Title:
Flexible Parameterization Strategies in Automotive 3D Vehicle Layout

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Introduction:
Parametric-associative 3D-CAD programs have become state of the art for design and development of complex high-tech products. Their ability to quickly adapt CAD models to new requirements by the possibility of modifying parameters and input geometry is supporting engineers to reduce development time throughout all phases of the engineering process. Furthermore, it offers the ability of creating and evaluating multiple design solution variants within a short time. Especially in automotive conceptual development, parametric-associative design methods offer a great potential for quick and efficient generation of geometry models as well as for the supply of subsequent engineering processes with required information. Two basic aspects are fundamental with respect to the conceptual definition phase. On the one hand, parametric-associative models are able to store defining product design knowledge within the CAD datasets, which enables engineers to reuse not only the sole geometry, but also the defining process in behind. On the other hand, modern CAD software offers automation possibilities, which enable an extension of the originating software functionalities by new and specialized ones, and the generation of entirely new engineering tools to support the solution finding of specific and complex technical design questions.
In order to provide the mentioned advantages effectively, an extensive planning phase is required, prior to the actual geometry modeling process [13]. This is necessary, because one benefit of parametric models comes with their continuous reusing. In order to obtain a maximum reusing factor of the model, it is necessary that modifications of the model can be retrieved either by changing defining parameters or by exchanging the input geometry. This requires that all possible design variations and design options have to be planned and thought ahead, prior the actual CAD model is created. Furthermore, the used features, parameters and relations have to be structured in a way that the model remains readable, and that design changes remain reproducible for the involved engineers.
The present paper is focusing on a special design task in automotive conceptual development – the vehicle architecture layout process. This job represents one of the most complex steps in conceptual development on top vehicle level. There are two reasons for that high degree of complexity: On the one hand, the automotive concept phase has a highly dynamic character. Requirements and boundary conditions can change quickly, since the process has to respond to new developments and situations on the global market [11]. On the other hand, the technology, which enables different functionalities and properties of the vehicle, is either not fully known or not completely described in this early stage of product development. By this, the traditional relatively rigid parameterization strategies, as used in parametric-associative design on regular part and product level, are insufficient. Additional challenges arise when taking into account the design process itself and the resulting interactions between OEM (Original Equipment Manufacturer) and engineering suppliers. In automotive development, a considerable share of design-related workload is not handled by the OEM alone, but being processed by

supporting engineering suppliers. Because of this situation of workload sharing, a lot of standardization work in modelling and parameterization is required, in order to merge the different types of design data, delivered by several companies, into one coherent 3D vehicle dataset.
In this context, the present paper introduces and discusses an approach that combines the advantages of parametric-associative design with geometrical and relational flexibility at the same time to face the high requirements on data structure and process integration in automotive conceptual development.

Problem statement:
As introduced in the former section, parametric-associative 3D-CAD software is not only used for traditional design tasks in automotive conceptual design, like modeling parts or building up assemblies, but also to manage the architectural layout of a vehicle in order to define the available space and positions for technical components. **Fig. 1** shows a typical vehicle 3D layout at an early development stage.

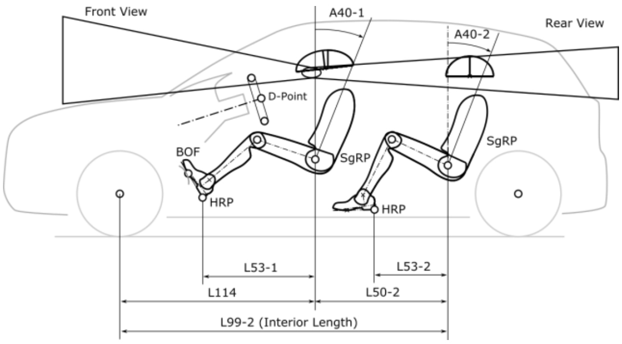

Fig. 1: Exemplary basic vehicle layout (y0 section view).

An early vehicle layout contains the general outer and inner vehicle main dimensions, including simplified ergonomical representations of driver and passengers. In order to retrieve an overview of the spatial situation, proportional parametric models can be used to estimate the extensions of the required space for specific technical components regarding their space requirements and the interaction with an initial car body design. In order to develop and evaluate the vehicle package, functional based space requirements, like necessary clearances to other components, have to be taken into account, in addition to sole geometric space investigations.
In a variable 3D-CAD layout model, the geometrical dimensions are controlled by parameters to enable the creation and analysis of different dimensional constellations and to evaluate their influences onto the vehicle architecture. Depending on the specific design questions, the sequence of development steps for the layout definition of a new car model may vary significantly for one project to the other. Initial car development can be done for instance from inside to outside or vice versa. Another possibility is to start from an existing vehicle platform, where basic dimensions are already defined.
Three main challenges are identified in automotive conceptual layout, in the context of parameterization strategies:

1. Ability of forming of model relations
2. Variable input data coverage
3. Preserving entire model integrity

The forming of relations is essential to a parameterization strategy concerning automotive 3D vehicle layout. Since the sequences of design processes are always different from project to project, the challenge for the development of a universal method for vehicle layout lies in the creation of a parametric-associative model, which supports model modification through adaption of parameters and exchangeable geometry. Because of this, there is no standard for required relations or their behavior available, which makes a default model parameterization impossible. The following example demonstrates a common conflict in a conceptual vehicle layout.

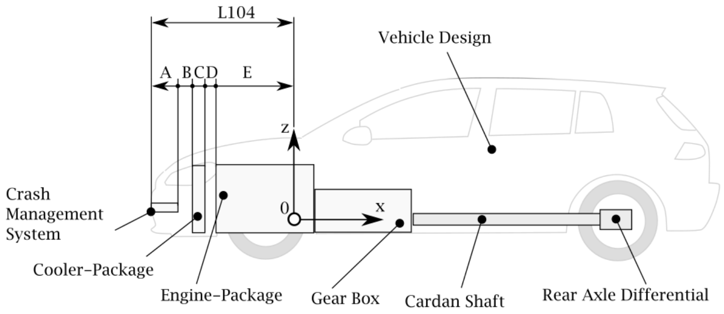

Fig. 2: Exemplary chained up dimensions in the vehicle front.

As illustrated in Figure 2, the overhang front (L104) of the vehicle results from the chained up dimensions in the vehicle front area, defined by the applied proportional 3D models. This is represented by a simple linear equation in the CAD model. From the styling point of view, the resulting overhang might be too long, which leads to discussions about alternative positions for the inflicted components along the vehicle longitudinal (x-) axis. Since this relation is not bijective, there is no unique solution for the involved dimensions, when defining a target value for the overhang front.

The variable input data coverage results from the described situation above, that both technology and required functions are not fully defined in this initial product development stage. Focusing the example above, the relations in the vehicle front are known, but the values for clearances and the dimensions of the proportional models might be not. A possible parameterization strategy therefore has to preserve model stability and data integrity even if input parameters are missing.

<u>State of the art:</u>

Modern 3D-CAD software provides a huge set of different parametric functionalities out of the box. Besides traditional design oriented software functions, which include specific knowledge based features like formulas, rules, checks and the possibility of integrating repetitive tasks by automation routines or scripted actions. An overview of parametric data occurring within a CAD model is illustrated in Figure 3.

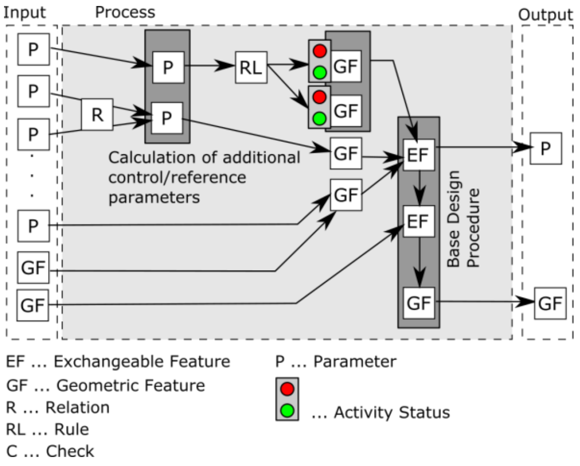

Fig. 3: General parametric data occurring within a CAD model.

From a general point of view, a CAD model is characterized by an input-process-output (ipo) structure. The input of the model can contain parameters and defining geometry. The process element contains the used design features, in order to generate required geometry and geometry-related data like center of gravity, inertia or other properties. The geometric features are structured chronologically according to the intended design history of the model. On top level of the used geometric functions, knowledge features can be applied for different use cases of the model. Mathematical relations (R) can evaluate functional properties of the model, or calculate further design parameters. Rules can control different design options of the model by in-/activating specific areas or sole features of the CAD model, or switch evaluating mathematical relations for the determination of functional properties. Exchangeable features allow the adaption to different input geometry without the need of modifying the model interactively. Another way to integrate knowledge into a model includes the use of automation interfaces. They enable the engineers to create user-specific functions, which can also be used by other designers, and to create entirely new tools based on and within the originating CAD system.
In this way, parametric models can become quite complex, when having implemented lots of knowledge-engineering features. This complexity can lead to problems in view of design work and data management, like irreproducible changes, lacking transparency and maintenance effort. Therefore, the use of such models is often restricted to a small range of specialized engineers [7]. For efficient work, it is a necessity to understand the implemented parameterization strategy of the parametric dataset.
From the automotive point of view, there exist a lot of highly specialized approaches and strategies to support the early design phase [1], [2], [3], [4], [5], [6], [8] and [9]. These approaches have the attempt in common, to provide essential package models as soon as possible in the design process, which enables the evaluation of both geometrical and functional vehicle properties. These approaches are more or less based on a rigid parameterization concept. This means, that defined relations are not considered to be modified, but only the defining parameters. As described in section 0, a rigid parameterization strategies are not sufficient to support the high requirements in the automotive conceptual development stage.

The flexible parameterization framework:
One effective possibility to support the described parametric-associative design task in conceptual vehicle layout includes the so called “flexible parameterization framework” (FPF). This type of framework provides a continuously running service, which supports the definition of parameters and relations in conceptual modeling processes. An overview of the general structure of the flexible parameterization framework is presented in Figure 4. The final paper will include a detailed description of the implemented algorithms, routines and services of the framework.

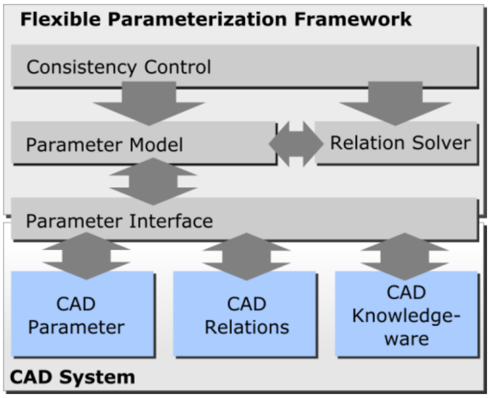

Fig. 4: General structure of the flexible parameterization framework.

The framework basic components are:

- Parameter Model
- Relation Solver
- Consistency Control
- Parameter Interface

The parameter model contains the definition of required parameter objects including parameters itself as well as necessary relations and additional checks or other knowledge ware functions supported by the CAD system.
The relation solver is responsible for a stable forming of relations, but it contains no mathematical definitions. It provides a set of rules and instructions, which define how to handle different types of relations within the layout model.
The parameter interface is responsible for exchanging parameter values and handle the relations and implemented knowledge-ware functionalities of the respective CAD dataset(s).
The consistency control is responsible for preserving the models geometric and functional steadiness throughout the development processes, which requires continuous checking if dependent parameters or relations have to be triggered in the model in order to preserve data consistency. This is achieved by an integration into the update routines of the corresponding CAD software. In the present approach, the sequence of these four functionalities replaces the origin update procedure of the CAD program. As soon as an update of the CAD model is failing, inflicting model areas within the parametrization structure are inactivated immediately. By this, the user receives a direct graphical and logical response of the current parameter constellation in the model.
All parametric and logical relations in the CAD model have to be “watched” by the parameterization framework. Since most of the models are not made from scratch and already stem from existing databases within a company, the flexible parameterization framework must be able to handle existing parametric models and to preserve the required data consistency as well. This is achieved by using the hierarchical structuring of the applied design features within the CAD dataset. A detailed description of these functionalities will follow in the final paper.

Conclusion:
The main objective of the automotive concept phase is to determine those design variants amongst the various possible solutions, which promises to be the best possible compromise in context of required vehicle functions and properties. This is impeded by the fact, that in the early stages of product development, the required vehicle functions and geometric models are often not fully defined, which leads to high geometric and functional uncertainty in the model. In addition, the boundary conditions of the vehicle project within the concept phase may change rapidly, since car manufacturers are forced to react on new developments on the global market. Because of these reasons, parametric-associative models are applied to quickly generate conceptual 3D models, in order to evaluate vehicle functions and resulting properties and to choose the optimal design solution.
In this context, the present paper introduces an approach for automotive architectural layout for managing the complexity due to multiple required parameterization variants of a single model. This so-called flexible parameterization framework provides the advantages of traditional parametric-associative design and offers the necessary relational flexibility at the same time. Automation interfaces of CAD software are used to implement algorithms, which form geometrical and functional relations according to the current project requirements, and provide user interfaces for interactive manipulation and management of the parameterization within the linked CAD dataset(s). In addition, the flexible parameterization framework ensures geometric stability of the involved CAD models. Through the flexible and open character of the approach, it provides extendibility for future adaptions and can be maintained easily to support consistent development processes and reproducibility of performed analyses within the layout model. Furthermore, the stated approach can be used in target-oriented combination with findings stated in [12], to achieve independency of the used CAD authoring system. This is especially important for automotive supplier companies, which have to support multiple CAD systems of their respective automotive OEM customers.

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