Design Configurator – Managing the Order Engineering Challenge in ETO Companies

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Configurators are fundamental tools in mass customization. Among sales and product configurators a new type of configurator is identified, described and analyzed for use in order-engineering field in capital goods industry: design configurator. It is used to automate the order engineering and decrease lead-time for product quotations and customized designs. By doing so it brings ETO companies closer to pure mass customization. By examining the concept of design configurator industry practitioners can understand the possibilities and limitations resulting from the taken approach to mass customization. This study will also benefit other industrial contexts when considering a configurator solution. By combining the whole of research on the design configurator and giving further research directions this study works as a baseline for connecting future research studies on similar areas.

Keywords: Configurator, mass customization, order engineering, information systems, design

Foreword

It was my hope and dream to one day be able to write on something that actually mattered. There was no other way if I wanted to stand behind my works and say I made an actual mark on somewhere. The world might not be hugely better place afterwards but at least this way the stain on the tablecloth will be visible... It was a long stretch of 3 years but with a solid purpose – bringing the whole concept under one understandable blob of creation. None of this would have been possible without the great work environment and former work colleagues of CIRCMI research group at University of Tampere. Especially Marko Mäkipää, who helped a young researcher get his feet wet and Timo Ingalsuo for the countless hours of argumentative reasoning for topics unknown. It is my strong intention and naïve hope that this study can be used for future research and direction of thought when considering the ETO challenge and configurators.

To my dear friend Tomi Hyvönen – the brightest star in northern hemisphere, after Sirius of course..!

"On the edge everything seems so clear – and then you trip." –RipperJack

Helsingissä 8.6.2014

Pasi Paunu

Contents

List of original publications

P. Paunu, M. Mäkipää, Design Configurators in a Project Business. In: *Bridging Mass Customization & Open Innovation. Proceedings of World Conference on Mass Customization, Personalization, and Co-Creation,* H. Chesbrough, F. Piller (Eds.), Lulu Inc, Raleigh, 2011, 44.

M. Mäkipää, P. Paunu, T. Ingalsuo, 2012. Utilization of Design Configurators in Order Engineering. *International Journal of Industrial Engineering and Management*, 3, 223-231.

P. Paunu, M. Mäkipää, Design Configurator Requirements for IS Integration. In: *Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014)*, *Lecture Notes in Production Engineering,* T. Brunoe, K. Nielsen, K. Joergensen, S. Taps (Eds.), Aalborg, Denmark, Springer International Publishing Switzerland, 2014, 129-138.

1 Introduction

Mass customization has been seen to bring solutions for the highly turbulent and fragmented field of mass production [Mueller-Heumann, 1993; Hart, 1995]. The general perception is that by enabling flexible processes and organizational structures mass customization can permit a company to provide “tremendous variety and individual customization, at prices comparable to standard goods and services” [Pine, 1993]. The term was first coined in [Davis, 1987] as to offer individual attention to a large number of customers in the mass markets of industrial economy through customized products and services similar to the markets of pre-industrial economies. Simply put mass customization is defined here as comprising of “the technologies and systems to deliver goods and services that meet individual customers’ needs with near mass production efficiency” [Tseng and Jia, 2001]. In the research field of mass customization, the paradigm is usually presented as a solution for companies manufacturing customized consumer products.

In the past few years more papers have examined the definition of mass customization (MC) from the perspective of capital goods industry where products have continued to be highly customized to customer specifications, vastly complex and built in job-shop facilities [Lampel and Mintzberg, 1996]. For capital goods industry, this is almost the exact opposite approach to mass customization than in consumer goods industry which starts of from pure standardization moving towards product and process modularity. Coming from the pure customization end of the MC spectrum it is especially challenging for an engineering-to-order (ETO) company to reach and benefit the field of mass customization. Customers demand products and services that match exactly their preferences but they also understand the flip side which consists of higher prices and longer delivery times because of the individual design and design process lead-time. For an ETO company the drive towards mass customization comes from the need of shortening delivery times, handling of product variety and cost reduction. This thesis examines, identifies and describes a solution for fulfilling these needs through a specific configurator defined here as the design configurator. It has practical implications and illustrated implementations which can be taken further in both research and development in the industry. The thesis also contributes to the stream of configurator research in the field of

MC and capital goods industry as it brings ETO companies' closer to mass customization.

The main theoretical approach used in this study is a conceptual-analytical research method supplemented by an illustrative case study to complement the concept and model of design configurator being described. The main research questions are: 1) what is a design configurator, 2) how can it be utilized in an ETO company in capital goods industry and 3) what are the requirements of a design configurator for information systems integration?

In previous studies like [Forza and Salvador, 2007; Myung and Han, 2001; Simpanen, 2010] similar configurator approaches have been introduced but none have been able to provide a comprehensive solution to handle the whole process of order-delivery chain in an ETO context. This study will show a new configurator based solution, utilizing parametric product models, which can bring an ETO company in pure customization closer to the core of pure MC. The concept will be identified, described and analyzed to illustrate a manageable shift toward mass customization.

The structure of the thesis is divided in to several sections each contributing to the overall definition and understanding of the design configurator. In Sections 1, 2 and 3 the background and definitions for the mass production and mass customization are given. In Section 4 the area of specialty in this study is presented and continued in Section 5 to clarify the differentiation and characterization of known configurators including the essence of this thesis the design configurator. Section 6 describes the research approach and objectives and Section 7 summarizes the three research articles shown last in the thesis. Finally the discussion and conclusions are given in Section 8.

2 Production and standardization

Throughout their history, industrial production and manufacturing have been forced to evolve and change breaking new ground for more competitive advantage in each era. From centuries of pure craftsmanship solely holding the economic production in its grasp the industrial revolution brought mechanization and machinery in its wake in the late nineteenth century [Pine, 1993; Mäkipää and Mattila, 2004]. This paved way for the next big paradigm shift in the form of mass production notably considered started from the assembly line of Ford Motor Co. Model-T car around 1913. In the idea of mass production it makes "goods at a consistent quality and affordable prices" [Blecker et al., 2005] meaning standardized products with the lowest cost possible. It is the "shared goal of developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them" [Pine, 1993]. While the model-T car is a perfect example of a standardized product and mass production ideology it also illustrates mass production's inherit challenge like Henry Ford so eloquently, though unintentionally, put it "Any customer can have a car painted any colour that he wants so long as it is black" [Ford, 1922]. The paradigm works best in the service of homogeneous markets where the customers only shift to another product if their needs are not fulfilled by one particular mass produced product [Lampel and Mintzberg, 1996].

Through this new way of specializing and standardizing work alongside manufacturing processes, also in some contexts named Fordism [Gilbert, 1992], mass production quickly lead to huge improvements in both lowering manufacturing costs and making throughput times faster. Specialized machines, repetitive work and strict workflow in the production line made it all quite manageable. Still, challenges were ahead. Globalization opportunities, shorter product life cycles and fragmented markets generated quite enough troubles for firms making a one-trick-pony kind of production. Customer demands and rapidly changing markets to niche specialties of mass produced products didn't help a very strictly designed manufacturing scheme. Mass manufacturing with high product variety could not deliver the low cost it was thought for. [Lau, 1995.] Another shift was in the horizon.

After the 1950s and some good years of economic growth the mass markets were quite saturated. The needs to satisfy specific customers' as well as the 'average' customer became more and more apparent. At this time companies either produced solely crafted e.g. customized products or went with the mass production way to output standardized goods [Duray, 2002]. Because of saturated markets where customers demanded more variability and unique features the world was about to shift towards a more unstable and less controlled state. In America this pushed production firms towards a new paradigm where customization and variety were created through quick responsiveness and flexibility - the heart of mass customization [Pine, 1993]. In the 1990s economies of scale based approach [Panzar and Willing, 1977] got a new companion, the economies of scope [Teece, 1980], where production was joined by both mass production and very high product variability [Mueller-Heumann, 1992]. It became possible to satisfy both large markets and have somewhat 'tailored' production. Swift advances in IT – technology and manufacturing have played a key role enabling this transition. Figure 1 illustrates the implications of these economies in mass produced products.

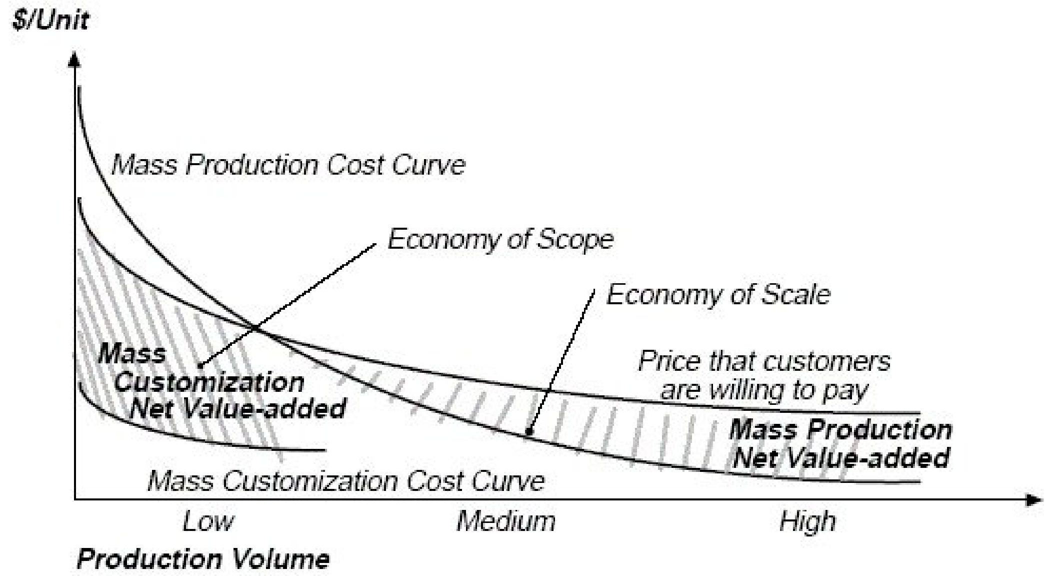

Figure 1. Economic Implications of Mass Customization [Tseng and Jiao, 1996]

In high-volume production, the expensive machinery, tools and engineering know-how can typically be covered by producing large volumes of goods getting them a lower average cost. However when trying to accommodate every customer's individual need a low production volume is almost impossible to avoid and might make production economically catastrophic. This is even if a higher price could be gained from the differentiated product and its purchase transaction. The manufacturing systems and processes are too rigid and inflexible. Contrary to former in economies of scale the production repetition must be increased, processes streamlined, size and speed of operation grown. Through a single process, a greater variety of products can be developed with lower costs. Advances in manufacturing industry and flexible production processes allow the reduction of the average cost per unit and lower lead-times which can make higher margins thus achievable. [Tseng and Jiao, 1996; 2001; Pine, 1993.] The road to mass customization is open.

3 Mass customization

The term mass customization was first anticipated by [Toffler, 1971] but later coined as 'mass customization' by [Davis, 1987] where it was described as being the solution for "targeting a large number of customers as in the mass markets of the industrial economy and offering them individualized attention, as in the customized markets of pre-industrial economies." [Mäkipää et al., 2012.] In this thesis a more pragmatic definition is used which states it to be "the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency" [Tseng and Jia, 2001]. Simply put mass customization is the ticket for turbulent and complex markets through flexible and quick responsiveness where people, processes, technology and units reconfigure themselves to give the customers exactly what they want. In addition it requires the right coordination of independent and competent individuals.

Mass customization (MC) is not something that a firm can simply move onto as the next best thing. It is already by itself a very dynamic and multifaceted concept that will require a firm to change large portions of its business strategies from process and product customization to customer-centric product creation involvement [Tseng and Piller, 2003]. One prominent illustration of this transition is the change of product and process in Figure 2.

Product change		Process change	
	Dynamic	Mass Customization	Invention
	Stable	Mass Production	Continuous Improvement

Figure 2. Product - Process change matrix [Boynton and Victor, 1991]

The horizontal axis describes the capabilities of change in a firm from stable and evolutionary to more rapid and dynamic state where the environment requires constant refinement of capabilities making the old know-how and experiences obsolete. This includes organizations ability to market, develop, produce and deliver its products. Similarly the vertical axis of Figure 2 illustrates the change of products from very standardized to highly customized goods and services. Typically a firm incorporating mass production sits in the lower-left corner of the process change matrix. It produces standardized products in a stable environment. However when markets demand change they move diagonally to the upper-right corner to make new inventions for their product line and come back after the generation of specialized processes are in place. Firms wanting to face the more turbulent market environment need to start moving to the lower-right hand corner where the continuous improvement of processes happens. A firm must be ready to re-engineer its capabilities to improve the flow of products which will eventually lead to the upper-left corner of mass customization. [Pine, 1993.]

When a firm starts to consider its path to MC, it needs to understand if the root ideas of MC are actually present yet. Firstly, flexible manufacturing and information technologies are required to enable the production system to deliver goods at higher variety and at lower cost. Secondly, there needs to be an increasing demand for product variety and customization from the customers on the market to which the firm is targeting its efforts, and thirdly a strong focus on strategies that place the individual customer in the production spotlight [Hart, 1995; Silveira et al., 2000]. In [Salvador et al., 2009] these are identified as the three fundamental capabilities which the company needs for MC to be properly adapted on its offerings: solution space development, robust process design and choice navigation.

For company to fully leverage MC strategy the first step is to understand the plethora of needs customers present and derive effective and manageable solution base to offer enough variability to nearly all customers individually. This is more than just a market research as the company needs provide large pools of customers the means of communicating and translating their needs into real product variants. This enables customers to also highlight needs that might have not otherwise been satisfied nor known beforehand. Second step is to provide testing and evaluation possibility for the created virtual product prototype. These have been seen to save costs for the company and create customer satisfaction. Third and the last part in the solution space development is the gathering of customer experience intelligence. The company needs to have a tool to combine the customer experience information from the toolkit software platform, meaning logs and other linked data, where the behaviors and product related transactions happen between the customer and the company’s product(s). [Salvador et al., 2009.]

In [Piller, 2004] the solution space development is similarly seen as comprising of three combining approaches to enable positive solution space development:

1. The differentiation of customized products & services
2. Production effectiveness
3. Customer integration through communication and commitment

This differentiation is very similar to [Salvador et al., 2009] but gives more emphasis on the definition of the whole universe of options and pre-defined components which determine “the universe of benefits that an offer intends to provide to customers, and then within that universe, the specific permutations of functionality that can be provided” [Piller, 2004].

To achieve the efficiency and reliability for increased product variability the company needs to seek solutions that enable a flexible automation in production whether the product is tangible or intangible. New technologies have made this possible with e.g. robots that can handle multitude of different tasks in the production line. More rigorous requirement is the ability to modularize processes and products. By this the company needs to be able to sift and segment processes in both operational and value-chain segments and link them to specific variability source coming from the customers’ needs. Finally the human capital needs to be closely managed so that individual employees from managers to floor craftsmen can handle new and more ambiguous tasks. [Salvador et al., 2009.]

Customers should not get lost in the universe of options while trying to match their individual needs. Therefore a company must employ a software, a type of a configurator, which can match and understand the characteristics of customer’s needs and offer, from the set of solution space options, close enough matches and recommendations. It should be able to reconfigure itself according to customers’ choices. The software should also enable the customer to interactively test the models of the platform which make recommendations. This intensifies the commitment for the customer through trial-and-error learning. [Salvador et al., 2009.]

4 Capital goods in manufacturing

In the field of mass customization, a large portion of research concentrates solely consumer goods. Also the vast amounts of literature of mass markets on consumer products and their customization reflect this notion. This study concentrates on the other end of the mass production spectrum to a field of industrial manufacturing and specifically Engineering-to-Order (ETO) business. A long time this specialized area was though impossible to implement true mass customization strategies and processes. This was namely due to a fact that the products in the industry are almost always uniquely built, highly customized and the demands of customers are different after every production cycle even with the same customer [Paunu and Mäkipää, 2011]. In addition the production process structure, expert customers, delivery time issue and products that require order engineering differentiate this field from the consumer goods even more. A detailed explanation of this is given in the [Mäkipää et. al., 2012].

Considering a simplified categorization of mass customization typology by [Duray et al., 2001] we can try to fit a typical ETO company into one of four different approaches based on the fact that mass customizers could be classified by two characteristics: 1) by the point where the customer gets involved in the production cycle with the specification of a product and 2) by the type of product modularity which is being implemented [Duray et al., 2001]. From this the four types of MC archetypes are listed:

1. Fabricators
2. Involvers
3. Modularizers
4. Assemblers

Unfortunately, the typology lacks a clear distinction between the edges of mass producers and pure customizers which makes the categorization of a typical ETO company here rather pointless. That is because an ETO company can be specified as belonging to any and all four archetypes of MC approach as it more or less utilizes all the angels in its business [Haug et al., 2009]. Still because a typical ETO company's products fall under the category of pure customization, it does not belong to the MC definition sweet spot. The company can benefit from the modularization and standardization of its offerings and thus from the movement towards MC, the top left corner of the process change matrix in Figure 2, but the inherit challenge still remains for the most products needing order engineering. Therefore to better understand the field of ETO in the MC spectrum we now divide the strategies of MC into eight different categories depending on the overall capability of the company doing mass manufacturing. In [Silveira et al., 2000] these MC strategies, a combined product of [Lampel and Mintzberg, 1996] and [Pine, 1997], are listed as generic levels of firms' strategy to implement mass customization: 1) Standardization, which is the lowest stage of MC consisting only on the pure standardization of products e.g. LEGO blocks 2) Usage, where the mass customization is understood to happen only after the delivery of the products as they are adapted according to different situations e.g. Lutron's lighting system noted in [Pine, 1997] 3) Package and distribution, where the goods are packaged different ways suiting e.g. specific market areas or segments 4) Additional Services and 5) Additional custom work, which both include additional custom work done to the ready-made product, usually at the point of delivery e.g. Ikea's furniture [Davis, 1987] 6) Assembly, where modular components are arranged to different configurations as per customers' requests as in Dell's computer order configuration platform [Dell, 2014] 7) Fabrication, depicting strategy where the product is custom tailored inside a specific pre-designed design e.g. men's black suits 8) Design, which denotes a fully customized product in collaboration with the customer and manufacturing to deliver the product exactly as the customer needs and wishes. [Silveira et al., 2000.]

In this study the main focus is on the last level of this framework, design. It is also from this level and edge of customization that this study shows how an ETO company can: 1) close the gap between MC and pure customization 2) increase the delivery speed 3) retain the price point of products and 4) do all this without losing too much of product variance and dynamic production capabilities. In Figure 3 this gap is illustrated from the point of manufacturing processes.

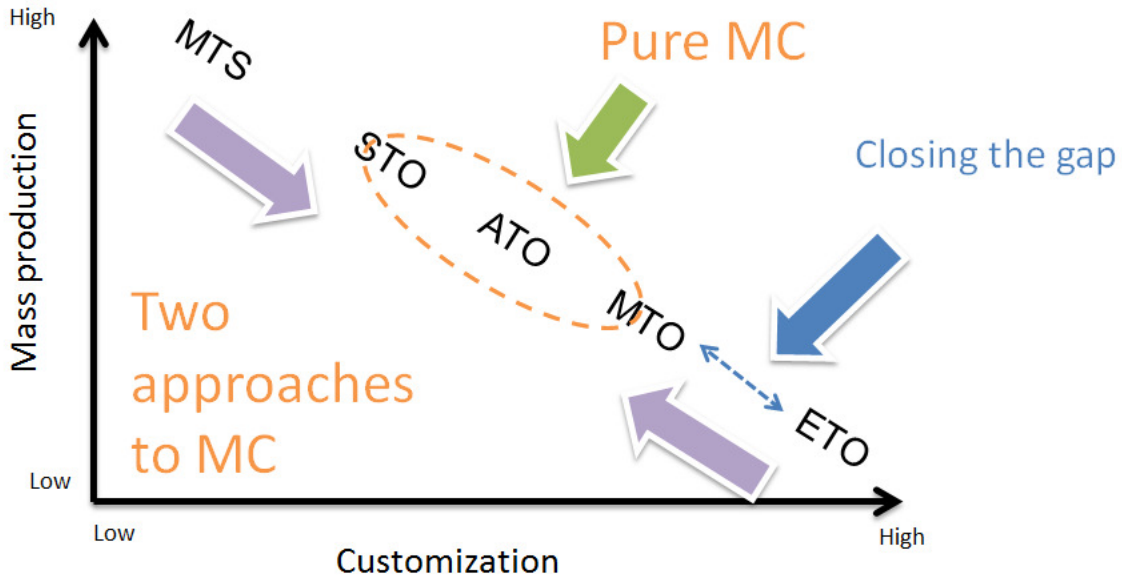

Figure 3. Manufacturing processes of mass production, modified from [Ahoniemi et al., 2007]

The horizontal axis describes the customization level of a company whereas the vertical axis shows the mass production ability. From a pure standardization point of make-to-stock (MTS) to pure customization of engineering-to-order (ETO) the middle part of pure mass customization, ship-to-order (STO), assembly-to-order (ATO), make-to-order (MTO), can be highlighted. Coming from two edge approaches a firm moves closer to a pure customization definition [Ahoniemi et al., 2007]. A similar way of differentiating manufacturing processes is seen in [Wikner and Rudberg, 2001] where a customer order de-coupling point (CODP) is introduced. The concept denotes the point where a product is linked to a customer order within the manufacturing process. In Figure 3 pure ETO strategy is shown to differ greatly from the other MC strategies as the engineering work needs to be done to each order while in other strategies it has already been done to some extent [Rudberg and Wikner, 2004; Haug, 2009].

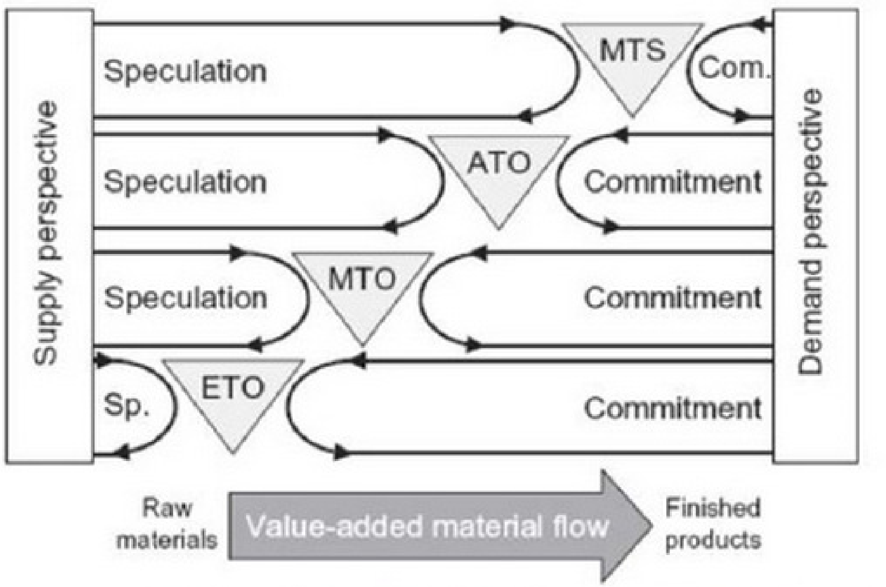

Figure 4. Customer order de-coupling point [Wikner and Rudberg, 2001]

In other words there is less supply speculation and more customer commitment in the overall process when moving downward in the CODP illustration from standardization towards pure customization in ETO. To summarize in [Haug, 2009] five distinct characteristics were found to illustrate the prerequisites for mass producers and pure customizers on the path toward mass customization: 1) product variety 2) customer view 3) manufacturing costs 4) business purpose and 5) configurator challenge. In this study the configurator challenge of an ETO company is explored in-depth.

5 Configurators

The essence of this thesis is configurators, namely a new concept called design configurator. The overall distinction between configurators is given here but the new concept only briefly explained as the gist of it is introduced and elaborated in detail in the articles that follow.

The basis for constructing any configurator is the design of a configurable product. This specifies the elements and the set of rules to combine a product that meets the customer's needs and requirements [Salvador and Forza, 2004; Tiihonen and Soininen, 1997]. These requirements are met by applying the process of a product configuration. The potential in this product configuration process can be expressed through the form of generic product structures which are commonly recognized as configuration models [Männistö, et al., 1996]. These models describe a specific product family which is a compound of all possible product variants that can be created generically through a given configuration model [Inala, 2007]. The connection to mass customization will now be defined.

As the key principle of mass customization states there should be a mechanism for interacting with the customer and gathering detailed information to define and translate the needs and wishes of a customer to a concrete product or service specification [Franke and Piller, 2002]. This often requires an instrument or a tool to gather customer requirements e.g. a configurator [Zipkin, 2001]. They provide choice navigation, a product combination and even a learning platform for customers, sales personnel and technical experts in varying contexts of consumer and capital goods industries. These interaction systems, thus, guide the user through the configuration process as a whole [Franke and Piller, 2002]. A good general definition of a configurator is that it's "software with logic capabilities to create, maintain, and use electronic product models that allow complete definition of all possible product options and variation combinations, with a minimum of data entries and maintenance" [Bourke, 2000]. In addition mass customization toolkits, here referred as configurators, were recognized in [Franke and Piller, 2002] to consist of three main components:

1. The core configuration platform for presenting viable variations, asking questions or showing design options, guiding the user through the configuration, and checking the manufacturability and consistency.

2. A feedback tool for presenting the current configuration by relaying the information of a design variant as visualization or by other forms e.g. a feature model, a functionality test or price information. The tool also provides the trial-and-error learning platform for the user.
3. Analyzing tools translating for the customers' order for construction plans, building materials and work schedules. These tools usually push the configuration information also to other departments e.g. manufacturing.

In existing literature there are often discussed only of two distinct configurators: sales and product configurators. This study extends this field by defining a third configurator, design configurator. Establishing a good classification between the three configurators, a comprehensive Table 1 of configurators can be observed in [Blecker et al., 2005] which was made to combine many different classification schemes in the research area of configurators.

Knowledge base	Rule-based	Model-based	Case-based	
Strategy	Fabricators	Involvers	Modularizers	Assemblers
Organization	Central	Distributed		
Internal/external	Internal	External		
Interaction nature	Online central data processing	Online local data processing	Offline	
Updates' execution	push	pull		
Scope of use	Single-purpose	General purpose		
Complexity	Primitive	Interactive	Automatic	
Integration level	Stand-alone	Data-integrative	Application-integrative	
Solution searching approach	Technical elements	Features		
Product life cycle support	Configurator without reconfigurator	Separate configurator and reconfigurator	Integrated configurator and reconfigurator	

Table 1. Classification of configurators [Blecker et al., 2005]

Though the matrix in Table 1 has been made from the standpoint of product configurators, it illustrates fairly accurately the plethora of options how a configurator could be made and from which point of view a company can and should consider a configurator to be implemented. The leftmost column represents the classification area and the columns to the right the choices in that classification. The dotted lines in the table represent an example in [Blecker et al., 2005] of a web based configurator and its implementation choices.

Continuing to distinguish the three configurator types, a typical sales configurator is used to gather customer requirements, preferences and choices and also demonstrate product qualities which can be translated into a specification of parts and production information [Heiskala et al., 2010]. Through these, an order can be actualized and the actual product delivered to the customer depending on the manufacturing model and strategy of the company behind the product or service. These configurators are mostly operated by sales personnel or customers directly and in capital goods industries by technical sales personnel [Mäkipää et al., 2009]. The crux is the central integration of customer to the supplier's value creation through the configurator. Usually a sales configurator offers a basic user interface through which the configuration process is maintained. An example of this can be observed in [NikeID, 2014] which is a web based shoe sales configurator. The dotted line in Table 1 also marks a valid sales configurator classification path.

Contrary to the sales configurator a product configurator is typically used internally by the company sales or technical personnel. They handle and support the transformation of product information, a set of the available attributes of components and combinations thereof, to a specific manufacturing scheme in order to produce goods being configured [Tiihonen and Soininen, 1998]. They may also use the output of separate sales configurator as the base input of their configuration process. More adequately defined a product configurator "captures and manages the definition of a unique product or variant" [Bourke, 2000]. Therefore, especially in capital goods industries, these configurators are usually made to handle the complexities of manufacturing that happen in the sales-delivery process of a company [Tiihonen and Soininen, 1997]. Often product configurators are built into or provided as modules in different product data management (PDM), product lifecycle management (PLM) and enterprise resource planning (ERP) systems to manage bill-of-materials with structural and cost information of product variants. In the classification matrix Table 1 a typical product configurator would have a dotted line crossing boxes: rule-based, modularizers, central, internal, offline, push, single-purpose, interactive, data-integrative, technical elements and configurator without reconfigurator.

An example of a product configurator can be viewed in [Tacton, 2014] which is a configurator solution for PDM, PLM, CRM and CAD integration.

Now a third kind of configurator is introduced: a design configurator. The main idea is to make automated order engineering processes possible for ETO companies and shorter their lead-times thus bring them closer to mass customization definition. The configurator handles the whole order engineering process and automates the tendering and design phase leveraging CAD and PLM platforms to generate a unique product variant from parametric skeleton models. Through this operation a ready-made bill-of-materials and product description with all needed documentation and other information are created. This can include the information ready to be pushed to manufacturing. Typical users for the configurator are the technical sales personnel in an ETO company. [Mäkipää et. al, 2012.] A similar configurator, named meta-configurator, was introduced in [Forza and Salvador, 2007] which also based its overall functionality to parametric models. The fundamental difference is that it enables the design of products through approximation, like in [Simpanen, 2010], whereas the design configurator makes the product final. Considering the design configurator against Table 1, a typical example of it would produce the following details as the dotted line's path: model-based (by logic engine), fabricators / involvers, central, internal, online local data processing, pull / push, general purpose, automatic, technical elements, integrated configurator and reconfigurator. In some cases the configurator is a hybrid of things and therefore can be seen to include more than one classification attributes from single characterization line. A good example of a design configurator was brought to public in [Cargotec, 2012]. A detailed definition, illustration and requirements are given in the articles of this thesis.

6 Research objectives and methods

This study as a whole and through each research paper focuses on using the conceptual-analytical research method as depicted in [Järvinen, 2001; Järvinen and Järvinen, 2004]. It also supplements an illustrative case study on the mix to complement the concept and model of the design configurator being described. The method answers a question of how to derive a theory, model or a framework to describe a phenomenon or parts of reality. In a case of explaining the usage of computer by a user this can be done 1) by deriving theoretical assumptions concerning the user or the computer 2) generalizing the results of previous empirical studies and the observations made by the researcher [Järvinen 2001]. General research objectives in the stream of these research articles are to identify, illustrate and explain a new configurator model within the framework of configurators in mass customization. This is done 1) by identifying a new configurator concept via the first research article which generalizes aspects of empirical feasibility study 2) next by establishing and illustrating the model within the framework of configurators in mass customization and 3) by explaining requirements for the established configurator through illustrative case example in the last article. The overlap and composition of articles connecting to larger area of mass customization are shown in Figure 5.

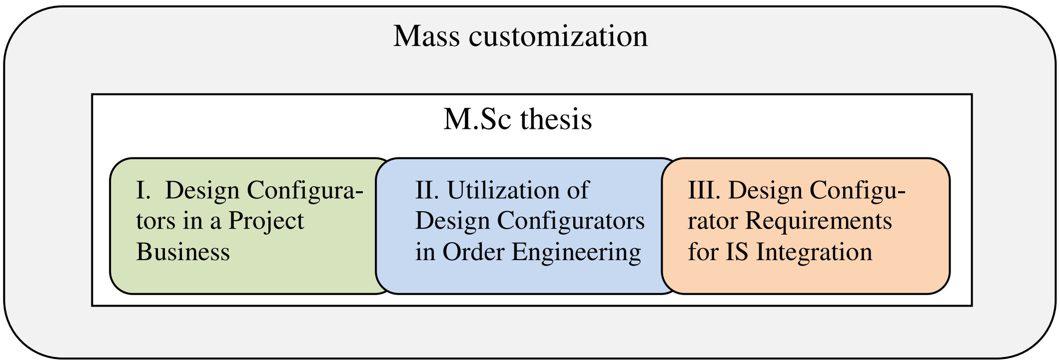

Figure 5. Overlay of all articles belonging to configurator studies in mass customization

The heart of these studies is in the capital goods industry where the most complex constructs need to be made as fast and high quality as possible. They contribute to the continuous research on configurators bringing in the engineering-to-order companies' challenge with a solution proposal into the mass customization field. Through critical thinking on the concept and examination of state-of-the-art research papers the whole of the design configurator model is determined in this study.

7 Summaries of original papers

The study involves three articles which are now summarized and given short introductions. The main focus is on the background and results of each study.

7.1 Design Configurators in a Project Business

The objective of the first paper was to identify and examine the role of a design configurator concept in a project business located in the capital goods industry. The paper is a continuum to an earlier stream of feasibility studies made to a company in cargo handling business. The hypotheses were that a semi-automated configurator concept could be implemented and it has positive results on the order-delivery engineering chain. The paper was wholly written and constructed by Paunu. The contributing authors' name was only added because he was the second author in the ICT feasibility study that was used as a background in the paper and therefore got noted for his contribution to the article.

An action research method [Susman and Evered, 1978; Lewin, 1946] was used to evaluate and provide a suitable solution for the next information systems development area of product configuration. Underlying product platforms including PDM/PLM, CAD, ERP and strength analysis tools were reviewed and a configurator based solution suggested and partly implemented to enable a faster tendering process as a whole.

Results were very promising as the firm started to shift towards a more capable PLM platform and integrated their parametric skeleton model library. Plans were made to implement a system of centralized configurator, later defined on our studies as, design configurator for the whole design engineering phase which includes the strength analysis and CAD drawing. Still, the paper also highlighted that an implementation of fully automated configurator is not a simple task and there are no real off-the-shelf products that can satisfy this niche and specific ETO area. Calculations of strength were the major challenge before implementation of full automation. Regardless of few bumps on the road, the possibilities of shortening the lead-times were fast-approaching.

7.2 Utilization of Design Configurators in Order Engineering

The second journal paper examined the design configurator concept more in-depth continuing the earlier study done in an ETO company. The objective was to illustrate and explain a new configurator model within the framework of commonly accepted configurators in mass customization: sales and product configurators. It established the concept as a third type of configurators in the context of capital goods industry. The hypothesis of the paper was that a design configurator model exists and can bring significant advances in the engineering-to-order business by decreasing lead-times and helping the firm to close the gap between mass customization and pure customization strategies. The work among authors in this paper was divided as follows: Mäkipää wrote the initial introduction and Section 2 but also gave valuable remarks on the conclusion. He also contributed in finding the case examples and examined them further. Ingalsuo wrote the configurators Section 3 with Paunu which was initially based on Paunu's earlier paper. The rest of the paper was written and constructed by Paunu. The corresponding author was Mäkipää because he had the most background in journal paper approval procedures.

A multiple case study [Järvinen, 2001; Järvinen and Järvinen, 2004; Yin, 1989] was employed to illustrate the concept of design configurator and evaluate its benefits and applicability in different industrial contexts. A paramount shift from a modular based approach to parametric design was argued as a basis for automation of an engineering-to-order process. An ETO company utilizing CAD models was seen to close the gap between full customization and mass customization if the proposed configurator concept was given to handle the whole configuration process. This change was seen to have significant impacts on job workflow as more work needs to be done to model, develop and maintain the parametric skeleton models which the configuration process manipulates. Shown cases illustrated the shift in ETO companies towards MC as parts of the design configurator concept were found in multiple platform solutions on product configuration.

The results of the paper suggest the eventual emergence of full-fledged design configurators in engineering-to-order field. The turbulent and highly competitive business environment magnifies the importance of faster response times for product quotations and higher quality that needs to be calculated with a reasonable prediction of gross margins.

This change is not without challenges in workflow transformation and integration requirements combining the whole process together. Establishing a new configurator to the field of MC in the context of engineering-to-order this paper extends the mass customization ideology to ETO products, which so far, have not been considered belonging inside the scope of MC.

7.3 Design Configurator Requirements for IS Integration

In the third and last paper the requirements of a design configurator are considered for information systems integration. The objective was to describe and analyze the basic requirements needed for a company to understand what a design configurator demands in order to be fully employed in an information systems environment. The hypothesis was that a design configurator can be employed for a craft manufactured product and its requirements on the IS integration is found. The paper was wholly written and constructed by Paunu excluding most parts in introduction and some remarks in conclusion by Mäkipää.

The research was mainly based on a conceptual-analytical research method with a supplemental illustrative case study explained in [Järvinen, 2001; Järvinen and Järvinen, 2004]. The paper continues in the stream of design configurator research and contributes to the field of mass customization toolkits with a background in capital goods industry. The paper illustrates a case of a downhill skis construction which in its most specific customization scheme is more or less based on crafted manufacturing processes. Through the explained structure and construction the paper analyzes an alternative configuration process and suggests an approach that enables an implementation of a design configurator to handle the designing and producing downhill skis. Requirements for this type of integration are determined and appropriate models examined.

The final paper demonstrates in its results that the technical possibilities of a design configurator can be drawn and requirements collected to observe, at least as a proof-of-concept level, a craft manufactured product being integrated closer to MC strategy. Five major requirements are thus identified to underline the most important aspects for a design configurator to master.

8 Results and general discussion

8.1 Discussion

The main purpose of this thesis was to identify and bring together the whole of research on the design configurator. As it is still a fairly new concept, this thesis builds the overall context for the articles which are limited in both space and open discussion on the subject. From this research study, the full connection of mass customization, configurators, especially the design configurator, and ETO in capital goods industry are realized. Because the core concept of a design configurator is multifaceted, the main research questions were divided into the tree articles.

The first article extends the ICT feasibility study done for a cargo handling company in which the concept were first realized and identified. General connections to mass customization was made through [Piller, 2004] which provided a stepping stone for understanding the whole of configurator ideology. By understanding the connection between the two extremes of mass producers and pure customizers [Tseng and Jiao, 2001] the potential of an ETO company being able to leverage MC became more and more apparent. From this realization the proposed solution for a PLM platform and an overall configuration software implementation to handle the whole process of configuration was made. The study also generated other research questions that became projects of their own.

The second paper, a distinct journal article, was a major update and important translator of a to-be established configurator concept. The article described and connected the concept to both MC and ETO approaches which in some ways were not seen in the research literature at that time. Similar ideas were found in [Forza and Salvador, 2007; Yücel et. al., 2012] but only partially. With a comparison to known configurator types and technical nuances the article argued the new construction of a configurator type. Additional cases shown contributed to underlining already made advances towards the design configurator concept in capital goods industry. Also the challenges faced in other areas of the company implementing the concept were examined e.g. workflow changes and manufacturing capabilities. The article was a key presentation for the concept and will be the source for an initial understanding point of origin for citations in the research field.

In the last article, a continuum of the new configurator concept, a proof-of-concept case illustration was made to determine the overall requirements for the design configurator when adapted to an almost pure craft manufactured product. Major impact to the paper came from [Forza and Salvador, 2007] which described many case examples for the continuum of configurators and especially for their most similar description of a design configurator called the meta-configurator. The idea was to present a simple enough case to illustrate the possibilities of the design configurator for a pure craft manufactured product and analyze the transition requirements perceived from the possible implementation. From five major requirements the paper now facilitates further analysis and examination of deeper requirements for an IS integration on the configurator concept in future research studies.

8.2 Conclusion

The shift towards mass customization is a huge challenge for any company launching from either side of the MC spectrum. Especially in the engineering to order business where the typical paths of product modularization and customer involving development are not sufficient to bring ventures closer to pure mass customization. This is simply because the majority of products are highly complex and requires individual customization to fit the unique measures, preferences and qualities needed by the customer. In the past few years this issue has gotten more attention in the research field of mass customization and few solutions, like the meta-configurator in [Forza and Salvador, 2007], have been suggested. This study sets forth a novel approach managing the engineering to order challenge by identifying, analyzing and describing a new parametric model utilizing the configurator concept. The design configurator contributes to a stream of configurator research in mass customization coming from the specialized area of ETO in capital goods industry.

The results in this study are very promising. The identified configurator concept was seen to bring a heightened competitive edge for the company applying it and the overall response times for product quotations and lead-times shortened [Cargotec, 2012]. That being said it was also discovered that there is no simple or fast solution for constructing a comprehensive design configurator. The complex nature of configured ETO products and multisystem environment make an off-the-shelf product hard to find. Another problem was found in the ability to make accurate strength analysis and corrections to steel structures automatically without modifying the end result to such proportions that it was no longer a suitable construct. For these reasons, another research project was started to remedy just that after the first ICT feasibility study. In the meantime a solution of applying ready-made calculations in certain intervals was made to enable at least semi-automation with the configurator. By implementing the concept also a non-technical repercussion was noted in the form of how work is organized. The configurator may replace some old jobs but also newer ones are born e.g. product architect, as more emphasis need to be given for the parametric models. The findings in the last article describing five overall requirements in IS integration supplement the logical construct of a design configurator as a whole.

Considering the limitations of this study few important ones need to be noted. At the start of the first article not all configurator concepts were fully understood or found in the literature which directed the taken approach into a rather niche area of research. For this reason a broader view of product configurator expansion possibilities was not explored in-depth though PLM platforms are very common in capital goods industry. Further, in the illustrated case examples a more diverse set should have been used to grant more validity for the generalization of the concept. Also even though the study had a strong setting in capital goods industry and ETO companies a comparison study to another field or specialization would have benefited the completeness and rigor of the study.

To apply the results found in this study, practitioners should first understand the limitations underlined by the heavy industry point of view. The concept has many partial implementations out there from which to take lessons learned material but a reader will benefit from first recognizing the potential and overall requirements identified and described in this study. Even if a reader only glances through this thesis but can see the possibility of mass customization for pure craft manufacturing company this study has fulfilled at least one of its primary goals and objectives.

Continuing the research of a design configurator a set of research questions can be derived from the thesis. 1) What are the full sets of technical and non-technical requirements of a design configurator? Further analysis of a full implementation will generate deeper specifications and reveal more interdependent flows of data and their requirements. 2) Can a design configurator be implemented in a non-tangible product configuration field? Expanding the target field examines the operability of the concept e.g. through a case or empirical test study. 3) What are the specifications of a configuration engine for handling complex conditions, constraints and abstract associations between high level concepts? A more theoretical or purely software development project can be made to widen the definition of the design configurator to include an even more complex configuration of products, attributes and contexts.

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Bridging mass customization & open innovation

MCPC 2011

Design Configurators in a Project Business

By Pasi Paunu, Marko Mäkipää

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Design Configurators in a Project Business

Abstract

Configurators are considered as an essential tool in mass customization. While sales configurators and product configurators are gaining a lot of attention this study extends the concept to design configurators in a contex of project business. In project business order engineering is an essential phase in order-supply chain. It provides crtical customer value but delays the start of production .An action research study was initiated to elaborate the concept of design configurator in order to automate order engineering process in a company producing cargo handling solutions. The study develops and evaluates the design configurator from a point of view of an ICT-feasibility study.

1. Introduction

A company in cargo handling solutions business called Firmtech (name changed) initiated a study on a design configurator concept for a project business. General objective was to shorten design throughput times with configurable products. For this purpose, several studies were initiated. Firstly, a configurator concept –study was conducted to evaluate a general concept of a design configurator, its input, information processing, and output, as well as benefits it would provide. This first study also showed some major problem areas to be solved before automated design configurator could be created, for example, treatment of strength calculation results in configuration process. Secondly, automated processing of strength calculation results –study was initiated to find a solution for treatment of strength calculation results, e.g. how to adjust CAD drawings according to Finite Element Method (FEM) results. Thirdly, ICT feasibility –study, reported in this paper, was launched to evaluate potential information systems solutions for configurator concept and to provide information for decision making of required information systems development areas.

In this paper we examine the possibility of a design configurator through an action research – research method described in (Susman and Evered, 1978) and Lewin (1946). The study included evaluation of required functionality and its interface between other systems, such as CAD, PDM/PLM, ERP, Sales Tool, Strength calculation software etc. Applications already in use were first evaluated since they provide the application environment for planned solution and place constraints limiting the potential solution. Also, some commercial software alternatives for a design configurator were assessed for being able to evaluate the feasibility of considered solution alternatives. With custom software almost anything is possible nowadays, but it might not be economically feasible to start from a scratch when compared to expected benefits. Thus, ICT feasibility study was conducted to find out potential solutions or sub-solutions for a design configurator.

2. Configurators in the industry

The increasing competition in the global market has put much pressure on the manufacturing business where the challenge to deliver both quality and high customer value with cost effective means has led to new ways in producing products faster and faster with more flexibility and variability in the design. For this need different kinds of configurators have emerged in the field of mass customization (Tseng and Jiao, 2001). The mass customization term by itself can be defined very pragmatically and precise to correspond "the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency" (Tseng and Jia, 2001).

The configurators can be divided as: 1. Sales / product configurators, 2. Production configurators and 3. Design configurators. In this paper we focus on the examination of design configurator concept as the possible solution for more automated order engineering process for tendering and product designing with CAD and PLM systems hastening the transfer of order from sales to manufacturing.

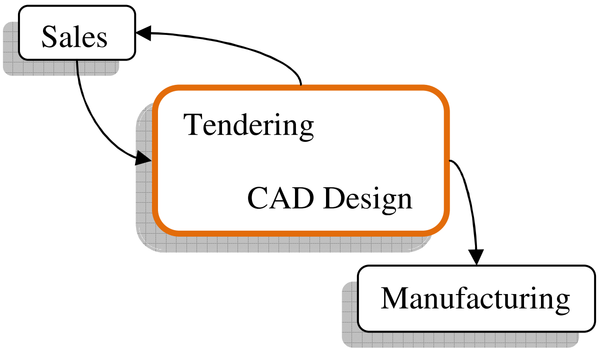

Fig. 1: Design configurator focus

To fully understand the differentiation of configurators we must first examine the requirements of mass customization by Frank Piller (2004). Piller suggests a solution space which can be drawn as triangle in figure 2.

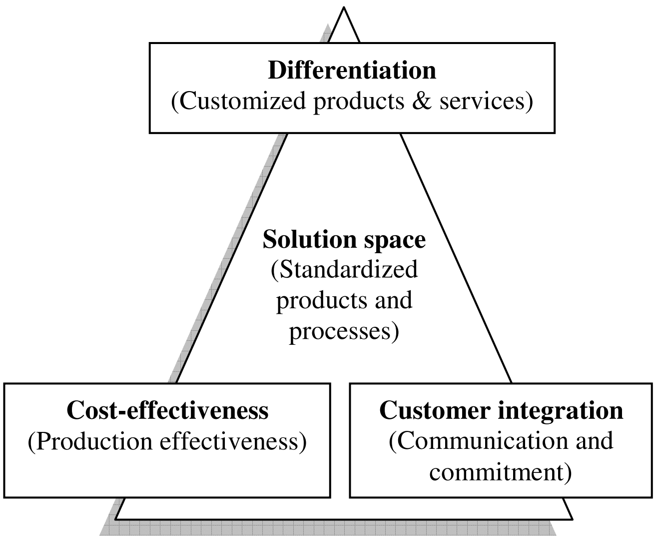

Fig. 2: Mass customization requirements Piller (2004) and Ahoniemi et.al (2007)

The idea in the triangle is that a successful adaptation of mass customization is based on a stable and standardized solution space where the company using it can respond relatively easy to different customer needs as long as the company stays inside the solution space borders. This way the customer specific product or service can be produced using standardized operational processes and ready-made product solutions. To successfully build a working solution space a company needs to assess all three of the triangle tip points (Piller, 2004):

- Cost-effectiveness
- Product and service differentiation
- Customer interaction and commitment

To this context configurators provide different views on how to implement production process and order handling within the solution space.

As we now start to look at the different configurators we may first divide them into four theoretical variations:

1. Primary
2. Forced sequence
3. Interactive
4. Automatic

In the first variation the selection of product components/modules are done from a pre-defined list. Forced sequence makes the selection of product components/modules happen from a list in certain order, reducing following available options after each selection. Interactive configurator makes each selection reduce other selection possibilities but the order of selections is then free. Last is the automatic selection which requires heavy modeling for transforming the use environment characteristics and user requirements to product features and components as the automation defines use-environment characteristics and requirements and not pure product components/modules from any list (Mäkipää, 2009).

In figure 3 we can see the connections of all the three configurators to the whole product environment.

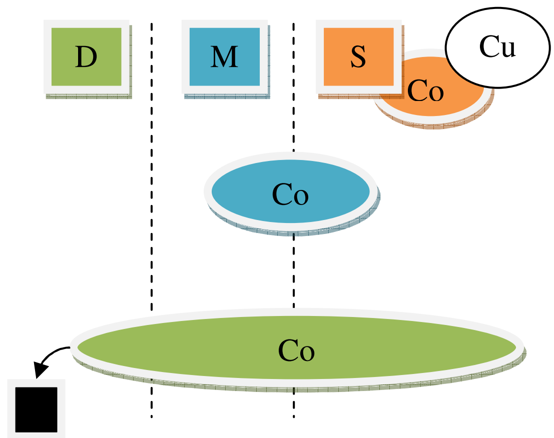

Fig. 3: Different configurator positions in production

In figure 3 the top most row illustrates design, manufacturing, sales and customer level. Sales configurator can be seen to connect sales and customer whereas production configurator works between the sales and manufacturing with no direct interaction with the customer. Design configurator in green can be seen to connect all the way to the design phase from the customer illustrating the initial parameters given through the product development process and ending in specific product (black box).

2.1. Sales configurator

A typical sales configurator can be seen to work between customer and sales either by operation of the company sales personnel or in custom software which the customer can use to make his choices for the product. When we compare the configurator to the process control methods figure 6 in Ahoniemi et.al (2007) we can see that the production and processes are mostly ship-to-order (STO) and in some cases assembly-to-order (ATO) based with the sales configurator where the products have less customization but high mass production rate.

2.2 Production configurator

A production configurator usually acts as a link between the PDM / PLM software and ERP systems environment where the configurator uses fixed product structures to construct product details. These details include the product variants with selection rules to generate the appropriate manufacturing structure and documentation for the product at hand. Comparing production configurator to the process control methods figure 6 presented by Ahoniemi et.al (2007) we see that production and processes with this configurator are more make-to-order (MTO) and assembly-to-order (ATO) based. The customization with ready-made components and ability to mass produce them are both on the average scale on the chart.

2.3. Design configurator

The fundamental difference with design configurator compared to sales and production configurator is that it extends the concept of configuration process e.g. producing customer specific individual CAD designs within CAD, PLM and ERP system environment. This engineering-to-order (ETO) process is previously considered belonging solely to pure customization having nothing to do with mass customization concept (e.g. Lampel and Mintzberg, 1996). With swift advances in ICT, especially in CAD and PDM tools, mass customization concept can now be extend to order engineering process as well.

In this concept the digitized product structures are kept e.g. in PDM system and then constructed via different selective parameters through the configurator. The product skeleton is then pushed onward to CAD designing software where the digitized product model can be handled parametrically. Each line and dot in the product model within CAD can be controlled by the design configurator and details updated via ERP or PLM environment as needed. In the control methods figure 6 by Ahoniemi et.al (2007) design configurator positions itself to engineering-to-order (ETO) where the customization is very high but mass production low.

3. ICT-Feasibility study for Firmtech

This study was started with an analysis of current applications in use to develop a comprehension of forthcoming environment of planned configurator. Few application providers were interviewed; other applications were evaluated by interviewing Firmtech's personnel and by getting acquaint with marketing material and technical specifications. Current applications place constraints that limit the possible solution space of a design configurator. Yet, current applications must not limit too much the solution search since some or few current applications can sometimes be replaced with one more powerful application.

Firmtech is using SAP as an ERP system and maintains item and cost information in SAP. The item codes are copied to master model to enable linkage between design and procurement. SAP PLM is used only to store order-related product drawings and item structure. Sales representatives use SAP Sales Tool for basic information about an order, but tendering request more detailed information for tendering purposes directly from customer.

Tendering drawings are currently produced with different CAD-system than final drawings. Tendering uses AUTOCAD to produce EKA drawings (Equipment Key Arrangement) for customer. In tendering phase only EKA drawings and steel weight are delivered for commercial offer. EKA drawings can be made in few minutes if a good template is found. In total the tendering phase only takes a day but the problem is that what is offered is quite generic information, estimation of steel weight and EKA-drawings. According to interviews it would be ok to use 2-3 days for tendering phase if more items could be attached and locked in to CAD-drawings already in tendering phase. However, the main focus of development should be in design phase following a successful tendering phase since it takes about 1000 hours just to fix the measures of final drawings. A design configurator could help in this process.

was a need to control Pro/E and configure its parametric models according to customer order. In addition, solution should be able to draw cost information from SAP and send product data to different other solutions such as PLM.

4. Configurator based solution

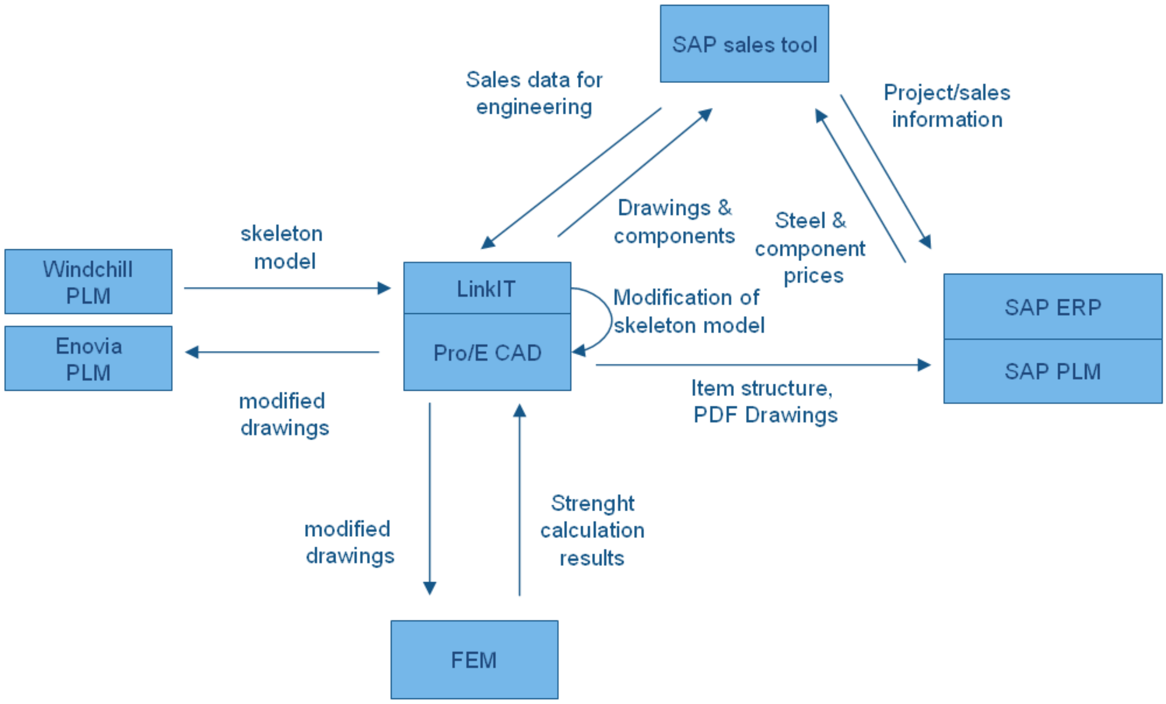

Fig. 4: Current application environment in Firmtech

The actual design phase is conducted with PTC's Pro/E CAD using parametric models. Master models (skeleton models) are stored in PTC's Windchill PLM and transferred to Pro/E for order configuration. The properties of master model are manipulated through build-in application LinkIT and its module Manage Properties. After configuration the altered drawing need to be sent to Ansys for strength calculation and possibly change some properties of drawings, e.g. steel thickness etc. Configured models are stored in Windchill PLM, pdf-versions are transferred to SAP PLM, and during the interviews Firmtech was in a process to implement Enovia PLM for a corporatelevel PLM system.

Difficulties for a design configurator arise from a need to conduct FEM calculations for steel structures and adjust drawings according to strength calculation results. Firmtech is currently using Ansys FEM application for strength calculations. Also, evident

As a result of analysis, this study landed to concentrate on to three general scenarios for a design configurator: 1) CAD-based solution, 2) PDM/PLM based solution, and 3) a separate configurator which we discuss here further.

Third scenario was based on separate configurator that drives and controls other solutions. This can be realized either with custom-built software or by utilizing some packaged configurator application as a base to build upon. Utilizing some commercial solution can lead to efficient process but might include problems with different integration requirements (CAD, ERP, PLM ,etc.).

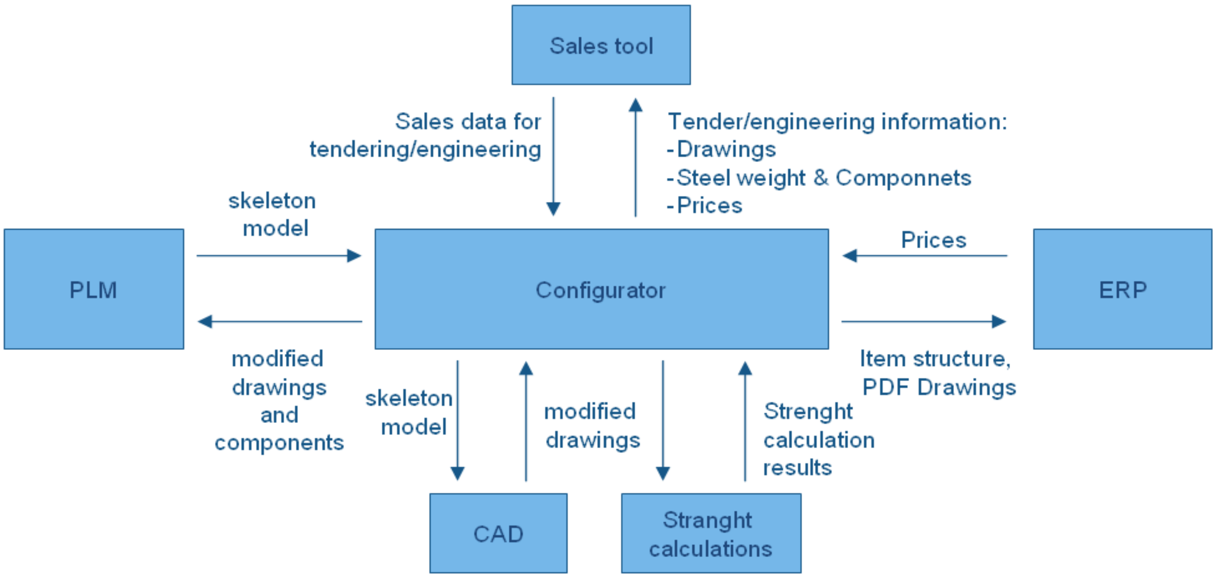

Fig. 5: Illustration of separate configurator based solution (scenario 3)

5. Conclusion

Although the analysis didn't turn up with an off-the-shelf solution some potential for constructing such was found. Firmtech is already using a LinkIT software build upon Pro/E to Manage Properties of parametric CAD drawings. Analysis of LinkIT solution provided possible sub-solution for a configurator concept, since its ability to control Pro/E could comprise a critical functionality of a design configurator. Also, together with other modules besides Manage Properties, the Drive-IT, Manage BOM and Publish Documents provide a lot, although not all, of aspired functionality.

Second promising source for a potential solution are commercial configurators that are built for product configuration. These configurators offer readily a lot of functionality to handle the configuration process, rules, and logic. Yet, they still require some added functionality and tailoring, especially for CAD integration to be able to produce individual CAD drawings with parametric models.

This ICT feasibility study extended the results of earlier configurator concept –study. The results show that implementation of a design configurator is not a simple task. There doesn't exist off-the-shelf software products nor even ready-made concepts for such a system. Analysis revealed also many difficulties in developing such a system, at least if the objective is to build totally automated system without manual intervention after initial input of product parameters. The biggest obstacle is related to treatment of strength calculation results of steel structures e.g. adjusting CAD-drawings according to results. Modeling the logic of design changes as a consequence of the strength calculation results might prove to be too difficult task when compared to benefits of such system. Most viable solution were found from a semi-automatic solution that includes minimal human intervention. Commercial software solutions that were evaluated in the study offer promising possibilities for such system, but it must be noticed that market screening was not comprehensive. Further evaluation of both commercial software possibilities and architecture of planned system was suggested.

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Customer Co-Creation in Central Europe
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DESIGN CONFIGURATOR : A TOOL FOR ORDER ENGINEERING

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Abstract: *Configurators are essential tools in mass customization. While sales configurators and product configurators have received a fair amount of attention, this study extends the research to order engineering with a concept of a design configurator. Design configurators can be used to automate order engineering, helping to decrease lead-time for product quotations and custom designs, and bringing ETO companies closer to mass customization. By establishing requirements for and creating a description of a design configurator, this paper establishes a base for further research on design configurators. Utilizing multiple case study method applicability and benefits in different industrial contexts are evaluated.*
Key Words: ***Configurator, order engineering, mass customization***

1. INTRODUCTION

Mass customization is seen as a promising approach for splintered mass market [1,2]. By using flexible processes and organizational structures [1], mass customization enables companies to "providing tremendous variety and individual customization, at prices comparable to standard goods and services" [3]. In [4], where the term mass customization was coined, it was described as a solution for reaching the same large number of customers as in mass markets of the industrial economy, and simultaneously treating them individually as in the customized markets of pre-industrial economies. The most of the mass customization literature describes mass customization similarly, as a solution for consumers of mass markets desiring more individual products.

In contrast to consumer product industries, where standardization and mass production have dominated markets during the last century, in the capital goods sector products have continued to be designed to customer specification and manufactured in job-shop facilities [5]. Thus, in the industrial B2B markets the approach to mass customization is most commonly exactly opposite to consumer business. Some mass customization theories and methods developed for mass producers can also be applied to Engineering-to-Order (ETO) companies, but others are not applicable in ETO. The reason for this is a basic difference between incentives for the two types of companies to implement MC [6]. For ETO companies, the thrust and drive for mass customization is for the sake of shortening delivery time, variation management, and/or cost reduction [7,8,9]. Customers have used to get individual service and individual solutions to match exactly their preferences, but the customer sacrifice [1] they are expected in return is higher cost of individual designs and longer delivery times due to design process lead time.

In the pressure of global competition the challenge ETO-companies are facing to is to continue delivering quality and high customer value while pressing costs down and shortening delivery time. Current definitions of mass customization highlight the large variety or even individual solution and cost efficiency. In capital goods industries, a third competitive factor is considered being equally or even more important: the delivery time. Thus, prevailing definitions of mass customization are biased and defective from perspective of an ETO company. A more adequate definition of mass customization for ETO-companies could be as follows: "Mass customization enables companies to provide large variety comparable to pure customization strategy at significantly lower costs and/or shorter delivery time".

Yet, in capital goods industry too we can see variation in the level of customization of products, processes and transactions. Many researchers have described a vast amount of approaches between the two opposite extremes: pure customization and pure standardization. When defining what mass customization is and what it is not, a continuum on possibilities is laid down from mass products to craft work with various levels of standardization/customization combinations in between. Common for all descriptions is that if the extent of customization penetrates order-delivery processes all the way to the design/engineering phase the approach is considered as a pure customization strategy or an engineering-to-order operation model [5,10]. The accuracy of this view is reassessed in this paper.

Just like in consumer business, also industrial markets seek solutions to fulfill individual customer needs in a cost efficient way, utilizing mass customization concepts. According to [11], the genus of mass customization is the customer co-design process. Customers are invited to participate in value creation process by defining, configuring, matching, or modifying an individual solution. Successful design of customer involvement in the definition process can create a flow phenomenon which increases customer satisfaction to process and consequently commitment to the end solution [11,12]. In industrial markets where somewhat more rational reasoning and buying behavior is considered, a successful design of product definition process can decrease customer sacrifice by saving customer's time, money and effort.

In consumer business, sales configurators are seen as valuable tool in collaborative product definition process guiding and educating the customer in the product definition. Sometimes sales configurator is followed by a product configurator that is needed to transform the product features defined in sales configurator to product components for production. Similar approach is also used in industrial markets, but usually the sales configurator is used by an expert sales person and more rarely the customer directly [8,13]. Also, many companies are using hybrid product strategy offering customers standard products, mass customized products, and individually designed products.

In this paper, we present a third kind of configurator, a design configurator. Design configurator is examined as a tool for automation of order engineering process for tendering and product designing purposes in capital goods industry. We will seek to extend the mass customization ideology to ETO-products which are so far considered belonging outside the breadth of mass customization. By automation of order engineering process with a design configurator mass customization ideology can be extended also to some level of ETO-activities. We will define the concept and requirements for a design configurator and will utilize multiple case study method to evaluate its applicability and benefits in different industrial contexts.

The rest of paper is divided to sections as follows. In Section 2, we debate on special qualities and objectives of mass customization of capital goods. In Section 3, extant literature on configurators is reviewed. In Section 4, the concept of a design configurator is defined. In Section 5, some case examples supporting the idea of design configurator is presented. In Section 6, conclusions are drawn and further avenues for research are suggested.

2. MASS CUSTOMIZATION OF CAPITAL GOODS

An explicit mass customization strategy is unique to the company developing and implementing it [1]. In addition to company specific differences, several more general characteristics can affect to optimal mass customization strategy. Industry and product type affects the need for customization and to the extent to which customization is economically viable with prevailing technology. For example, mass customization of shoes has different requirements for and utilizes different techniques of mass customization than mass customization of digital content, e.g. personal radio or personal news portal etc. Also, consumer goods industries in general differ from capital goods industries, where more rational decision making of the industrial buyer is assumed and is guiding the development and selection of applicable mass customization methods. Approach direction to mass customization is also recognized as a critical factor when implementing mass customization, whether on mass or custom manufacturing [7]. Between these two extremes is continuum of other industries that calls for diversity of MC strategies [5].

Capital goods industry differs from consumer businesses in numerous of ways. Suppliers' product offering may be targeted to customer's production process or to be included in customer's end product. The industrial buyer is usually an expert of customer domain and possesses high level of requirements and product related knowledge. Also, B2B customers are considered being more rational buyers seeking optimal balance between product qualities, price and delivery time/accuracy. Typical offerings of capital goods companies span over a number of standard products, mass customized products, and products requiring order engineering or even new product development. In addition, life-cycle and value-added services are often offered separately or as a bundled product [14].

Customization strategy, or ETO-model, is widely used in capital goods industry to provide critical customer value. Customers typically have distinctive process or product related needs that require adjustment of offerings to specific customer requirements, realized with order engineering. Typical sales process is organized as twofold: external sales units are responsible for customer interaction, collecting customer requirements, taking care of the customer relationship, and for pricing decision, whereas internal sales support team is responsible for order engineering, cost calculations, and defining the delivery time. External sales are located near the customer and centralized internal sales support has high level of product expertise. The unique customer requirements, complex products, and organization of sales in capital goods sector introduce many challenges to operations and organization of sales.

Efficient customization might be difficult to achieve in high-tech or knowledge-intensive industries, such as many capital goods industries. In [15] it is described the qualities of order quotation process based on surveys conducted in UK and USA. Only 4% of respondents had never faced problems in meeting the proposal dates, whereas half had lost contracts due to proposal delays. An average project size amounted to 2 million GBP of which 12% was spent in advance in preparing the offer. Time spend for preparing the offer was in average 138 hours in sectors with normal product complexity, 772 in high complexity sectors and as much as 1030 in electronics and telecom sector. In effect, 62% of these hours never led to a contract. Especially larger companies suffered the biggest problems in both staff-hours and hit rates; up to 2881 hours were spent for offers per a realized contract. And still, the lack of accuracy in offers and estimates are exposing companies to significant commercial risk in the order fulfillment phase [15].

Mass customization and product configuration is proposed as an efficient solution to these problems, enabling large product variety while decreasing lead time and costs in every phase of order-fulfillment process.

And for sure, many industrial products too can benefit from modularization and standardization of modules, achieving increased competitiveness compared to ETO approach [8]. But for a large amount of products individual customization is still needed because of unique measures, qualities and preferences required.

Technological development is seen as one possible solution for achieving cost efficient customization in ETO companies. For example, in [16] an industrial company is described proceeding from mass production to efficient and effective customization with aid of new technologies. The company Ross Controls, producer of pneumatic valves and air-control systems, focused on learning relationship with the customer and expanded their capabilities to meet each customer's changing needs. They utilized CAD design libraries to reuse old designs, quickly customize them to the specific needs of each individual customer, and utilization of direct electronic linkages to production for achieving speed and cost efficiency.

The main distinctive principle of mass customization is a mechanism for interacting with the customer and obtaining specific information in order to define and translate the customer's needs and desires into a concrete product or service specification [17]. Thus, mass customization often requires a mechanism enabling elaboration of customer requirements, e.g. a configurator [18].

3. CONFIGURATORS

The increasing competition in the global market has put much pressure on the manufacturing business where the challenge to deliver both quality and high customer value with cost effective means has led to new ways in producing products faster, cheaper and with large flexibility and variability in the design. For this need different kinds of configurators have emerged in the field of mass customization [19]. Configurators are focused on collecting enough information to define the product, service or more recently a bundled offering [14].

In some sources the mass customization term has been defined in a very pragmatic way to highlight the importance of technological development and the role of IT-systems: "the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency" [19]. The role of different kinds of information systems is highlighted in case of mass customization since information can be regarded as the most important factor for the implementation of mass customization [20]. Compared to mass production, mass customization necessitates a direct customer relationship in interactive definition of the product, gathering product related information from customer. Compared to pure customization, in mass customization this information needs to be gathered in a more structured and disciplinary way to support cost efficiency. Mass customization is successful only when it can cover this need for information and communication both purposefully and efficiently [20]. If the customer interaction has been designed poorly, customers can be overwhelmed by the number of choices during product configuration [21,22].

In [17], configuration is defined as:

"Configuration means to transfer customers' wishes into concrete product specifications. While the solution space is set up at the enterprise level, elicitation activities take place with every single customer's order. For new customers, first a general profile of their desires and wishes has to be built up. This profile is transformed into a concrete product specification and order. For re-orders made by regular customers their particular existing profiles have to be used. The old configuration may be presented and customers just asked for variations. The objective is to make subsequent orders of an existing customer as easy, efficient and fast as possible – an important means of increasing customer loyalty."

This definition too resembles the consumer business, but similar issues can be identified in B2B sector. For example, customer profile can affect directly to product requirements, i.e. different safety regulation in different countries, which is reoccurring requirement.

Also, an important aspect in achieving effective mass customization operation model is the definition of fixed solution space set before hand. The customer interaction process to configure the product inside this solution space should be made as convenient as possible. Automation of many activities is a vital part in this. Configurators are used to support in the definition process of suitable products and for automatically constraining the choice alternatives to the limits of the solution space. Tiihonen [23] presents the configuration process, where he divides the process into three stages, in each having their own type of configurability.

In extant literature, configurators are typically divided to two main types of configurators: 1. Sales configurators and 2. Product configurators. Sales configurators are used to collect the customer requirements, preferences, and selections. They are used by the sales personnel, more typical in capital goods industries, or customers directly. Product configurators are used to translate customer requirements to product structure for production. Product configurators are typically used by internal sales support or automatically according to input from sales configurator.

In addition, a third type of configurator can be identified: a design configurator. In this paper we focus on the examination of design configurator concept as a possible solution for more automated order engineering process for tendering and product designing. By automation of some previously manual tasks with a design configurator, integrated to CAD and PLM systems, transfer of order from sales to manufacturing can be hastened.

The fundamental difference with design configurator compared to sales and product configurator is that it extends the concept of configuration process, e.g. producing customer specific individual products, by creating individual CAD designs within CAD, PLM and ERP systems environment. This ability to automatically create unique drawings for components and products differs from sales and product configurators and justify the introduction of third class of configurators: Design configurators.

Sales configurators are typically focused to collect customer order for wide variety of mass customization models, and even for virtual mass customization models. In addition to manufacture-to-order and assembly-to-order operational models, they can be used also for more light-weighted customization. One of these models, suggested for automakers, utilizes locate-to-order operational model, a virtual and more cost-efficient version of build-to-order model [24]. In cases like this the sales configurator operates more like a selector for standard products [25]. The focus of sales configurators is to collect enough customer information for product definition.

Product configurators, on the other hand, focus on configuring the product structure for production, to identify items from solution space fulfilling the customer requirements. They utilize readily designed component and module libraries and matching and selection rules to build a coherent product structure. Sometimes the collection of customer requirements is integrated with product structure definition functionality, i.e. sales and product configuration functionality is implemented to one configurator solution, whereas in other cases the configuration models are detached to separate sales and product configurators.

Design configurators too need to collect customer requirements and might also include configuration of readily designed components, in addition to creating new drawings. Similarly, sales and product configuration functionality can be integrated to design configuration functionality in one total configurator solution, or these functionalities can be realized in separate but interoperable configurators. But distinct for design configurator, is its ability to create new components and modules.

This kind of adjustment to match to the exact needs of customer and to create new CAD drawing for new components and modules and whole products was previously considered belonging solely to pure customization and having nothing to do with mass customization concept [5]. With swift advances in ICT, especially in CAD and PDM tools, mass customization concept can now be extended to order engineering process as well.

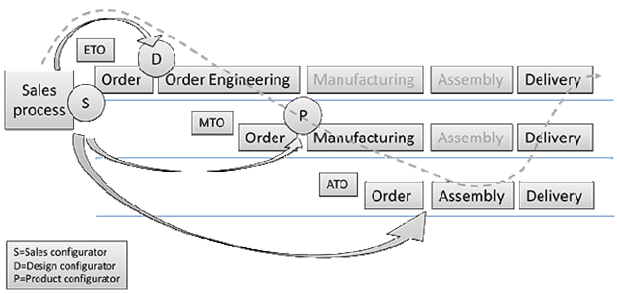

Fig. 1. Different configurator positions in order-delivery process

Figure 1 illustrates the typical uses of different types of configurators in different operational models. According to core functionality of each configurator type, each configurator can be locate to different phase of order-delivery process. The sales configurator can be located to between customer and sales or between external sales and internal sales support. The role of product configurator can be located to between the sales and manufacturing/assembly with no direct interaction with the customer.

A typical sales configurator can be seen to work between customer and sales either by operation of the company sales personnel or in custom software which the customer can use to make his choices for the product. When we compare the configurator to the process control methods figure 6 in [13] we can see that the production and processes are mostly ship-to-order (STO) and in some cases assembly-to-order (ATO) based with the sales configurator where the products have less customization but high mass production rate.

A product configurator usually acts as a link between the PDM / PLM software and ERP systems environment where the configurator uses fixed product structures to construct product details. These details include the product variants with selection rules to generate the appropriate manufacturing structure and documentation for the product at hand. Comparing product configurator to the process control methods figure 6 presented by [13] we see that production and processes with this configurator are more make-to-order (MTO) and assembly-to-order (ATO) based. The customization with ready-made components and ability to mass produce them are both on the average scale on the chart. In order to achieve desired efficiency it is claimed that modulization of product is an essential requirement [3]. One essential aspect of product configurator (like sales configurator) is that it acts as a user interface between the user and more complex PDM/ERP systems, thus simplifying tasks and responsibilities of user. As such a product configurators aim to tackle the difficulties of information linking when combining, selecting and mapping commercial and technical product data in the configuration process. Doing so it enhances the efficiency and responsiveness of companies which are key components when considering mass customization and product variety management. [26].

In addition to user group focused division of configurators, they can be divided into four theoretical variations according to knowledge modelling requirements and support they provide to users:

1. Primary
2. Forced sequence
3. Interactive
4. Automatic

In the first variation the selection of product components/modules are done from a pre-defined list. Forced sequence makes the selection of product components/modules happen from a list in certain order, reducing following available options after each selection. Interactive configurator makes each selection reduce other selection possibilities but the order of selections is then free. Last is the automatic selection which requires heavy modeling for transforming the use environment characteristics and user requirements to product features and components as the automation defines use-environment characteristics and requirements and not pure product components/modules from any list [8]. Another suggested division classifieds configurators into fabricators, involvers, modularizers and assemblers [27].

In addition, other type of configurators are also mentioned and described in the literature, with some similarities and relevance to design configurator introduced next. In [25] also a parametric component configurator is described for managing components whose parameters (such as length, width, height, diameter, etc.) change continuously, e.g. radius of a round table. Yet, no new drawing of the component is necessary in these cases, since delivering the varying parameter alongside with the product definition to production is enough. Also in [28] a parametric configuration is introduced that "enables the creation and selection of a product design without the necessity of pre-engineering and rules-based product documentation". Yet, even in [28] no new components are automatically designed, rather a larger assembly of pre-designed components/modules and their geometric and physical relationship is configured. A parametric configuration will "customize product designs; generate lists of features and parts for the product design; to generate a price quotation; and to enhance other post-design processes".

In [25] also a metaconfigurator is introduced for supporting a designer to rapidly “come up with a general product design that, even if approximate, must be reliable”. A meta configurator might include complex rules such as technical regulations, safety standards, aesthetic features, economic aspects etc. to “provide tentative solution to to the designer” [25]. Design configurator introduced here can include similar rules but the target is to achieve final and complete design of individually customized products. Similar cases to design configurator are also already introduced in the literature. For example, in [29] a tool for the design of customized biomedical devices was introduced. A parameterization tool was used to modify the tracheal stent’s general dimensions to fit a specific patient.

Thus, some case examples and literature has already emerged toward a design configurator concept, but more precice and clear definition and description and positioning of the concept is still required.

4. A CONCEPT OF DESIGN CONFIGURATOR

Design configurator extends the scope of mass customization and configurators towards the engineering processes. One primary characteristic of design configurator is that it requires a transformation from modular based product design approach to parametric design. Utilization of parametric CAD-models offers close to comparable variety to pure customization while offering possibilities to automation in model manipulation. Therefore it increases solution space compared to manufacturing-to-order approach while lowering lead time and possibly also engineering costs compared to engineering-to-order approach.

Thus, design configurator affect the variety level, costs and delivery time on way or other, depending on approach direction, from MTO or ETO, as illustrated in figure 2.

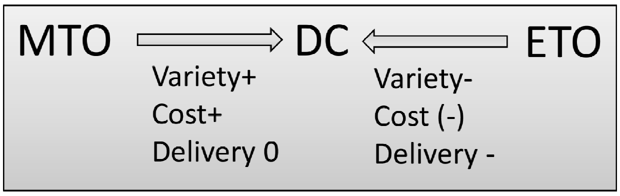

Fig. 2. Effects of a design configurator on variety, costs and delivery time when approaching from MTO or ETO

In this concept the digitized product structures are kept e.g. in PDM system and then constructed via different selective parameters through the configurator. The product skeleton is then pushed onward to CAD designing software where the digitized product model can be handled parametrically. Each line and dot in the product model within CAD can be controlled by the design configurator and details updated via ERP or PLM environment as needed. In figure 3 design configurator now bridges engineering-to-order (ETO) process closer to mass customization .

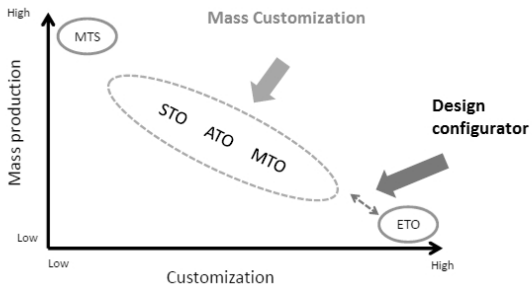

Fig.3. Design configurator in relation to mass customization (modified from [10]).

A design configurator hence enlarges the solution space from where all the product variations can be thought to reside. Basically it enables almost infinite variations though only inside the defined borders of the product specification which have been parameterized. Conceptually defined the design configurator handles the order engineering process as a whole. It takes input from sales, makes CAD design using some pre-defined models and in the end forwards its output to production. The key is in automating the design stage in order engineering and thus shortening the engineering lead-time. Automation can also lead to fewer design mistakes caused by human error and it can reduce repetitive manual work.

While research suggests that modularization is the essential requirement of effective mass customization implementation in MTO using product configurators, it is not necessary in ETO using design configurators. The essential factor in configuration of design is parametric models and supporting manufacturing system. This also have an organizational impact, when repeating part of engineering work can be automated and manipulated using configurator. Main design tasks are then linked in maintaining the parametric models, while the product variations are generated semi-automatically.

Looking at the impacts of design configurator on a corporation coming from either MTO or ETO side it can be argued that design configurator will affect the order engineering work significantly and thus, the organization of new activities and jobs should be designed jointly according to Socio-Technical System View [30]. This is because design configurator is an information system that involves complex interactions between people, machines, and the work environment.

There are several attributes and requirements which can be attached to a design configurator and one such list is seen below with a division between non-technical and technical requirements.

Designing principles of design configurators (non-technical):

- Regarding to socio-technical system view, design configurator is designed to certain task in certain social context and a fit should be found between these.
- The complexity of the task affects to how much resource is needed to complete the task. A design configurator should either decrease the amount of required resources for the completion of the task or to provide other advantage, such as better quality or shortened delivery time.
- What parts of the total effort are automated with the design configurator and what parts are done manually should be considered according to evaluated impact on business.
- The impact might be difficult to calculate, e.g. will the shortened throughput time lead to increased amount of orders? In some cases the solution might provide tangible cost savings which are easy to calculate and provide justification for the investment. In other cases, justification is probably based more on expectations on increased competitive capability leading to increased amount of orders. With design configurator, the amount of orders is not anymore linearly connected to needed personnel resources and thus, increase in orders/quotations will lead to increased cost-efficiency of order engineering with design configurator.

Designing principles of design configurators (technical):

- Ideally the configurator should be centralized in the order-production process where it can both initiate and handle the design process as a whole.
- It must operate then CAD-system with parametric models and optionally make queries with ERP, PLM and other needed software and push ready-made drawings to production when the order is finalized and accepted.
- Depending on the production environment the logical model and specific implementation place of design configurator must be thought thoroughly as various implementations can lead to very different levels of underlying model complexity and overall challenges in construction.

Because of the diversity of MC strategies between the mass and custom manufacturing mass customization practices can be implemented into ETO business with various ways. Inside these strategies the implementations of configurators also vary and in the case of design configurator different strategies can also be listed. In addition to fully automated configuration process a variety of partial configurators exists [25]. Below are few examples of these implementation strategies from very partial level configuration process to fully automated one. These examples were also found from the case studies and from literature.

- offering component library, utilizing standard components in design
- offering assisting design tools for standard solutions
- Re-Use of designs
- Parametric CAD-models
- Automated

5. CASE STUDIES

Next, we present three short cases to illustrate the current development in ETO companies toward mass customization. Cases also demonstrate that a continuum of different strategies and methods exists also inside what we have here labeled as a design configurator.

5.1 Case Peikko Designer [31,32,33]

Peikko Group is 1965 founded family owned company specializing in composite beams and fastening products for concrete connections. They provide innovative solutions to help customers make their building process faster, easier and more reliable. Their target is to supply a large selection of concrete connections and composite beams both for precast and cast-in-situ (cast-in-place) solutions in wide variety of applications.

Peikko Group's vision is to be the leading company in the field of fastening technology for concrete constructions (both precast and cast-in-situ) and with Deltabeam composite beam for slim floor structures. This leadership for Peikko means innovativeness of products, high recognition among designers and end-users, and local presence globally.

To aid different companies in deciding and utilizing Peikko’s structural solutions Peikko have created a specific design and calculation software for its customers which is focused on assisting structural architects in their jobs. This free and interactive 3d designer platform can be used to design and calculate bolted column foundations and punching prevention reinforcement structures. The end result can be exported to AutoCad and all the component details with calculation results can be printed out. The main benefit using the software is the ability to calculate the actual results with the real structures which can then be exported to other design environments. Peikko also offers design components to other design environments like AutoCad where Peikko’s structures are added as product library to the underlying program.

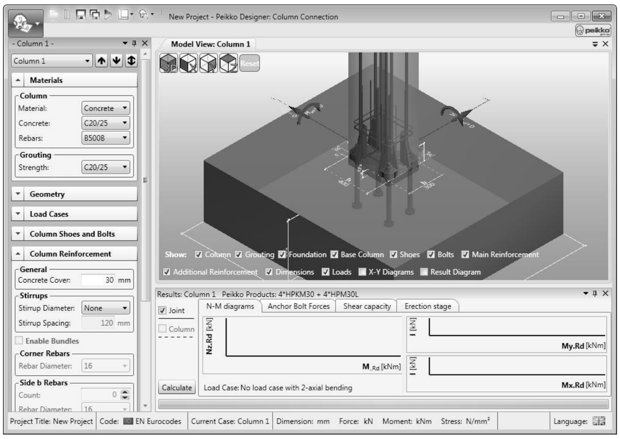

Fig. 4. Peikko Designer

The main benefit having Peikko's design components as a product library are the up-to-date details on the structure components that Peikko regularly maintains. This way the designer can be assured that he uses right kind of structures and can view the end result with calculations immediately on his overall product.

5.2 Case Cargotec MacGregor [34,35,36]

Cargotec MacGregor, part of Cargotec corporation, offers integrated cargo flow solutions for maritime transportation and offshore industries. One of their product groups are hatch covers.

Each merchant ship design is a complex puzzle of thousands of components and materials with varying requirements. Hatch covers are a vital part of this puzzle. Cargotec and its partners have developed a systematic and fast computerized configuration model for side-rolling hatch covers, which reduces design throughput time, improves productivity and provides a platform for consisted quality throughout.

Hundreds of customer requirements are compressed to a few dozen engineering parameters. Computer modeling finds an optimal customized solution by analyzing data systematically and quickly. Shortening the process speeds the purchase of critical parts. This brings competitive advantage, increases productivity and saves on costs.

As a result, design lead-time was reduced from average of 8 week to one or two days.

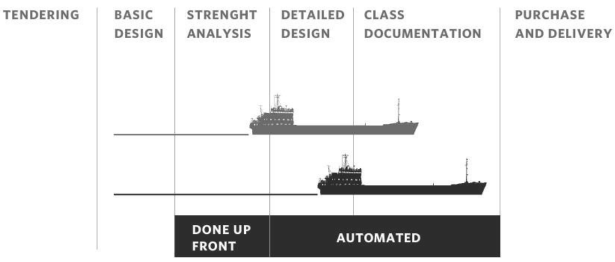

Fig. 5. Change in engineering activities [36]

A typical project needs four separate model configurations and about 30 drawing are automatically produced from each hatch model, which fully describe the design for the shipyard, manufacturing and the ship classification society.

5.3 Case Asoma Studio [37,38,39,40]

Asoma plc is a 1942 founded producer and a contract manufacturer of technically advanced precision components using a vacuum forming method. Their production method uses heat and negative pressure to shape plastic sheets. The advantages of vacuum forming over other manufacturing methods include low mould costs, lightweight, shock-resistant and readily shaped products, rapid R&D, and a 100 per cent material recycling rate. Their customers are typically leading enterprises in the automotive and electronics industry, the engineering and appliance sector, and the hospital and sanitary industry. Asoma offers services from product development to full production of ready-made products according to customer requirements. Minimal start-up costs and rapid R&D phase of vacuum forming enable short series production and ETO operations.

Asoma's vision is to generate added value for its customers at all stages of the R&D process from design to final manufacturing. The most important question in sales process is whether or not Asoma's manufacturing technology fits for the customer's product. In order to speed up the sales process Asoma launched a portal service called Asoma Studio in the beginning of the 2012.

Asoma Studio offers tools for customers and enables them to evaluate their designs against Asoma's production technology, calculate costs, manage the order process of even large projects, and view, comment and adjust 3D-models with designers. It saves time in customer new product development process and enables 3D-designing even if the customer wouldn't have their own design tools. It also educates customers about possibilities and limits of different technologies, applicability of materials and costs of production, fostering customers' NPD-processes. It also stores and manages all documents and comments related to order process ensuring up-to-date design documentation during the whole order-delivery process.

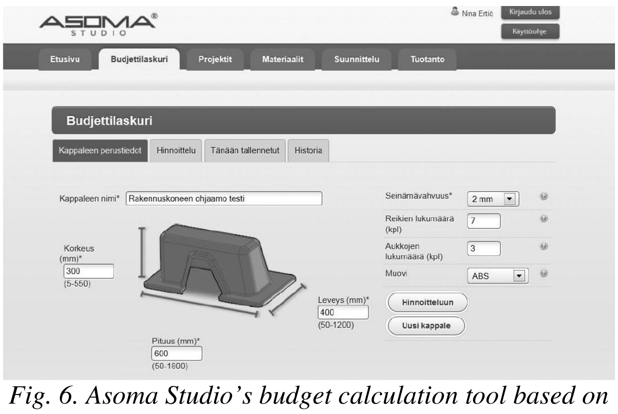

Fig. 6. Asoma Studio's budget calculation tool based on different measures, material selection, material strength and number of holes [40].

Asoma studio is built on cloud service and is based on Microsoft technologies and CadFaster 3D collaboration tool. It provides tools for collaboration, streamlining the sales process and order engineering, cost calculations and for project management.

6. CONCLUSION

As cases demonstrate, many companies are already offering different kinds of engineering tools to assist customers in the product definition process. Increased global competition lead to automation and digitalization in non-cost-competitive-countries, not only in production but also in product development activities, order engineering being in the front line. Current development and these first examples suggest that eventually full blown design configurators for order engineering will be constructed as a solution to increased competition in industrial markets. Design configurators promise faster response times for product quotations and order engineering process, critical for winning orders in turbulent business environment.

Design configurators enable fast response and can decrease order engineering lead time even dramatically, but they also require modeling capabilities of complex products, sophisticated design systems and maintenance. As such, they do not necessarily decrease costs but rather change how the work is organized. With design configurators, the most of the order engineering work is done in advance, i.e. modeling the product architecture, scalability, qualities, options, and their legal variations. Needed work for order engineering become more stable and incessant from nature; fluctuation in demand does not anymore have such dramatic effect on needed workforce, merely more computing power is utilized. Some of the old job vacant become unnecessary (order engineer) and new job vacant emerge (product architecture designer, product variation manager, product modeling expert, etc.). Benefit for competitiveness arise from better response ability to customer quotations and orders.

However, some difficulties still exist, such as handling the FEM calculations feedback and adjusting the design automatically accordingly.

Future research is needed to improve our understanding of CAD-level configuration process, required IT-system integration, the use of and effect that design configurators will have in order engineering process, and limitations of design configurators.

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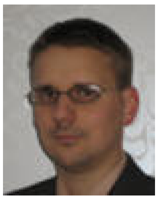

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Design Configurator Requirements for IS Integration

Pasi Paunu and Marko Mäkipää

Abstract Configurators are essential tools in mass customization. While sales configurators and product configurators have received a fair amount of attention, a new type of configurator has emerged for area of order engineering: design configurator. Design configurators can be used to automate order engineering and decrease lead-time for product quotations and customized designs. Thus, they can bring ETO companies closer to mass customization. In the literature, the concept of design configurator has been suggested and this paper examines the requirements of such configurator for IS integration through illustrative case example. By determining the requirements and integration possibilities of design configurator, this study will greatly benefit different industrial contexts when considering a configurator solution.

Keywords Configurator · Engineering to order · Design · Information systems · Integration · Requirements

1 Introduction

Competitive market dynamics push companies to offer ever more variety to customers and even treating them individually by reconfiguring their product or service to meet each customer's needs [1]. At the same time, increased cost competition drives companies to reduce costs directly or by developing new products that deliver what customers need more cheaply [2]. Generally, increasing

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product variety negatively effects cost efficiency, resulting in potentially weaker competitive position. Hence, those companies, which can deliver sufficient variety at competitive cost structure, can achieve an important market advantage over less efficient and less effective competitors [3].

A challenge for most companies craft customizing their products today is to continue delivering quality and high customer value while curtailing costs and shortening delivery time. Mass customization is proposed as a promising approach to compete in this kind of competitive environment [4, 5]. By using flexible processes and organizational structures [4], mass customization enables companies to provide "tremendous variety and individual customization, at prices comparable to standard goods and services" [6].

The center of mass customization is the customer co-design process. Customers are invited to participate in value creation process by defining, configuring, matching, or modifying an individual solution, inside a large but fixed solution space [7]. Configurators support this process by collecting customer needs and matching them to predesigned product features. Traditionally, configuring a product, rather than designing it, has implied that no component design activities are needed to define the required product variants [3]. However, advances in technology, especially in parametric 3D CAD and design automation tools, has contested the definition of design activity excluded in product configuration.

While sales configurators and product configurators have received a fair amount of attention in the literature, this study explores a third type of configurator for use in craft customization: a design configurator [8]. With advanced information technology utilizing modeled engineering knowledge, a design configurator can be used to automate design activities and decrease lead-time for product quotations and customized designs. This brings the potential to respond quickly to customer requirements and generate a range of variant designs to meet specific requirements [9]. Thus, design configurators can bring craft manufacturers closer to mass customization.

Sales configurators are typically used by customers themselves or by professional sales personnel. They offer an easy to use interface to place an order in digital format and to make sure that product specification is completed and error free. When used together with product configurator, sales configurator typically collects the customer requirements and delivers them for product configurator for precise product definition generation. When used as a stand-alone system, sales configurator either locates the best matching product for customer requirements or configures the product from major modules and options. With complex products with high level of offered customization, a product configurator can be used together with sales configurator or as a stand-alone solution for internal sales. It is typically used to combine and verify composition of component and modules to create a validated customized product. Design configurators, on the other hand, are based on parametric configuration of components, modules and whole products, instead of merely modular configuration of predesigned components and modules. It produces individual drawings by manipulating parametric 3D CAD models, yet inside predefined limits, offering greater possibilities for customization. It can be used as a stand-alone solution for internal sales or sales support, or it can be used together with sales and product configurators. If used in combination, sales configurator is used to collect customer requirements and to produce sales documentation, product configurator configures the modular parts of product and the design configurator generates CAD drawings for parametric features of the product.

In the literature, few practical examples can be found [8–10] as well as proof-of-concepts [11] showing first efforts toward complete design configurator. Also, an approach for modeling manufacturing requirements in design automation has been discussed [12]. This paper contributes this stream of research of configurators by describing an example of craft manufactured product and the information systems integration requirements it places for a fully operative design configurator. The research method is mainly conceptual–analytical research method supplemented with an illustrative case study. The study is based on existing literature on configurators, the conceptual definition of a design configurator, illustrative case example and subsequent analysis for information system requirements

The rest of the paper is structured as follows. In Sect. 2, an example product is introduced to illustrate a craft customizable product and its qualities. In Sect. 3, the configuration process for defining the product is presented. In Sect. 4, the requirements for information systems integration to build a design configurator are drawn from the basis of configuration process of an example product. Finally, in Sect. 5, the paper is finished with conclusions, limitations, and future research recommendations.

2 Case Downhill Skis

Downhill skiing, also called as alpine skiing, is a sport in which the skier slides down snow-covered mountains or slopes wearing skis with fixed-heel bindings. Skis used for sliding downhill are a construct of narrow strip of wood, plastic, metal, or combination thereof worn underfoot to glide over the snow. Substantially longer than wide and characteristically employed in pairs, skis are attached to boots with bindings, either with a free, lockable, or permanently secured heel [13].

Modern type of downhill skis have over a hundred years of history behind them originating from Norway circa 1850, but the skis of the old have very little resemblance with the typical downhill skis mass produced today [14, 15]. They come with various shapes and forms and have multitude of options for a customer to choose from. Even though the variety in ski models is quite large, the basic construction attributes in manufacturing are quite simple: the width, length, turn radius (accomplished by sidecut), and the rocker type of the skis. These four basic features of the ski combined with the skier's height, weight, and personal style preference are the starting points for making good downhill skis.

Looking more closely on the construction of skis the baseline design has five major manufacturing layouts [16, 17]:

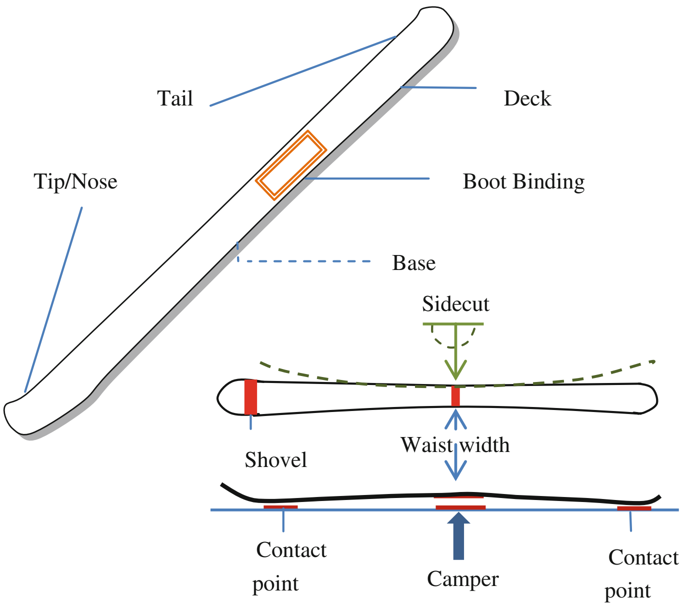

Fig. 1 Downhill skis outer features

- Classic wooden, made out from one single long wood piece
- Laminated wood, made out of two pieces of wood glued together
- Laminated metal and fiberglass, which uses laminated wooden core with aluminum or fiberglass housing sheets
- Torsion box, which has wooden core that has initially been wrapped in wet fiberglass
- Cap design (also called single-shell), where the wooden or foam core is housed in all three sides of the ski in plastic cover.

After the design layout is chosen, the layering of different materials begins. By mixing and layering different materials, the skis are made to perform better various kinds of tasks and they will have very specific characteristics. The outer features of skis, as illustrated in Fig. 1, have the last say in the matter of overall handling, but whether the skis are required to perform hard and quick turns or float the skier on top of a very powdery snow, the inner layers make the performance sustainable. The layers act in many ways, e.g., stiffening or reinforcing the skis, but they also carry a graphical significance when finishing the product according to customer specific details.

In Fig. 2, the molding of ski is illustrated where all the layers with different materials come together and form the actual skis. Depending on the manufacturing process style, the skis can still take part in many different sanding and grinding

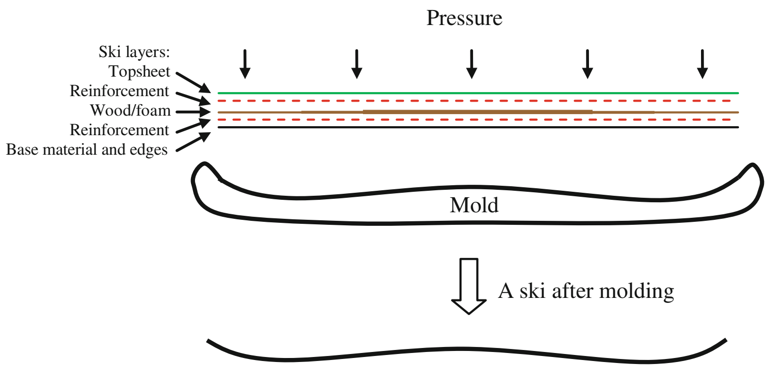

Fig. 2 Ski materials in molding process

operations after the heat molding has been done. Some methods also leave the graphical decals installation to the end phases though usually they are done before molding.

3 Configuration Process

The manufacturing of modern skis has significantly changed from the artisan workmanship of the old days to mass production of today's commercialism. Mass production has pushed the cost and efficiency to their limits, but there is still demand for more personalized and customized products [6, 18]. Because of this reason there still are companies that make high-end skis with custom tailoring almost totally by hand, arguing that their way of doing retain the best of artisan know-how and quality not easily achieved using other construction methods [19, 20]. The downfall with this kind of workmanship is usually both delivery time and price of the final end product.

In article [8], a design configurator has been suggested as a solution for the challenge of bridging pure customization closer to mass production and hence mass customization [21]. To better understand this notion, we next concentrate on the configuration process of such configurator by examining the illustrated downhill skis case example.

One possible representation of a generic configuration process is shown in [22] where the overarching process consists of three temporal interdependent phases; commercial configuration process, commercial configuration, and technical configuration. The starting point is the customer's supply of initial information about the product specification needs which then initiates the activity where all the information negotiated "identify the complete and congruent commercial description of the product that best fits the customer's requirements" [22]. The second phase, commercial configuration, illustrates the specific features and

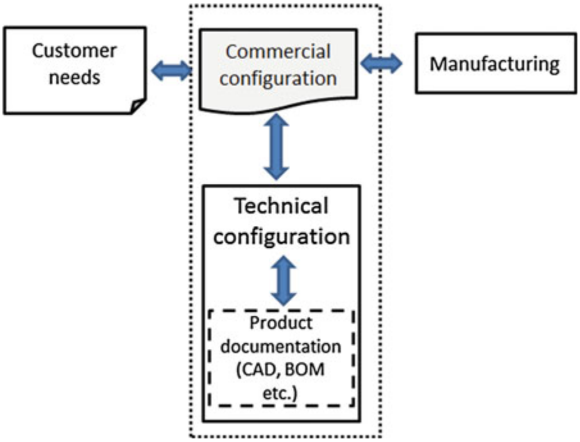

Fig. 3 Design configurator configuration process

characteristic of the product, which the customer is willing to buy and the seller is willing to sell. After this, the technical configuration can be generated where the commercial description of a product is used for the creation of product documentation of such product variant [22].

Though generic this configuration process, as illustrated in Fig. 3, does not entirely apply when we consider the configuration process of a downhill skis with design configurator. The main reason is that all the configuration activities happen inside the design configurator, which now controls the process and guides the user to best satisfy his needs on the ski product.

When the user first initiates the configuration process, he inputs physical details of himself like weight, height, and foot size into the configurator. This denotes the start of the commercial configuration. The user then starts to define the performance characteristics of the skis by selecting appropriate ski design on which the configurator helps the selection. This can include features like the environment (powder, alpine-touring, etc.) or skill level of the user.

This kind of configuration highly resembles the features of sales and product configurator, and it can be argued that design configurator actually performs as one complete configurator but it also depends how the strict definition is made. For example, [23] give three alternatives for sales configurator operations: structure based, feature focused, and performance focused. A design configurator may adapt various function logics but is highly depended on the information systems environment.

After the first configuration decisions, the user starts the main phase: technical configuration. The technical configuration process of downhill skis can be divided into three larger steps:

- Selection of the base construction design of skis: Laminated, torsion box, or single-shell type
- Applying different material layers according to base ski design
- Choosing the outer feature design by performance characteristics illustrated in Fig. 1.

When the user selects, modifies, and tests the skis design, by applying various layering materials like reinforcement metals or fiberglass pieces, the configurator guides the process by offering different setup combinations. It also limits the illegal positions and materials defined by the underlying decision logic in the configurator. These steps are further divided into smaller decision points where the more detailed materials and measurements, e.g., geometric information are given for the product but for the purpose of this simplified example they are not exhaustively listed here.

The fundamental factor with this configuration process is the uses of parametric models, which enable the configurator create new CAD drawings based on the user given data and also construct the normal product documentation (bill-of-materials among other things) on the go. This means that the configuration enables almost infinite variations within the defined borders of the product specifications, which have been parameterized. This is completely different from the basic modular design of selecting only ready-made components from some component library into the design. After all required features have been listed and attached, the product is then ready for the configurator to push to manufacturing which handles the end production according to the specific product documentation details created by the design configurator.

4 Requirements for Information Systems

In the literature, there are few practical examples [8–10] as well as proof-of-concepts [10, 11], which show steps toward more comprehensive and complete design configurator solution. These examples usually show only part of the whole configuration process discussed in Section 3, thus lacking the connection to fully incorporate a true design configurator. From a closer analysis of the configuration process of the downhill skis example, we can now present the information systems integration requirements for a fully operative design configurator.

The requirements can be divided into five distinctive parts. First is the need for visual configuration interface toolkit which acts as the window for the whole configuration process. Similar application concept can be observed in [8, 10] (Asoma Studio case) where both toolkits rely on web browser functionality for their visualization framework. This framework is then used to communicate all the user manipulated data through the second requirement: main configuration process manager based on appropriate logic engine. The purpose of this process handler is to work much like the expert system in [11]. The difference is that the knowledge is shared between different systems and the logic engine determines needed actions between systems and configuration decisions. This possesses the requirement of interoperability of different systems where the process manager is also able to launch and operate other systems.

In the next phase of the configuration process, the customer is seen to start the definition of skis technical specification. He needs to modify the structure,

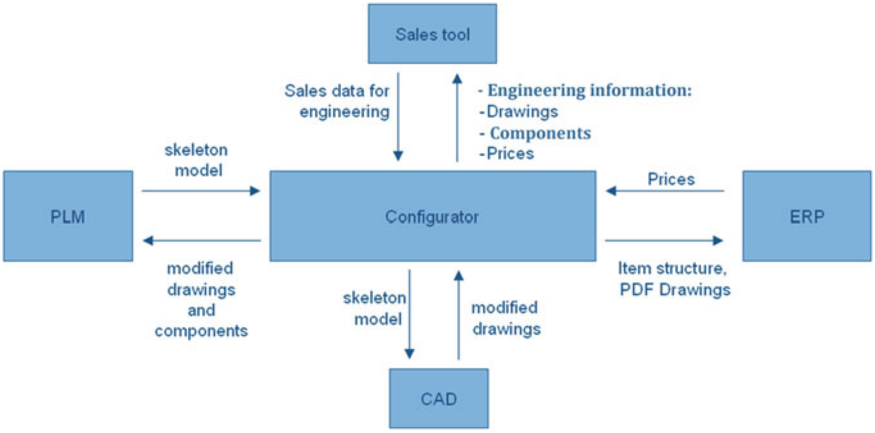

Fig. 4 Design configurator integration schematic

geometrics, and possibly other item details which now raise the third requirement for the IS integration, parametric skeleton model platform. There are many different ways to implement such a knowledge repository, and one suggestion has been an integrated PDM system for product configuration concept [24]. In this example, the PDM platform would also include the logic rules for the overall process handling and configuration management. Other example is the Cargotec MacGregor case [8] where PLM is used only to store the skeleton model information and then the final product documentation. This includes the history data and changes to the model variants. This leads to the fourth requirement of product variant and compilation of product costs for price formation. This can be done via ERP which would then contain the cost information for all the items, materials, and work needed in the skeleton models, product variants, and final documentation (e.g., BOM) of the end product [25]. The last requirement is the interface integration to CAD system. When the user changes details of the product through the visual configurator interface process manager launch and operate the CAD system to provide efficient and accurate depiction of the product and communicate the changes through the logic engine to both model storage (e.g., PLM or PDM) and manufacturing systems (e.g., ERP). Illustration of this requirements schema is shown in Fig. 4.

The final connection to manufacturing happens from the central logic rules system which will send the final customer modified product to physical construction when examining the skis example.

5 Conclusion

Technological development extends the possibilities of efficient customization. A concept of design configurator is suggested to extend the use of configurators to order engineering. Previous research has elaborated on the concept, showed some proof-of-concepts and partial operational cases. However, both research and practice is still in its infancy.

In this paper, we examined the information systems and integration requirements that the concept of design configurator necessitates. For the illustrative case example, we found five major areas that the design configurator must master:

1. visual configuration interface,
2. configuration process manager,
3. management of CAD skeleton models and product variant data in PDM/PLM,
4. compilation of cost information from ERP and manufacturing orders, and
5. interface integration to CAD to manipulate drawings.

With capabilities in these five areas, a design configurator is able to master whole process of commercial and technical configuration and provide accurate and detailed tenders and manufacturing orders, without the need for manual intervention. Yet, practical implementation of such configurator might generate new, so far unrevealed requirements.

Further research is suggested to contribute our understanding of technical requirements and solutions of design configurators as well as business benefits and organizational consequences of utilizing design configurators in various contexts.

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