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PARAMETRICAL CAD MODELS AS A DATABASE FOR MASS CUSTOMIZATION CONFIGURATION PROCESSES

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1. Introduction

Mass Customization (MC) is one approach to deal with the continuous increasing demand for individualized products with delivery times and prices comparable to mass produced goods [Piller F. 1998] The idea is to conduct a hybrid approach between traditional mass production based on cost reduction through synergy effects and single part shop fabrication. While trying to offer individualized products for every single customer there are still benefits from cost reducing effects like those of mass production. So far most of the research has been focused on areas in business administration to develop and proof different theoretical business models for MC. To give a comprehensive overview over all fields of Mass Customization the Collaborative Research Center (CSR) 582 was founded at the Technische Universität München. This Center consists of several sub projects dealing with topics from business administration, computer sciences, product development, logistic, process planning and rapid manufacturing. Therefore the CSR was divided in three subsections: customer interaction, individualized product development and manufacturing of individualized products. The project presented in this paper is situated in the second section and is named "Modeling and Analyzing of Individualized Goods". The major aim of this project is focused on creating individualized Computer Aided Design (CAD) data during a configuration process. Based on a common product model [Janitza D. 2003], that was developed in an interdisciplinary workgroup, a reference product is modeled which defines a basis for the customer interaction process. Using these CAD-model customers are enabled to

- choose variants,
- use construction kits,
- define geometries,
- choose colors,
- choose materials,
- modify product functionalities.

To guarantee a valid product the customer input is supervised and analyzed at all times. Once the configuration process is completed a thorough defined CAD-product is available for further use (e.g. semi-automated process planning) within the product lifecycle.

In order to accomplish this intensive integration of the customer in the product development process, different methods and tools have been developed. This paper describes an approach, which in a first step, incorporates customer needs in a reference product and in a second step integrates the customers themselves in the final design processes of the product development. For the creation of the reference products, state of the art CAD-systems including all kinds of functionalities are used (see section 5).

2. Background

The approach to use CAD-models as a database for configuration processes is divided in three different steps. In the first step the potential customers' desires are integrated in a conventional product development process. Therefore conventional methods are adapted to fit the new requirements (see section 3). A CAD-reference-product, which builds the platform for future configurations, is modeled in the second step. In a third step engineering knowledge is integrated in the created data allowing technical inexperienced customers to define consistent products. The following two sub-sections describe some methods and approaches concerning the last two steps.

2.1 Approaches to flexible CAD-models

Multiple methodologies have been developed and presented on this topic. Platform and module techniques are used in an approach to manage the divergent objectives between production efficiency and product individuality. While [Siddique Z. 2001] tries to identify common platforms with the use of mathematical tools, others deal with concepts to create variable products while harmonizing potential targets.

Further approaches deal with the parametrization in product modeling [Anderl R. 1994]. These papers give a general overview about the possibilities in using parametrization during the product developing process. Describing the functionalities of modern Computer Aided Design (CAD) Systems [Mendgen R. 1999] offers general methods to design parametrical products. More specified papers [Cox J.J. 2001] present examples for parametrical models. All these approaches deal with the parametrization within the product development process. Their aim is to allow fast changes within the product structure. In all cases there is no description of any customer integration to deal with the flexible product, nor do they offer any configuration possibilities.

2.2 Knowledge Based Systems

Knowledge Based Systems (KBS) emerged from artificial intelligence research around 1970. They were developed from the idea to create a computer program that performs tasks usually done by a human expert using heuristic knowledge. One of the most common application is MYCIN which was developed for the diagnosis of blood infections [Shortlife E.H 1976].

The major problem of KBS is to map human knowledge as a software. One approach to model a KBS is to differentiate two components, the knowledge base and an inference engine [Swift K.G. 1990]. The knowledge base contains the basic knowledge of the domain, including facts, beliefs and heuristic knowledge. Furthermore it also contains information about the usage of the stored information. The inference engine contains reasoning methods that act upon the input data and the knowledge in the knowledge base to solve the stated problem. Additionally explanations for derived solutions are given. These approaches are highly specified and in most cases have not met the expectations yet. The necessity of complex software interfaces with CAD-systems is another major disadvantage of these systems. The presented approach aims at creating all necessary information and knowledge, using the same CAD-systems in which the product was modeled.

3. Adapted product development cycle

The aim of the presented project is to integrate customers within the product development cycle. Therefore an adopted product development cycle was created, which is based on standardized product development methods [VDI Richtlinie 2221 1993]. This method instructs and supports engineers in defining, developing and designing their products. First of all tasks are defined and specified and the functional structure is acquired by a team of engineers in iterative steps. Next, the team starts a search for solution principles and structures the product in practicable modules. Finally the product development is completed by designing the main modules and the details of the whole product.

In the adopted cycle (see figure 1) the first two tasks remain similar. Only influenced by general customer requirements the team of engineers defines task and acquires the functional structure of the product to develop. But on entering stage three, the search for solution principles, there is a change compared to the conventional methods. A pre-planning of flexible product structures has to be done by the engineers. This leads to a higher number of different solution principles creating a basis for a group of degrees of freedom, that will later on support the customers in their configuration processes. While performing the next step, structuring the product in practicable modules, enhanced product information has to be specified, that is needed to finalize the generated degrees of freedom. These two steps are still done without any customer interaction as engineer knowledge is needed to reduce the product complexity (see section 4).

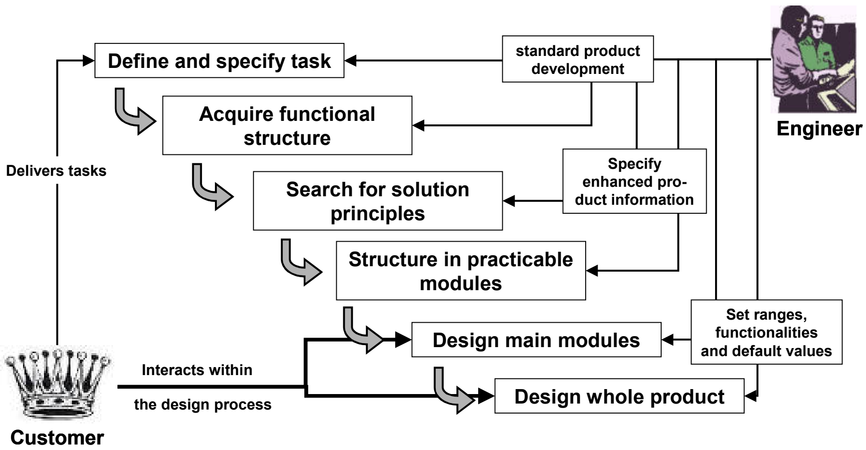

Figure 1. Adapted product development cycle

Once this is done, the gained information is transformed in a product model [Janitza D. 2003] leading to a CAD-model. Compared to the conventional process the engineers do not model one specified product but are creating a flexible model by defining ranges, dependencies, default values and functionalities using the pre-planned degrees of freedom (see section 5). At this point the interaction process starts and the customers can use the defined set of degrees of freedom to finalize the product development cycle by specifying their own personal product with the help of software tools.
These modifications are best described as product changes at a very late stage of the product development cycle. Contrary to MC, conventional methods try to avoid these late changes as they cause an immense increase of costs compared to changes in the early phases of the product development.

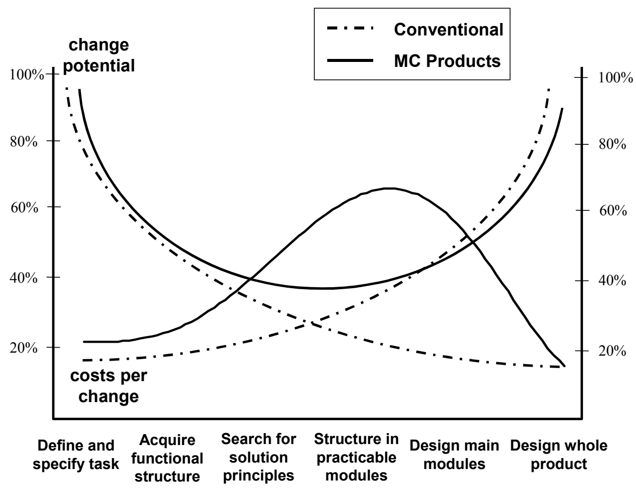

Figure 2. Costs per change in the adopted development cycle

By investing more time and specifying enhanced product information in the earlier phases MC tries to adopt to this changed requirements. On the one hand this leads to an increase of costs for changes in the middle of the development cycle as they need more engineering power but on the other hand the needed time for predefined changes and therefore modification at the last stages can be reduced rigorously. Figure 2 abstractly shows the cost per changes for conventional methods [Ehrlenspiel K. 1998], completed by newly derived graphs for the MC approach.

4. Reducing design model complexity for customer interaction

Section three describes the new tasks for the different stages of the adapted product development cycle. While searching for solution principles and structuring the product in practicable modules the engineers have to specify enhanced product information. This information is used to integrate additional knowledge within the product structure in order to create a flexible model for subsequent customer interaction processes. To describe the needed information a theoretical model is used. Figure 3 shows the difference between *problems* and *tasks* [Wellniak R. 1994]. In this definition a *task* transforms an initial state in a well defined final state by using an explicit analytic solution. This way such tasks can easily be computed by machines using pre-defined algorithms. Further more there are *problems*, that are defined by a barrier that can not be overcome by a standardized analytic solution. In this case a new analytic solution (e.g. a combination of existing solutions) has to be derived in order to obtain the final state. To create this new solution the application of "intelligence" becomes necessary. Whilst there are countless definitions of the term of intelligence, the intelligence in this case refers to the capability of human engineers to use their personal knowledge to obtain a creative solution by combining it with all kinds of different input information.

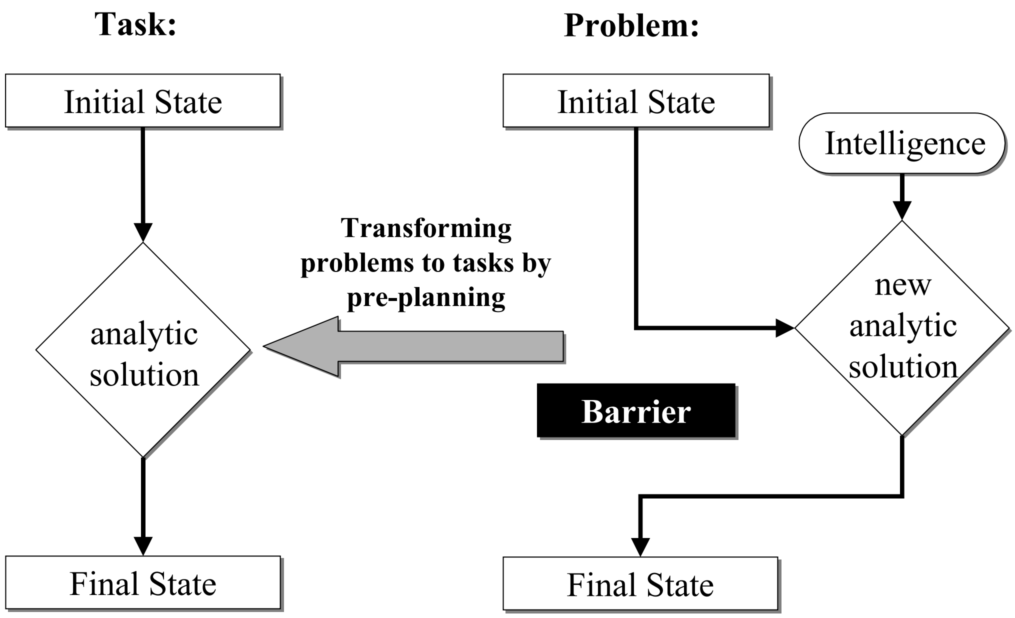

Figure 3. Transforming Problems to Tasks

A multitude of different approaches deals with the creation of Artificial Intelligence (AI), but so far no approach really managed to map human knowledge (especially common sense) to a software tool. Thus, problems can not be computed by machines and average customers don't have the capability to create the necessary technical solutions, therefore it becomes necessary to transform all problems of flexible product modules into tasks by pre-planning and pre-defining different solutions. Pre-defining results in a set of degrees of freedom that are implemented within the CAD-structure of the product model (see section 5). This way a flexible, comprehensive Database is created, which is used to instance specific solutions by the customers, while the integrated knowledge guarantees a valid product at any time.

5. Knowledge integration within CAD-data

In order to accomplish the aim of modeling highly flexible CAD-models instead of specified solutions for one specific task, it becomes necessary to integrate further product logic within the CAD structure.

This may be achieved in many different ways e.g. by defining dependencies, rules, construction sets, external parameters, constraints, etc. This section will describe the knowledge integration with the help of three examples:

(1) Defining bi-directional dependencies, at first glance quite a simple task, has proofed to be virtually impossible over the past years [Amft M. 2002]. Using a modern CAD-software including knowledge ware packages, with the help of a small trick, we were finally able to attain this goal. As a general rule, once a dependency between two parameters is set, it is not possible to use the second parameter for any other dependency anymore, which leads to unidirectional relations only. The problem was solved by defining two inactive dependencies between the two parameters and one extra rule, that supervises the customers input and activates the necessary dependency while the other remains inactivated until it is needed. This way, there is no conflict between the two relations and the customer is enabled to modify either parameter number one or two.

(2) In another approach it is not only necessary to define relations between two single parameters but to choose specific sizes for an axis due to the customers choice of the wheel diameter. This example was put in action within the model of a high density cleaner (see figure 4) by implementing a rule base and a construction table. Once the rule notices a change in the diameter of the wheel, it checks which component from the construction table fits best. This way costs can be reduced by using standard components at places of no or only little interest to the customer.

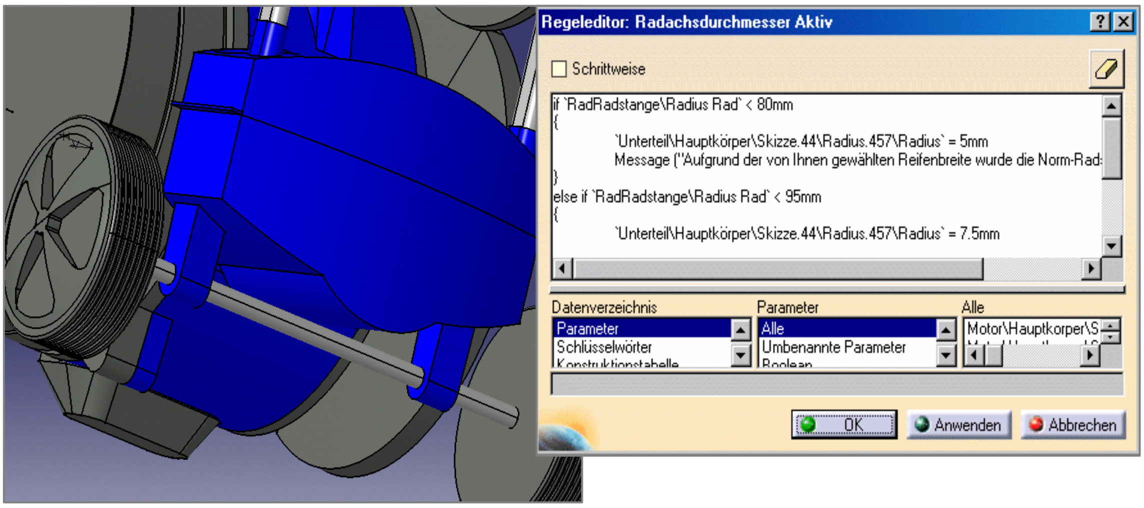

Figure 4. Dependency between axis and wheel diameter

(3) The third example is more complex , dealing with the maximum range of single part values within the high density pressure cleaner. The customer is enabled to adapt the height of the push bar to his personal desires. This is easily done by the change of one external parameter, that adjusts all necessary parameters through dependencies and formulas. But in the event the height is chosen too low, the push bar would clash with the case of the cleaner. As the CAD-software does not react to this incident it has to be taught to do so. By measuring certain distances between the push bar and the case in real time and controlling them with the help of rules, the CAD System is enabled to react on input data, that would lead to a loss of functionality or producibility. Instead, proper values for the parameters in action are chosen and the customers are informed of their wrongdoing.

These are only three examples for the integration of knowledge within the CAD-data. There is a multitude of different others solutions, that are partially dealt with in our project, in order to make future CAD-product models more and more flexible for an efficient and easy configuration process.

6. Conclusion & Future work

This paper presents a possible approach for the intensive integration of the customer within the product development process. Existing methods to deal with the complexity of product development cycles have been adopted to fit the new requirements for individualized products. By investing more time and engineering power in the middle stages of the product development, it is tried to save costs for late changes. This additional work is necessary, for the purpose to transform *problems* to *tasks* in order to guarantee a computer based support for the configuration of individualized products through technical unskilled customers. Formulas, rules, dependencies, constraints, and other subsections of the CAD-functionalities are used to implement the necessary information within the structure of the CAD-model. Once this is done, the model is used as a database for Mass Customization configuration process resulting in consistent CAD-information, which builds the base for subsequent tasks e.g. semi-automated process planning.

Future work will concentrate on the development of tools and methods to optimize the knowledge integration within the CAD-structure. Recurring events as well as standard procedures have to be identified to increase the efficiency of this processes. Another task deals with the integration of all different results form the collaborative research center to one comprehensive software tool. Parallel, an evaluation of chances and risks for potential industrial applications will be accomplished.

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