BENEFITS OF AUTOMATION OF MODULAR PRODUCT IN ORDER-RELATED ENGINEERING PROCESS.

Lappeenrannan–Lahden teknillinen yliopisto LUT

Konetekniikan diplomityö

2022

Ida Autio

Examiners: Professor Harri Eskelinen

M.Sc. (Tech) Pasi Sutela

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Konetekniikka

Ida Autio

Modulaarisen tuotteen suunnittelun automatisoinnin hyödyt tilauskohtaisessa suunnittelussa

Konetekniikan diplomityö

2022

77 sivua, 10 kuvaa, 4 taulukkoa ja 2 liitettä

Tarkastajat: Professori Harri Eskelinen ja DI Pasi Sutela

Avainsanat: modulaarisuus, CAD-automaatio, suunnitteluautomaatio

Työn aiheena on modulaarisen tuotteen suunnittelun automatisoinnin hyödyt tilauskohtaisessa suunnittelussa. Työssa tutkitaan tuotteen modulaarista tuoterakennetta, sen etuja ja haittoja tilauskohtaisessa suunnitteluprosessissa, sekä suunnitteluautomaation mahdollisuuksia suunnittelun tehostamisessa. Työn avulla pyritään osoittamaan modulaarisen tuoterakenteen ja tilauskohtaisen suunnittelun yhteys, sekä miten tämän päivän suunnitteluautomaatiota voidaan hyödyntää modulaarisen tuotteen suunnittelussa.

Modulaarisuutta käytetään hyväksi monimutkaisissa tuoterakenteissa. Moduuli on yksikkö, jonka komponentit ovat voimakkaasti toisiinsa yhteydessä, mutta heikosti liitettyinä muihin tuotteen moduuleihin. Tuotteen modulaarisuudella tähdätään asiakastarpeiden huomioimiseen mahdollisimman kustannustehokkaalla tavalla. Työn tuloksena voidaan havaita modulaarisuuden tuovan useita etuja, kuten suunnittelun ja kokoonpanon nopeus sekä laajempi tuotevalikoima. Suunnitteluohjelmien ominaisuuksia hyödyntämällä voidaan vähentää virheiden määrää suunnittelussa ja generoida tarvittavia kuvia nopeammin.

Työ on tehty Sulzer Pumps Finland Oy:n toimeksiantona. Työ on osa yhtiön sisällä toteutettavaa laajempaa CAD-projektia, ja työn tarkoituksena on tehdä taustaselvitys siitä, onko Sulzerin pystysekoittimien CAD-suunnittelua kannattava sisällyttää CAD-projektiin, jossa siirrytään käyttämään uutta mallinnusohjelmaa. Työn teoriaosa totetetaan kirjallisuuskatsauksena, jossa tutkitaan modulaarisuuden ja CAD automaation keskeisistä käsitteitä. Käytännön osuudessa vertaillaan eri CAD-ohjelmien sekä automaatiotyökalun ominaisuuksia, ja miten ne tukevat suunnittelutyön tehostamista.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

School of Energy Systems

Mechanical Engineering

Ida Autio

Benefits of automation of modular product in order-related engineering process

Master's thesis

2022

77 pages, 10 figures, 4 tables and 2 appendices

Examiners: Professor Harri Eskelinen, M.Sc. (Tech) Pasi Sutela

Keywords: modularity, CAD-automation, design automation

The topic of this Thesis is the benefits of automation of modular product in order-related engineering process. The study examines the product's modular structure, its advantages and disadvantages in order-related engineering process, as well as the possibilities of design automation in terms of more efficient engineering process. The study aims to demonstrate the connection between modular product structure and order-specific design, as well as how today's design automation can be utilized in the design of modular product.

Modularity is used in complex product structures. A module is a unit which components are strongly interconnected, but weakly connected to other modules of the product. The product's modularity aims to taking customer needs into account in the most cost-effective way. As a result of this study, it can be observed that modularity brings several advantages, such as faster engineering and assembly processes and a wider product range. By utilizing the features of design programs, the number of errors in the engineering process can be reduced and the necessary drawings and documents can be generated faster.

The work is implemented for the requirements of company Sulzer Pumps Finland Oy. It is part of a wider CAD project carried out in the company and the purpose of this study is to investigate the benefits of including vertical agitator products in the CAD project, where a new modeling program is adapted. Theory part of the study is a literature review, which examines the central concepts of modularity and CAD automation. In the practical part, the features different CAD software and automation tool are compared, and their efficiency on supporting engineering process is evaluated.

ACKNOWLEDGEMENTS

This work was carried out in Kotka for Sulzer Pumps Finland Oy and I would like to thank my supervisor and examiner Pasi Sutela for given me the opportunity to combine work and studies and for supporting me during this process. I would also like to express my gratitude for professor Harri Eskelinen from LUT, whose guidance and expertise helped me through difficult moments.

In addition, I would like to thank my family for their support. I started my studies as a mother of one and I am graduating as a mother of two. These few years would not have been possible without the support of my husband Aleksi, thank you for your continuous encouragement and patience during my studies. I also want to thank my dad Vesa-Matti for always looking after the children when needed and supporting me to continue my studies.

In Kotka 15.11.2022

Ida Autio

Table of contents

1 Introduction

In this work, the current status and development needs of Sulzer's vertical agitator are considered. There are a wider CAD related project going on in the company where a current 3D CAD software is changed into another 3D software. The CAD engineering of vertical agitator differs from the other products, since it is implemented with a 2D software and the purpose of this work is to consider, should the CAD engineering of vertical agitators also be included to the new software. The modular product structure of vertical agitator is also considered in order to achieve deeper understanding of the effect of the structure on the selection of the CAD software. Scientific publications and studies have been made on the development of various design processes and modular design, but the perspective is general and does not fully correspond to the company's situation. In the literature review, the concept of modularity and its applications are introduced as well as the concept of CAD-automation. The literature review also considers 2D- and 3D-design and how modularity is implemented in them.

The practical part of the thesis analyzes the modular structure of the vertical agitator and the degree of modularity in it. It also considers the current engineering practices and the occurring problems. A SWOT-analysis is created from the order-related engineering of the modular agitator, in which the connection between modularity of the agitator and the order-related engineering process is investigated in more detail. The analysis also examines the problem areas in the current engineering process. Based on the analysis, factors that can be used to improve the design are defined, as well as features the CAD-software should have in order to support the engineering process of agitator. The practical part of Thesis also considers NX-software, of which use is being implemented in the engineering department in the future, as well as Rulestream automation software and the benefits of its advanced automation features.

1.1 Background and motivation

Often, especially with configurable products, data management may be very fragmented and might locate in several different systems. Different software is used for sales, design and production, and for example, sales does not utilize the same product information with design, but utilizes its own tools designed especially for sales process. Production might have another system for production control and material management. This means that the company may have several overlapping programs and systems, which contain at least partially the same information, but are not synchronized with each other, making the management of product models difficult.

The need for customization often increases with customer requirements, and this increases the amount of information within the product model. Modulation aims to create alternative parts of the assembly, thus creating a structure for the product that can be changed in a controlled matter. The module is therefore a functional entity based on customer needs (Laakko 1998, 16). The structure and operation of the product can be clarified by dividing it into parts, so that a wider product selection can be achieved with fewer parts.

The current engineering process of a vertical agitator is carried out with a combination of company's ERP and a 2D-software. A special feature in the engineering compared to company's other products is that, despite the standard structure of the product, each agitator must be customized according to customer's tank dimensions. This means that customer-specific design is required already at tendering phase. The engineering process itself can be seen as a multi-phased entity, which requires a lot of consideration and a wide-ranging management of information and software use.

The author of the thesis is employed by Sulzer and has worked especially in the order related engineering of vertical agitators. The need to improve the design process of vertical agitators has been concretely identified, although no actual background research has been carried out on the subject.

1.1.1 Sulzer Pumps Finland Oy

Sulzer industrial group is focusing on fluid engineering and sustainable pumping, agitation, mixing, separation, and application technologies. Sulzer was founded in 1834 in Winterthur, Switzerland where its headquarter still operates (Sulzer 2022a). Overall Sulzer has a little over 15000 employees and 180 manufacturing plants and service centers worldwide. The operation consists of three operational divisions, which are Flow Equipment, Services and

Chemtech. The flow Equipment division is specialized in pumping solutions providing pumps, agitators, compressors, grinders, screens and filters. Services provide maintenance and repair solutions for Sulzer’s products and Chemtech specializes in chemical processing and separation technologies for chemical industry (Sulzer 2022b).

Sulzer Pumps Finland Oy (SPFIN) was founded in 2000 when Sulzer acquires Ahlstrom Pumps (Sulzer 2022c). The head office of SPFIN is located in Karhula, Kotka where the pump factory and service center are operating. Along production and services, in Karhula there are also other supporting functions, such as sales and marketing, product development and research center, HR and finance and global IT support. SPFIN also has service centers in Mänttä, Oulu and Rauma, product development of HST turbo compressors in Helsinki and domestic sales department in Vantaa. SPFIN product portfolio consists of pumps, agitators and turbocompressors and related accessories. The pump types manufactured are process pumps, double suction pumps, MC® -pumps, vertical pumps and multistage pumps.

Sulzer agitators consists of vertical agitators, horizontal agitators, submersible mixers and special related products. Salomix® -product family includes SSF-, SSA-, SLR/SLT- and SL-side mounted horizontal agitators and L- top mounted vertical agitators, which are manufactured in Karhula Pump Factory. L-agitators form a modular system, and depending on the operating unit type, LM-, LV-, LA- or L-agitator types are available. LM-agitator is a direct drive agitator, LV-agitator is a gear-driven with no bearing frame. L-agitator type is a gear-driven model with bearing frame and LA is a belt-driven agitator with a bearing frame (Sulzer 2021).

1.2 Research problem

There is a need to develop the order-related engineering process of vertical agitator into more designer-friendly direction. The engineering process is currently being slowed down by both the lack of product manual and the unavailability of the library components required in dimensional drawings. In addition, managing the drawing software itself requires a large part of design time, since it is not the department’s primary program in use and there is little support for its use. In the absence of product guidelines, engineering becomes difficult with more complex product variants, as information is transferred as spoken information from one engineer to another. The CAD design of other products in the order-related engineering department is implemented with 3D software, but with vertical agitators the CAD engineering is implemented with 2D software.

1.3 Goal

The aim on this thesis is to study the enhancing the engineering process of vertical agitator by utilizing features of CAD-software, taking into account the special features of order-related engineering and the modular structure of the product. The enhance of engineering also aims to shorten the device-specific engineering time. Time management can be seen as one of the characteristic of high-quality design, and a careful review of product structure facilitates the engineering work and reduces the time spent on engineering. In addition, this also supports the preparation of possible product manual which also enhances the order-related engineering of vertical agitator.

There is a wider CAD project ongoing in the company, where the current 3D software is changed into Siemens NX -software, and the purpose of this study is to provide an overview of advantages of different software types and adding automation to CAD engineering in order to make the engineering process more efficient.

The study can also be utilized in other development projects related to agitators, for example improving engineering process for other vertical agitator types. The subject is also significant for the development of the author’s own professional skills, because when working among the design of agitators, familiarizing with the product structure improves professional competence. The purpose of the Thesis is to examine the key problem areas that are observed among the order-related engineers of agitators, which are long order-specific engineering time, the lack of key information and laborious modeling process.

1.4 Research questions

The research problem of the study consists of the description of the order-related engineering process of vertical agitator and the identification of related problems. The Thesis examines the modular structure of agitator and explains its benefits in order-related engineering process and engineering software. The research problem is approached with following research questions: “*What is the degree of modularity of vertical agitator?” “Where could* *modularity be increased and why?" "How is modularity implemented in different design programs?" "How to improve engineering process of vertical agitator with new CAD-software?".*

1.5 Research methods

The study is divided into two parts, of which the first is carried out as a literature review. In the literature review, the concepts of modularity and CAD automation are examined with the help of previously published scientific articles and researches on the subject. The case study examines the current stage of order-related engineering of vertical agitator and its modular product structure. The development needs are considered with the help of SWOT-analysis and a possible CAD software and an automation tool are presented. Farquhar (2012) describes case study as an empirical study based on knowledge and experience. Case study collects and analyzes information and limits its topic to a specific area, making it easier for the researcher to examine the topic.

1.6 Scope

The study is limited to only LV-vertical agitator, and the gained results can be seen as a possible further development idea to extend for other agitator types. Another limitation is the order-related engineering process. The basis of the study is to focus only improving the stages of order-related engineering process, a further development idea could be, for example, refining the possible design tool to support sales. The price comparison of different CAD engineering software and tools is also excluded from the study and left as a possible further research idea.

2 Modularity

The terms modularity and modular are widely used, and although the meaning varies a little, in general modularity means dividing a bigger system into smaller pieces. The term modularity refers to predefined interfaces of a product that can be used in dividing the product into functional modules. Usually, each module has its own particular function in the product design. A product can be defined as modular when its parts has clearly defined functions. The degree of modularity in a product can vary completely from product to product (Seppänen 2019). Modular product is characterized by a variety of parts, unlike integrated products, which are as decided at the time of design (Huhtala & Pulkkinen 2009, 155).

Ulrich (1995) defines modularity as a design property of product architecture and according to Sanchez and Mahoney (1996) modularity is a form of a special product architecture which creates independency between different components by standardizing their interfaces. With these standardized interfaces changes in one component will not require changing other components, so with modularity it is possible to create different product models with different characteristics and functions. This also gives a possibility to create new functions to a product by designing and replacing one component, without redesigning the whole product.

Andreasen (2011) describes a module as product entity that has a distinct function from a function or organ point of view, but also has interfaces and interactions with other entities. He defines modularization a function that aims to create variety for customers but at the same time reduce the complexity in the company’s operations. Andreasen (2011) sees modularity as a relational property that has no meaning to analyze unless its benefits to a certain company area is known.

Although definitions of modularity vary depending on the point of view, there is still common characteristics with definitions. These are combinability, changeability and replaceability and module standardization (Kong et al. 2009). With these characteristics it is possible to design and manufacture components with large scale of variants in order to meet individual needs. Modularization of a product or a system is a multistage and complex process because there are many functional and physical interactions as well as strategic aspects that need to me considered, and it takes place in the product development phase of the product (Rossi et al. 2019).

2.1 Modular product structure

In order to understand the concept of modularity, it may also make sense to understand the broader concepts above it. Product family refers to a group of products which have both common and different characteristics. Products and their structures can be viewed from several perspectives, including perspective of use and assembly as well as sales and sourcing. Product families consists of individual products, in which case product family is a set of product variants. The variation is presented, for example, on the changes in product structures. Product structures consist of the basic elements of a product and the relationships between them. (Huhtala & Pulkkinen 2009, 139.)

Product family consists of a set of products that have some similar features and consist of product platforms and variations. The product platform can be understood as a basic unit of the product family, to which product variations are created by adding module variations. The product platform also includes interfaces and common structures. (Huhtala & Pulkkinen 2009, 139.) Modularization refers to the design of products and product families in the form of modular features. Modular product structures are structures of a product or product family that show gradual properties of modularity (Windheim 2020).

Modularity aims to enable higher variability of products which is a key element in mass customization. A higher degree of customization can be achieved by replacing, adding, or deleting modules. In general, products can be divided into modular or integrated models, depending on the manufacturing method. The main differences between these product models are how the functions are divided and the way the interfaces are distributed. Modular system can consist of many different elements that are fitted together with simple interactions that are designed according to a standard pattern (Salonitis 2014). Modularity is defined to be an organizing strategy for complex processes and products and modular system consists of modules that are loosely attached together. These modules can be mixed due to the standardized interfaces. (Cardini, Pero & Sianesi 2012.)

Modular product structure has two characteristics, each module performs one of more functions and the interactions between modules are well defined and necessary for the basic functions of the product. In ideal case, each function of the product is implemented as its own module, i.e., there is only one function in one module and the interactions between the modules are kept to a minimum. This kind of structure enables changes in individual modules without the need to modify other modules in order the product to perform its function. This also allows the independent design process of individual modules. (Österholm & Tuokko 2001, 9.)

In mechanical engineering modularity in system design means that the product is divided into subassemblies from which the final product is assembled. This offers several advantages over traditional design, such as more flexible product structure and the possibility to modify the functions or features of the product by changing one module of the product. When the modular design of a product is well-designed, it is possible to replace one module without changes in other parts of the product. (Kontinen 2016, 8.)

There are many relatively independent modules in a modular product architecture. As said, these modules have pre-designed standard interfaces, which support interchangeability between modules. In addition, to being seen as a physical part of a product, modules can also be seen as implementers of product's sub-functions (Huhtala & Pulkkinen 2009, 159). There can also be seen technical and strategic modularity in a product. Technical modularity refers to the possibility to substitute a component at the interfaces and strategic modularity can fulfill functionality with one or more components. These technical modular interactions can be either functional or physical interactions and strategic modularity can be seen as a group of functions with one or more similar features. (Rossi et al. 2019.)

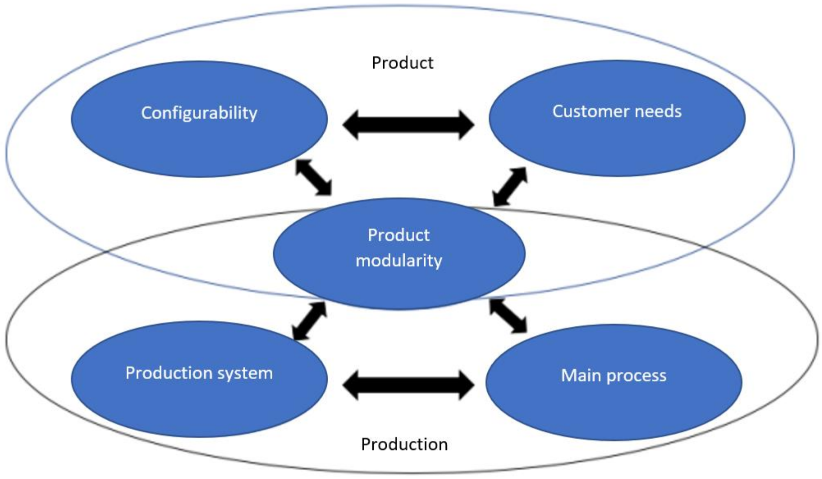

Figure 1. Modular product structure connecting production and client specific needs (Lapinleimu 2001, 152).

According to Lapinleimu (2001), modular structure is ideal for production, when the client specific requirements can be obtained by selecting suitable variants from the modules, as illustrated in figure 1. So, the modularity of a product can be seen to be in the center of combining the product and production. When modularity is comprehended this way, it is important that all the modules and parts of the product must comply with the agreed interfaces and manufacturing principles in order to guarantee the functionality of the modularity.

Product configuration is often addressed with modular product structure. More and more products are customizable to customer needs. For example, ordering a computer online, it is possible to choose from different CPU's and main memory sizes and choose the suitable hard drive and so on. When the product gets more complex, the number of options increases, and the situation gets more complicated with thousands of different combinations.

Product configuration is a process that supports these different choices and provides an opportunity to offer customized products. With configurated products, the configuration software needs to be advanced enough to consider large amount of data from large range of sources, for example customer needs, production methods and constraints and product-assembly knowledge. (Sinz et al 2007.)

Configurations are different product structures that can satisfy different needs. More specifically, configuration refers to a designing activity in which the designed product is assembled from pre-defined sub-options that adapt to the rules set for them. Typically, configurators refer to an automation based on the selection of predefined geometries and parts (Hiltunen 2017, 22). Configuration is based on the development of products that can be modified in such a way, that the product variations can be modelled even up to one 3D-model. Often, product variations are viewed through substructures. There are general structures developed for the product family to manage the variability. The end result of configuration is a set of alternative components (Huhtala & Pulkkinen 2009, 139).

2.2 Types of modularity

Modularity can be divided in different ways depending on the perspective. Lehtonen (2007, 89) present two main types of modularity which are modularity aiming at configuration and modularity related to the life cycle of the product. In modularity aiming at configuration, any block of a system is defined to be a module when it has assigned interface and it can be seen as a part of a modular system. Modular system is a system that consists of these blocks and the system also involves the interchangeability of the blocks. In this definition, the modules can be interchangeable in the same place of a product, or one module can be used at different product variations. In order to achieve module interchangeability, it is important that there are no functional connections between modules. For this reason, no functions should be shared between two or more modules (Österholm & Tuokko 2001, 35).

Modularity related to the life cycle refers to a situation where modularity is not related to the configuration of the product. This type of modularity can be divided into three categories: manufacturing-based modularity, maintenance-based modularity and modularity based on logistical reasons. (Lehtonen 2007.)

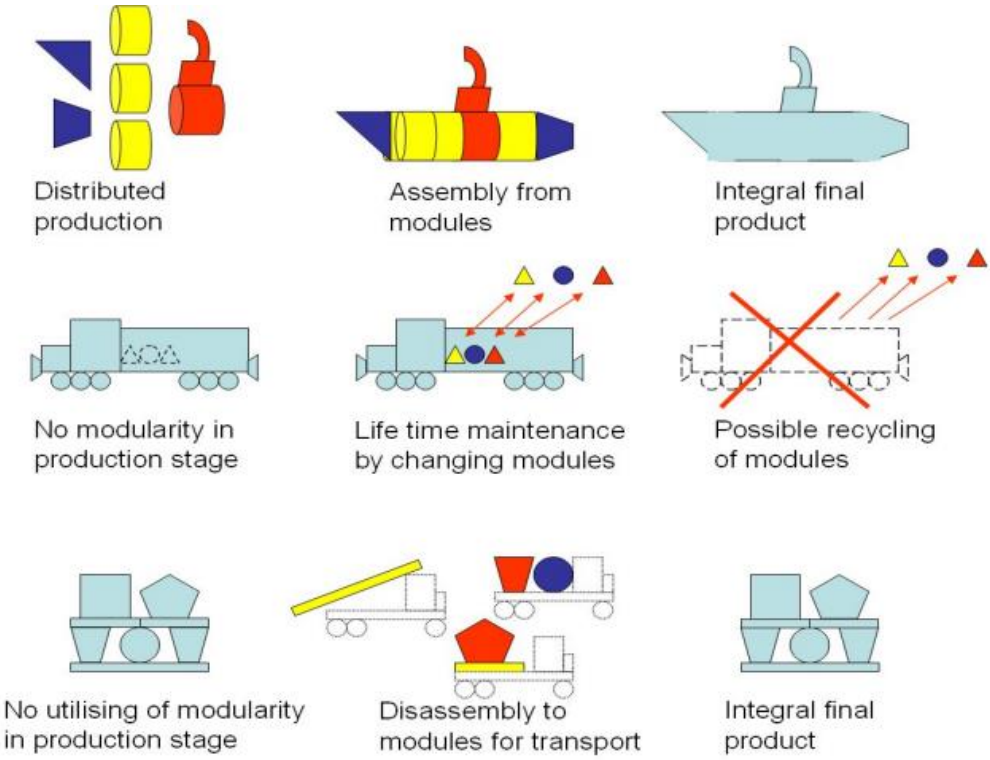

Figure 2. Types of life-cycle-based modularity (Lehtonen 2007).

Figure 2 illustrates the types of modularity related to the life cycle; the modules are marked in bright colors at the stages of their life cycle where their modular structure is utilized. In manufacturing-based modularity the production of different modules is decentralized, after which the modules are brought together. After this, modularity is not seen in the final product. In maintenance-based modularity, there is no modularity in the production phase, but it is seen in the maintenance during the product's life cycle which can be done by changing modules. It is possible to recycle the modules at the end of the product's life cycle. There is no utilization of modularity in production phase in modularity based on logistical reasons. The final product is assembled and then disassembled into easily transportable modules. The modules are assembled again to the final product at the final destination of the product. (Lehtonen 2007.)

Another way of defining types of modularity according to Österholm and Tuokko (2001) is to divide modularity into six types illustrated below in figure 3:

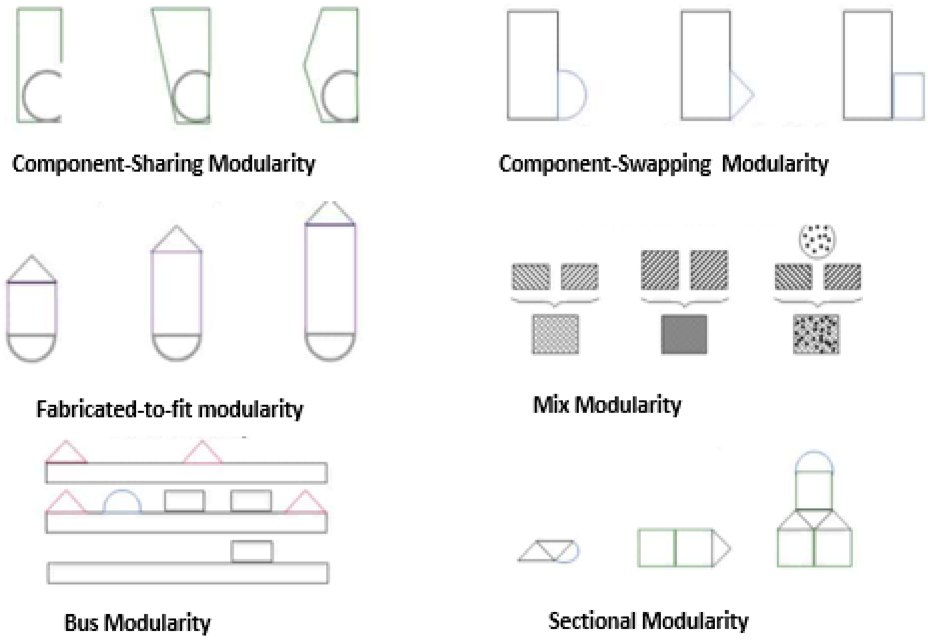

Figure 3. Different types of modularity (Adapted from Ulrich & Tung 1991)

The first four types can be seen as closed systems where it is possible to share, swap, fabricate and mix components, and the latter two types are open systems where modules are formed in bus or sectional arrangement. Closed systems usually have more strict placement restrictions when open systems are more flexible. In sectional modularity product variants are formed quite freely from modules that can be combined in several ways using standardized interfaces. In bus-modular design, the modules also have standardized interfaces that allow a wide variety of modules to be attached to the base module in several different positions. (Österholm & Tuokko 2001, 11.)

Component-swapping modularity refers to a system where at least two or more different component can be compounded to the same base product. Component-sharing modularity means that the same component can be used in various different products and fabricated-to-fit modularity refers to a system where one of more standard components are used together with a parametrically modified component. Mix modularity can be seen as a combination of previous three types. (Österholm & Tuokko 2001, 11.)

2.3 Benefits of modular product structure

Benefits of modular structure, especially in production, is that it leads to shorted lead-time when standard modules are usually simpler to assemble (Marshall 1998) and details in production are minimized and simplified by modular structure (Suolahti 2009). It also shortens the design time of the product, when there are a lot of standard components (Österholm & Tuokko 2001) and small number of parts and variants in a product (Shaik & al. 2014), so more time-consuming specified design is required in special orders (Pahl et al. 2007). In modular products, there are a possibility for wider product range when more product variations can be assembled from similar modules (Marshall 1998). Modular product structure also enables more accurate estimation of delivery times (Pahl et al. 2007), when design and production consist of standard modules, where the engineering and assembly time can be estimated based on repetition.

Modular product structure usually also leads to better quality of products, when there are less defects and component waste (Pahl et al. 2007). Overall, there are generally lower supply chain costs observed in modular products compared to integrated products (Shaik et al. 2014). The tendering and engineering phase are faster, when there is usually ready documentation related to modular product (Pahl et al. 2007) containing standard modules and components. Pre-production and parallel production processes are also suitable for modular product, where part of the product can be prepared in advance or modulars can be assembled at the same time (Marshall 1988).

The production of modules can also be outsourced, which also improves the quality of production because modules are bought as ready and tested components and possible faults are defected before the final assembly. This also releases storage capacity when modules can be bought when needed and enables the use of just-in-time -production strategy (Marshall 1998). Product development time is also generally shorter with modular products when there is a possibility to use parallel design processes, and also making changes to existing product is easier when changes in one module usually don’t require changes in other modules if the modular structure is well-designed (Österholm & Tuokko 2001).

Weaknesses of a modular product is that customer specific needs are harder to implement if they don’t fit into the modular structure (Pahl et al. 2007) which complicates product customization. The product structure might be too hard, when a large number of variants might lead to physically large products and the product data management containing all the product information must be well-organized. The amount of product variants might increase over time due to different projects and variant management must be optimized. The definition of optimal modular structure may be hard, when both user's and manufacturer's interests should be taken into consideration (Pahl et al. 2007) when designing a modular product structure. There is also a risk of over-designed products when modular product may include unnecessary structures.

2.4 Degree of modularity

Determining the degree of modularity is not always important, especially if the benefits of modularity have been shown to exist in a particular product design. On the other hand, if changes are made to the design of the product or the modular structure of the product is questioned, it is often necessary to define the degree of modularity. In general, a product with a higher degree of modularity has more modular components or subassemblies compared to a product with a lower degree of modularity (Gershenson, Prasad & Zhang 2004). In order to measure the degree of modularity, a several methods have been introduced in literature.

Voss and Hsuan (2009) describe five different dimensions related to defining modularity: interfaces, degree of coupling, components and systems, commonality sharing and platform, while Mikkola (2006) describes four key elements determining the degree of modularization to be interfaces, components, degree of coupling and substitutability. Interfaces are described as linkages between components and in modular product structure the interfaces are usually standardized. This enables the easy change and mixing of components, which is a requirement in, for example, mass customization. With non-modular products (integral products), the interfaces are usually not defined as clearly as with modular products.

Degree of coupling indicates how loosely or tightly product structure is coupled in terms of its constituent components. All thought product's components are linked to each other, and they have interdependence, their mutual relations can be loose, and this allows the system to broke down into smaller units or modules (Voss & Hsuan 2009). Modular product structure is based on loosely coupled design, because this kind of design allows the addition of a single component without changes in other components of the product. Commonality sharing and substitutability refer the possibility to use the same component in several different products of the same product family. Modular product platforms refer to strategies that are used in product architecture enabling, for example, mass customization.

Pakkanen et al. (2015) identificates five elements of modular systems. These elements are partitioning logic, set of modules, interfaces, architecture and configuration knowledge. These elements are part of every modular system. The configuration knowledge is an important element, because it is used as a base to create different variations to the modular product. In configuration process, customer requirements are used as an input and the result is an individual specification of the product. The purpose is to convert customer requirements into modules by connecting the selected element into configurations. The product families formed by configurations have the following characteristics: each product is adapted to suit the needs of a specific customer; every individual product is defined as a combination of pre-designed components or modules and previously developed product structure is used if it meets the given requirements (Pulkkinen 2007).

The partitioning logic presents the reason why a particular module division has been selected. With the help of partitioning logic, the properties of the product can be clearly presented. Interfaces determine the dependency ratio and interchangeability of the modules and are one of the key factors for achieving modular system (Fatima & Bræk 2016). The architecture provides information on how the modules and their interfaces are placed in the finished product. It aims to present the information about what kind of options can be created from the product with the help of available modules (Pakkanen et al. 2015).

Different methods for measuring the degree of modularity have been developed, each of which has its own strengths and weaknesses. In measuring modularity, to different ways can be identified, which are related to interfaces and functionalities. The principle of first method is that the more interfaces there are, the lower the degree of modularity is. According to another method, the more functions a product has, the lower the degree of modularity is (Cabigiosu & Camuffo 2017). Newcomb et al. (2003) have created a method for measuring modularity from two perspectives. First one observes how well the modules correspond from different viewpoints and correspondence ratio is calculated. The second perspective measures incidental interactions between modules.

3 CAD-automation

The purpose of automation is to facilitate human work, when the operation of a machine, equipment or process can be controlled by means of automatic control or adjustment without continuous human supervision or control. According to Groover (2014) advanced automation often performs its tasks more reliably and with higher quality than a human. Groover (2014) presented reasons, when automation is profitable and from organization's point of view, these include increasing labor productibility, reducing labor costs, mitigating the effects of labor shortages, reducing lead-time in manufacturing, and avoiding the costs of not automating. He also saw that reducing routine manual tasks and accomplishing processes that cannot be done manually as the benefits of automation.

Computer-aided-design systems, CAD-systems are widely used in various design tasks in the engineering industry. CAD is described as a design activity that utilizes the effective use of a computer to create, modify, analyze or document an engineering design (Groover 2014). In literature, the term CAD-automation refers to a process, where the production of CAD-models is either partly or fully automatized. In CAD-automation, the features and design tools of a CAD-software are utilized, and it is used especially in the implementation of repetitive, monotonous tasks.

CAD-automation is used to support CAE, computer-aided engineering. Computer-aided engineering can be seen to cover all the methods, where computer-based tools are used to support the engineering process. Another much used term is CAM, which refers to computer-aided manufacturing. The relations of these terms are illustrated in figure 4 below:

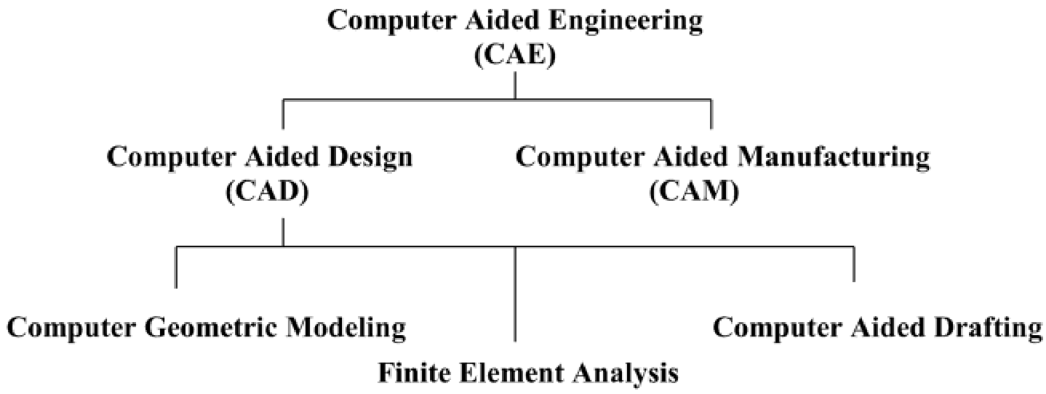

Figure 4. CAE- methods (Shih 2018).

Computer geometric modeling is a computer-aided design method which has increased its popularity over the last decades. The first generations of CAD programs were non-interactive and users had to create program-codes to generate two-dimensional shapes. When computing power improved, new types of user-friendly 3D CAD programs became on the market and CAD technology expanded from simple drafting to complex computer-aided design. (Shih 2018.)

Product information has been documented, stored and transferred in a very traditional way until recent years: with a two-dimensional technical drawing. However, the product modeling has been done in three-dimensions for decades. The reason 2D-drawings are still needed alongside the 3D product model are the long traditions and different information system platforms (Rapinoja 2016). According to a survey conducted by Finnish CAD/CAM Association, already in 2013, 62 percent of Finnish mechanical engineering was done with a 3D-CAD software, as illustrated in figure below. The large amount of 2D-software use can be partly explained by the prevalence of 2D-software in other fields, for example in industrial electrical or pipeline design.

According to the survey, the share of 2D design in electrical engineering in 2013 was up to 89 percent (Paloniemi 2017, 18). Earlier, in 2011, the results of a global survey commissioned by PTC on the 2D/3D distribution indicated that 3D-software accounted for 41 percent, while 2D design accounted for 12 percent. 47 percent of the respondents used both 2D and 3D software in their work (Paloniemi 2017, 19).

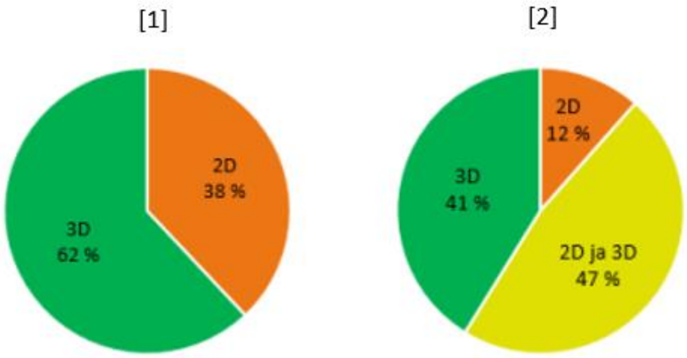

Figure 5. 2D/3D distribution in Finnish mechanical engineering in 2013 [1] and distribution in CAD-software worldwide in 2011 [2].

The survey of PTC also explored the reasons for using 2D-software, and the main reasons were that 2D technology is well mastered by the important team members and it is easy to work with 2D design data. One major reason was also the cheapness of 2D-software. Changing the old operating methods was also perceived as too difficult (Paloniemi 2017, 19). As seen from these results, 2D-design doesn't seem to have better features than 3D-desing, but the results implicate that the design has been done in 2D before.

According to a Worldwide CAD Trends 2018/19 Survey by Business Advantage, 69 percent of 626 respondents reported using 3D-modeling in their work. The usage of 3D-modeling is highest in manufacturing sector and in large companies. 75 percent of the respondents reported planning to use 3D also within 3-5 years. According to the results, 2D-software usage was also at a high level with 67 % using it currently in-house. Its growth potential, however, was described as very limited: potential increase in usage was only 1 percent in the next 3-5 years. (Worldwide CAD Trends 2018/19.)

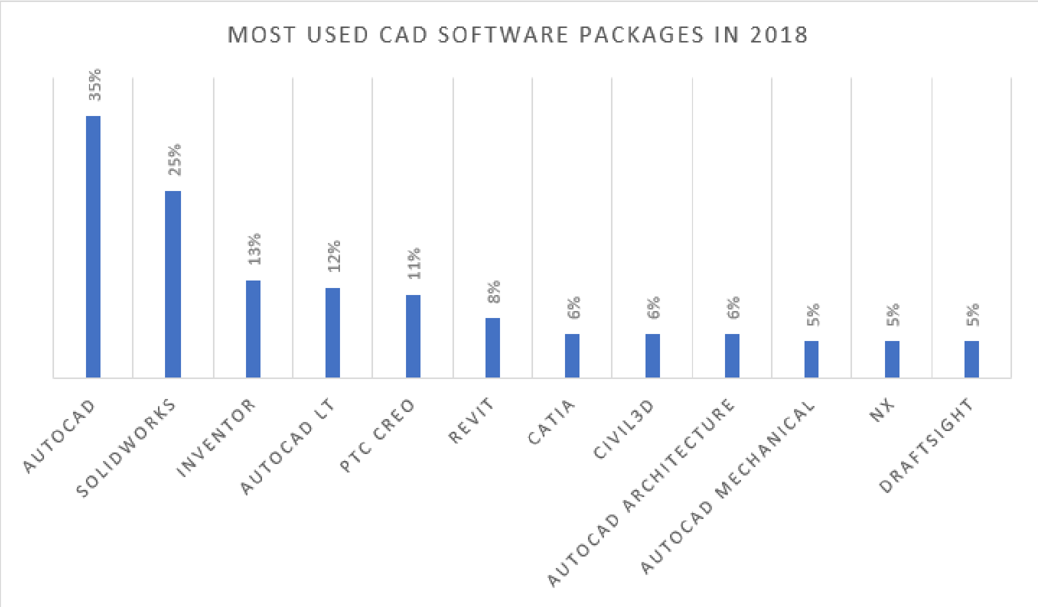

Figure 6. Most used CAD software worldwide in 2018 (according to Worldwide CAD Trends 2018/19

The most used CAD-software according to the Business Advantage's survey are listed in a figure 6. Respondents were asked to name three most used CAD packages used in their organization, and it can be seen that AutoCAD is the most used and it is especially used in architecture, engineering and construction industry. SolidWork was the second used software in 2018, and it is used in manufacturing industry (Worldwide CAD Trends 2018/19). According to the Finnish CAD/CAM Association survey, the most used mechanical engineering software in Finland in 2013 was SolidWorks and the second most used was Autodesk Product Design Suite, which includes both AutoCAD and Inventor software.

3.1 Levels of CAD-automation

The figure 7 illustrates the levels of CAD-automation according to Salchner et al (2016). The lowest level is non-parametric model, which means the model has been created with specific dimensions and geometry. The variation afterwards is hard or impossible because there are no relations created in the model. This is a typical method of creating new 3D-models, where a new model is made from scratch, or an existing model is used as a base model. The features in the model are created with fixed geometry and dimensions that are not designed to be modified without breaking the model and automation is not utilized at all.

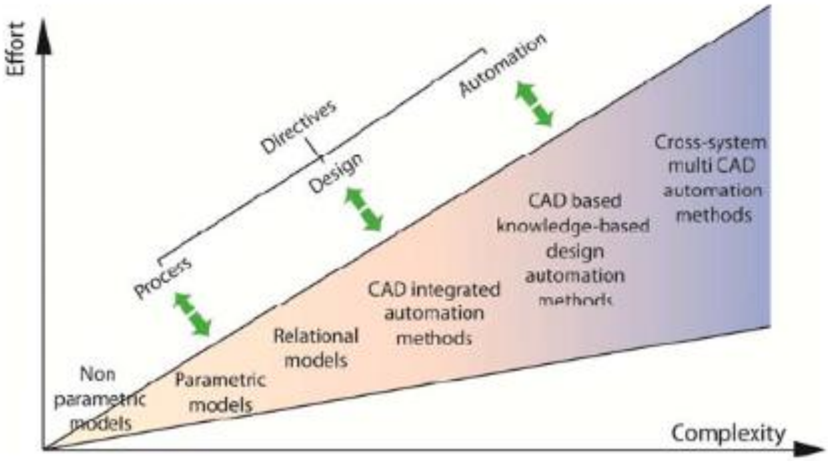

Figure 7. The levels of CAD-automation according to Salchner et al. 2016.

The next level is parametric model which refers to CAD-models that are based on parametric-associative design methods and include different variable values (Salchner et al. 2016). The CAD-model is designed based on different parameters that can be changed, for example dimension, geometry, material, tolerance, or some other relevant information. In parametric modeling, there is a programming code, such as a script that is used to define the wanted variable in the model. One of the major advantages of this kind of modeling is that the geometry of the model can be changed easily and there is no need to redraw the model when changes are needed (Fu 2018).

The third level of automation (figure 7), relational models, are parametric models which have parameters that are related to each other. This level is the final level that can be implemented with CAD-software’s own designing tools and features (Hiltunen 2017, 17). The interaction between CAD-elements is achieved by using rules, check or loops that help to define the relations between parameters. For example, it is possible to set limitations for a model to prevent it from breaking.

The level of CAD integrated automation methods is a first level of automation where an external tool integrated to CAD-software is used. This level is represented, for example, by CAD-automation features added to product configurators. CAD based knowledge-based design automation methods represent more advanced stage of CAD integrated automation methods. In this level, it is possible to develop design automation tools, such as design generators, that work independently from the CAD-system and include, for example, integrations to other applications (such as Microsoft Office, Visual Studio), customized graphical user interface, scripting language independent from CAD-system and allows continuous software development (Salchner et al. 2016). In this stage of CAD-automation, the information and know-how related to the product model is stored in a specific application instead of the CAD-system itself and CAD-software is used to visualize the construction created by the design generator (Hiltunen 2017, 18).

3.2 2D-design

In 2D-design the term CAD refers more likely to computer aided drawing than computer aided designing in its wider perspective. In 2D -drawing three-dimensional object is described in one plane in different projections and the work sketch is directly drew, which is the desired outcome in most situations (Pere 2012, 11). The advance in 2D-drawing is that it is easy for the designer to not draw unnecessary details and produce information only necessary for the manufacture. This makes the drawing process quicker and drawings clearer when it only contains relevant information (Paloniemi 2017).

There are a lot of tools mitigating drawing in 2D-designing software's. Drawing process is accelerated by copying and mirroring features, so not all features are needed to draw from the beginning if similar features has already been drawn before. Standard parts can also be brought to the drawing as a block, that can contain intelligence, such as how the block acts when scaled. Layers also mitigate 2D -drawing, when each line is assigned for a certain layer, which contains information about the color, thickness and type of the line. Layers can be hidden, when all the lines assigned to the layer disappear, which can, for example, make it faster to select desired features for copying. (Aouad et al. 2011, 38-40.)

The advantages of 2D- drawing is that is similar to hand drawing and different software can be used quite effectively even without the most sophisticated features. There are some tools developed to hasten the dimensioning and title block filling in 2D -programs, but it is still quite slow. Making parts list, for example, must be done manually in most of the 2D-software.

It is usually easy to detect errors, such as overlapping, in 2D-designing, but managing complex geometries might be often difficult. Perceiving and drawing complicated objects in two dimensions is challenging and it might require several different projections in order to achieve understandable drawing. One of the advantages in 2D-designing is that the number of files is usually quite small (Paloniemi 2017), the geometry of the object is drawn in the model side and dimensioning and, for example, manufacturing markings, are done in the drawing side. Modeling and drawing sides are included in the same file, so it is possible to have all the drawings of different sub-assemblies of the main assembly in one file (Paloniemi 2017).

The details of a product are specified in the 2D-drawings generated from a 3D-model. The drawings contain information about the dimensions, tolerances and other product-specific information that are essential in order to present or manufacture the product. Many CAD-programs automatically generate the geometry of 2D-drawings, but dimensioning and specifying the product information, for example marking tolerances or welds, must usually be done manually and is a time-consuming task (Rapinoja 2018). The product definition must be done carefully so that the manufacturability of the product can be guaranteed. One problem related to 2D-drawings is that it can be difficult to visualize the shape of complex parts, and such a part requires several additional views.

Automating 2D-drawing is hard in many cases, some tools are designed for that depending on the level of automation. Automation in 2D-design can be changing old drawing to desired by its simplest. One of the biggest weaknesses in 2D-drawing is that changes in sub-assembly drawings are not updated in the main assembly drawings automatically, but these must be updated manually. It is slow and increases the possibility of errors. It is also challenging to make models that have intelligence when making changes. For example, it is difficult to make a model that would change other dimensions in predetermined formula when changing one dimension manually. (Pere 2012, 22.)

3.3 3D-design

3D-designing programs offers several benefits that 2D -programs cannot provide. 3D-modeling can save costs in the long run, for example in the design of new products and the production of prototypes. 3D-modeling can be used to make dimensional and manufacturing drawings, but the greatest benefits are achieved when it is used to align parts and ensure the functionality of the structure (Tuhola & Viitanen 2008).

3D-modeling refers to designing the object in three dimensions. The 3D- product model can be utilized more efficiently compared to 2D-model, for example when studying the operation of the device such as in form of collision analyzes (Hietikko 2011, 21). Another advantage or 3D-modeling is that any changes in the model are automatically updated in all of the drawings containing that model.

In 3D-modeling, the parts and assemblies look correct and can be given all the physical and mechanical properties that the manufactured product actually has (Tuhola & Viitanen 2008). There are different 3D-models, in practice they are either surface models or volume models. In surface model, only the surface parts of the object are defined, and the model cannot be used for example to directly calculate the weight of the part. This modeling approach is commonly used to design molded and extruded products (Tuhola & Viitanen 2008, 21).

The more common way is to model volume model of the part, which allows, for example, weight calculation, collision analyzes and strength calculations of the model. (Pere 2012, 18.) This is also called a solid model or just 3D-model. 3D-model contains information about the appearance of the part and where there is material in the model and where there is not. The presentation is clear, and the model can be viewed as it actually is.

Usually, the 3D-model is produced by drawing a two-dimensional geometry and extruding it perpendicularly, along a defined path or around an existing axis. The majority of 3D-software is feature- and history-based, which means that the model contains information about the used features in a chronological order. This feature history enables the editing features afterwards. There are many similar tools in 3D -modeling as in 2D- drawing. The features of a 3D-model can be mirrored, copied and duplicated so there is no need to model the same thing multiple times. (Paloniemi 2017.)

As mentioned, product definition is normally made into 2D-drawings, model-based definition (MBD) offers a new way to define a part. In MBD, the data is defined directly in the 3D model (Rapinoja 2018). In this case, a separate 2D-drawing is not necessarily needed at all. Model-based definition enables machine readability, whereby the model travels directly from one system to another and all the necessary design information is carried along with it. In the traditional product definition, both the 3D model and the 2D drawing must be managed, but in MBD, updating the 3D-model is enough (Uski 2021).

Model-based definition could be seen as a future trend in computer-aided engineering. All the information in the model can be utilized, for example, programming toolpaths and different measuring paths as well as welding robots. Benefits of MBD are improving competitiveness, reducing production costs, shortening delivery times, improving quality, meeting customer requirements, achieving more visual presentation, always using the right model, avoiding errors, general efficiency and having only one model instead of several documents (Uski 2021). As computer-aided manufacturing becomes more common, the importance of 2D-drawings probably decreases and 3D-models will become the main end product of design (Pere 2012, 18).

3.4 Selection of CAD-software

CAD software package is generally a big investment for the company and the selection is carefully considered. The required features should be specified after the company’s needs. At least modeling features, creation and management of assemblies, creation of product families, production of documents, connections to other systems or software, additional modules, data transfer, maintainability user interface should be considered (Laakko, 1998, 29). When comparing different software, it should be noted that no absolute best solution can be determined. The determining factor is always the intended use, user’s requirements and needs. According to a Wolfe’s study, when choosing a 3D software, it should at least have capable and efficient 3D design features, good support, short learning curve. Compatibility with customers and suppliers, software’s built-in applications and its reliability and stability should also be considered (Wolfe 2010).

According to a study by Mercer, important features when selecting a CAD software are user-friendliness, added features, compatibility, efficiency and effectiveness, program support and service, price and company needs (Mercer 2000, 15-28). In the selection process, it is important to evaluate how efficiently the software package is at creating the types of products the company makes, for example sheet metal part company, the tools for making sheet metal parts and flat patterns should be efficient. In many cases, it might be convenient to select a software that is widely used among suppliers and customers, because it reduces the need to convert files if 3D files are exchanged a lot.

Though 3D models are widely used in engineering and product development, many manufacturers and suppliers still need 2D drawings. The drafting features should also be considered according to the company's needs, and CAD system should be able to export drawings to all popular formats, such as PDF, DXF and DWG (Wolfe 2010). Some companies need to have analytical tools or PDM software integrated to the CAD system, and the application programming interface should also be evaluated to fit the company's requirements. Many CAD suppliers have online support and built-in tutorials in the software to help to reduce the learning curve. There are online communities for many popular CAD systems, and in the other hand many of these systems are taught in local schools, which helps hiring newly graduated (Wolfe 2010).

One factor influencing the choice of CAD software is the purchasing price. For many companies, it is one of the most important factors when selecting a system. It should be noted that there isn't always a correlation between price and higher functionality and sometimes a lower priced CAD software might have the needed functions and meet the company's needs. In general, there are different licenses available depending on the CAD software. The license can be a subscription license, where the license fee is paid annually, or a perpetual license that is paid once and might include some annual support or maintenance fees. Licenses can be user or device specific, user licenses are based on user ID, usually the user is automatically authenticated when running the program. Device specific licenses are usually tied to a specific device using serial numbers. Network license, or floating license is a license type where the server hosts any number of licenses, which can be used on any computer on the server's network.

3.5 Modularity in CAD-software

Modular product structure enables the change of corresponding components in CAD assembly so that the functionality of the product is maintained. In this way, every component of the assembly can be changed without affecting the product's functionality. The modular model has a product structure to which changes can be made in a controlled manner. (Laakko & al. 1998). The features of design programs that support the modularity are the functions that make it easier to modify CAD-models. Such features include, for example, features of parametric modeling and definition of interfaces.

The assembly consists of a set of components, and when planning the assembly, the order in which the parts are brought into the assembly, should be considered, as well as how they are attached to each other and what their mutual relationships are. In current parametric CAD systems, design information can be added to the model by defining design parameters and constraints (Laakko et al. 1998). 3D-modeling enables the examination of physical properties of the components on a computer, to fit them into mutually suitable entities, and to examine their various interfaces. In a 2D environment, incompatibility of components is more difficult to notice (Tuhola & Viitanen 2008). In 2D-software, replacing components is commonly done by changing the geometry manually, and this must be done to all drawings generated from the assembly separately.

Parametric design is a computer-based design method that processes the object's geometry as variables. The dimensions or other geometric properties of the object can be changed as the design process progresses. Changes are managed using an algorithm. An algorithm is a set of commands that define certain tasks, instructions or rules to achieve a certain goal (Tanska & Österlund 2017). A parametric model usually consists of several algorithms.

Parametric modeling helps to control the model geometry by the use of design variables. The geometric definitions, for example, dimensions, can be varied at any time of the design process. User define the key parameters with the help of features, which are predefined parts or construction tools. A part is a set of technical features that can be modified or changed at any time. The benefits of parametric modeling are that geometric or dimensional constrains and relational parametric equations can be used to capture design intent. It also allows to update the entire system, parts, assemblies and drawings, after changing one parameter of complex design (Shih 2018).

4 Case-study: vertical agitator

This chapter introduces the modular structure and design practices of vertical agitator. Salomix L-agitators are used in various industrial applications for mixing and agitation process liquids. The main application areas are clean and lightly contaminated liquids, viscose liquids, fibrous slurries, liquids containing solids and with high gas content. Vertical agitators are used mostly in pulp and paper industry, but other industry areas for Salomix agitators are water and wastewater treatment, chemical industry and metal and mining industry.

LV-agitator is mounted on top of a tank to a fixing flange or a separate fixing frame, and due to its wide structural variation, it is suitable for agitating at different stages of the production process. Optimal agitation efficiency is achieved by the combined effect of the agitator, its placement and tank geometry. The agitator is selected for the application based on the process and other conditions and is not suitable to be used in substantially different conditions. The order-related engineering process of vertical agitator refers to the design process, where the structure of agitator is varied in order to meet the customer’s requirements after the order is confirmed.

Benefits of order-related engineering is that it is suitable for implementation for individual customer requirements (Gosling & Naim 2009). Customers of this kind of engineering environment are used to products being designed just for them (Haugh et al. 2009) which increases the level of customization. Engineer-to-order production requires a dynamic interface between production and engineering (Gosling & Naim 2009) where it is possible to adapt quickly, for example, order changes. There is also the benefit of smaller storage capacity needed, when production operates with small material stocks and materials are bought order specific. With customized products there it is possible to achieve wider product range, when a large number of variants are engineered based on customer requirements. In general, engineered-to-order products are typical for project-specific industries, where schedule orientated approach is valued, deliveries must be on time and use of just-in-time-strategy is applied.

4.1 Indicators of structural modularity

The principles of measuring the degree of modularity were introduced in chapter 2.3. These principles give a good overview on modular design in general, but when focusing on modular product itself, next five indicators should be considered:

- Interfaces
- Subassemblies
- Components
- Continual geometry
- Manufacturing stages

Interfaces indicate the modular connections how components are connected to one another, and the more standard interfaces there are in a product, the more modular the product is. Subassemblies usually are modular solutions, meaning their geometries remain constant regardless of the other variants of the product. All the standard parts can be described to be modular. For example, a gear is a familiar modular part, where there are multiple variants that are determined by market, such as different gear ratios and shaft positions and attachments for different IEC-motors

Continual geometry increases the degree of modularity. For example, in casted parts, certain chamfers and fillets are usually standardized, because with certain material, the expansion and contraction are of a certain type, and releasing part from the mold requires a certain chamfer. This decreases the design time, when models with the same geometry can be copied and modified. Manufacturing stages can be considered modular. For example, a standard weld, where the weld remains the same but the object in front of the welding robot changes. When combining all these indicators, the more the product has mutual interfaces, subassemblies, mutual parts, continual geometries and similar manufacturing stages, the better modularity has been realized.

4.2 Modular structure of vertical agitator

The operating unit of LV-agitator consists of either a motor and a gear or a gearmotor. The standard configuration includes only one motor and gearmotor manufacturers and two gear suppliers. There are 10 standard IEC- motor sizes selectable in a standard configuration. There are fifteen different gear size options for helical mounting position and nine for helical-bevel mounting position with the first gear supplier and three for both mounting positions with the second, depending on the motor power and gear ratio. The modular structure is illustrated in figure 8.

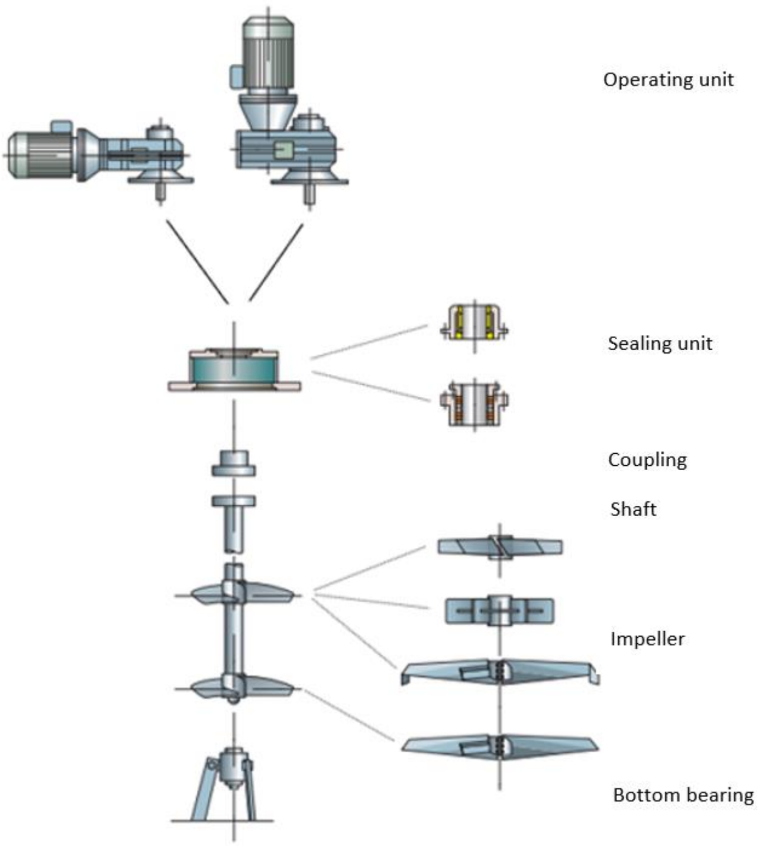

Figure 8. The modular structure of LV -vertical agitator

The sealing can be either N-, G- or DC- type, where N-type means there are no shaft sealing, only overflow ring attached to the coupling. The G-version includes a pressure-proof lip seal and DC-version stands for a double-acting mechanical seal. The G-version requires a fixing flange between the gear flange and the tank, and in DC-version there are a mounting adaptor included. The DC-version is presented in figure 4. Agitators equipped with blades, only the

N-version is standard and in propeller agitators N-, G- and DC-versions are included in standard configuration.

The coupling module consists of six different coupling sizes that are determined according to the outside diameter of the coupling, and the suitable coupling size is selected according to the gear size. The standard agitator configuration includes six different shaft diameters, and the length is always selected according to the customer’s tank dimensions. The vertical agitator can be either a propeller or a blade agitator according to the impeller choice. There are two different propeller types, one of which has four different size options and the other has two. With blade agitator there are little over thirty different size options depending on the selected shaft diameter. The lowest module, looking at the installation direction, is bottom bearing, which is selectable, but should be selected if the length of the shaft exceeds six meters.

The modular structure of LV-vertical agitator simpler than other vertical agitators, as it does not contain a separate bearing frame, but the coupling is attached directly to the gear shaft. Interfaces are standardized and must be designed only when using non-standard parts. The operating unit is a sub-contracted module, and the gear and motor connection include an adaptor part which is included in the gear module and ordered with the gear. Each gear size has a different flange drilling and shaft diameter for the agitator end connection, so there must be a different fixing flange and mounting adaptor for every gear size.

Each gear size also requires its own coupling model due to the variation in gear shaft end, and with six different standard coupling diameter, the amount of standard coupling models is 58. Coupling is attached to the secondary shaft with a cylindrical joint and a key. The shaft is flange mounted. Modularity is well realized in the interface between coupling and shaft, because there is a standard connection dimension in every coupling size, i.e. total of only six different connection dimension. This reduces the amount of required shaft models.

As a standard design of agitator structure, one or two propellers can be attached to the shaft. CP-propellers are equipped with three fixed blades and have a cylindrical bore and they are fastened onto the solid shaft with socket set screws. MX-propellers are propellers with three removable and adjustable blades. In special cases, other mixing elements can be attached, such as turbines or discs, but these are not a part of the standard product structure of the LV-agitator. Blade agitators are equipped with AF- and AFX-blades, which are attached onto the shaft in one or more levels. A long shaft is usually equipped with a bottom bearing attached to the bottom of the tank.

The description above of agitator's modular structure is the company's way of presenting the product's modular structure. On the other hand, the operating unit can also be counted as a subassembly unit, in which case the modules inside it are motor and gear. Gear and motor both are modular parts, where there are multiple variants that are determined by market, such as different gear ratios and shaft positions and attachments for different IEC-motors. All the standard parts can be described to be modular.

The modularity of manufacturing stages is often thought through welding or installation steps of a robot. The assembly of agitator is performed manually, and machined and welded parts are subcontracted, so the in-house assembly is mainly the final assembly of the modules. A special feature of the final assembly of vertical agitator is that the product is usually delivered to the customer in more than one piece. The installation of long shaft in the customer's site should already be considered in the design phase and for example, the impeller is fitted in final assembly, but delivered loose and the final attachment takes place in the customer's site. In the final assembly, the agitator is therefore assembled and partially disassembled for transport and installation at the customer's end.

Each manufacturing stage can be thought of as a module, and the more similar content there are in the manufacturing stages, the higher the degree of modularity is. Non-standardized variants usually require planning in advance in terms of assembly, but the assembly stages of a standard product remain the same regardless of the agitator size. This facilitates the organization of the installation place and the necessary tools and expedites the assembly, as the installation place can be organized to support the assembly stages. The final assembly of vertical agitator is simplified by the fact that all the joints are mechanical joints, which can be used to limit the number of tools needed, and on the other hand also ensure the removal of the modules, for example for maintenance.

When considering the degree of utilization of modularity in the structure of vertical agitator, it can be considered through interfaces and functionalities. As stated in chapter 2, the more interfaces the product has, the lower the degree of modularity is. If interfaces are thought of as the physical attachment points where different modules connect to each other, their number is directly proportional to the number of modules. The number of interfaces varies slightly depending on the structure of agitator, for example the sealing versions determine whether there is mounting adaptor between the agitator body and the tank.

Another way of measuring modularity is based on how many functions the product has, the more functions there are, the lower the degree of modularity is. In the case of vertical agitator, each structural module has its own clearly defined function. For example, the operating unit brings the driving force to the device and the coupling transmits the power to the agitating element. The shaft also transmits the power but it also connects the agitation element to the body of agitator and ensures the right placement of agitation element in the tank. The agitation element creates the desired flow in the tank and bottom bearing prevents the vibrations of the device. On the other hand, when considering the agitator as a single device, the function is to achieve the desired agitation process and there are no shared functions.

4.3 Design practice of vertical agitator

The modular product architecture of the agitator is mainly managed in company’s ERP, which is SAP, and the product structure and configuration rules and productized variants are updated there. There is no official commercial configurator to support the sales process, but the offers and pricing take place with the help of sales’ own instructions and tables. As a selection aid, an Excel-based selection program has been created, which is based on pre-designed modules. LV-agitator is divided into two types, it is either propeller agitator or blade agitator. The auxiliary tool only works with propeller agitators and separate selection table is used for selecting blade agitators. The dimensional drawings for tendering phase are created with 2D-software by order-related engineers.

Order-related engineering or engineered to order (ETO) refers to engineering process which is a typical in situations where customer needs a specific product. The customer’s order starts the designing process, and the product is manufactured according to customer’s needs. Order-related engineering typically takes places at a close interface with production and procurement. These kinds of situations, where order related engineering is needed, are for example when equipment must be dimensioned according to the application environment. The amount of engineering might vary in ETO, it might mean for example a small adjustment of standard measures or designing a whole new functionality for the product.

The factors influencing the agitator selection are the height and diameter of the customer’s tank and the estimated length of the agitator shaft, the density and viscosity of the process liquid and the required agitation level (low, normal or strong). The number and diameter of propeller is also entered into the selection tool, which recommends a suitable diameter, but this is also freely selectable. Based on this information, the necessary shaft power and motor size are calculated. The selection tool offers possible shaft solutions for the customer to choose, but there are some limitations, for example with certain shaft thicknesses there is a specified maximum length in order to prevent resonation.

5 SWOT-analysis

There are many advantages of modular product structure as well as ETO-design practices, and a SWOT-analysis has been formed for both. A basic SWOT-analysis is a four-field table, where a topic's internal strengths and weaknesses and external opportunities and threats are listed. Inner strengths column lists those things that have been achieved within the organization and that contribute to the sales of the product or service or create a competitive advantage. Weaknesses, on the other hand, deal with those internal issues that, due to the company's own actions or inaction, affect the product or service negatively (Pöytäniemi 2013). The external factors of SWOT-analysis are opportunities and threats. Unlike internal factors, there is no possibility to influence on these factors, so company must adapt to them (Ghazinoory et al. 2011).

When applying the methods of an 8-field SWOT-analysis, the strengths and opportunities are compounded into success factors, which indicate the inner factors that constitute a competitive advantage. Combining weaknesses and opportunities presents actions based on opportunities that can be used to reduce weaknesses. The combination of threats and strengths presents ways in which the effects of threats can be countered. By combining threats and weaknesses, crisis situations are observed, where internal weaknesses meet external threats, and what motivates to deal with weaknesses. (Pöytäniemi 2013, 20.)

Table below presents the SWOT-analysis made from the engineering and modular structure of LV-vertical agitator. SWOT-analysis was also made for modular structure in general, as well as order-related engineering process, which are presented in the appendix 1 and 2. These two analyses were used as a basis when comparing the agitator's modular features and features of order-related engineering process in the more detailed analysis below

Table 1. The SWOT-analysis of vertical agitator

INTERNAL FACTORS	
STRENGTHS + (S)	**WEAKNESSES – (W)**
• Simple product structure • Well-known product • Engineering and assembly expertise • Reliable subcontracting chain • Variation of product (in limits of modular structure) • Easy assembly and maintenance • Small storage capacity needed • Recycle	• Variation of product (features outside standard structure) • Engineering at tendering phase • Time consuming ORE-process • Product information scattered • 2D-software hard to use
EXTERNAL FACTORS	
OPPORTUNITIES + (O)	**THREATS – (T)**
• Technological development, innovations • Intelligent features of new software • Wider product range • Life cycle approach • Forest bioeconomy	• Economic crises • Other supplier difficulties • Labor shortage • Changes in directives, legislation
(O+S) OPPORTUNITIES+STRENGTHS:	
- Parametric modelling, 3D - Sales configurator	
(O+W) OPPORTUNITIES+WEAKNESSES:	
- Product model, product manual to expedite ORE - Automated drafting / design generator for simple processes	
(T+S) THREATS+STRENGTHS:	
- More supplier options	
(T+W) THREATS+WEAKNESSES:	
- Material shortages - Loss of sales	

5.1 Strengths

Vertical agitator can be seen as a well-known product and the engineering expertise in the company is strong. The simple product structure is a major advantage of vertical agitator. It leads to shorted lead-time in production, when standardized modules are easier and faster to assemble compared to integrated products. The assembly consists of the final assembly of subcontracted modules, and as mentioned earlier, the modular connections are jointed together by mechanical connections, so no welding or machining is needed, and assembly can operate with limited variation of tools. The number of modules is relatively small which also simplifies the final assembly. The assembly takes place at one installation location, so not much transfers or lifting is required, and it is possible to assemble all sizes of the product at the same installation point and the employee turnover in final assembly is low, which enables workers to specialize to the specific product.

The supply chain for outsourced components is reliable and production can operate with small material stocks. Order-related engineering process offer the benefit of small final product stock, where final products are shipped very quickly and with modular structure of agitator it is possible to operate with small material stock due to simple structure and interfaces where only limited number of connecting components are needed. Buying components when needed, also releases storage capacity. Outsourcing module manufacturing improves the quality of production and reduces costs when modules are bought as tested components where possible errors and faults are observed.

Prerequisite of order-related engineering is a dynamic interface between engineering and production, and collaboration is good between agitator assembly and engineering department where information about errors and design changes are transferred quickly. The entire sales-engineering-production chain must be flexible enough to adapt order changes even at a long stage of production. In engineered-to order type of design process also enables the improvement of engineering skills, especially when designing client specific features.

The engineering phase is also faster when the order adapts to the standardized modular structure which has only a small number of parts and variants and special engineering is required only in special cases. When similar modules are constantly used, it improves the quality of production when less errors occur due to repeatability. Another benefit of agitator’s modular structure is that it is suitable for many different customer needs by variating standard modules. Engineered-to-order type of production serves customers, who are used for products customized for their needs (Haug et al. 2009), and agitators are always designed to fit a specific tank. For example, with standard parts it is possible to choose more wear-resistant material without any geometrical or dimensional changes on the component.

In generally, the assembly and maintenance of a modular product is easier, when only the serviced module can be removed. Because vertical agitator is located on top of a tank, the maintenance requires the stopping of the process and heavy lifting in order to perform maintenance, but on the other hand, the agitator doesn’t contain many serviceable components. Unfastening the modules is made simple due to mechanical joints and module specific spare part kits are designed in order to keep spare part costs low. The recycling of modules is easier, when for example, a shaft is made of one material and doesn't require separation of different materials. The modular structure as well as order specific engineering offers the possibility to design a structure where certain harmful materials are limited to minimum number of modules and the usage of materials can be designed to support the reuse and recycling of modules.

5.2 Weaknesses

Within a modular structure, it is difficult to adjust to all customer requirements, if they are outside the agitator's standard modular structure, so order-specific requirements can be implemented in certain limits. Variation of product with features outside the standard modular structure is one weakness of the vertical agitator and these kinds of features require more time and capacity used in order-related engineering. As mentioned in strengths-column of SWOT-analysis, production of a modular product can operate with small material stocks, but this can also lead to weakness of longer lead-time, when modules are bought as out-house production. In this case, if there is as damaged or faulty component or sub-assembly it is sent back for repair and only minor errors can be repaired in-house.

Despite the simple product structure of the LV-vertical agitator, there is usually a lot of engineering required in the tendering phase. Customized dimensional drawings are required, and this work doesn't always lead to an order but is time consuming. As presented in the figure 9, the number of dimensional drawings made at tendering phase is almost half as large as the number of devices delivered. As seen in the figure, for example in 2020 there was 298 dimensional drawings of LV-agitators made and 145 LV-agitators delivered. The table does not give a completely accurate ratio between the delivered equipment and the drawings made, as some of the drawings may have led to an order only the following year.

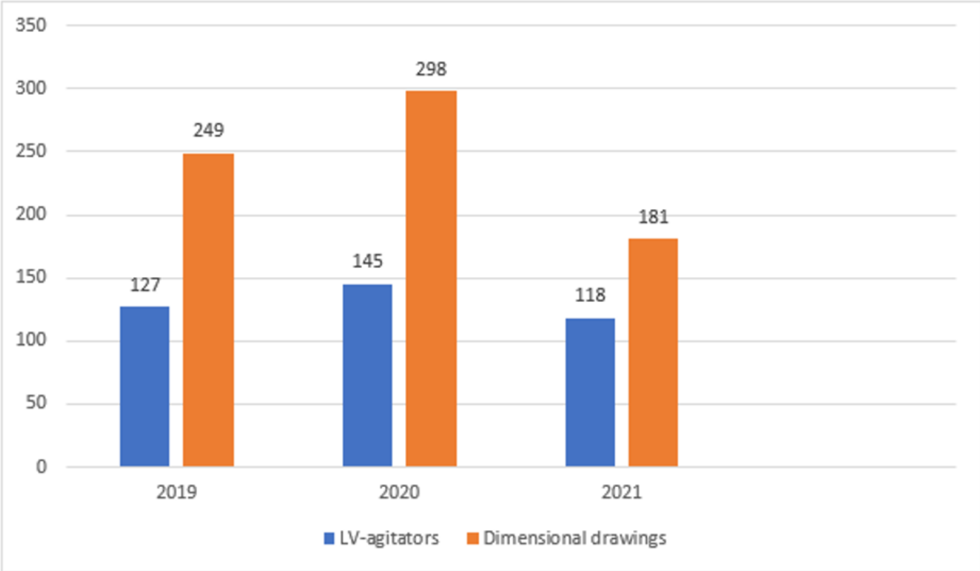

Figure 9. The relation between delivered LV-agitators and dimensional drawings made.

Overall, the order-related engineering process of vertical agitator is generally perceived as challenging by engineers, as a large part of the time is spent on making the drawings, and at worst, even two different CAD-software is used. The degree of modification of the library components of the 2D-program used in the design is high and searching for similar previous orders as a basis is tedious. One disadvantage of using the 2D-software is that newer generation of engineers may no longer learn how to use the software in their studies and learning the 2D-drawing takes its own time during the orientation.

The lack of product manual also complicates the engineering process, and the product information is scattered. The number of different product variants and specialties increases over time due to different projects and product data management for all variants needs a well-organized system. The current engineering process allows information to be dispersed to individual engineers, and this special expertise should be made more accessible to everyone. When engineering expertise is improved with designing client specific features, the acquired know-how should be stored, so it could be utilized in the future.

5.3 Opportunities

The external aspects in SWOT-analysis describe such external variables that cannot be influenced by company's own actions, but which can have an impact on its activities. In the case of vertical agitator there are trends like technological development and increase of environmental thinking. LV-agitators are mostly used in pulp and paper industry, which has a strong base in Finland. As traditional as the forestry sector is, as part of emission reduction goals and climate measures, more focus has been directed to forest bioeconomy and new bioproducts.

The wood processing industry has faced challenges in recent years, and many factories have been under the threat of closure due to the years-long decline in demand for printing and writing paper. On the other hand, the market situation for pulp is also experiencing fluctuations, and especially the increase of online shopping has increased the demand for packaging materials. (Hiltula 2020). The growing demand for forest industry products (Lindström 2021) is also explained by emission reduction, carbon neutrality and circular economy goals. Cellulose has been described to correspond to many megatrends because it combines renewability, recyclability, and biodegradability. The mitigation of climate change will increase the global demand for industry products (Lindström 2021).

The modular structure can enable more wider product range and more customer specific needs can be answered in the limits of modular structure when modularity is well-designed and applied. The development of new product and innovations in the pulp and paper industry can lead to the development of new manufacturing methods, where different kind of agitation conditions are required. With modular structure of agitator, wider product range can be achieved, and it is possible to vary the product to be suitable for new type of processes. The technological development extends to various engineering tools also, and it is possible to utilize new intelligent features of software even more.

Along with the increasing environmental concerns, life cycle approach has long been an integral part of product design. In addition, the consensus of sustainable manufacturing has emerged (Yu & al. 2011). The modular structure facilitates the assessment of the environmental impact of individual modules and development of production in a more sustainable direction. When the environmental impact of an individual module can be assessed, the life cycle can be determined to the final product regardless of the different module variations it contains.

5.4 Threats

External threads of agitator are also related to various global trends, of which economic crises make it difficult to sell and manufacture equipment. They can lead to difficulties in the subcontracting chain and material availability issues, long delivery times and make forecasting difficult. Especially components purchased from standard suppliers are prone to difficulties it there are only few suppliers, and the process of tendering subcontractors is not flexible.

In many engineering fields, the labor shortage has worsened (Ammattibarometri 2022) and as the skilled labor force decreases, the workload may become too large for an individual engineer. The recruitment of the ORE-department may also be difficult because the area’s university of applied sciences does not offer training directly related to mechanical engineering. Also changes in directives and legislation, for example due to increased environmental issues or safety aspects, causes a minor thread to the design and product, and the product structure must be flexible enough to adapt to these kind of changes.

5.5 Extended SWOT-analysis

Succes factors (S+O) of vertical agitator and its design are found when the simple modular product structure, engineering skills and the intelligent features of software are combined. The product structure of vertical agitator is quite simple and contains few modules, but on the other hand a lot of product variations. Dimensional drawings must always be made order specifically and adding automation to CAD-process mitigates the drawing process. The current method for drawings is the use of 2D-software but switching into 3D would enable the use of parametric models and increasing the amount of automation in engineering.

The use of more advanced software would also enable the creation of sales configurator in the future. The order specific engineering is based on a modular product structure, and when a design tool that offers modular solutions is used in the sales phase, a situation where features unsuitable for the modular structure are selected, is avoided. The configurator can fulfill the customer’s need for customization, i.e. it shows that the product is varied based on the customer’s wishes, but all choices take place within the limits of the standard product structure, so the cost-effective design and manufacture of the product is ensured.

When weaknesses are addressed with opportunities (W+O), it is possible to make the product information management easier and hasten the ORE-process with utilizing different features of CAD-software. A product model, that contains all the necessary information for engineering, can be made. At the same time, going through the product structure and design rules related to the structure of agitator, enables, for example preparation of a product manual or detailed designer instructions. This also facilitates the orientation of new employees, when the information needed for engineering is in one place. It is also possible to transfer specialized knowledge and silent knowledge to the product model so that information is gathered from engineers papers and folder into easily accessible electrical form.

Customized dimensional drawings are needed in tendering phase, and drafting is generally perceived as time-consuming among engineers. As stated in figure 9, the engineering work made in the tendering phase doesn’t always lead to an order. More efficient way of creating tendering drawings without minimum amount of engineering could be achieved by more sophisticated features of CAD-automation software. CAD systems can be utilized as automated drafting generators that can prepare accurate drawings quickly and simple design tasks can be handled with the help of CAD automation.

Combining the modular structure and the customer’s need for customization can be challenging, and as stated in the SWOT-analysis, some of the features that are not part of the structure might me hard to implement. On the other hand, the agitator’s standard modular structure is designed in such a way that it can be modified to fit the customer’s tank and the length of the shaft, the number and size of mixing elements and the dimensioning of the drive unit are made on the basis of the process data and tank geometry. This shows that each agitator is designed for a specific customer and the connection between modular structure and order-related engineering exists. If the need for customer-specific customization is to be considered more in the future, it is possible to identify certain functions or reliability-increasing factors, for example sensors or monitoring systems, which are easy to connect to the agitator order specifically at customer’s request, when a place and connections have been planned for them.

Controlling threats with the help of strengths (T+S) requires analyzing the effects of economic crises, and it is difficult to assess their impact on agitator and its engineering process. The supplier difficulties cannot be influenced by own actions, but can be prepared for, for example, by purchasing critical components in advance. Although there are standard suppliers for many components, with higher degree of modularity, it would be possible to buy, for example, an operating unit from any manufacturer. In this case the delivery difficulties of one manufacturer do not slow down the production of the agitator. This would require adding modularity to interfaces, i.e. suitable connection dimensions should be increased for more gear suppliers. With the help of CAD-automation and a suitable software, it is possible, for example, to define certain parts or materials in the product model and when these are used in a project, the software automatically increases the standard delivery time.

Combining threats and weaknesses (T+W) indicates challenging situations what the engineering of agitator might face. As mentioned, different economic crises and supplier difficulties might lead to material shortages and component availability issues that can slow down the production. Possible labor shortage combined with time consuming engineering might at worst even lead to a loss of sales if the delivery time becomes too long.

5.6 Criteria for the CAD-automation

When the pros and cons of modular structure of vertical agitator and it's engineering process were considered in form of a SWOT-analysis, some general requirements for a CAD-software can be made. The CAD-software should at least have the following characteristics in order to answer the current problems identified:

- Easy to use
- Training available
- Customer support available
- Integration with NX

The program should be easy to use and there should be training and customer support available. The integration with NX is mentioned, because, as stated earlier, it is going to be the engineering department's primary CAD-software to use and if some else designing tool is considered, the NX integration should be available. When considering the product model and 3D-model it would be good to have:

- Easy creation of new parts and assemblies
- Design rules and parameters can be stored to product model
- No programming skills required
- Product model easy to update and maintain
- Possibility to use Excel to generate expression files
- Possibility to create BOM based on the 3D-model
- Possibility to generate simplified 3D-client models easily

Overall, the production of 3D-models should be easy and the parameters that can be used in order to easily update and modify the assemblies, should be easily implemented and will not require programming skills. The product model should be able to store all the relevant information, but there should also be possibility to create dummy client models easily. When considering the 2D-drawings, the CAD-automation tool should be able to:

- Possibility to bring customer's tank drawings into the software
- Possibility to calculate agitator forces etc. automatically
- Manufacturing drawings can be created easily with small adjustment
- Changes in assembly are updated automatically to all views where assembly is used
- Drawings comply with machine drawing rules

Since the agitator is presented in customer's tank in the dimensional drawings, the possibility to bring customer tank drawings is essential for the CAD-tool. The customer's tank drawings are always sent as a dwg-files, so there should be an easy way to handle these files in the CAD software. The manufacturing drawings could be generated easily with just a small adjustment and all the drawings comply with the machine drawing rules.

More criteria can be derived when considering the modularity in CAD-software. If modular structure is utilized in the design, the CAD-tool should support the easy modification of the model. For example, it should support the creation of parametric modules, in which case geometry or dimensions can be changed in the assembly with easy predefined parametric changes. In this way, for example, a parametric module can be created from the operating unit, where changing the motor size automatically updates the gear size.

The CAD-tool should also support the import of models sent by suppliers without modification need, or with easy modifications. For example, if a seal outside a standard structure is used, then this step model provided by the manufacturer should be easily imported into the program without additional scaling. Some manufacturers offer ready parametric models for which the scale is defined when importing them into the program, thus ensuring that the component is the correct size in customer's model.

If modularity is taken further in design, the program should support the creation of functional modules. These would be, for example, machined parts, for which surface roughness requirements and tolerance requirements would come directly from the feature-based system based on the choice of material and dimensions. The use of such functional modules would facilitate and unify the design practices. This kind of modularity could be increased in the design of vertical agitator with the help of suitable CAD-automation tools.

6 Siemens NX and Rulestream

In this chapter the features of the NX-software and Rulestream automation tool are introduced. As stated earlier, the order-related engineering and the dimensional drawing generation is separated and the images are done by 2D-software. In this study, it is assumed that the possible transfer to 3D-software will be implemented with the NX because the engineering department is implementing it for the use for other products as well in the future. The chapter introduces NX in general and Rulestream, which is connected to NX as a separate engineering tool and what kind of value would this engineering tool bring to an order-related engineering of vertical agitator.

API stands for application programming interface, and it is a set of programming rules and codes that handles data, construes responses and transports information between an application and the web server. API specifies how different applications are interacting with one another and allows the integration with another applications.

CAD API means interface that allows to access functions of CAD application. Most CAD systems are general, so they are not aimed at any specific industry or to model certain types of products. With CAD API it is possible to add desired functionality into the CAD application, optimize the operations and modify the CAD process to meet the individual requirements. Some CAD API’s have a free access, such as in SolidWorks, AutoCAD, SolidEdge and Inventor. NX Open is a licensed application programming interface.

6.1 NX- designing environment

NX is a 3D-designing software developed by Siemens and it includes CAD-, CAM and CAE -tools. NX can be used in Windows, Linux, Mac Os and Unix operating systems. NX can be used in all phases of a product, from product development and concept design to engineering and manufacturing with its integrated toolset. The basic philosophy of NX is that it provides a wide range of different designing properties and features without any mandatory plugins, though plugins can be very useful in many cases. NX integrates knowledge-based principles, industrial design, geometric modelling, different analysis tools, graphic simulation and concurrent engineering (Leu & al. 2016). NX is composed of several applications that all share the same common database.

NX software combines different designing tools such as industrial design, geometric modelling, graphic simulations and concurrent engineering. It is possible to model standard geometry parts but also more complex free-form shapes and to integrate solid and surface modeling techniques. (Leu & al. 2016.) In NX, as in many other 3D-softwares, modules are presented as assemblies and subassemblies. Assemblies can include all the components that are required in the real product, and they can be named matching the company's ERP system's names.

There are some tools in NX that helps automating the design, such as sheet metal tools that allow modeling folded patterns to sheet metal components and user can enter initial values into the program, for example the folding angle, and the program generates the final folded model. In this way, both folded and unfolded model can be added into the manufacturing drawing. There is a possibility of parametric modelling in NX by utilizing relations. With different dimensions of the part, mutual dependencies or different calculation formulas can be created.

There are a wide range of other functional tool options in NX too, that can be implement as needed, such as modelling product design (parts, assemblies, structures), routing electrical cabling design, routing mechanical piping design, manufacturing programming (computer-aided manufacturing) and different simulation, testing and analyzation tools and tooling design options. There is an integration option with Microsoft Excel, that can be used to generate expression files to load in NX, and these files contain the parameters that are transmitted to the parametric models.

Teamcenter is another software developed by Siemens and it is an PLM (Product Lifecycle Management) software. The lifecycle management of a product includes the management is all four stages of the product: design, development, manufacturing and deprecation. The Teamcenter features include, for example, the management of product structure and documents. The final configuration of Teamcenter is always planned for each company individually, there is possibility, for example, to integrate different CAD-software to

Teamcenter. This means it is possible to transfer information from CAD to Teamcenter and vice versa.

One key element of NX solid modeling is the use of feature-based parametric modeling technique, which automates the design and revision procedures with the help of parametric features. Simple parametric models are quite easy to create with NX, by setting up the units and part name and determining the type of the base feature. The most common types of base features used are extrude, revolve or sweep operations. Then a rough two-dimensional sketch is made of the basic shape of the base feature and constraints and dimensions are added into it. The sketch is transferred into 3D- solid and additional parametric features are added. The model can be modified if needed and 2D drawings generated from the model.

One of the requirements of CAD software for the vertical agitator was that the dwg-files can be easily imported into the program. With NX there is a possibility to generate 3D-model based on imported dwg-file, and this could be a solution with simple tank geometries. Sometimes geometries may be challenging with several different manholes, flanges, piping and planes inside the tank and if these details must be presented, extruding them from sketch to solid model is challenging.

NX Open is the application programming interface of NX, and it is used to write programs to customize NX. NX Open has a wide range of different functions, and they enable for example creating parts, assemblies and drawings. It is possible to create custom user interfaces in order to enter data and import data from outside the NX. NX Open is the most common interface of the NX where most of the NX programs are programmed and the programming language can be chosen by the user. The supported languages are C++, VB.NET, Java and C#. (Siemens 2019.)

6.2 Rulestream ETO

Rulestream ETO (Engineering to order) is a Siemens PLM Software’s software used to build design automation modified to specific needs. It is an environment that enables to capture the product knowledge and information without building a program from scratch. In Finland Rulestream is supplied by Ideal PLM, which divides products into five categories: standard products, CTO-products (configured-to-order), HCCTO-products (high complexity configured-to-order), ETO-products (engineered-to-order) and true custom products, illustrated in figure 10:

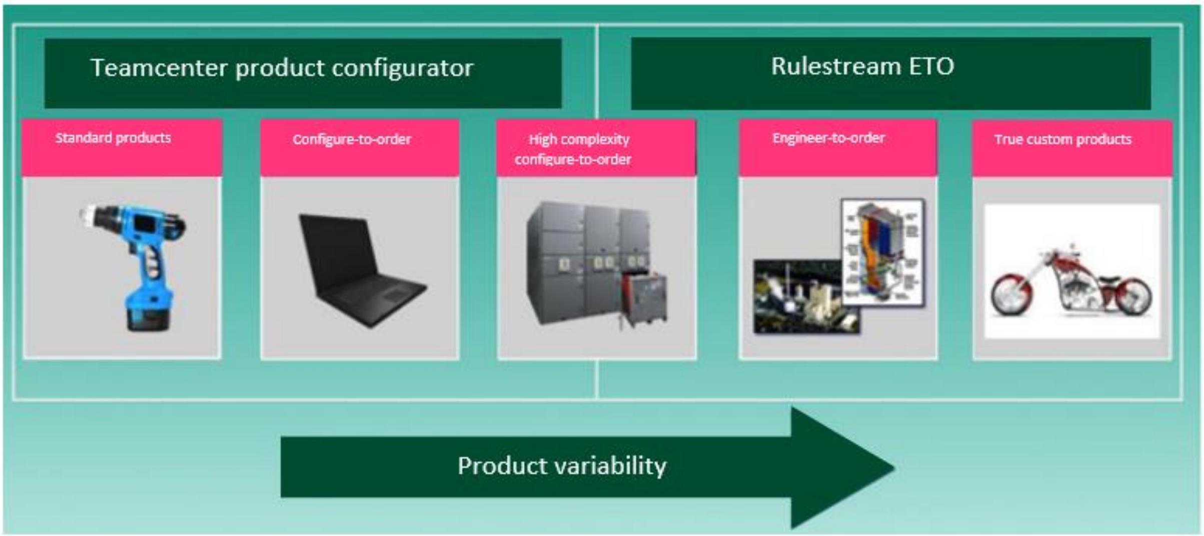

Figure 10. Teamcenter and Rulestream software with their applications (according to Hiltunen 2017).

As seen from the figure, Siemens Teamcenter is suitable especially for standard and CTO-products. Teamcenter is a PLM-software that includes PDM- functions and different sales and design configurators (Hiltunen 2017). Standard products are typically a large volume products which have no variation available. Configured-to-order -products are mass products and variation is available based on existing configurations. High complexity configured-to-order products are usually medium volume products with a numerous possible variations. They differ from CTO-products in that there are more possible combinations and new ones are created during the engineering. Typically, with these products, CAD-integration is not very important, it is enough that the BOM is produced in order for the product to be manufactured, all other design information is already predetermined (Tjurnev & Renko 2022).

Engineer-to-order is a process where the majority of the engineering is done based on the client specific needs and only few of the components have been designed in advance. Design generator has to create new 3D-model and manufacturing drawings based on the design rules and product data in order to fulfil the orders. These generators for ETO-products contain the product model and its design rules, and the volume of the product is typically medium or low (Hiltunen 2017). For ETO-products, CAD plays a significant role, as there are usually no drawings ready to utilize, so drawings and other documentation must be created to support the process from sales to manufacturing (Tjurnev & Renko 2022).

In ETO-process, engineers are typically very engaged and have to serve both sales and manufacturing, which can slow down both processes and create overload in engineering process. Rulestream aims to fasten the design process especially for ETO-products, but it is also suitable for example complex CTO-products (Tjurnev & Renko 2022). In the implementation of Rulestream, engineers work in the center due to their best product knowledge and the basic idea of the software is that the design rules and product model can be written without any programming skills. All the design rules are collected in a written database and permanent rules are collected separately from changing data (Hiltunen 2017).

When data is collected into Rulestream, two basic questions are answered: why and when. (Tjurnev & Renko 2022). Why a specific component is included in the assembly and if there is a requirement related to the assembly, for example a specific pressure for a pump, how is it implemented. Through these questions the rules and codes are built in Rulestream. It is usually useful to get static information from other systems which can be integrated into Rulestream, so the information can be retrieved from the system where it is maintained. For example, material prices can be very dynamic and there might be daily variation, instead of estimating the prices within some system, the information is retrieved from another system where it is real time.

Rulestream also serves as a platform where the rules can be run again, so in the configuration phase, where the customer’s requirement data is collected, the information previously entered into the system can be utilized, and outputs are produced based on the inputs given by the customer, in practice documents for either sales or manufacturing. All the requirements are saved into the system and can be utilized again, and it is possible to review what has been requested and what has been produced. Rulestream integrates with multiple tools that can be used to produce output information that serves either in sales, engineering or manufacturing. All the produced data can be stored into Teamcenter, that serves as PDM system, and it can also be retrieved from there, so previously configured products can be used, and previous design can be utilized.

Rulestream can be integrated with multiple CAD software, the most used are Solid Edge, NX, Creo Parametric, SolidWorks and AutoCAD. Despite its scalability with different CAD-programs, Rulestream can also be used independently from CAD. The other useful integrations are Microsoft Office and JT Visualization. It is possible, for example, to export the BOM as a Word-document or generate only BOM's with Rulestream and present light-weight JT-geometry (.JT-files) instead of actual heavy CAD-files.

6.2.1 Design automation with Rulestream

First step of using Rulestream is configuration, where a new project is defined or an old one is continued or copied. In this phase, customer data is entered, or an existing customer selected, and initial data is defined for the product to be designed that is called line item. The required initial data is selected according to the type of product, and these can be, for example, application or a more specific product type. The desired delivery date can also be entered and set a rule in the background that determines a sufficient manufacturing time for the product, whereby a date set too close warns of a wrong choice.

The operating conditions are also defined for the product, i.e., the parameters that influence the definition of the product are programmed into Rulestream. These parameters for vertical agitators would be, for example, the process or the mixed fluid, consistency, tank volume and tank diameter. In addition, the customer may set some requirements too, for example the wanted gear type. In addition, other factors can be programmed into Rulestream that influence the choice of the product. Also, it is possible to program various rules that can stop designing if wrong or conflicting parameters or values are selected.

The user interface is clear and similar to many 3D CAD- programs. In the feature tree on the left, i.e., the process tab, the steps of the configuration process are defined, which are determined according to the product to be designed. The interface of Rulestream is real-time, every selection made gives input and feedback right away. According to this real-time user interface, the choices made at each stage have an immediate effect, either visually or by other means, so that it is possible to see what is being done at all times. For example, changing the gear size or increasing the rotation speed can be made to affect automatically to the selected motor size with the help of rules.

It is possible to use other in-house calculation software as a support tool with Rulestream. Through the command prompt, another program can be started where input values are entered and the results are obtained back to Rulestream. All product information does not need to be imported into Rulestream, but can be retrieved, for example, from ERP-system during the configuration phase. For example, motors can be listed in Rulestream so that the information is automatically retrieved from ERP where it is maintained, and if there are changes in the ERP-system, the selection list is automatically updated in Rulestream. In addition, accessories that can be selected for the product can be added during the configuration phase and different rules or notes can be created for them to prevent making wrong choices.

CAD program is opened via Rulestream and it automatically assembles the product assembly based on the choices made in the configuration phase. In addition to standard components, parametric components can be added where, for example, certain dimensions can be determined before assembly is complete. The NX session is fully interactive, meaning that if some components need to be examined more carefully, it is possible to see what is related to it in the model in the feature tree. Additional features can also be added and model can be supplemented with special features. In addition to the 3D-model, a drawing is also often required and Rulestream generates the drawing to NX and updates the views automatically.

The BOM-structure of the product can be viewed easily using Rulestream. Various reports can be generated to the process tab, and due to the Word-integration, BOM table is immediately available as a document form which shows the necessary components and possible selected accessories. It is also possible to generate sales documents or similar, that mostly consist of standard text, but to which dynamic text fields can be added that can be automatically updated via Rulestream, e.g. product type, pressure, temperature, delivery date etc. All integrations are interactive, and if there are additional requirements or changes at a later stage, the information can be quickly updated in both NX and Word. When the configuration is complete, the model can be saved and all the entered data, documents and the 3D-model are saved for later use. When Rulestream is closed and a previously configured line item is opened again, it is possible to view what was previously configured and which document are related to the line item and what kind of 3D-model is generated.

7 Results

In this chapter, the results of the study are presented. In the beginning of the practical part of the study, the modular structure of vertical agitator was examined though different aspects of structural modularity. The product structure is quite simple and the number of modules is moderate. Determining the degree of modularity is difficult, and for more detailed analysis, some method of defining modularity should have been used. There are many possible product variants, but the vertical agitator can still be seen to be quite moderately variable, which the modular product structure fits well. Modularity can be deeply embedded into the product structure, but its benefits should be identified. Modularity is not beneficial just for its own sake, but it is worth implementing if it is found to be commercially viable and the company’s organizational structure supports a modular product.

7.1 Scientific contribution

Scientific contribution of this study consists of analyzation of the modular structure of vertical agitator and its design practices. The benefits of vertical agitator and its order-related engineering process were demonstrated with the help of SWOT-analysis. There are a lot of research done of modular product structure and ETO-engineering processes, but in this study, a SWOT-analysis was made of modular structure of vertical agitator and its order-related engineering process. It was concluded that the simplicity of modular product structure helps in design and final assembly, and a possibility was seen to transfer into parametric modeling and creation of possible configurator in the future.

There were some areas where modularity could be utilized more. Increasing modularity would be justified in interfaces, if more supplier options for the modules are desired. In this case, more interfaces, for example, for different gear suppliers should be designed. Functional modules could also be utilized more in design, with the help of CAD automation tools, modules could be designed in such a way that certain material requirements would be associated with certain quality characteristics. In 2D-software the modularity of agitator could be increased by having more components that could be scaled up to next component size by changing the scale of the component.

According to the levels of automation presented in chapter 3.1, the current 2D-CAD system presents the lowest level, non-parametric models, while the use of NX itself presents level three, relational models. This is the final level that can be implemented with software's own designing tools and features. Rulestream represents CAD-based knowledge-based design automation method, since it is an external tool offering more advanced level of automation. The current practice of creating dimensional drawings with 2D-software was perceived as challenging and switching into 3D-software would speed up the generation of drawings, especially if the features of parametric modeling were utilized. The advantage of current CAD engineering software is that the customer's tank dwg-drawings can be utilized easily without converting or importing.

7.2 Concrete applications

The study presented few design automation methods, Siemens NX- software and Siemens Rulestream automation software. More detailed price comparison of different solutions was excluded from the study, but the use of current 2D software was seen to present the basic level, as continuing its use would not require significant additional costs if only minor improvements were implemented, for example supplementing the component library. The licenses for NX already exist for the ORE-department, because along with the CAD project it will be the primary CAD-software in the future. The basic level modeling with NX is seen as creating standard library components and modeling is implemented manually in such a way that features of parametric modeling and automation are not utilized. This type of modeling would incur low costs in component modeling. It is difficult to estimate both the costs of current software use and transferring to 3D software without more detailed research.

The three options cannot be directly compared, since Rulestream is not a CAD software itself, but used as an automation tool alongside with NX. The implementation of Rulestream automation would cause clear costs, but more precise license costs are not available without a more detailed quotation. The implementation of Rulestream would also require external help in creating the automation needed. There are companies that specialize in custom programming of automation tools like Rulestream, and implementation of Rulestream would require the use of such services.

The table below summarizes the three options considered: the current practice of using 2D software, implementation of 3D software (NX) and implementation of more advanced design automation software Rulestream:

Table 2. The effects of different CAD software types

	Advantages	Disadvantages	Future
Continuing with 2D software	-Simplified drawing -Small number of files -Axially symmetrical parts -Drawing expediting tools -Component library complement easy -Easy to utilize customer's tank drawings	-No analyze/simulation -tools -No automated BOM or title block filling -Hard to visualize complex geometries -Not possible to automate weight calculation	-CAM with 2D toolpaths -Automation options and easy scripts -Significance of 2D-drawings most likely to reduce
Implementing NX	-More automation options -Parametric modeling -Quick drawing process -Improved product definition, PLM -Consistency in design	-Transferring into 3D time consuming -Training needed -PDM must be planned	-CAM and MBD -Automation possibilities
Rulestream automation	-Fully automated design process -All necessary product definition information in the model -Simple interface, no programming skills needed -Integration with NX	-Implementation cannot be done without external help -Requires implementation of NX and Teamcenter -Requires interaction between CAD and ERP	-Sales configuration -Model-based design

When considering the criteria for CAD-software identified in chapter 5.6, the current 2D-software answers poorly to these criteria. The possibilities of utilization of modular structure were found to be low in 2D-design systems. With 3D-software, such as NX the product definition in three-dimensions allows more precis description of the product. There are features that allow the automated weight calculations, easy creation of manufacturing drawing and quick changes and updates of the model.

NX also supports the creation of parametric models, which was recognized as one form of modularity in CAD software. It also supports the criteria for 3D-model allowing easy creation of new parts, possibility to store design rules and parameters to product model, easy script writing, possibility to use Excel to generate expression files. There is also possibility to create BOM based on the 3D-model and simplified client models. There is a possibility to bring customer's dwg-files into NX, but it requires an extra work phase when extruding it into a model. The advantage of the current 2D-software is that the needed customer drawings are the same file format.

The advantage of 2D-software used currently is that it reminds of hand drawing, and the work drawing is drawn directly, which is also the desired result. All the unnecessary features can be left out and include only relevant information for the customer or manufacturer. The current engineering process also produces a small number of files, since the work drawings are directly generated and in general, the file size of 2D-drawings is very small. The possibilities of automation in 2D-software are much more limited compared to modern 3D software and they are more of a drawing support tools. Automation in 2D can be as simple as copying and scaling parts. There is no analyze or simulation tools available, and because material information cannot be included to parts, the weight calculation cannot be automated, which increases the time spent on the drawing.

With 2D-drawings it might be hard to visualize the geometry of complex objects or assemblies. On the other hand, the way of presenting objects in two-dimensional way is suitable for many simple parts, especially for axially symmetric parts it might even be the simplest way of presenting their shape. When considering the vertical agitator, such parts are shafts, couplings, mounting frames and fixing flanges. Manufacturing drawings for these kind of parts are relatively easy to generate, though there is no automated BOM-generating tool or weight calculation tool. BOM is currently added manually, and this causes a threat of inconsistencies and errors. There are BOM migration tools available for AutoCAD Mechanical, with which it is possible to generate BOM, but this would require a change of the way drawings are generated at the moment. If manufacturing drawings are required, they are generated as one drawing, instead of several parts and assemblies, which automated BOM creation would require.

Modularity could be increased in current design software by utilizing the built library components for the vertical agitator and complete the library with all the necessary components. Modeling all the needed components as 2D-drawings doesn't require programming skills, even though takes a little time. The modules could be designed as ready-built blocks, where scaling options could be used to modify the part quickly. In 2D-software the modularity of agitator could be increased by having more components that could be scaled up to next component size by changing the scale of the component.

Many modern 2D software enables some automation, for example user can write scripts that can be used to automate repetitive procedures. However, these are in authors opinion, functions that can be handled quite easy with software’s own tools, such as earlier mentioned copy, scaling and mirroring tools. Writing rules and programming automation is time consuming and the achieved benefits should be carefully considered. Other future possibility with 2D software is CAM options. The model-based definition was introduced in chapter 3.3, where a 3D-model was described as a base unit in computer-aided manufacturing processes. 2D-drawings cannot be used in a same way because it contains only two-dimensional information, but it can be used to use two-dimensional toolpaths, which is a simple form of computer-aided manufacturing. However, the meaning of 2D-drawings is estimated to decrease in the future due to increase of computer-aided manufacturing.

The 3D-model is the most common source of 2D-drawings and the basic principles of modeling are generally easy to adapt with every program when the engineer masters the use of one. The biggest advantage in the case of vertical agitator is, that its modular structure can be exploited through parametric modeling. In this case, small geometrical changes can be handled automatically by defining new dimensions. The automation options are generally better with NX compared to AutoCAD Mechanical. There are analyzing and simulation tools available and with the basic features of NX it is possible to automate the generation of weight table and title block filling. With the help of this kind of simple automation it is possible to generate 2D-drawings quickly, and changes are easier to manage, when changing component will generate changes automatically to all assemblies including that part. With the help of automation, a large part of the repetitive work steps can be eliminated, and drawings no longer need to be drawn line by line, this also unifies the drawing practices.

NX offers a wide range of designing tools even without any additional software. The parametric modeling options for a plain structure such as vertical agitator are quite good, since the variables are quite simple. The integration with Excel helps in more complex parts, where more calculations and relations are needed and maintaining and controlling the information might become difficult. Excel is a well-known listing tool, that is familiar for most of the engineers, so without NX Open knowledge, Excel-driven parametric models might be a good solution as a starting point. After the product data is gathered into, for example, an Excel-file, and some simple parametric models are created, it is still possible to upgrade to something more integrated and user-friendly using NX Open.

Rulestream is an extremely scalable design software that can be integrated with many programs. There is a clear benefit of creating a design generator with Rulestream, that the resources of order related engineering can be reallocated to other design activities. As stated in chapter 6.2, Rulestream is compatible with many applications, but its implementation requires a lot of work. The demonstration of Rulestream illustrated an engineering process where the drawings can be generated with a simple process of inputting pre-defined initial values. The whole process from sales to manufacturing can be supported with Rulestream automation. When considering modular product like vertical agitator, the configuration is the phase where the product is defined. This is done already in the sales phase, so the possibility of a sales configurator is the most important feature of a CAD system, and Rulestream offers this possibility.

The disadvantage of Rulestream is that, based on the demonstration seen, the implementation of the software requires external help. On the other hand, after the design automation has been planned to meet the needs of the design process of vertical agitator, the use of the automation is quite simple. The use of Rulestream requires the use of NX and Teamcenter, because Rulestream offers the level of automation where PDM system should be linked to software in order to utilize its features. The current level of product data management of vertical agitators is drawing-orientated, there is no 3D-models and the CAD system and ERP system are separate from each other.

7.3 Generalized results

Transferring from 2D-software to 3D-software requires a lot of work, since the 3D-model library is very limited. Modelling the essential parts of vertical agitator product structure should be carefully considered; the parts should be modelled in a way they are easy to modify and update. NX is feature- and history-based software, i.e. the model retains information about the features and the time sequence of their creation. The main advantage of this is that the model can be easily modified afterwards. The 2D-drawings of vertical agitator are still needed and are easy to generate from 3D-model. It is possible to create needed projections and there are no conflicts between projections. The shape of a complex part is easy to illustrate with isometric projections. The product definition is improved with 3D-models that can contain more information about the part, such as material information, compared to 2D-drawings. Use of NX offers the possibility of combining CAD and PLM systems, where the needed product information is stored in Teamcenter. This allows, for example, to attach real-time data to the part, such as stock codes, material information or other type of dynamic information, such as prices.

There are more designing tools in NX compared to 2D-software, but creating intelligent parametric models require engineering skills. Models must be carefully designed in order to gain added value from them. The NX program is new to the order-related engineering department, its basic use requires training. Modeling the library components and creating parametric models requires more training as well, even though creating simple rules is simple with the basic features of NX and no programming skills are needed, though basic understanding of programming languages is helpful. The bigger number of files and their relationships set higher requirements for PDM (product data management) system, and it must be well organized. A fully automated design process with NX requires such a level of know-how that it requires help from outside the engineering department.

The direction of 3D-designing is quite certainly in model-based definition after the generalization of computer-aided manufacturing. It is possible to produce relevant information from the 3D-model directly to the machine tool with the help of G-code, which is most common numerical control programming language. This is especially helpful for milling curved surfaces and programming multi-axis machining centers. There are most likely more automation options available in the future due to constant development, and these can be utilized in the engineering process.

8 Discussion

The advantages and disadvantages of modular product structure and order-related engineering process were analyzed with the help of SWOT-analysis (listed in the appendix). An answer was sought to the questions: *What is the degree of modularity of vertical agitator?" "Where could modularity be increased and why?"*

The modular structure of vertical agitator was analyzed, but as stated, determining more precise degree of modularity would have required the use of some recognized calculation formula. The author felt that it was not relevant for the topic of the work but concluded that based on the agitator's functionality and interfaces, the modularity has been utilized well in the product structure. There were some areas where modularity could be utilized more. If more supplier options were wanted, the modularity should be increased in interfaces. If selecting a 3D software with more advanced design automation tools, functional modules could be utilized in the design process. If continued with the current CAD software, modularity could be increased by having more scalable components.

The challenges with modular structure and ETO-process were discovered to be the variation of a product. Modular structure itself doesn't support variation outside the standard structure and the key challenge is to determine the level of modularity that still manages to meet the customer's requirements and where the customer can be offered the opportunity for customization, without the modular structure suffering.

Another research questions were related to CAD automation: *How is modularity implemented in different design programs?" "How to improve engineering process of vertical agitator with new CAD-software?".*

Different software support modularity by the features that enables the easy change of design. In 2D software there is very limited options for automating the drafting process, but with sophisticated features of 3D software, there are many tools that help automating the process. Parametric modeling was found to be the easiest and designer-friendly way that has many advantages, such as fast and easy modification of the part at any stages of design. The major strengths of 3D-software are the possibilities of automation. The changes can be made to 3D-model easy and fast if the model has been created smart and the possibility to changes has been considered while modeling. 3D-model built smart can be considered as one level of automation and different parameters can be added quite easy. The modern CAD software is based on the idea that user does not need to know how to program, but the features of parametric modeling can be utilized with easy expressions. If only 2D-software is used also in the future, the automation possibilities of generating a drawing should be explored more.

The engineering process is also improved when, in case of transferring into 3D-software, the product structure is carefully examined and the information needed for the engineering process is connected to the product model. This enables the creation of product manual as well. The dimensional drawings could be made faster with design automation, this prevents the engineering time to be used at tendering phase. More efficient way of creating tendering drawings without minimum amount of engineering could be achieved by more sophisticated features of CAD-automation software. The current design practice allows errors to recur, but parametric modeling with NX reduces errors when there are rules involved in the design process. The Rulestream, on the other hand, has a lot of visual and design-blocking features if incorrect choices are made.

8.1 The comparison and connections with former research

There was a lot of relevant information available of modular product structure as well as engineer-to-order process. A lot of research data has also been produced on CAD-automation, so compiling the literature review was easy. SWOT-analyses were made of the modular product structure and the order-related engineering process where their advantages and disadvantages were considered, which can be found in the appendices.

Combining these two topics with a vertical agitator was challenging and required a careful examination of the agitator’s product structure and its design practices. Based on this examination, a SWOT-analysis was made of the of the modular product structure and the order-related engineering process of a vertical agitator. Due to the uniqueness of the topic, it is difficult to make a comparison with previous research, because no previous research was found on the modular product structure of vertical agitator in the order-related engineering process. The study was carried out in a constantly changing environment, which caused its own challenges to the implementation of the work.

8.2 Objectivity, realibility and validity

The printed literature sources used in this thesis have commonly been used as a learning material and were easy to find. The electronic literature sources were found in the university’s library database and most of the sources used in the literature review were directly related to the topic. Some of the sources did not actually deal with the modular product structure in as much detail as author would have hoped, but combining the existing information from different sources, clear points of convergence with the research topic have been obtained.

Literature related to CAD automation was also easy to find both as a printed and electrical source from the university’s library database. Most of the literature sources were frequently cited in studies concerning similar topics, such as modular product design and cad automation. The validity was ensured by a multi-step SWOT-process. By combining SWOT-analyses of modular structure and ETO-design process with the SWOT-analysis of vertical agitator, a detailed analysis of the strengths and weaknesses of its structure and design process was formed.

8.3 Assessment of the results and sensitivity analysis

As the practical part of the study was implemented as a case study. The nature of a case study is empirical and based on knowledge and experience, and case study collects and analyzes information in order to limit the topic to a specific area. Some generalizations are presented in the SWOT-analysis, where the order-related engineering process of vertical agitator is described to be challenging and engineers felt that a large part of the time is spent on making the drawings, and at worst, even two different CAD-software is used. These argument are derived from a workshop that was held during the thesis process. The workshop participants were engineers involved in the order-related engineering of vertical agitators.

8.4 Key findings and conclusions

Even though the dimensional drawings are still needed, and 3D step models are still quite rarely requested, it should be considered what is the most reasonable way to produce 2D drawings. Generating them with a 2D software has its advantages and disadvantages, but a 3D software also offers beneficial features for generating dimensional drawings. With a 3D software the modular product structure can be utilized more, when functional and manufacture-based modules can be created. The order-related engineering process can be improved, when the workload can be reduced from the tendering phase with more efficient way of generating dimensional drawings. When the product data information is considered, it is possible to include much more product information to the model. While 2D blocks contain only two-dimensional data of the component, 3D model can contain variety of information such as materials, stock codes, subcontractor information and so on.

The idea, of which implementation the author would like to contribute with this study and its results, is the way the product is seen. The product itself should be seen as a configurable set of data, where the real value is the CAD-model itself, with a structure that includes all the different variety of design options. This is kind of a different level thinking and sometimes takes even an experienced CAD-designers to come to that complete understanding. The implementation of new ideas into design practices is a slow process, and usually new ideas may encounter resistance. When work has been done in the same way for a long time, it requires a lot from the organization to adapt to new ideas, and the support of company’s management is significantly high when marketing new engineering practices.

8.5 Novelty value of the results

New theoretical information about modular structure or CAD automation was not produced, but the purpose was to apply existing knowledge to the case of vertical agitator. In the practical part, information about the agitator structure was gathered and analyzed and new knowledge about the utilization of modularity was formed.

8.6 Generalization and utilization of the results

The aim to this study was to produce a product-specific analysis of the challenges of the current state of the engineering process of vertical agitator, and how these could be answered with utilizing its modular structure better as well as utilizing the features of modern CAD software. Based on the practical part of the study, the connection between modular structure and order-related engineering process can be better understood in the future. Based on the analysis of the product, software criteria were also produced, which can be used to compare different software solutions.

8.7 Topics for future research

The benefits of modular product structure and design automation has been examined in this thesis, as well as where modularity could be increased and what features of design automation support the modular structure. However, based on the study, it is difficult to estimate how much benefit can be achieved from the transition from 2D drafting to 3D design. For the information, further research should be done on the topic. For this purpose, a 3D model of vertical agitator could be made, and suitable subassembly selected for easy parametrization. The results presented in the study support the assumption that the features of parametric modeling would make engineering more efficient.

A further research could also be carried out of more accurate cost estimation and payback time for different CAD engineering alternatives in order to determine which level of automation would be the most cost-effective.

9 Summary

The topic of this Thesis was to examine the benefits of automation of modular product in order-related engineering process. The study examined the product’s modular structure, its advantages and disadvantages in order-related engineering process, as well as the possibilities of design automation in terms of more efficient engineering process. The study aimed to demonstrate the connection between modular product structure and order-specific design, as well as how today’s design automation can be utilized in the design of modular product.

Modularity is used in complex product structures. A module is a unit which components are strongly interconnected, but weakly connected to other modules of the product. The product’s modularity aims to taking customer needs into account in the most cost-effective way. As a result of this study, it was observed that modularity brings several advantages, such as faster engineering and assembly processes and a wider product range. By utilizing the features of design programs, the number of errors in the engineering process can be reduced and the necessary drawings and documents can be generated faster.

The work was implemented for the requirements of company Sulzer Pumps Finland Oy and the product presented in the study is vertical agitator. The study was divided into a theory part, which is a literature review of the central concepts of bot modularity and CAD automation. The key steps in practical part were the review and analysis of the product structure of agitator and familiarization with design automation. The study offers information to support the decision-making process either to include or exclude the CAD engineering of vertical agitators into the wider CAD-project and improvement ideas for the engineering process.

References

Andreasen, M.M. 2011. *45 Years with Design Methodology.* Journal of Engineering Design, Vol. 22, No. 5, pages 293-332.

Aouad, G., Wu, S., Lee, A. & Onyenobi, T. 2011. *Computer Aided Design Guide for Architecture, Engineering and Construction.* Routledge, London 2012.

Cabigiosu, A. & Camuffo, A. 2017. *Measuring Modularity: Engineering and Management Effects of Different Approaches.* IEEE Transactions on Engineering Management, Vol 64, No. 1, pages 103-114.

Cardini, M.,Pero, M. & Sianesi, A. 2012. *Linking product modularity and innovativeness to supply chain management in the Italian furniture industry*. International Journal of Production Economics, Vol. 136, No. 1, pages 207-217

Farquhar, J.D. 2012 *Case Study for Business.* SAGE Publications Ltd 2012.

Fatima, U. & Bræk, R. 2016. *Modular Solutions to Common Design Problems Using Activities and the Interface-Modular Method.* International Conference on System Analysis and Modeling. 9th International Conference, SAM 2016.

Fu, F. 2016. *Design and Analysis of Complex Structures.* Design and Analysis of Tall and Complex Structures. Butterworth-Heinemann, 2018. Pages 177-211.

Ghazinoory, S., Abdi, M. & Azadegan-Mehr, M. 2011. *SWOT Methodology: A State-of-the-Art Review for the Past, A Framework for the Future*. Journal of Business Economics and Management, Vol. 12, No. 1, pages 24-48.

Gershenson, J.K., Prasad, G.J. & Zhang, Y. 2004. *Product Modularity: measures and design methods.* Journal of Engineering Design, Vol. 15, No. 1, pages 33-51.

Gosling, J. & Naim, M. 2009. *Engineer-to-order Supply Chain Management: A Literature Review and Research Agenda.* Internal Journal of Production Economics, Vol. 122 (2009), pages 741-754.

Groover, P. 2014. *Automation, Production Systems, and Computer-Integrated Manufacturing.* 3rd Edition. Pearson Education Limited. Edinburgh Gate.

Haug, A., Ladeby, K. & Edwards, K. 2009. *From Engineer-to-Order to Mass Customization.* Management Research News, Vol. 32, No. 7, pages 633-644.

Hietikko, E. 2011. *SolidWorks – Tietokoneavusteinen suunnittelu.* 4th edition. Publication series of Savonia University of Applied Sciences D5/12/2010

Hiltula, K. 2020. *Paperin laskeva kysyntä ajaa tehtaita alas, mutta Kemin biotuotetehtaan toteuttamista se ei uhkaa – ympräistölupaa odotetaan lokakuussa.* An internet article. Yle. [Referred 10.6.2022] Available: https://yle.fi/uutiset/3-11563749

Hiltunen, V. 2017. *CAD-integroitujen suunnitteluautomaattien hyödyntäminen teollisuusyrityksen tuotesuunnittelussa*. Master's thesis. Aalto University.

Huhtala, P. & Pulkkinen, A., 2009. *Tuotettavuuden kehittäminen - Parempi tuotteisto useasta näkökulmasta.* Tampere: Teknologiateollisuus

Jacobs, M., Vickery, S.K. & Droge, C. 2007. *The Effects of Product Modularity on Competitive Performance: Do Integration strategies mediate the relationship?* International Journal of Operations & Product Management, Vol. 27, No. 10, pages 1046-1068.

Kong, F.B., Ming, X.G.,Wang, L., Wang, X.H. & Wang, P.P. 2009. *On Modular Products Development.* Concurrent Engineering 2009; Vol. 17, No. 4, pages 291-300.

Kontinen, T. 2016. *Modulaarisen tuoterakenteen suunnittelu*. Bachelor's Thesis. JAMK University of Applied Sciences.

Laakko, T. 1998. *3D-CAD-suunnittelu*. 1st edition, WSOY Porvoo.

Lapinleimu, I. 2001. *Ideaalitehdas: Tehtaansuunnittelun teorian kiteytys.* 2nd edition. Tampere, Tampereen teknillinen korkeakoulu.

Lehtonen, T. 2007. *Designing modular product architecture in the new product development.* Doctoral Thesis, Tampere University of Technology.

Leu, M.C., Ghazanfari, A. & Kolan, K. 2016. *NX 10 for Engineering Design.* Missouri University of Science and Technology. [Referred 15.6.2022] Available: https://web.mst.edu/~mleu/nx_manuals/nx10.pdf

Lindroos, J-E. & Lohivesi, K. 2006. *Onnistu strategiassa.* WSOY pro, Helsinki.

Lindström, M. 2021. *Ilmastonmuutoksen hillintä kasvattaa metsäteollisuuden tuotteiden globaalia kysyntää.* Metsäteollisuus [a blog text]. [Refferred 10.6.2022] Available: https://www.metsateollisuus.fi/uutishuone/ilmastonmuutoksen-hillinta-kasvattaa-metsateollisuuden-tuotteiden-globaalia-kysyntaa

Little, D., Rollins, R., Peck, M. & Porter, J.K. 2000. *Integrated Planning and Scheduling in the Engineer-to-Order Sector.* Internal Journal of Computer Integrated Manufacturing, 2000, Vol. 13. No. 6, pages 545-554.

Marshall, R. 1998. *Design Modularisation: a Systems Engineering Based Methodology for Enhanced Produtct Realisation.* Loughborough University

Mercer, T. 2000. *CAD/CAM Selection for Small Manufacturing Companies.* A Research Paper. University of Wisconsin. Available: https://minds.wisconsin.edu/bitstream/handle/1793/39603/2000mercert.pdf

Miller, T.D. & Elgård, P. 1998. *Defining Modules, Modularity and Modularization: Evolution of the Concept in a Historical Perspective.* Proceedings of the 13th IPS Research Seminar, Fulgsoe, Aalborg University.

Newcomb, Rosen & Bras. 2003. *Life cycle Modularity Metrics for Product Design.* 2003 EcoDesign 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing, pages 251-258.

Pahl, G., Beitz, W., Feldhusen, J. & Grote, K.H. 2007. *Engineering Design – a Systematic Approach.* Third Edition. Springer-Verlag London Limited 2007.

Pakkanen, J., Juuti, T. & Lehtonen, T. 2016. *Brownfield Process: A method for Modular Product Family Development Aiming for Product Configuration.* Design Studies. Vol. 45, part B, pages 210-241.

Paloniemi, M. 2017. *Siirtyminen 2D-suunnittelusta 3D-suunnitteluun.* Master's Thesis. Aalto University.

Pere, A. 2012. *Koneenpiirrustus 1 & 2.* 11.painos. Kirpe Oy, Espoo 2012.

Powell, D. 2014. *A New Set of Principles for Pursuing the Lean Ideal in Engineer-to-order Manufacturers.* Procedia CIRP, 17, pages. 571-576.

Pulkkinen, A. 2007. *Product Configuration in Projecting Company: the Meeting of Configurable Product Families and Sales-Delivery Process.* Doctoral dissertation. Tampere University of Technology.

Pöytäniemi, E. 2013. *Luomutuotteiden vientipotentiaalin analyysi.* Pro Luomu Ry. [Referred 20.6.2022] Available: https://www.yumpu.com/fi/document/read/15731933/luomutuotteiden-vientipotentiaalin-analyysi/21

Rapinoja, J-P. 2018. *Tuotemäärittely 3D-malleissa.* Valokynä, Vol. 4/2018, pages 8-11.

Rapinoja, J-P. 2016. *Malliperustaisen tuotemäärittelyn (MBD) mahdollisuudet.* Metsta-raport. [Referred 12.7.2022] Available: https://metsta.fi/wp-content/uploads/2020/08/MBD-raportti-2016.pdf

Rossi, F., Arfelli, S., Hu, S.J., Tullio Antonio, M.T. & Freiheit, T. 2019. *A Systematic Methodology for the Modularization of Manufacturing Systems During Early Design.* Flexible Services and Manufacturing Journal, Vol. 31, No. 4, pages 945-988.

Sanchez, R. & Mahoney, J.T. 1996. *Modularity, Flexibility and Knowledge Management in Product Organization Design.* Strategic Management Journal, Vol. 17, No. S2, pages 63-76.

Salchner, M., Stadler, S., Hirz, M. & Mayr, J. 2016. *Multi-CAD Approach for Knowledge-Based Engineering.* Computer-Aided Design and Applications. Vol 13, No. 4, pages 471-483. ISSN 1686-4360.

Salonitis, K. 2014. *Modular design for increasing assembly automation*. CIRP annals. Vol. 63, No. 1, pages 189-192.

Seppänen, K. 2019. *Modulaarisen tuoteperheen ja tuoetarkkitehtuurin suunnittelu*. Bachelor's Thesis. LAB University of Applied Sciences.

Shaik, Rao & Rao. 2015. *Development of Modular Manufacturing Systems – a Review.* The Internal Journal of Advanced Manufacturing Technology (2005) 76, pages 789-802.

Shih, R. 2018. *Parametric Modeling with NX 12.* SDC Publications.

Siemens. 2019. *Getting started with NX Open.* Siemens Guide. Siemens Product Lifecycle Management Software Inc. Available: https://docs.plm.automation.siemens.com/data_services/resources/nx/1847/nx_api/common/en_US/graphics/fileLibrary/nx/nxopen/NXOpen_Getting_Started.pdf

Sinz, C et al. 2007. *Configuration.* IEEE Intelligent systems. Vol 22, No. 1, pages 78-90.

Sommerville, I. 2016. *Software Engineering*. 10th edition. Pearson Education Limited 2016.

Sulzer. 2022a. *Our company*. Website of Sulzer. [Referred 15.4.2022] Available: https://www.sulzer.com/en/about-us/our-company

Sulzer. 2022b. *Our divisions.* Website of Sulzer. [Referred 15.4.2022] Available: https://www.sulzer.com/en/about-us/our-company/our-divisions

Sulzer. 2022c. Sustainably successful since 1834. Website of Sulzer. [Referred 15.4.2022]. Available: https://www.sulzer.com/en/about-us/our-company/history/21st-century

Sulzer. 2021. Sulzerin sekoittimet –webinar. [Referred 15.4.2022] Available: https://www.youtube.com/watch?v=gkx_Jp-62mo&t=605s

Tanska, T. & Österlund, T. 2014. *Algoritmit puurakenteissa – menetelmät, mahdollisuudet ja tuotanto.* DigiWoodLab. Oulun Yliopisto. Julkaisu B 32. 1.painos.

Tuhola, E. & Viitanen, K. 2008. *3D-mallintaminen suunnittelun apuvälineenä.* Tammertekniikka 2008, 1.painos. Gummerus Kirjapaino Oy, Jyväskylä.

Ulrich, K. 1995. *Product architecture in the manufacturing firm.* Research Policy 24(3), pages 419-440.

Ulrich, K. & Tung, K. 1991. *Fundamentals of product modularity.* Design -Manufacture Integration 1991 39, pages 73-79

Windheim, M. 2020. *Cooperative Decision-Making in Modular Product Family Design*. 1st edition. Springer Berlin Heidelberg, 2020.

Wolfe, L.S. 2010. *9 Criteria for choosing a 3D CAD System.* [Referred 10.6.2022] Available: https://www.solidworks.com/sw/docs/Top9_WP_2010_ENG_FINAL.pdf

Worldwide CAD Trends 2018/19. Business Advantage. A Survey Results report, available: https://www.business-advantage.com/CAD-Trends-Results-2018.php

Yang, L. 2013. *Key Practices, Manufacturing Capability and Attainment of Manufacturing Goals: The perspective of Project/Engineer-to-order Manufacturing.* International Journal of Project Management, Vol. 31, No. 1, pages 109-125.

Yu, S., Yang, Q., Tao, J., Tian, X. & Yin, F. 2011. *Product Modular Design Incorporating Life Cycle Issues – Group Genetic Algorithm (GGA) Based Method.* Journal of Cleaner Production. Vol.19, issues 9-10, pages 1016-1032.

Österholm, J. & Tuokko, R. 2001. *Systemaattinen menetelmä tuotemodulointiin.* MET-julkaisuja no. 21/2001. Metalliteollisuuden Keskusliitto MET. Vantaa 2001.

Presentations and interviews:

Uski, P. 2021. Etteplan. Webinar about current trends. 20.10.2021 via Teams.

Tjurnev, E. & Renko, J. 2022. Ideal PLM. Presentation. 29.4.2022 via Teams.

Appendix 1. SWOT 1: Modular product structure.

INTERNAL FACTORS	
STRENGTHS + (S)	**WEAKNESSES – (W)**
• **Simple product structure:** standardized modules are easier to assembly (Marshall 1998), easy jointing in final assembly, one assembly location requires no heavy transports. Details in production minimized and simplified by modular structure (Suolahti 2009). • **Shorter design time:** a lot of standard components (Österholm & Tuokko 2001), small number of parts and variants (Shaik & al. 2014). Specified design required only in special cases (Pahl et al. 2007) • **Control of schedules**: more accurate estimation of delivery times and designing time (Pahl et al. 2007) • **Better quality**: less defects due to repeatability in assembly, less component waste (Pahl et al. 2007). • **Ready documentation**: Faster tendering and design process (Pahl & al. 2007)	• **Customer specific needs hard to implement** in modular structure (Pahl et al. 2007): hard to customize products if needs don't fit into modular structure, increases the design time • **Hard structure**: Standard structure includes a lot of variants, well-organized product data management is required. • **Increased amount of product variants**: amount of variants increases over time due to different projects and orders. If all variants are added to model library, management of models becomes time consuming, if amount of variants is kept small, there is need for more project/order specific engineering.
EXTERNAL FACTORS	
OPPORTUNITIES + (O)	**THREATS – (T)**
• **Outsourced modules**: Only tested and intact modules bought (quality improvement), modules bought when needed (storage capacity), complex manufacturing processes outsourced, standard suppliers (collaboration) • **Recycle** of modules: possibility to plan recycling and limit the use of harmful substances to minimum number of modules • Easier **maintenance and replacement of modules**: module specific service and replacement (Pahl et al. 2007).	• **Economical crises:** supplier difficulties, long delivery times, hard to forecast availability

Appendix 2. SWOT 2: Order-related engineering.

INTERNAL FACTORS	
STRENGTHS + (S)	**WEAKNESSES – (W)**
• Suitable for implementation for **individual customer requirements** (Gosling & Naim 2009). Customers of ORE design environment are used to products being designed just for them (Haug et al. 2009). • **Dynamic interface between production and engineering** (Gosling & Naim 2009): enables improved control of the process (quick feedback, collaboration). • **No final product stock:** production operates with small material stocks, components and materials bought order-specific, required storage space is small	• **Cost estimation** not always accurate**:** the product details are designed when the order is confirmed • **Engineering required also in tendering phase:** this work doesn't always lead to an order • **Complex products and increased number of variants**: a well-organized product data management required • **Pre-production not usually possible:** forecasting demand is difficult due to the customized products (Powell 2014). • **Long delivery times** for customer: due to small material stocks • **The amount of re-work** is bigger in ETO-chains due to poor coordination between departmens (Little et al. 2000), and the nature of ETO-chain (possible order changes in late stage of production)
EXTERNAL FACTORS	
OPPORTUNITIES + (O)	**THREATS – (T)**
• **Wider product range:** a large number of product variants when products are engineered based on customer requirements • Order-related engineering -products typical for **project-specific industries** (Yang 2013): schedule orientated approach, on time deliveries, JIT-strategy • **Specialized knowledge** and engineering skills improved due to complex products and special variants.	• **"No standard ETO-product"** (Little & al. 2000): the use of non-standard components can be high • **Customer first- thinking:** common feature of order specific products is order changes during manufacture (Little et al. 2000): agility of manufacturing processes needed