INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

# GUIDELINES FOR THE DEVELOPMENT OF INDIVIDUALIZED PRODUCTS

J. Ponn, C. Baumberger and U. Lindemann

*Keywords: individualized products, product development, design guidelines*

## 1. Introduction

In order to cope with higher market pressure induced by the number of competitors and the necessity of an increasing customer orientation, companies have begun to individualize their products. This trend brings about new challenges for product development. New processes are required for the translation of the needs and requests of specific customers into individualized product definitions. These processes involve an explicite integration of the customer and a customer-specific adaptation of product properties [Lindemann 2003]. Also, flexible predefined product structures are needed which make a fast derivation of individualized products possible. Appropriate methods, tools and guidelines promote efficient processes and high product quality. With this contribution we present an approach defining form and content of design guidelines for the support of individual product adaptation processes. The work is part of a collaborative research activity dealing with the development and production of individualized products close to the market which involves partners from several disciplines such as mechanical engineering, information technologies and business management.

## 2. Individualized goods and product development

Before going into the actual topic of the paper, design guidelines, an overview is given over the background of product individualization and the implications on product development.

### 2.1 The concept of individualized products

The situation in many branches of the manufacturing industry nowadays is characterized by the need for competitiveness and customer orientation. A high number of competitors tries to win the favor of potential customers which leads to increasing market pressure. Customers also tend to not being easily satisfied anymore with standard off-the-shelf products which explains the necessity of explicite consideration of customer needs. Companies have started to deal with this situation by offering a large variety of product variants. In recent years, this has led to complete individualization of products in order to provide customers with solutions that fit exactly their needs. Trends like mass customization are successful in clothing and other industries. For mechatronical consumer products this remains still a challenge and demands for changes in the way products are developed and manufactured.
A fundamental problem of product individualization is the higher complexity in products and processes that has to be coped with. Scale effects, one of the most important cost reduction potentials in mass production, are not as easily achieved, when unique product and component properties, forms and features lead to batch size reductions. Therefore flexible product structures and new innovative manufacturing procedures are needed in order to create new economic potentials. After all, customers are not likely to spend a significantly higher amount of money than for mass produced goods.

## 2.2 Implications on product development

A higher variety in individual choices for the customer implicates a higher complexity, which leads to time- and cost-consuming processes and overpriced products. These circumstances demand for a two-stage development process. The first step is the customer-independent definition of a flexible product structure. Various degrees of freedom for individualization are determined, based on prognosticated customer requests, and incorporated into a master product structure. The intensive structure planning phase is an essential prerequisite in order to enable a fast product adaptation. The adaptation process is defined as the customer-specific derivation of an individual product solution. Customers are explicitely integrated into the product definition process. The generated solutions are reintegrated into the product structure. Also, the gained process knowledge is retained. Therefore, each adaptation process contributes to the increase in the potential to provide future customers with individualized products. Requirements for successful adaptation processes are e. g.:

- high level of interaction and customer integration in order to generate product solutions, which fit to customer-specific desires and needs
- standardization and automatization of process elements to a great extent, thus enabling rapid and efficient processes
- user-orientated visualization of product and process information, thus reducing complexity
- translation of gained product and process knowledge into an appropriate format, thus enabling the reintegration into the company's potential

In order to meet the formulated requirements, strategies for an efficient process management are needed. An approach to handle product adaptation processes and to allow for flexible process control is the application of a process building blocks strategy. A process building block is a process element described by an input information, which is turned into an output information during a value adding activity. There exist supporting methods and tools which can be assigned to specific processes. On a macroscopic level, four phases of the adaptation process can be distinguished as shown in figure 1.

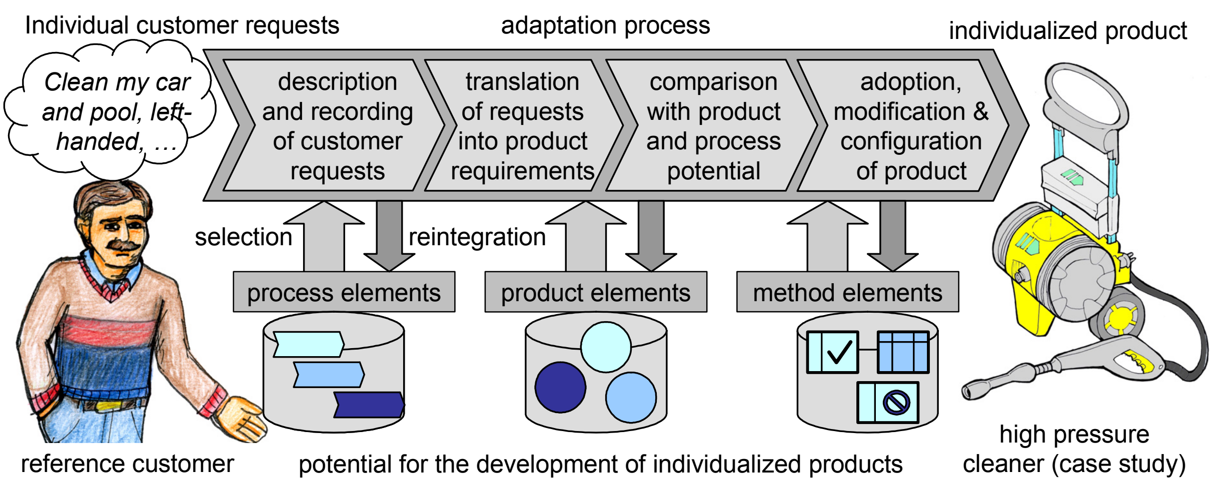



**Figure 1. Simplified model of the adaptation process**

A case study was conducted with a high pressure cleaner as exemplary product. Within the scope of the project, customer-specific characteristics relating to the cleaner were formulated and translated into product features. Also, an individualized prototype was built. The case study helped identifying different potentials for individualization, classifiying necessary adaptation processes and developing approaches for a methodological support. Required design activities and adaptation processes on a detailed level depend, among other things, on the novelty of a specific customer request. A known and recurrent customer request might be realized by standard components. Here no adaptation is necessary, the selection of components can be automated. For known tasks such as cleaning car, patio or swimming pool, specific nozzles and accessories can be selected according to certain configuration

rules. If requests are similar to those expressed by former customers, processes are required, in which only size, arrangement and dimensions of parts are changed within defined limits set by the product structure (variant design). Or the embodiment is adjusted to changed requirements (adaptive design). An example is the height of the drawing bar, which might have to be adjusted to the individual height of the customer, allowing for better ergonomics in transport of the cleaner. However, if customers come up with completely new requests, which are not yet represented by solutions within the existing product spectrum, an original design process is necessary. A customer might express the desire to equip the high pressure cleaner with a child lock, a function not predefined during the planning phase of the product structure. But there exist degrees of freedom within the product structure which allow the realization of a lock in the casing and the pistol. The design task here comprehends the search for suitable solution principles, e. g. if the lock can be realized mechanically or electronically.
The example illustrates that the adaptation of individualized products requires processes of different types which have to be realized within a short period of time, such as the search for solution principles, the optimization of ergonomics etc. Methodogical support to accelerate these processes and to guarantee the quality of the solutions, can be found in the form of design guidelines, which are addressed in the next paragraph.

## 3. Designs guidelines for the support of rapid product adaptation processes

In order to develop guidelines for the rapid adaptation of individualized products, an investigation was carried out in order to create a survey of form and content of existing methods and tools which provide guidance through the product development process. Furthermore, criteria were derived for the classification of these methods and evaluation whether specific guidelines are relevant within the context of particular adaptation scenarios. Exemplary design guidelines are described below divided into the categories Design for Manufacturing, Design for Individuality and Design for Adaptation.

### 3.1 Design methodology and design guidelines

Guidelines for the design process serve the purpose of generating higher-quality solutions to technical tasks while achieving the solution in an efficient way. They are derived from general objectives and task-specific constraints. According to design methodology [Pahl & Beitz 1996], there exist three general objectives of design tasks, which are the fulfilment of the technical function, the attainment of economic feasibility and the observance of individual and environmental safety requirements. In addition, certain aspects have to be taken into account such as ergonomics, production methods, quality control, maintenance, recycling etc. Resulting constraints and requirements affect function, working and construction structures, and also influence one another. Three established methods respectively tools supporting the attainment of the objectives mentioned above are checklists, design catalogues and design for X guidelines.
*Checklists* offer assistance in design tasks by listing essential aspects to consider in certain situations. Thereby, neglecting important details is avoided, which can save time and expensive iteration loops. They can be applied throughout all phases of the product development process: for the formulation of the list of requirements during the clarification of the task, for the search of form alternatives during the conceptual design phase etc. Checklists provide designers with a useful procedural order and a systematic check on each step or simply stimulate the designers imagination.
*Design catalogues* are collections of known and established solutions to design problems and should provide quicker, more problem-oriented access to the accumulated solutions. They contain data of various types and solutions of distinct levels of embodiment. Thus they may cover physical effects, principle solutions, machine elements etc. They may contain the most comprehensive range of solutions possible, or the most essential ones. In the past, such data were usually found in company catalogues or standards. Problems with design catalogues in the classical form are the extent of the solution spectrum and the associated difficulties in scanning all solutions for significance while keeping the effort low. However, paper catalogues are more and more replaced by digital databases combined with search mechanisms for an automated support of finding relevant information. Design catalogues usually contain classifying criteria, which determine the structure of the catalogue and have

an influence on their practicability. The main part of the catalogue contains the solutions, which are represented as sketches, drawings or illustrations. Finally, solution characteristics are listed which are important for the identification and selection of appropriate solutions [Roth 1994].
Most design guidelines deal with “right” design with respect to specific requirements or constraints such as production, ergonomics etc. This is also called *design for X* where the “X” represents the particular aspect to be taken into consideration. A guideline is typically characterized by a textual description of a desired or undesired property in a design. In addition, two graphical representations display an improper respectively an improved execution of the design [Huang 1996, Koller 1994].

### 3.2 Criteria for the classification and evaluation of design guidelines

In the analysis of these methods a number of criteria could be identified which represent the basis for an evaluation concerning the application of guidelines within specific adaptation processes. From the list of criteria four are described here within this paragraph.
Considering the *level of generalization*, design guidelines can range between general and specific. Three basic rules or principles should apply for all embodiment designs: clarity, simplicity and safety. These principles, which might seem obvious, are rather general and have to be specified in order to use them as guidelines. They are difficult to put into practice, if there is a lack of detailed information on how to reach these objectives. Specific guidelines, however, containing information on how to deal with particular geometrical, material, manufacturing or other characteristics, are difficult to transfer to different design tasks because of their limited validity. Guidelines can either *relate to the product or the process*. Most design for X guidelines focus on product characteristics, describing verbally and graphically how to specifiy structure, layout, form etc. of a component or assembly. Process guidelines, on the other hand, support an efficient and systematic proceeding, e.g. by the description of an optimal sequence of process steps. The *level of embodiment* refers to the phase of the design process in which the guideline can be applied. Early phases of the process demand for more abstract, later phases for more specific guidelines. The *binding character* expresses how compulsory the fulfilment of a guideline is. Restrictions by law or normative standards have to be complied with in any case whereas other guidelines rather serve as recommendations for a better design. This consideration is necessary when guidelines focussing on multiple aspects such as ergonomics vs. safety are contradictory and lead to a conflict of objectives.

### 3.3 Guidelines for the adaptation of individualized products

There already exists an abundant number of design guidelines of various forms, content and field of application. The aim is rather to select or be provided with appropriate existing guidelines in particular situations than to generate new ones. The pool of guidelines can be understood as part of the company’s potential for product adaptation along with the spectra of product and process elements (see figure 1). Therefore, guidelines can also be seen as method elements, to be selected from the pool and adapted to specific boundary conditions. Three particular aspects, which have to be emphasized for the development of individualized products, and corresponding guidelines are presented within the next three chapters (see also figure 2):

- The possibilities and constraints of available manufacturing techniques have to be considered.
- Different forms of individuality and individualization have to be taken into account.
- The adaptation process itself has to be supported in all phases.

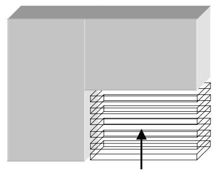
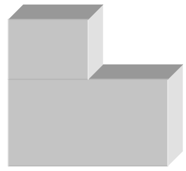
### 3.4 Design for Manufacturing

In general, Design for Manufacturing means designing for the minimization of production costs and times while maintaining the required quality of the product [Pahl & Beitz 1996]. It also implies creating product definitions (specification of layout, form, materials) which are suitable for the intended or available manufacturing procedures and allow manufacture and assemble at all. Very often, the possibilities and restrictions of certain manufacturing procedures have implications on the form of a product (e. g. casting requires tapers from the split-line). The form of a product, on the other hand, is an important aspect for the choice of the appropriate manufacturing procedure.

**Design for Individuality**

| Guidelines | Examples |
|---|---|
| **Product Fit** | |
| Consider personal characteristics | • Biometrical adjustment<br>• Physiological adjustment of HMI |
| Consider ambient characteristics | • Geographical, climatic conditions<br>• Social conditions |
| **Product Form** | |
| Consider personal taste, style and aesthetics | • Individual form of chassis/casing<br>• Individual painting<br>• Logos, initials |
| **Product Function** | |
| Define product functionality within individually adjustable range | • Modular product design<br>• Additional functions through corresponding accessories<br>• Functional extensibility of the product |

**Design for Manufacturing**

| Guideline | Improper Execution | Proper Execution |
|---|---|---|
| **Drop-based Rapid Manufacturing** | | |
| Choose geometry or position of the part in the machine in a way that supporting structures are avoided or at least reduced. |  supporting structure |  no supporting structure |

**Design for Adaptation**

| Process phase, activity | Guidelines |
|---|---|
| **Customer Interaction** | |
| Description and recording of customer requests | • Turn implicite desires and needs into explicite requests<br>• Classify scenarios for product use |
| **Product Modification** | |
| Translation of requirements into product properties | • Use of parametric product description |

**Figure 2. Exemplary Guidelines – Design for Manufacturing, Individuality, Adaptation**

Therefore, product design and manufacturing procedures exert mutual influences. In this context, the task of guidelines is to create transparency of those influences and to provide support in specifying the design parameters in order to optimize manufacturing parameters.

Manufacturing procedures suitable for the production of individualized products possess following characteristics: enabling of small batch sizes, flexibility with respect to geometry and materials, automatization of former manual tasks, and others. Various manufacturing procedures, which are all more or less characterized by these aspects, are being developed in the collaborative research center, such as innovative sheet metal forming or laser joining techniques. Here, in particular the procedure of drop-based rapid manufacturing shall be regarded. It represents a further development of rapid prototyping techniques which is able to handle the final material and allows for better surface quality.

Implications on design can relate to parameters such as structure, form, geometry or material. They are expressed as requirements, possible choices and limitations. Influences can be displayed on general technological feasibility, productions times and costs. The determination of material combinations is for example of major importance for the selection of adequate joining techniques. For rapid manufacturing part, the minimum dimensions depend on material strength, the maximum dimensions on the size of the machine. And for certain forms of rapid manufacturing parts, supporting structures are required. By designing for rapid manufacturing, these supporting structures are to be eliminated or at least reduced (see figure 2 for an exemplary guideline).

Guidelines for optimising product design concerning those manufacturing procedures were developed by conducting interviews with specialists in the area of these techniques. They were worked out in the form of checklists and classical design for X guidelines, formulated in a rather general or more specific form. They can be selected depending on boundary conditions resulting from customer requests, affected elements within the product structure and necessary adaptation processes.

### 3.5 Design for Individuality

The objective of Design for Individuality guidelines is an optimization of product structure and design with respect to best possible consideration of individual customer requests, needs and desires. Various forms of individualization can be distuinguished depending among other things on the motivation for individualizing a product from the customer's point of view. The factors which are regarded here are product fit, form and function. A possible motivation is the desire of *individual fit*. This might imply an ergonomic handling of the product or an adequate suitability of the product for specific ambient conditions. In the example of the case study this could mean an ideal height of the drawing bar or the ideal form of the chassis for storing the high pressure cleaner in the garage. Another factor is the *product form* which has to correspond to the customer's preferences and personal style. In addition *product functionality* can be individualized since the intended use of the product may vary from one customer to the next.

Within the product structure, there exist various degrees of freedom for individuality. These are by definition all possible choices for the customer concerning product characteristics. Depending on the affected degrees of freedom, different adaptation processes are necessary. With respect to product fit, guidelines for optimised ergonomics may apply. Design for aesthetics guidelines can serve for form individualization. Finally, in order to realize customer specific functions, guidelines for modular product architectures can be considered. Examples are illustrated in figure 2.

### 3.6 Design for Adaptation

Design for Adaptation aims at efficient adaptation processes through general product design on the one hand and systematic proceeding on the other hand. Each phase of the whole process (as specified in figure 1) calls for different product and process guidelines. Exemplary guidelines are shown in figure 2. Short development times and effort are among other things obtained through an effective knowledge management. A key factor within this context is the recognition of repeated customer requests. This is facilitated by turning implicite desires and needs into explicite requests. Other key factors are the reuse of existing elements within the product structure to the best possible extent and the reintegration of experiences from previous adaptation processes into the company's potential.

## 4. Summary

The rapid adaptation of individualized products based on predefined product structures and, therefore, the derivation of product definitions which fit exactly to specific customer requests, demands for methodological support in order to comply with general and specific requirements. Design guidelines dealing with Design for Manufacturing, Individuality or Adaptation help achieving more efficient processes and higher product quality. They can also be regarded as part of a company's potential to create individualized product definitions. An adequate classification is important for the selection of particular guidelines to support specific adaptation process elements, in which customer requests are linked to elements of the product spectrum and turned into individual product properties.

### Acknowledgement

We thank the Deutsche Forschungsgemeinschaft DFG for funding this project in the scope of Sonderforschungsbereich 582 "Production of Individualized Products Close to the Market", as well as Kärcher GmbH, Winnenden, our partner from industry for the good collaboration and their extensive support.

### References

*Baumberger, C., Lindemann, U., Ponn, J., "Development of Individualized Mechatronic Products – Rapid Adaptation of Product Properties Due To Individual Customer Demands", Proceedings of the 2nd Mass Customization and Personalization Conference 2003, Munich 2003.*

*Huang, G. O., " Design for X", Chapman & Hall London, 1996.*

*Koller, R., „Konstruktionslehre für den Maschinenbau", Springer Berlin , 1994.*

*Lindemann, U., Baumberger, C., Freyer, B., Gahr, A., Ponn, J., Pulm, U., "Entwicklung individualisierter Produkte", In: Reinhart, G., Zäh, M., "Marktchance Individualisierung", Springer Berlin, 2003.*

*Pahl, G., Beitz, W., "Engineering Design – A Systematic Approach", Springer London, 1996.*

*Roth, K. "Konstruieren mit Konstruktionskatalogen – Band II: Konstruktionskataloge", Springer Berlin, 1994.*

Josef Ponn, Dipl.-Ing.
Technische Universitaet Muenchen, Institute of Product Development
Boltzmannstr. 15, 85748 Garching, Germany
Telephone: +49 (0) 89 289 15141, Telefax: +49 (0) 89 289 15144
E-mail: ponn@pe.mw.tum.de