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Supporting Design Reuse in Engineer-to-Order Context: A Systematic Literature Review

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Abstract: Delivering Engineering-to-Order (ETO) products takes months or even years. Quotation preparation and engineering in the sales-delivery-order process is lacking design reuse as individual deliveries are started from scratch. Modularisation and platform approaches could help move from individually designed products to a solution approach based on design reuse. The purpose of this study is to clarify whether a method supporting development of ETO product utilizing Module Systems and Design Reasoning Patterns exist in the literature. This systematic literature review is part of the Design Research Methodology carried out as conceptual review to clarify what is already known about the selected topic. No methods or design process was found, but some ideas and tools supporting design reuse in ETO context exist in the literature. Support is needed for design reuse in ETO context and literature related modularisation in Configure-to-Order context needs to be investigated in future research.

Keywords: Engineer-to-Order (ETO), Design Reuse, Process, Methods, Systematic Literature Review

1 Introduction

Companies delivering highly customized products in High Value Low Volume (HVLV) context are facing multiple challenges when it comes to the nature of Engineer-to-Order (ETO) strategy. Typical products for companies utilizing ETO strategy are capital products such as power stations or metal processing plants, delivered only a few per year (Vollmar and Gepp, 2015), designed precisely to fit customer requirements in the sales-delivery process. To overcome the competition, products should be sold at lower price and delivered in a shorter time than other competitors to ensure success in the bidding process. Technical proposal preparation is time consuming and requires involvement of expertise and product knowledge, such as product documents, drawings (formal knowledge) or implicit rules from people with technical expertise (tacit knowledge) (Raffaeli et al., 2017). Due to uncertainty and varying customer requirements, engineering is usually made after the product sales process leading to longer delivery times compared to consumer products. In addition, potentially time spent on preparing the quotation based on customer requirements before contract of sale could be wasted if a competitive tendering is lost. Pakkanen et al. (2022) claims that by modularizing investment goods, time required by the engineering design is reduced. Also, standardisation, modularisation and platform approaches could help move form individually designed ETO product to a solution approach based on reusing predesigned, reusable standard modules (Gepp et al., 2016). Typical to Configure-to-Order (CTO) strategy, the product family is designed before sales-delivery process and customized according to customer requirements, enabling reuse of design knowledge. By utilizing modularisation and platform approaches in HVLV context cold result in shortened lead times as well as less time could be required for designing a customer specific delivery.

Academic research indicates a lack of methodologies supporting implementation of standardization, modularization and platform approaches in Engineer-to-Order companies (Gepp et al., 2016) as well as lack of models, methods and tools supporting the creation of a platform approach utilizing assets other than components and modules is identified (André et al., 2017). A need is recognized from the industry (Juuti et al., 2023) to support artefact design including Module Systems and Design Reasoning Patterns in HVLV context. According to Pakkanen (2013), Module System information consists of five categories of information: modules, interfaces, architecture, configuration knowledge and partitioning logic (design rationale resulting in the desired module division). Product entities requiring delivery specific engineering could be controlled by capturing design knowledge in Design Reasoning Patterns (DRPs). Lehtonen (Lehtonen et al., 2016) argues that DRPs describe how designing of a physical product should be done, including logical sequences about designing. In addition, DRP models describes, why the design is as it is, enabling the reuse of DRPs in the product development. Together, Module Systems and DRPs could help ETO companies develop products based on reusable assets with the flexibility of customer specific assets, reducing engineering and shorten lead times. By configuring pre-designed Module Systems, less engineering is required in the sales-order-delivery process compared to the traditional, way of delivering ETO products as project deliveries. The use of Module Systems with ETO imposes new demands on the design support and the design process; the design process should support design before the delivery project (developing a Module System, for example) and the design done during the delivery project (how to design ETO entities without damaging the benefits of modularisation, for example).

Aim of this article is to clarify whether design support for development of ETO products utilizing Module Systems and DRPs exist in the literature. A literature review is conducted to find answer to following question: *1) Which design methods support developing ETO products consisting of Module Systems and Design Reasoning Patterns in the literature?*

2 Research approach

This research is carried out using systematic literature review as part of the Design Research Methodology (DRM) by Blessing and Chakrabarti (2009). Aim of the research is to point out gaps in existing literature and illustrate areas that still need to be explored. The literature review was carried out as a conceptual review to clarify what is already known about the selected topic. Search protocol followed in this literature review is presented below in figure 1. In both searches language of the papers was limited to English only. Search query strings used are illustrated in the figure 2. In all four searches, certain key words for outlining the title were used and as for abstracts. Scopus [1] search covers both search cases: title and keywords, and title and abstract. In the second search of Scopus and Web of Science (WoS), subject area was limited to "Engineering".

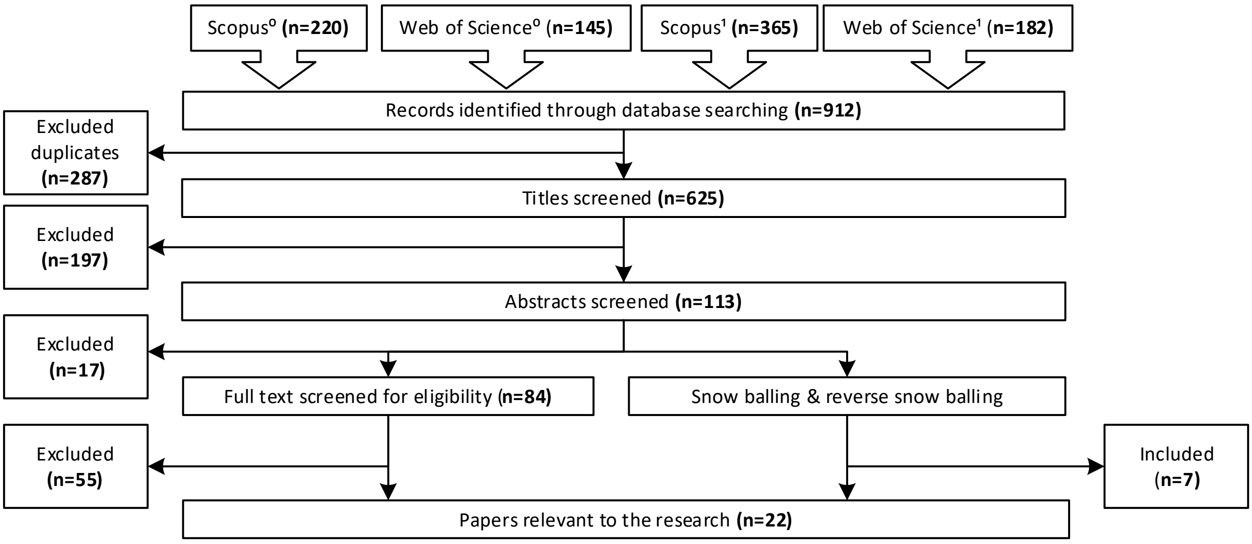

Figure 1: Protocol used in the literature review

Total of 912 records were identified through database searching from 2 different databases: Scopus and WoS. Exclusion criteria for titles and abstracts was selected based on the approach of this paper. Found records were excluded whether record title did not give any hints toward modularisation, configuration, customisation, module systems, architecture, modules, design reasoning patterns, partitioning logic, configuration knowledge, interfaces, or design reuse in ETO context. From the screened abstracts, papers were excluded whether the context did not match. For example, papers related to manufacturing were excluded and papers related to engineering were included. A total of 84 papers were screened for eligibility. During the screening, snowballing and reverse snow balling were conducted and papers relevant to the approach were included. Papers with least potential for supporting the selected approach or with irrelevant context were excluded. Due to lack of articles supporting ETO product development with Module System and DRPs, articles supporting ETO artefact modularisation, configuration and design reuse were included to this literature review and will be presented the next section.

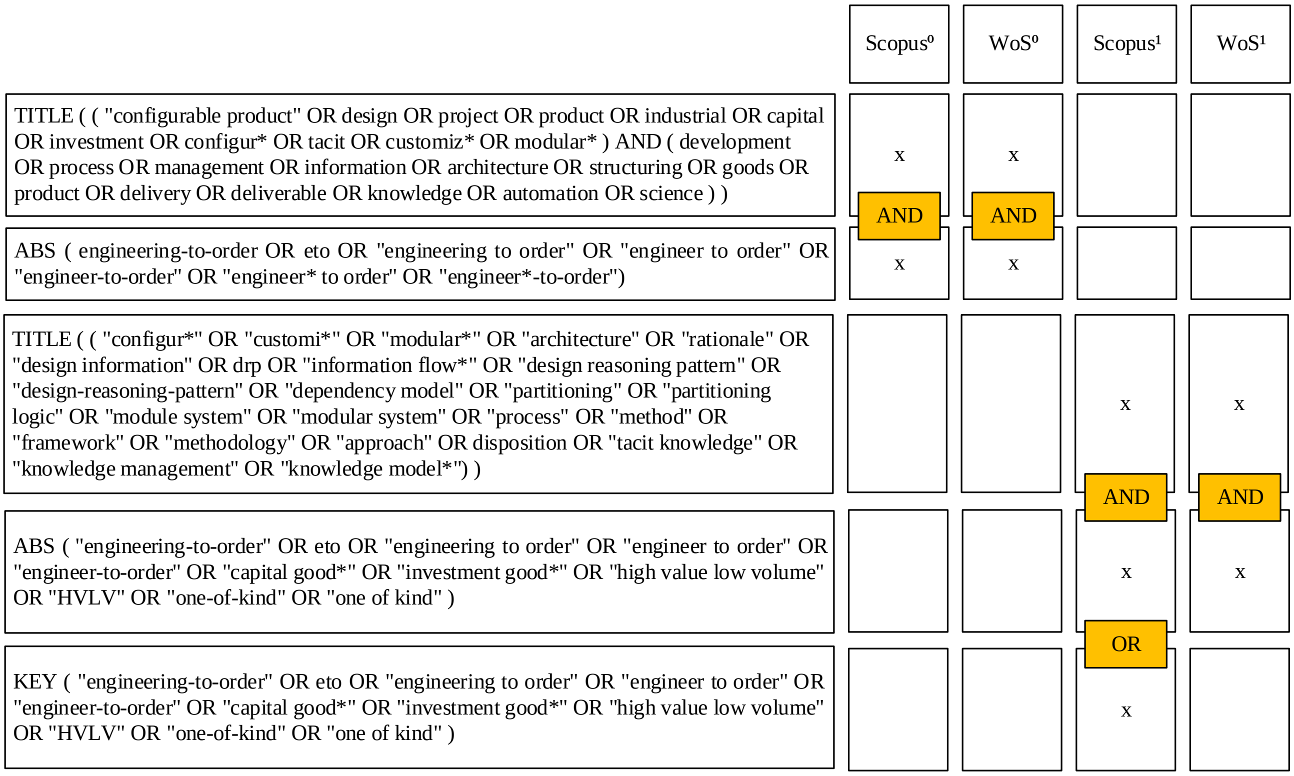

Figure 2: Search query strings used in the literature search

3 State of Art: methods supporting design reuse in ETO context

Methodological support for implementing standardisation, modularisation and platform approaches in ETO context is narrow (Gepp et al., 2016). A framework for planning and implementation of standardization programs in ETO business is presented by Vollmar and Gepp (2015). Authors describe standardization program as an approach to manage complexity by modifying the product structure of the industrial plant. Implementing standardization programs ideally modify design approach towards use of predefined modules. A design platform approach is presented by André et al. (2017) consisting of company's pre-existing resources such as synthesis resources (people, guide-lines, methods, lessons learned, relations), assessment resources (behaviour models), geometry resources (parametric models) and constraints (internal limitations, law, customer requirements). The design platform approach supports generalisation and reuse of company's resources such as methods and processes. A concept "design asset" is introduced by Elgh et al. (2018), being part of the design platform approach. The design assets do not only include pre-defined modules and components on different level of abstraction, but also information, models, methods, and knowledge such as product structures, process models and activities. Product structures, components and lessons learned could also be included in the design asset.

Poorkiany et al. (2017) presented a method for capturing & sharing design rationale by using IBIS (issue-based information system) method for design rationale capture, and design automation system for building product family model containing design rules and design rationale. A method supporting design information reuse and maintenance is introduced by Poorkiany et al. (2018) allowing information share in multiple formats and levels of detail. By using Queston, Option & Criteria (QOC) method, process of design alternative evaluation was captured including design rationale. Also, single source publishing made possible to provide different views of the design information. Raffaeli et al. (2017) proposed a method to formalize design and manufacturing knowledge including data acquisition from the past projects such as customer requirements. In the proposed method, general data such as standards and catalogues and tacit knowledge is acquired, modules are identified upon grouped functions and connected to a generic product architecture, various Design Structure Matrices are built to solve different dependencies and cost estimation of the product is calculated. Løkkegaard et al. (2023) suggested a three-step method for identifying profitable reference architectures withing company's existing solution space. Authors explain that within an ETO solution space, the term reference architecture is applied to characterize the essential solutions derived for achieving profitability in project execution.

Challenges when applying product configuration for ETO capital goods are identified by Christensen and Brunoe (2018), gradual determination of product characteristics as an example. A three step framework for identifying possible applications of Product Configuration Systems (PCS) is proposed by Kristjansdottir et al. (2017) assisting companies to justify their investments in PCS whether it is a commercial or technical PCS. A three-step framework is presented (Kristjansdottir et al., 2015) for identifying of the most beneficial parts of engineering processes where Product Configuration Systems could be utilized. The framework's first step consists of identifying potential PCS by defining main objectives for the system and based on that commercial and technical PCS are identified. In the second step company's current IT is aligned to support the configuration systems. Final step establishes an overview of the PCS applications. Shafiee et al. (2015) suggested an approach for comparing a new product order being configured with previous made configurations stored in company's internal systems allowing reuse of modules across product families and increased commonality across different products. Reduced complexity in product range and reduced engineering hours could be achieved when parts from the previously designed products are reused. Kristianto et al. (2015) proposed a system level configurator based on templates, consisting of multiple configurable products. A conceptual framework for stage configuration is presented by Christensen et al. (2018), enabling postponement of configuration decisions and therefore the management of product specifications on different aggregation levels. In a stage configuration, a stage-wise commitment of product specification is facilitated through the sales order process. Authors claim that benefits of stage configuration is a product configuration without generating excessive and unnecessary information. Zhang et al. (2023) established a two-stage configuration design framework for ETO products supporting the selection of optimal technical bid solutions. The first stage of the framework consists of design of a product architecture configuration design based on constraint satisfaction problems and Bayesian networks. In the second stage a multi-objective optimal configuration model is developed out of physical modules aiming at minimum production cost.

A dynamic, structure-based product family modelling approach to the sales-delivery process of ETO products, Adaptive Generic Product Structure (AGPS) is presented by Brière-Côté et al. (2010). The approach enables systematic aggregation of product variants and their components as well as reuse of previously developed product variant components to reduce customer-driven design costs and shorten lead times. An adaptive product platform is presented by Levandowski et al. (2015) making possible to cope with changing customer requirements in low-volume ETO manufacturing. Authors also presents a two stage ETO configuration design approach for platform execution in which modularized and parametrized product platforms are configured on an architecture level and product architecture with parametrized components are configured on scalable level ending up to a fully configured product variant. Markworth et al. (2017) presented a five-step approach to identify potential improvements in the product family modular structure. By mapping previous CTO and ETO and predicted customizations, potential product module improvements could be identified and new modules defined & current modules re-defined. According to Mustonen and Harkonen (2022), ETO business could improve their negotiations and tendering by productization. Use of commercial and technical product models enables benefits such as more consistent understanding of the offering, more distinct design changes through maintained product structure and improved price and lead time estimates. A product family model is presented by Petersen (2007) making product configuration in multiple abstraction levels possible. Instead of configuring the product family model at once, product could be configured on a generalized level and the product is configured in more detail as more information about the product is available. Nardelli et al. (2019) Proposed a knowledge-based approach for rapid definition of ETO product structure. In addition, a framework to support knowledge repository is defined for cost estimations covering the entire product life cycle and for searching new solutions for products by analysing customer requirements.

Table 1 shows the results presented in the selected articles selected in this state of art. Not only methods, approaches or frameworks were found, but also some challenges, possible solutions, concepts, and guidelines were found supporting ETO product development.

Table 1. References and potential support found from the literature

Reference	Result	Potential support in ETO context
Andre et al., 2017	**An approach** supporting the development of customised products when traditional platform concepts do not suffice	Design information reuse
Briere-Cote et al., 2010	Adaptive generic product structure **approach**	Design reuse
Christensen and Brunoe, 2018	Main **challenges** identified and **possible solutions** in applying configuration for complex engineered capital goods	Tackling identified challenges in configuration of capital goods
Christensen et al., 2018	**Conceptual framework** in committing order specifications, postponing configuration decisions according to the maturity of the sales order	Product configuration
Elgh et al., 2018	A platform **approach** enabling customisation, reuse and production standardization	Design information reuse, customization, standardisation
Kristianto et al., 2015	A system level configuration **approach**	Reducing complexity of a product configuration
Kristjansdottir et al., 2015	**A framework** for identifying the critical parts of the engineering processes for beneficial use of PCS & prioritization of PCS projects	Product engineering processes with PCS
Kristjansdottir et al., 2017	A three-step **framework** to identify different applications of PCS	Identifying possible applications of utilizing PCS
Levandowski et al., 2015	**An approach** for ETO configuration design	Product configuration design
Løkkegaard et al., 2022	A three-step **method** for supporting identifying profitable reference architectures within ETO company's existing solution space	Identifying profitable solutions to be executed in a project
Markworth et al., 2017	**Framework** with the aim of creating a product overview with a post perspective on requirements to improve the modularity of the product platforms	Improve product configurability
Mustonen and Harkonen, 2022	**A generic model** for commercial and technical productization in ETO business	Productization, design reuse
Nardelli et al., 2019	**An approach** for the rapid definition of the product structure related to a ETO product, including the early cost evaluation in configurations	Company knowledge reuse
Petersen, 2007	**Concepts and guidelines** for product family modelling supporting configuration on multiple abstraction levels	Product configuration
Poorkiany et al., 2017	**A method** for capturing and sharing design rationale	Issue-Based information system (IBIS) method, Design rationale capture and share
Poorkiany et al., 2018	**A method** to support capture and structure of design information share the information in different levels of details	Design information capture, structure, share
Raffaeli et al., 2017	**An approach** to acquire and formalize the design and manufacturing knowledge of a company	Design and manufacturing knowledge acquisition and formalization
Shafiee et al., 2015	**An approach** for comparing a new order that is being configured with previous made configurations	Product configuration
Vollmar and Gepp, 2015	**A framework** providing s a structured guideline for the planning and implementation of standardization programs in ETO business	Standardisation
Zhang et al., 2023	A two-stage configuration design **framework** to help making the right decision for a complex ETO technical bid solution	Product configuration design, technical bid solution

Based on the analysed literature, table 2 presented below was formed to aggregate the concepts used to describe the concepts found in the literature. In the top row, references are listed. In the leftmost column, concepts potentially relevant to the context of this article were extracted from these references. Concepts containing multiple definitions were separated based on the definition used. Concepts are classified based on their relevance to each other, and beside the concept, a definition is presented based on the definition found in the reference marked with an x.

Table 2. Concepts found from the literature review

Concept	Definition	Andre et al., 2017	Briere-Cote et al., 2010	Christensen and Brunoe, 2018	Christensen et al., 2018	Elgh et al., 2018	Gepp et al., 2016	Kristianto et al., 2015	Levandowski et al., 2015	Løkkegaard et al., 2022	Markworth et al., 2017	Mustonen and Harkonen 2022	Nardelli et al., 2019	Petersen, 2007	Poorkiany et al., 2017	Poorkiany et al., 2018	Raffaeli et al., 2017	Shafiee et al., 2015	Vollmar and Gepp, 2015	Zhang et al., 2023
Platform	A set of general systems, used to create range of products (Meyer and Lehnerd, 1997)								x											
	Use of standardised modules in different products or projects (Jose and Tollenaere 2005)						x													
Product platform	Technology applied to several products (McGrath 1995)					x														
	A group of related products (Simpson et al., 2006)					x														
	Collection of assets shared by a set of products (components, processes, knowledge, people and relationships) (Robertson and Ulrich, 1998)	x				x														
	A set of subsystems and interfaces forming a common structure from which products can be developed and produced (Meyer and Lehnerd 1997)					x					x									
	A set of common components, modules or parts from which a stream of derivative products can be created (Kristianto et al., 2015)							x												
Design platform	Composed of different objects related to processes, synthesis resources, product constructs, assessments resources, solutions and projects (Andre et al., 2017)	x				x														
Module-based platform	Consists of a set of interchangeable modules (Simpson, 2004)					x			x											
Scalable platform	Adaptable by changing design variables (Simpson, 2004)					x														
Product family model	Generic model of a product family (Jørgensen 2003, as cited in Petersen, 2007), describes the types of components that can be configured (Petersen, 2007)													x						
	Includes executable design definitions and structured design rationale (Poorkiany et al., 2017)														x					
Product family architecture model	Includes product's functional perspective, technical view and physical view (Jiao and Tseng, 1999)																			x
Product model	Describes all possible product variations with predefined set of components (Hvam et al. 2008)			x																
	Represents functionality and interactions between functions (Markworth et al., 2017)										x									
Design asset	Platform model consisting of predefined modules and components, information, models, methods and knowledge (Elgh et al., 2018)					x														
Design knowledge	Design definition describing the results of the design (e.g. a CAD model) or design rationale (Poorkiany et al., 2017)														x					
Design rationale	Explains the purpose and reasons behind the design (Poorkiany et al., 2017)														x					
General product architecture	Defined as functional diagrams and hierarchies of implementing modules (Raffaeli et al., 2017)																x			
Modular architecture	"...the construction of a building from different instances of standardized components, and in manufacturing it is used for interchangeable units that are used to create the product variants." (Ulrich 1994, as cited in Shafiee et al., 2015)																	x		
Modularized product architecture	One-to-one correspondence between functional elements and physical structures, minimized unintended interactions between modules (Ulrich and Tung, 1991)					x														
Product architecture	The arrangement of functional elements, the mapping of functional elements to physical components, and the specification of interfaces among interacting physical components (Ulrich 1995)									x	x		x							
Plant architecture	Functional and physical structures of a plant (Vollmar and Gepp, 2015)																		x	
Reference architecture	The derived principal solutions for profitable project execution within an ETO solution space (Løkkegaard et al., 2022)									x										
Adaptive generic product structure	A dynamic product structure-based product family model, based on the GBOM model (Levandowski et al., 2015)		x																	
Generic product structure	Structure that includes all different variations of the product in a single structure (Saaksvuori & Immonen, 2008)											x								
Product structure	A set of objects and their relationships, together representing a structural aspect of a product (Brière-Côté et al., 2010)		x																	
Module	A text fragment or a text chunk with a specific topic (Poorkiany et al., 2018)															x				
	Includes clearly defined relation to customer requirements or product functions, clearly defined interfaces, physical product structure (Eppinger and Ulrich, 2000, as cited in Markworth et al., 2017), could be defined based on common process step or knowledge (Markworth et al., 2017)										x									
	Independent building block of a larger system with specific function and well-defined interfaces (Hölttä-Otto, 2006)												x							
	Building blocks of a product with specified interfaces (Erixon 1998)								x											
	A bundle of components, assemblies or systems with specified interfaces decoupled form a technical system or industrial plant, or a complete plant (Aerni, 2004, as cited in Gepp et al., 2016)						x													
Module drivers	Set of motives to help identifying modules (Elgh et al. 2018)					x														
Black box	Describes the system without knowledge or assumptions about its internal make-up, structure or parts (Krippendorf, 1986, as cited in Petersen, 2007)													x						
Grey box	Elements in a system for which partial knowledge is available (Skyttner 2005, as cited in Petersen, 2007)													x						
Specialization	Removal of one or more certain configuration choices (Petersen, 2007)													x						
White spot	Incomplete configuration (Kristianto et al., 2015)							x												

4 Results

The analysis of literature search is visualised in Table 1. It compiles all the papers found from the literature review as well as the results shown in the papers. Table 1 indicates that there are some potential approaches, models, frameworks, guidelines, and ideas supporting engineering of configurable products and design reuse in ETO context. A clear method or process was not identified from the existing literature that would support the development of ETO products utilizing Module Systems and Design Reasoning Patterns.

It is noticed that concepts such as Module System, Partitioning Logic and Design Reasoning Patterns are not appearing in the table 2, indicating a potential gap of research to support development of ETO products consisting of Module Systems and DRPs. Poorkiany et al. (2017) discusses on structured design rationale, but it is not clear what might be the scope of such product family model. It is difficult to anticipate customer requirements beforehand and ETO context is known of having difficulty to define product family, mainly due to project-by-project type of working. In projects the structured design rationale may not get enough attention under the time pressure. According to the definition of Module Systems by Pakkanen et al., (2013), Partitioning Logic is a part of a Module System. It supports the change management of the Module System during its lifecycle. Therefore, a complete ETO solution consisting of multiple Module Systems and ETO entities might benefit having a documentation on its Partitioning Logic and what kind of design reasoning pattern lead to this specific partitioning. Currently there are no such concepts found in the literature describing the partitioning of an ETO product delivery into entities also containing Module Systems.

Most of the concepts focus on the synthesis or artefact as outcome, only some authors focus on the design process, too. Table 2 indicates that some of the concepts, such as “platform”, “product platform”, are on very abstract level thus not providing design support for actual engineering work.

5 Discussion

In this study, answer to a question was found by conducting a systematic literature review. The Answer to the research question: *Which design methods support developing ETO products consisting of Module Systems and Design Reasoning Patterns in the literature* is that no suitable method covering entire development process were found in this literature, however, these findings form the literature could support the development of ETO products with Module Systems and Design Reasoning Patterns.

There are limitations in this publication. First, the literature search was conducted by using only two data bases, Scopus, and World of Science affecting the first research question. Second, the selected search strings might not have included all relevant concepts of the research issue. Relevant articles might not have been found due to this. Also, there might be research conducted on the selected topic using unfamiliar concepts.

As seen in the table 2 presented earlier, similar concepts could include different definitions. This is a challenge to be tackled when considering the future product development methods. Concepts such as module or platform presented in the literature are ambiguous and should have more specific definitions to avoid misinterpretation not to mention concepts which have not yet been defined or presented. When inspecting and defining the concepts, it would be important to elaborate the author’s doctrine and canon. Knowing the background and approach of concept’s introducer could be beneficial when considering potential research gaps.

As a conclusion, this study illustrates areas that still need to be explored to support design reuse in ETO context, especially when modularisation and Module Systems are used as means for design reuse. Also, use of DRPs in the HVLV artefact design should be further investigated. It would also be reasonable to find support for design reuse in ETO context form the literature on modularisation in CTO context.

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