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BUSINESS MODELS FOR CUSTOMER CO-DESIGN

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Abstract: *For over two decades, mass customization proved to be a powerful competitive strategy to overcome the oxymoron of developing and marketing individualized products with the efficiency and at a price of mass production goods. Most authors agree that solution space development and product configuration are two key tools for the success of mass customization. These allow the acquisition of customer needs as well as their translation into a product specification in the sense of a customer co-design tool. In this paper, templates for different customer co-design activities related to the degree of customization are presented and discussed for the business types of mass customizers and suppliers of product-service-systems.*

Key Words: ***Mass Customization, Co-Creation, Product Configuration, Business Models, Product-Service-Systems***

1. INTRODUCTION

Due to market segmentation and saturation effects as result of globalized markets, companies in various industrial sectors differentiate their offering according to a wide specter of customer needs. These tendencies, named as new market dynamics by Bliss, show up in business-to-consumer as well as in business-to-business contexts [1].

Managing the resulting complexity in all stages of the product lifecycle, be it order acquisition, product development, manufacturing or marketing becomes critical to the company's success [2].

Here, mass customization gave proof of solving the oxymoron of manufacturing products tailored to a customer's individual needs and requirements at nearly mass production efficiency and costs.

It is generally accepted that solution space development and product configuration are two key tools for the success of mass customization. Flanked by methods of variant design, such as design platforms and modular design kits like used in automotive development [3], these tools allow the acquisition of customer needs as well as their translation into a valid product specification in the sense of a customer co-design tool [4].

1.1. Motivation

The impact of contemporary information and communication technologies on mass customization, i.e. product configuration systems, either sales configurators or design tools in the meaning of knowledge-based-engineering systems, is generally accepted. To foster these capabilities, a company has at first to define the customization model for the offered products which is not only depending on the different customer needs. Moreover, it also has to meet the manufacturing facilities of the company as well as its value chain. Then, this portfolio of capabilities has to be presented and communicated to the customer via suitable sales support systems [5].

But also in the context of product-service-systems (PSS), where the focus shifts from a singular translation of requirements at one point in time to monitoring needs and accompanying customers during the whole product lifecycle and beyond, the use of solution space development and product configuration prospers. Here, it is also prerequisite to define degrees-of-freedom regarding product properties and functional building blocks for all PSS-components, regardless whether hardware, software or service [6].

Different typologies of mass customization have been discussed which are usually differentiated by extent or point in time of the possible customization [7]. Nonetheless, the relation of business typology, business model, customization strategy and design task is still under investigation. The present article documents the current state of our research regarding these aspects that targets both mass customizers and suppliers of product-service-systems. In detail, mass customizers and suppliers of PSS are compared within a business typological framework and templates for different co-design activities related to the degree of customization are discussed.

1.2. Structure of the Paper

The remainder of this article is organized as follows. Section 2 contains a brief introduction of mass customization and product-service-systems which are then classified into the same business typological framework. Afterwards in section 3, different business models based on the degrees-of-customization are presented and discussed regarding solution space elements, design tasks, relevant knowledge implementation into product models and production strategies in the following section 4. In section 5, the above considerations are used to derive an exemplified business model for co-creation activities. The final section 6 draws a conclusion and drafts further research questions.

2. BUSINESS TYPOLOGYCAL FRAMEWORK

In the following section, mass customization as a competitive strategy is derived from the product-process-change-matrix. Afterwards, product-service-systems are characterized comparatively and integrated into an extended business typological framework.

The term business typology in context of this article is used in the meaning of Miles and Snow who classified companies based on the relation of competitive strategy, corporate structure, business processes and management theory [8].

In contrast, a business model is understood as distinct model in which way benefits for customers or different corporate actors in the supply chain are generated and returned as turnover for the company [9].

2.1. Mass Customization

Introduced as business typology for explaining different competitive strategies, the product-process change matrix was presented by Boynton et al. in 1993 (fig. 1). All four possible business types are classified regarding the two dimensions product change and process change. Here, product change stands for the demand for new products and services whereas process change addresses all deployed procedures and technologies for developing, marketing and manufacturing them [10].

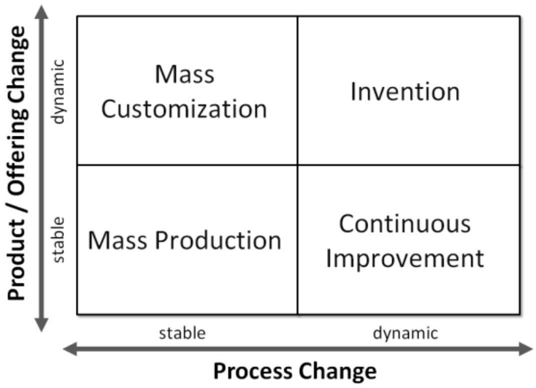

Fig. 1. *Product-Process-Change-Matrix* (acc.to [10])

Both types of change can either be stable, which means slow and foreseeable, or dynamic in the sense of fast, revolutionary and generally unpredictable. Within the fields of the matrix the four basic business models invention, mass production, continuous improvement and mass customization are differentiated.

Mass Customization is the business model where a dynamic offering change and a stable process change come together. The idea behind is, that customer specific products can be tailor-made by the use of flexible but stable processes with mass production efficiency. Taking into account that only the customer himself is able to formulate his specific needs and requirements, Piller suggests that "MC refers to a customer co-design process of products and services, which meets the needs of each individual customer with regard to certain product features. All operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes [11].

On the other hand, the emphasis on "mass" and the coherent product development methods and manufacturing technologies clarifies the delimitation to traditional single-part production.

One of the major characteristics of the MC business model is its ongoing capacity “to produce product variety rapidly and inexpensively. In direct contradiction of the assumption that cost and variety are trade-offs, mass customizers organize for efficient dynamics” [10]. To do so, all material and information flows have to be organized in a network structure of generic, reusable, flexible and modular units. Pine points out that it is essential not to pre-engineer or pre-align those units to some single known end product but to reflect the realizable portfolio of capabilities. Ideally, all corporate processes, either administrative or related to goods and service realization, are set-up as modular design as well which is configured with regard to the individual customer order. In the broader sense this comprises the aggregation of the whole supply chain [12].

For a detailed compilation of characteristics and a discussion of the success factors for mass customization refer to [10] and [13]. The literature also contains an overview of successful implementations in capital goods industry, mobile communications industry, food and beverages, clothing and footwear as well as financial services.

A discussion of the other competitive strategies is beyond the scope of this article, for a detailed description of the other three business types refer to [10].

2.2. Product-Service-Systems

Core of the product-service-system (PSS) concept is the integration of product, software and service development into one common development process. As result, the focus is shifted from selling products and / or services separately to selling functionality or corporate capabilities. So, a PSS can be understood as "customer, lifecycle and sustainability oriented socio-technical system, solution or offer" [6].

Some authors restrict the business case for PSS only to business-to-business applications. In this case, the PSS is a result of a value co-production which is conducted within a supply chain, based on a common development process [14].

Critical success factors for developing and implementing PSS is on the one hand the ability to adapt to customer requirement changes rapidly and efficiently as well as to anticipate these changes in the early phase of PSS development. Basically, this can be done via use of modular and parametric designs, so the PSS is altered by exchange of components or reconfiguration / re-parametrization. On the other hand, the customer requirements, either explicit or tacit, have to be captured and monitored [15].

Mont emphasizes especially the benefits of PSS for manufacturing companies. With respect to upgrade and modernization possibilities, additional customer value is generated. Furthermore, suitable product structures provide the possibility to easily dismantling and disposal or repair and re-marketing of individual PSS components. On the other side, customer relations intensify due to the requirement analysis and monitoring [16].

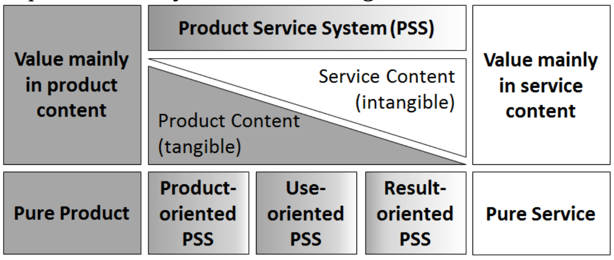

Fig. 2. *Main Categroies of PSS* (acc.to [17])

Tukker set up a framework to characterize different PSS, where, in principle, product-oriented, use-oriented and result-oriented PSS and the resultant business models are distinguished (fig. 2):

- Product-oriented: Product related services, e.g. startup and initial operation, maintenance contracts, supply of consumables, financing plans; Advice and consultancy, e.g. training, logistics optimization.
- Use-oriented: Product lease, product sharing, product pooling.
- Result-oriented: Activity management or outsourcing, pay per unit, functional result.

Furthermore, Tukker rates eight formulated PSS types their influence on the market value of the solution offered to the customer, costs for the provider, use of capital and mutability [17].

Related to the presented product-process-change-matrix PSS can be assessed regarding both change dimensions based on the previous characterization.

Regarding the product or the offered functionality respectively, PSS imply a change of customer needs over time. This should be considered when developing PSS, however, nature, extent and timing of the change can not be predicted in advance. In the model of the product-process-change-matrix that corresponds to a dynamic product change.

The company's internal processes for synthesis, production and distribution of customized solutions must be designed largely stable. This is partly due to a rapid reaction capability to changing customer requirements, on the other hand lifecycle management of PSS calls for that stability, also with respect to the subsequent disposal or re-marketing of PSS components as raised by Mont.

2.3. Product-Process-Baseline-Change-Matrix

Integrating PSS in the product-process-change-matrix would thus result in no difference between mass customizers and suppliers of PSS, as both are represented by dynamic product change and stable process change. For a better differentiation the existing typology has to be extended by another change dimension which we name baseline change (fig. 3).

The term baseline is used in this context in the same meaning as in configuration management where it stands for a fixed product variant. From this, subsequent product states are derived, other variants and versions are compared with the baseline and in general, changes to the baseline can be evaluated and documented [18].

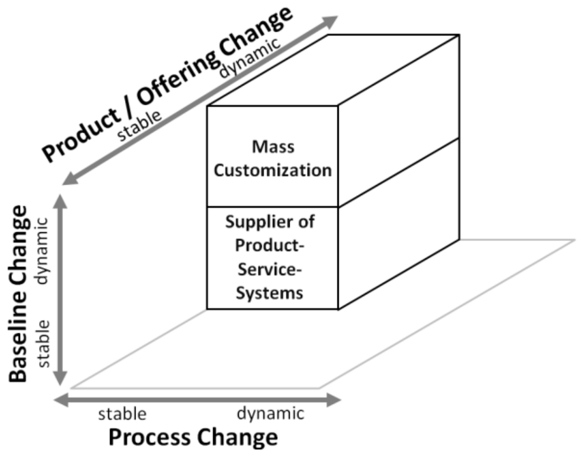

Fig. 3. *Product-Process-Baseline-Change-Matrix*

A stable baseline change encountering a stable process change and simultaneously a dynamic offering change allows the supplier reacting on changes by adaption of existing, perhaps already deployed product and service components as targeted in PSS development. On the contrary, a dynamic baseline change leads rather to substituting a solution already in use. Here, mass customizers synthetize a new best-fit solution for the actual customer requirements [19]. Note, that from the authors' viewpoint none of both business types is neither restricted to business-to-business nor business-to-consumer contexts. With regard to the complex market situations that correspond to the business types, such simplifications are not adequate.

3. DEGREE OF CUSTOMIZATION

In order to meet differing customer requirements the customer co-design process synthetizes the product configuration out of the stable solution space. As Böer states, “the goal is to correctly identify the customization options and dimensions meant to satisfy the customer needs” [20].

In this context, business models result from the type of customization and the according customer involvement. As discussed in [5] a possible differentiation of degrees of customization can be concluded from the influence the customer co-design process takes on the manufacturer’s value chain. It is not limited to the supplier itself but also to the correspondig supply chain. Note, that the concept is not restricted to offering physical products but also services or PSS. Nevertheless, the majority of the known and documented implementations refers to physical products so we will discuss the degrees of customization related to products, their manufacturing and product-oriented PSS. A transfer to service engineering is beyond the focus of this article.

A way of customization that does not effect the manufacturing processes of a supplier at all is named *tuning customization*. Here, an existing standard product is taken as baseline and refined by another partner in the supply chain which may include dismantling of parts of the existing product. So, the offering can be adapted to special applications (e.g. police cars, outside broadcast vehicles), individual design (e.g. in the automotive sector done by companies like AMG or quatro) or in general to markets with only few customers. In this model the customer integration can be very high since the standard product can possibly be adapted to all customer needs.

Another type of customization is *set-up customization* which is appropriate in particular for mechatronic devices. As Jørgensen states, most functional issues of such devices are provided via software, e.g. the acceleration curve of a combustion engine which is adjusted via the engine control unit [21]. Another example is the mobile applications ecosystem. Its behaviour is controlled differently by the installed apps but the physical part of samrtphones or tablets is kept the same. The process of manufacturing is not influenced and so stable [22]. Nevertheless this level has an impact to product data management and configuration management since the different versions of firmware and software have to be managed as well.

With respect to *cosmetic customization*, Gilmore and Pine define that a standard product is presented differently to different customers. In the original specification this addresses commonly the packaging of a product [23]. Some authors argue that customer value is not raised noticeably in order to realize competitive advantages. This may be espacially true in business-to-consumer context but in business-to-business this type of customization is widely used for food and beverages industry (e.g. cereals or frozen food). Nevertheless, from our point of view, within cosmetic customization also altering the outer appearance of the product itself is allowed to a defined degree (e.g. painting colour). So, this degree of customization takes only little influence on the production process, machining keeps stable.

The most prominent way of customization is *composition customization*. This corresponds to the common assemble-to-order strategy where different sub-assemblies (in general: buildings blocks) are assembled together to a product using standardized interfaces [24]. If the building blocks are set-up as modules their production process can be kept stable which meets the requirements of postponement. Due to the fact that a common parametric data model for physical, virtual and service components is still missing, this type of customization is widely used in PSS configuration [19].

The type *aesthetic co-design* differs from the aforementioned. Here, the customer has an impact on product design as well as manufacturing since he is able to modify the outer appearance of a product by himself not only regarding colour or texture but shape (e.g. casings of white goods). Therefore, particular manufacturing processes are needed such as additive manufacturing or high speed cutting. Nevertheless, all functional building blocks are kept stable and so their manufacturing processes.

A very far-reaching degree of customization is *function co-design*. In opposite to the aesthetic co-design here also the functional building blocks are determined by the customer. This reflects the actual discussion on open innovation [25] and is still a big challenge to manufacturing companies.

In addition to the aforementioned degrees of customizations another type of co-design activity is based on the complete design automation of a product or service so that customers have access to all neseccary knowledge and synthesis systems to adapt a product completly to their use-case.

3.1. Solutions Space Elements

For each of the resulting customization business models, different solution space elements have to deployed from which the customer can choose or start detailing.

Product / service baselines are used in the meaning of predefined feasible variants which may exist virtually or as deployed artefact. As solution space element a baseline sets up a starting point for the individualization, an initial design or a reference configuration for changes, alterations and (pricing) calculations. The more complex the artefact to be configured and the more options can be chosen, the more appropriate is the use of an initial baseline.

Building blocks may be used in various ways. On the one hand they represent modules for product assembly and related services. Especially for composition customization all building blocks must have known standardized interfaces to use all benefits of modularization. On the other hand several building blocks may be linked to packages or a design platform so that the solution space is structured and not all possible combinations of building blocks may be addressed. With regard to mechatronic devices, software, either as firmware or applications, is treated as functional building block.

Set-up customization, aesthetic co-design and design automation call for parametrization. The characteristic value ranges have to be defined before the customer can choose his parameter set. In simple cases this refers to minimum and maximum limits, in case of more complex relations it has to be considered how different parameters influence each other in sense of a simulation or constraint model so that only suitable solutions are presented.

3.2. Design Tasks

Setting up the solution space and its elements is only the first step. Moreover, the exploration of the solution space has to be structured so that requirements can efficiently be transferred into a technical specification which leads to a feasible individual solution. Here, automation potentials should be exploited wherever possible. Applying the principles of knowledge-based-engineering (KBE) by implementation of explicit design and process knowledge into digital prototypes is one solution. Applications of these principles range from parametric CAD models with implemented mathematical and logical constraints to interactive technical product configurators [26].

But generally, before a KBE-system is modelled, it has to be defined what type of tasks the system has to perform, what user input is needed and in which way knowledge has to be applied in order to create feasible solutions to the given design problem [27].

Basically, design tasks are differentiated into two groups. Analysis refers to all activities where a system or product already exists (to a certain extent) and its behavior or properties are examined by predefined methods. In contrast, synthesis corresponds to all activities where a system has to be constructed according to some given requirements [28].

Regarding the possible automation of relevant design tasks in product and service engineering or more general the support of a human designer by knowledge-based systems a further differentiation of synthesis tasks can be made with respect to the particular problem solving methods which are addressed. To those belong [27]:

- (Synthetic) Design: Designing a structure that fulfils certain requirements – result: artefact description.
- Configuration Design: A subset of synthetic design where all components are fully predefined. Another known label of this task is composition – result: artefact description.
- Assignment: Creating relations between two groups of objects – result: mapping set 1 on set 2.
- Planning: Generating an ordered set of single activities to meet certain goals – result: action plan.
- Scheduling: Creating a schedule of temporally sequenced activities – result: mapping activities on timeline and resources.

In times of parametric CAD, there exists another type of synthetic task which is parametrization [29]. Here, a given design has defined degrees-of-freedom regarding dimensions and topological constraints. These have to be eliminated according to given requirements and constraints, e.g. a base frame for a mounting rack which can be varied within certain lengths and heights. From point of view of software engineering parametrization corresponds to the solution of a constraint-satisfaction-problem.

3.3. Knowledge Implementation

When solution space and design tasks are clarified, the relevant knowledge has to be implemented both into the overall KBE-system and the solution space elements. Generally, the underlying design problem is transferred into a configuration problem.

Depending on the customizable artefacts, different knowledge elements have to be implemented into the configuration models. To these elements belong:

- Functions: Especially regarding synthetic design and configuration design descriptions about functions, their in- and outputs as well as knowledge about resource consumption and allocation.
- Components: Same as functions but linked to the building blocks of an offering. May contain hard- and software elements.
- Constraints: Mathematical, logical or physical relation between two functions or components and mapping of functions and components.
- Restrictions: Sub-group of constraints, defines areas in the solution space which are permitted due to manufacturability, design interfaces or strategic issues (e.g. product family planning, etc.).
- Interfaces: Sub-group of constraints which define physical or logical interfaces between two functions or components as well as the possible information, energy and material flows.

Therefore, three different reasoning techniques may be used [30]:

1. Rule-based reasoning: The knowledge representation relies to design rules, i.e. IF-THEN-ELSE-statements. Rules are fired procedurally and can execute subordinate rules or delete them from the working memory in order to realize more complex tasks. A major disadvantage of this kind of systems is their lack of separation between domain knowledge and control strategy. Many authors agree that this results in bad maintainability when the system exceeds a certain amount of rules.
2. Model-based reasoning: The limitation of the possible solution space is done based upon a physical and/or logical model (constraint-based) or by representation of resource consumption and allocation (resource-based).
3. Case-based reasoning: In this approach, the knowledge representation is not explicitly modelled as rules or constraints. The knowledge necessary for reasoning is stored in cases that represent former approved configurations. Depending on the degree of maturity of the inference engine the system either is limited to search for existing solutions, which match exactly to a given requirements profile, or the system is able to assort a set of existing cases, which represent the best-fit. Highly developed case-based systems are able of mixing or altering exiting cases in order to adapt them to new situations.

3.4. Production Strategies

Regarding manufacture of the customized artefacts, various production strategies as well as combinations of them are suitable. Nevertheless, in most contexts a significant strategy can be found.

- MTS: Make-to-Stock, prefabrication of the whole end product based on demand predictions.
- ATO: Assemble-to-Order, prefabrication of standard modules which are assembled to the customer end product when the customer order is processed.
- MTO: Make-to-Order, all components are manufactured when the customer order is processed, no prefabrication.
- ETO: Engineer-to-Order, customized components are designed when the customer order is processed.

3.5. Intermediate Result

From our point of view, based upon the business models according to the degree of customization which in the remainder we name business models for co-creation, templates for the co-design activities may be formulated. Refer to table 1 for an overview.

For tuning customization, a baseline for an existing product or for parts of it must be known which may be customized. This includes knowledge about interfaces, so that the exchanged components match to the baseline. Basically, the co-design process is of type configuration design because in the majority of cases the building blocks for exchange are already predeveloped. Examples are multiple in automotive engineering. For configuring, knowledge about realized or modified functions and components must be formalized as well as knowledge about constraints (assignment of tuned parts to multiple baselines) and restrictions. Predominant production strategy is MTO, if market potential is high enough also MTS.

Looking at set-up customization, the foundation for all customization activities is also a product baseline. In addition, as solution space elements parameter value ranges and software building blocks need to be defined. The co-design task corresponds to parametrization with knowledge about functions, constraints and restrictions. As production strategy MTS is advisable. Examples can be found in electrical engineering.

As third type, cosmetic customization likewise uses product baselines. When considered as predefined building block, the assignment of color and packaging can also be done via configuration design under consideration of constraints and restrictions. Since all machining is the same for each product, the prevailing production strategy is MTS.

For the classical composition customization, all suitable building blocks including their interfaces have to be set up as solution space elements. If a design platform is basis for configuration, a baseline may be defined as well. In automotive engineering it is a common approach to define style editions and packages which also may be understood as baselines. The resulting configuration co-design task uses functions or components, which are assembled-to-order, as well as their constraints and restrictions.

Table 1. *Templates for Co-Design Activities related to the Degree of Customization*

Degree of customization	Solution Space Elements	Significant Co-Design Task	Implemented Knowledge	Significant Production Strategy	Comment
Tuning Customization	Product Baseline and Building Blocks with known Interfaces	Configuration Design	Functions, Components, Constraints, Restrictions	MTO	Requires disassembly of prefabricated products.
Set-Up Customization	Product Baseline and Parameter Value Ranges, Software Building Blocks	Parametrization	Functions, Constraints, Restrictions	MTS	Software applications may offer new functionalities, software itself is not co-designed.
Cosmetic Customization	Product Baseline, Painting and Textures, Packaging	Configuration Design	Constraints, Restrictions	MTS	May target only on packaging.
Composition Customization	Building Blocks with standardized Interfaces, (Product Baseline)	Configuration Design	Functions, Components, Constraints, Restrictions	ATO	All components fully predefined.
Aesthetic Co-Design	Baseline for Targeted Functions, Baseline for initial Design and Parameter Value Ranges	Parametrization	Components, Constraints, Restrictions	MTO	Restricted due to design interfaces or manufacturability.
Function Co-Design	Building Blocks with standardized Interfaces	Synthetic Design	Functions, Components, Interfaces, Constraints, Restrictions	ETO	Includes creative design of new components.
Design Automation	Product Baseline and Parameter Value Ranges	Parametrization	Functions, Components, Interfaces, Constraints, Restrictions	MTO	Requires implementation of all available engineering knowledge.

Aesthetic co-design is based upon a parametrization process. The customer uses an initial design which is altered according to predefined value ranges. Relevant connection points to a base plate or other design interfaces are defined as constraints. The definition of restrictions includes e.g. machining spaces, minimal wall thicknesses. Components are made-to-order.

With respect to function co-creation, an ETO-strategy is set up, customer and supplier design functions together under consideration of interfaces, constraints and restrictions. The sophistication of this model is very high when the customer shall be able to perform designs without or with only little assistance of the supplier since all relevant engineering knowledge has to be formulated in the corresponding design system.

In design Automation the solution space element is again a product baseline with a physical or logical model in the background. Ranges for all adjustable parameters must be defined as well as their constraints and restrictions, the design task is parametrization.

4. SET-UP OF A MC BUSINESS MODEL

In this section the design of parts for a tea brewing machine is presented as application example (fig. 4). As particular feature of this tea brewing machine the adaptability to the kitchen or room furniture is provided which is achieved by exchangeable covers. Since the functionalities and the basic design of the machine remains the same, this degree of customization can be defined as aesthetic co-design.

Marketing identified two key customer groups: The first is hoteliers who want to distinguish themselves from competitors by integrating also electrical devices into the room concept for the single categories they provide. The second group of key customers is consumers who are willing to pay a premium price for a customized tea brewing machine.

For the first, a constant demand and lot sizes with up to 500 pieces is estimated, the latter has an inconstant demand and lot sizes in the range of 1 to 5 pieces are predicted. The matrix above indicates that Additive Manufacturing is suitable and has to be considered in product development and value chain.

Fig. 4. *Tea Brewing Machine*

According to the presented templates, aesthetic co-design calls for parametrization as design activity for casings or in this special case the modifiable covers. The corps of the tea brewing machine is the design baseline which ensures the functionalities and which defines the interfaces to the covers as relevant constraint. The solution space contains various initial designs for the covers which may be altered by use of a design configurator (fig.5). The possible value ranges are restricted due to the manufacturing process.

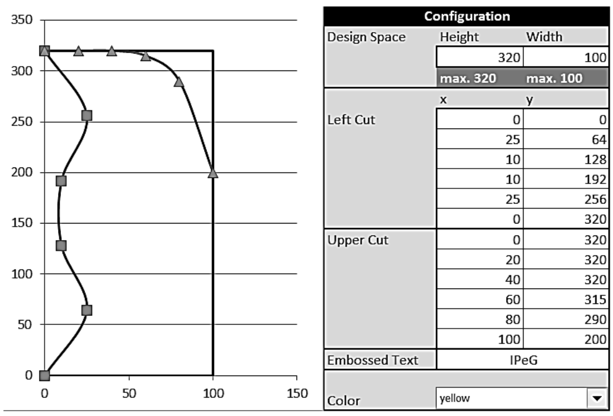

Fig. 5. *Cover Configurator*

The covers will be manufactured in ABS plastics on a laser sintering machine, so no additional support structures have to be taken into account. Nevertheless, the process restrictions, for example minimal wall thicknesses or the dimensions of the process chamber, have to be implemented into the configurator. Additional to the shape, the color can be chosen from a given list since the processed parts are dip-coated.

Fig. 6. *Cover Variations*

According to the maximum dimensions of the coverings, which are restricted due to the limitations of the process chamber, a maximum count of 60 pieces can be manufactured in one job. The build time is approx. 30 hours including cooling, cleaning and dip-coating. Switching to a SLS machine with a bigger process chamber would allow a parallel production of 320 pieces in one job at duration of 90 hours. An example of different cover configurations is depicted in fig. 6.

5. CONCLUSION

In the present paper, different business models for mass customization have been presented. The models are based on the degree of customization and the according customer integration. For the single business models we showed relevant solution space elements, the significant co-design tasks, implemented knowledge and production technologies.

The templates show the complexity of the co-design activities. The more influence the customer gets on the product definition, the more knowledge has to be implemented in the tools for solution space development, so that the customer may only define valid product variants.

The presented framework demonstrates what elements have to be considered when a co-design task is planned and implemented. Future research targets on concretizing the templates regarding knowledge implementation. Different reasoning techniques are suitable differently for each of the co-design tasks of synthetic co-design, configuration and parametrization. It has to be examined if a significant reasoning mechanism can be identified. Furthermore, the overall product complexity that can be reached in each of the business models has to be assessed.

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