant to consider. However, as indicated in the application of the suggested method in the two industrial cases, it provides, in its current form, operational, and useful support for identifying profitable areas within an existing ETO solution space. This is supported by a comparison of the suggested approach to cost analysis with the approach previously used in Company A, which revealed an average difference of around 15% when assessing total project costs. Specifically, the suggested approach, on average, assessed project profitability to be 15% less than previously indicated. This was due to several complex cost factors not being included in the existing approach. Thus, in terms of assessing the profitability of historical projects, the added detail regarding the complexity cost factors of the suggested approach seemed to significantly improve the basis for decision making.

A challenge regarding the application of the suggested method concerns data availability, as different kinds of project information exist depending on context, and some information might not be documented at all. Furthermore, the number of projects from which it is possible to extract relevant data can be low due to the generally long lead times in the business. In the two industry cases, lead times ranged from approximately 1 to 5 years, and it was possible to extract data from 51 projects where complete plants had been delivered. As the suggested method applies an analytical approach rather than a mathematical one and includes input from key stakeholders, it is our understanding that it supplied a sufficient basis for drawing conclusions in the two cases. However, in the future application of the suggested method, it is necessary to discuss whether sufficient data exist in the given context.

The suggested three-step method has been tested and refined through action research studies in the two ETO companies, one of which can be categorised as a basic ETO, and the other as complex ETO (Willner et al., 2016a). Despite their differences regarding engineering complexity, the cases suggested that the proposed method was beneficial in both companies. Nevertheless, additional research activities are needed to generalise the use of the method. This includes the testing of other ETO companies and the evaluation of their effects over a longer timeframe. However, the method addresses a significant challenge in an industry with low order reptation rates, which makes it difficult for decision makers to assess the probability of achieving the desired profit margins. Future research activities should also include detailing how to model reference architectures and how to practically represent dimensions, design variables, and constraints.

Furthermore, an area for exploration could be the application of simulation to identify different optimums within existing solution spaces based on profitability analysis. However, similar to existing approaches to documenting design knowledge, a simplified representation of the ETO product is considered useful as design support. Thus, for providing operational support for ETO companies in successful project execution, the abstract and high-level definition of reference architectures is, at this stage, considered suitable to establish a reference for profitable project execution within the scope of this paper.

Conclusion

The main contribution of this paper is the suggested three-step method for supporting ETO companies in identifying profitable reference architectures within their existing solution space. When operating with an ETO strategy, the ability to capitalise on existing design knowledge is essential for successful project execution. Several methods exist to capture design knowledge in formal and informal product models (e.g. André et al., 2017; Elgh, 2014; Brière-Côté, Rivest and Desrochers, 2010). Such methods, however, mainly focus on documenting the structural ~~and~~ functional properties of reference designs, whereas there is limited support for ETO companies when determining which reference architectures ~~are~~ the most profitability. The present research addressed this gap by developing a method for identifying reference architectures under the consideration of profitability, which was tested in two industrial cases representing an ETO context with a low-order repetition rate.

The case studies demonstrated the value of including additional details about complexity cost factors. Specifically, the case studies showed that including such details highlighted some parts and modules as significantly more or less profitable than simpler methods would show. Furthermore, the cases also indicate the value of including profitability as a guiding factor for defining design references. The study thereby contributes to the literature on profitability in ETO projects (e.g. Mortensen et al., 2010; Gepp, Foehr, and Vollmar, 2016; Johnsen and Hvam, 2018), and it extends the literature on the use of design references (e.g. Grabenstetter and Usher, 2014; Hooshmand, Köhler, and Korff-Krumm, 2016) to an ETO context.

ETO companies may apply the proposed method as a means for improving the solutions offered to their customers, as well as to reduce the costs. Specifically, the use of reference architectures may be used as a means of eliminating less efficient solution types and directing customers to more beneficial ones. From the ETO company perspective, the use of reference architectures makes it possible to identify and eliminate less profitable solution types, as well as to reduce the needed engineering work involved in customer orders.

However, it was difficult to quantify the direct effects of applying the suggested approach in the two cases, since ETO projects are generally executed within a long timeframe and are even longer prospect to changes. To further generalise the suggested approach, additional testing in other ETO contexts and an assessment of the effects over a longer period of time are needed. Nevertheless, this study contributes to the field of identifying design references in an ETO context by including profitability as a guiding factor for defining design references.

References

André, S., F. Elgh, J. Johansson, and R. Stolt. 2017. "The Design Platform–A Coherent Platform Description of Heterogeneous Design Assets for Suppliers of Highly Customised Systems." *Journal of Engineering Design* (28) 10-12: 599-626. doi: 10.1080/09544828.2017.1376244.

Angelov, S., P. Grefen, and D. Greefhorst. 2012 "A Framework for Analysis and Design of Software Reference Architectures." *Information and Software Technology* 54 (4): 417-431. doi: 10.1016/j.infsof.2011.11.009.

Baskerville, R. L. 1999. "Investigating Information Systems with Action Research." *Communications of the Association for Information Systems* 2 (19): 1–31.

Böhm, B., C. Cârlan, A. Sohr, S. Unverdorben, and J. Vollmar. 2021 "Architectures for Flexible Collaborative Systems. Model-Based Engineering of Collaborative Embedded Systems." In W. Böhm, M. Broy, C. Klein, K. Pohl, B. Rumpe, and S. Schröck (eds), *Model-Based Engineering of Collaborative Embedded Systems: Extensions of the SPES Methodology.* Cham, Switzerland, Springer, pp. 49-70.

Brière-Côté, A., L. Rivest, and A. Desrochers. 2010. "Adaptive Generic Product Structure Modelling for Design Reuse in Engineer-to-Order Products." *Computers in Industry 61 (1): 53-65*. doi: 10.1016/j.compind.2009.07.005.

Van Brussel, H., J. Wyns, P. Valckenaers, L. Bongaerts, and P. Peeters. 1998. "Reference Architecture For Holonic Manufacturing Systems: PROSA." *Computers in Industry 37 (3)*: 255-274. doi: 10.1016/S0166-3615(98)00102-X.

Bruun, H. P., N. H. Mortensen, and U. Harlou. 2014. "Interface Diagram: Design Tool for Supporting the Development of Modularity in Complex Product Systems." *Concurrent Engineering* 22(1): 62–76. doi: 10.1177/1063293X13516329.

Christensen B., T. D. Brunoe. 2018. "Product Configuration in the ETO and Capital Goods Industry: A Literature Review and Challenges." In S. Hankammer, K. Nielsen, F. Piller, G. Schuh, and N. Wang (eds), *Customization 4.0.* Cham: Springer. https://doi.org/10.1007/978-3-319-77556-2_26

Closs, J., M. A. Jacobs, M. Swink, and G. S. Webb. 2008. "Toward a Theory of Competencies for the Management of Product Complexity: Six Case Studies." *Journal of Operations Management* 26 (5): 590–610.

Coughlan, P., and D. Coghlan. 2002. "Action Research for Operations Management." *International Journal of Operations & Production Management* 22(2): 220–240. doi: 10.1108/01443570210417515.

Custódio, D.T., G. L. R. Vaccaro, F. L. Nunes, G. Vidor, and L. D. Chiwiacowsky. 2018. Variant Product Configuration of Industrial Air Handling Units in a MTO Environment. *International Journal of Advanced Manufacturing Technology* 95: 1025–1037. https://doi.org/10.1007/s00170-017-1171-7

Dixit, V., A. Chaudhuri, and R. K. Srivastava. 2019. "Assessing Value of Customer Involvement in Engineered-To-Order Shipbuilding Projects Using Fuzzy Set and Rough Set Theories." *International Journal of Production Research* 57 (22): 6943-6962, DOI: 10.1080/00207543.2019.1572928

Elgh, F. 2014. "Automated Engineer-To-Order Systems - A Task-Oriented Approach to Enable Traceability of Design Rationale." *International Journal of Agile Systems and Management* 7 (3/4): 324-347. doi: 10.1504/ijasm.2014.065358.

Elgh, F., J. Johansson, M. Pookrkiany, R. Stolt, and D. Rudberg. 2018. "Traceability of Decisions in Product Realization Processes of Custom Engineered Products." In *Proceedings of the 15th International Design Conference, DESIGN*, Dubrovnik, May 21-24.

Elgh, F., and S. Sunnersjö. 2003. "An Automated Cost Estimation System for Variant Design Based on the Method of Successive Calculus." In *Proceeding of the International Conference on Engineering Design, ICED03*, Stockholm, August 19-21.

Fixson, S. 2005. "Product Architecture Assessment: A Tool to Link Product, Process, and Supply Chain Design Decisions." *Journal of Operations Management* 23 (3/4): 345-369. doi: 10.1016/j.jom.2004.08.006.

Foehr, M., M. Gepp, and J. Vollmar. 2015. "Challenges of System Integration in the Engineer-to-Order Business." In *Proceedings of the 41st Annual Conference of the IEEE Industrial Electronics Society*, Yokohama, November 9-12.

Gepp, M., M. Foehr, and J. Vollmar. 2016. "Standardization, Modularization and Platform Approaches in the Engineer-To-Order Business-Review and Outlook." In *Proceedings of the 10th Annual International Systems Conference, SysCon 2016*, Orlando, April 18-21.

Grabenstetter, D., and J. Usher. 2014. "Developing Due Dates in an Engineer-to-Order Engineering Environment." *International Journal of Production Research* 52 (21): 6349-6361. doi: 10.1080/00207543.2014.940072.

Hansen, C. L., N. H. Mortensen, and L. Hvam. 2012. "Calculation of Complexity Costs – An Approach For Rationalizing A Product Program." in the Proceedings of NordDesign Conference, Alborg, August 22-24.

Harlou, U. 2006. "*Developing Product Families Based on Architectures*, *Contribution to a Theory of Product Families*." PhD diss. Technical University of Denmark.

Haug, A., K. Ladeby, and K. Edwards. 2009. "From Engineer-to-Order to Mass Customization." *Management Research News* 32 (7): 633-644. doi: 10.1108/01409170910965233.

Haug, A., S. Shafiee, and L. Hvam. 2019a. "The Causes of Product Configuration Project Failure." *Computers in Industry* 108: 121-131.

Haug, A., S. Shafiee, and L. Hvam. 2019b. "The Costs and Benefits of Product Configuration Projects in Engineer-to-Order Companies." *Computers in Industry* 105: 133-142. doi: 10.1016/j.compind.2018.11.005.

Hegge, H. M. H., and J. C. Wortmann. 1991. "Generic Bill-of-Material: A New Product Model." *International Journal of Production Economics* 23 (1-3): 117-128. doi: 10.1016/0925-5273(91)90055-X.

Hicks, C., and T. McGovern. 2009 "Product Life Cycle Management in Engineer-to-Order Industries." *International Journal of Technology Management* 48 (2): 153-167. doi: 10.1504/ijtm.2009.024913.

Hicks, C., T. McGovern, and C. F. Earl. 2000. "Supply Chain Management: A Strategic Issue in Engineer to Order Manufacturing." *International Journal of Production Economics* 65 (2): 179-190. doi: 10.1016/S0925-5273(99)00026-2.

Hobday, M. 2000. "The Project-Based Organisation: An Ideal Form for Managing Complex Products and Systems?" *Research Policy* 29 (7-8): 871-893. doi: 10.1016/S0048-7333(00)00110-4.

Hooshmand, Y., P. Köhler, and A. Korff-Krumm. 2015. "Development of a Reference Architecture Model in the Machinery and Plant Engineering Sector", in the Proceeding of the *26th Symposium Design for X*, Herrsching, October 7-8.

Hooshmand, Y., P. Köhler, and A. Korff-Krumm. 2016. "Cost Estimation in Engineer-to-Order Manufacturing." *Open Engineering* 6 (1): 22-34. doi: 10.1515/eng-2016-0002.

Hubka, V., and W. E. Eder. 1988. *Theory of Technical Systems.* New York, Springer-Verlag.

Hvam, L., C. L. Hansen, C. Forza, N. H. Mortensen, and A. Haug. 2020. "The Reduction of Product and Process Complexity Based on the Quantification of Product Complexity Costs." *International Journal of Production Research* 58 (2): 350-366. doi: 10.1080/00207543.2019.1587188.

Hvam, L., N. H. Mortensen, and J. Riis. 2008. *Product Customization*. Berlin: Springer.

INCOSE. 2015. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, *4th edition, Hoboken: John Wiley and Sons, Inc.*

Jensen, P., H. Lidelöw, and T. Olofsson. 2015. "Product Configuration in Construction." *International Journal of Mass Customisation* 5 (1): 73-92. doi: 10.1504/ijmassc.2015.069601.

Jiao, J., and M. M. Tseng. 2000. "Fundamentals of Product Family Architecture." *Integrated Manufacturing Systems* 11 (7): 469-483. doi: 10.1108/09576060010349776.

Johnsen, S. M., and L. Hvam. 2018. "Understanding the Impact of Non-Standard Customisations in an Engineer-to-Order Context: A Case Study." *International Journal of Production Research* 57 (21): 6780-6794. doi: 10.1080/00207543.2018.1471239.

Johnsson, H. 2013. "Production Strategies for Pre-Engineering in House-Building: Exploring Product Development Platforms." *Construction Management and Economics* 31 (9): 941-958. doi: 10.1080/01446193.2013.828846.

Kingsman, B. G., and A. A. De Souza. 1997. "A Knowledge-Based Decision Support System for Cost Estimation and Pricing Decisions in Versatile Manufacturing Companies." *International Journal of Production Economics* 53 (2): 119-139. doi: 10.1016/S0925-5273(97)00116-3.

Kristjansdottir, K., L. Hvam, S. Shafiee, and M. Bonev. 2017. "Identification of Profitable Areas to Apply Product Configuration Systems in Engineer-To-Order Companies." In the Procceedings of the 8th World Conference on Mass Customization, Personalization, and Co-Creation, Montreal, October 20-22.

Lewin, K. 1946. "Action Research and Minority Problems." *Journal of Social Issues* 2 (4): 34-46.

Jacobs, M. A., and M. Swink. 2011. "Product Portfolio Architectural Complexity and Operational Performance: Incorporating the Roles of Learning and Fixed Assets." *Journal of Operations Management* 29: 677–691.

Johnsen, S. M., K. Kristjansdottir, and L. Hvam. 2017. "Improving Product Configurability in ETO Companies." *in the Proceedings of the 21st International Conference on Engineering Design, Vancouver, August, 21-25*.

Magnusson, T., and N. Lakemond. 2017. "Dual Role of Architectures in NPD." *R&D Management* 47 (1): 36-46. https://doi.org/10.1111/radm.12142

Martin, M., and K. Ishii. 1996. "Design for Variety: A Methodology for Understanding the Costs of Product Proliferation." In *Proceedings of the ASME Design Engineering Technical Conferences and Computers in Engineering Conference,* Irvine, August, 18-22.

Myrodia, A., and L. Hvam. 2015. "Identification of Complexity Cost Factors in Manufacturing Companies." In *Proceedings of the 22nd EurOMA Conference*, Neuchâtel, Switzerland, June 28 - July 01

McGovern, T., and C. Hicks. 2006. "Specifications and Supplier Development in the UK Electrical Transmission and Distribution Equipment Industry." *International Journal of Production Economics* 104 (1): 164-178. doi: 10.1016/j.ijpe.2004.08.005.

Meyer, M. H., and A. P. Lehnerd. 1997. *The Power of Product Platforms*. New York: *The Free Press.*

Mortensen, N. H., L. Hvam, A. Haug, P. Boelsifte, C. H. Lindschou, and S. Frobenius. 2010. "Making Product Customization Profitable." *International Journal of Industrial Engineering: Theory Applications and Practice* 17 (1): 25–35.

Nakagawa, E. Y., P. O. Antonino, and M. Becker. 2011. "Reference Architecture and Product Line Architecture: A Subtle But Critical Difference." In *Proceedings of the European Conference on Software Architecture*, Essen, September, 13-16.

Orfi, N., J. Terpenny, and A. Sahin-Sariisik. 2011. "Harnessing Product Complexity: Step 1 Establishing Product Complexity Dimensions and Indicators." *Engineering Economist* 56 (1): 59-79. doi: 10.1080/0013791X.2010.549935.

Parry, G., and A. Graves. 2008. *Build to Order: The Road to the 5-Day Car*. London: Springer.

Rahim, A. R. A., and M. S. N. Baksh. 2003. "The Need for a New Product Development Framework for Engineer-to-Order Products." *European Journal of Innovation Management* 6 (3): 182-196. doi: 10.1108/14601060310486253.

Reason, P. and H. Bradbury. 2001. *Handbook of Action Research.* Thousand Oaks, CA: Sage.

Schleich, H., J. Schaffer, and L. F. Scavarda. 2003. "Managing Complexity in Automotive Production." In *Proceedings of the 19th International Conference on Production Research*, Valparaiso, 29 July–2 August.

Shafiee, S., L. Hvam, and M. Bonev. 2014. "Scoping a Product Configuration Project for Engineer-to-Order Companies." *International Journal of Industrial Engineering and Management* 5 (4): 207-220.

Shafiee, S., L. Hvam, and K. Kristjansdottir. 2015. "How to Analyze and Quantify Similarities Between Configured Engineer-to-Order Products by Comparing the Highlighted Features Utilizing the Configuration System Abilities." In the *Proceedings of the 17th International Configuration Workshop*, *Vienna, September, 10-11*.

Silventoinen, A., *A. Denger, H. Lampela, and J. Papinniemi.* 2014. "Challenges of Information Reuse in Customer-Oriented Engineering Networks." *International Journal of Information Management* 34 (6): 720-732. doi: 10.1016/j.ijinfomgt.2014.07.001.

Stokes, M. 2001. *Managing Engineering Knowledge: MOKA: Methodology for Knowledge Based Engineering Application*s. London: Professional Engineering Publishing Limited.

Ulrich, K. 1995. "The Role of Product Architecture in the Manufacturing Firm." *Research Policy* 24 (3): 419-440. doi: 10.1016/0048-7333(94)00775-3.

Willner, O., D. Powell, M. Gerschberger, and P. Schönsleben. 2016a. "Exploring the Archetypes of Engineer-to-Order: An Empirical Analysis." *International Journal of Operations and Production Management* 36 (3): 242-264. doi: 10.1108/IJOPM-07-2014-0339.

Willner, O., J. Gosling, and P. Schönsleben. 2016b. "Establishing a Maturity Model For Design Automation in Sales-Delivery Processes of ETO Products." *Computers in Industry* 82: 57-68. doi: 10.1016/j.compind.2016.05.003.