Advanced Computer Aided Design Methods for Integrated Virtual Product Development Processes

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ABSTRACT

State of the art computer aided design (CAD) systems offer a wide range of possibilities, not only in the common field of mechanical design, but also in terms of knowledge re-utilization as well as the implementation of analysis procedures and automated routines. An important factor for successful product development is the optimized interaction between the design process itself and simultaneously performed operations based on efficient computer aided methods and strategies. The present publication introduces and discusses advanced methods for the creation of integrated virtual product development processes by implementation of knowledge-based design strategies, product-specific simulation procedures and automated routines into a comprehensive virtual product model within the CAD environment.

Keywords: parametric-associative design, knowledge-based design, integrated CAD.
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1 INTRODUCTION

Virtual product development includes complex linked processes in different technical and economic areas. The development cycle of complex mechanical products is divided into several phases, whereby each phase covers different procedures. In modern development processes, the interaction of the different disciplines provides a basis for efficient engineering processes. In this way, the data transfers between these sections and the organization of workflow have to be carefully planned. Due to the large number of steps and the different departments involved (e.g. engineering supplier, component developer and styling studios), an effective organization of both human effort and data flow presents a significant challenge for the project and process management.

Industrial development processes have included collaborating methods for many years. More powerful information technology (IT) systems and the possibilities of virtual engineering and data management have supported an increase of data exchange and have opened new ways of co-operating. Modern development strategies, such as concurrent engineering and simultaneous engineering, are only possible with modern networked processes. As one of the application-oriented experts, Meywerk introduced the interrelations of computer aided methods within complex virtual product development processes [10]. Integrated development strategies, including parametric-associative geometry creation, interlinked with simulation and computation procedures, have to be applied to fulfill the requirements of the multidisciplinary working packages, especially in early development phases. This fact is pointed out by Hoffmann in one of his publications [7]. The interaction between different working fields is an important factor of success. In virtual development, the product model is displayed in different ways to account for the product structure list, the conceptual cost structure, weight- and mass lists, finite element meshes, styling models and of course a three dimensional- (3D-) CAD model structure. All of these representations of a product model serve for specific fields of development and are generated and maintained in different departments. In most common development processes, these subareas are treated more or less separately and the data transfer between the disciplines is focused on the tasks in each area. In case of complex products, this procedure can lead to an opaque development, which has to be monitored carefully and with a significant organizational effort.

The implementation of parametric-associative model structures and programmed routines enables an effective data transfer between the different working tasks and supports a user- friendly handling. The presented methods of integrated CAD result in universal applicable product representation models, which serve as a central unit for both design- as well as simulation procedures. Combining the requirements of styling, design and simulation, the presented methods and strategies are able to support an improvement of data quality and a reduction of cost- and time effort in engineering based development processes at the same time.

2 PARAMETRIC-ASSOCIATIVE DESIGN

CAD systems use computational graphics algorithms to reproduce real objects in a virtual environment. The main features of virtual product representation, which were developed in the second half of the 1990s, provided the foundation for the fast-growing expansion of computer-aided applications in research and development. In his publication, Weissberg describes the possibilities of modern computer aided design methods in view process integration and optimization during the last decades [14]. Currently, various software solutions for computational product generation are available on the market, but these solutions generally use similar algorithms for the representation of geometry. Depending on the specific type of application, styling software enables the creation of smooth surfaces for product shaping, design software offers functionalities for engineering focused product creation processes, and calculation software facilitates the derivation of calculation models for further simulation procedures.

Parametric modeling techniques in 3D-CAD utilize linkages of geometry objects with geometric constraints and dimensional data. The general possibilities of parametric computer aided design are discussed in detail by Lee, [9]. This separation of geometry elements of the CAD model and the corresponding parameters is characteristic of parametric design. A geometry variation is accomplished by changing the input data of the corresponding dimensional constraint associated with a new computation cycle. The exertion of influence on the parameter values is managed either by direct data input or by means of equations. In the latter case, parameters are able to supersede the equation arguments. The recalculation implies an examination of the model consistency as a requirement for the possibility of a geometry adaptation. The degrees of freedom of associative models are only in part ascertained by direct input of specifications. The remaining requirements for an unambiguous determination are defined by means of relations to geometrical elements, such as a sketch.

Associative design operations include relations and dependencies directly between geometrical objects. Geometrical linkages are defined as a part of the creation process and create parent-children dependencies. As an example, the offset surface from an existing surface is directly related to the basis surface; a modification of parent elements leads to an update cycle of the offset geometry. Modern CAD systems offer the possibility of multi-model links, which enable the definition of associative functionalities between (formerly independent) components in assembly structures. This characteristic supports the implementation of far-reaching geometrical connective relations through the use of comprehensive functionalities.

Parametric-associative design combines the possibilities of parametric design and associative functionalities. The realization of parametric geometry control and interlinked geometry elements enables an enhancement of 3D-CAD product representation with mathematical and logical functionalities. Parametric-associative CAD models include much more than purely product geometry representation. They are able to contain additional information and functionalities, joining components, parts and modules. CAD processes of complex products are based on the assembly of numerous components, units and groups in digital mock ups (DMUs). In this way, it is important that parametric-associative design is used not only for the definition of single-component geometries on part level, but also for driving component positioning and other features on assembly level. The implementation of parameters, constraints and relations within an assembly structure allows the linkage of components aiming at a systematical and structured control of their positioning within superordinated systems (multi-model design).

The success of parametric-associative modeling is directly influenced by the design methods and strategies applied. The implementation of interconnections between geometry elements and parameters requires an integrated modeling process, which expands the effort of former non-parametric geometry creation. In particular, the development of complex product structures with a large number of various components and modules requires the implementation of design-process related guidelines, which include detailed instructions regarding the parameterization strategy. The possibilities of parametric-associative design lead to numerous approaches for the improvement of design processes itself during the last years. Exemplary, Salehi introduced an approach, which considers identified factors and indicators from previous sections and relationships between design relevant parameters [12], and Shea deals with automated optimization cycles for variant studies within prescribed design algorithms [13].

Besides various design-relevant functionalities, modern CAD systems offer enhanced modules to support the entire development process. These include an integration of (formerly) stand-alone simulation software tools, such as finite element programs, multi-body simulation software and others as well as the capability for the integration of problem-oriented automated routines and algorithms into the design process [9]. The linkage of model geometry and controlling parameters not only improves the design process itself. Parametric-associative software packages offer various possibilities for associative product development and bring design closer to traditional engineering tasks (convergence of CAD and CAE (computer aided engineering)). The efficiency of simultaneous engineering procedures often depends on a close integration of the applied software packages, in which an intelligent data transfer structure between geometry generation and simulation processes can reduce time and engineering effort.

3 ADVANCED COMPUTER AIDED DESIGN METHODS

Different phases of development are characterized by different degrees of parameterization of the applied product models. In conceptual and pre-development phases, a high degree of parameterization is essential for a successful development. In these phases, a high degree of freedom is required for the investigation of multiple variants and variant studies. In addition, improvements on the product are performed step by step, which requires highly flexible models. These flexible parametric models support a connection of different procedures by integration approaches and via specific interfaces, as well as via parameter exchange. In the phase of series development, the model structures are less flexible. Incorporating production-relevant aspects and a high level of detail require an intensive processing of individual components. In case of the design of complex products, the workload is performed in different departments and often supported by engineering suppliers. This importance of collaborative virtual engineering by use of integrative design strategies is discussed by Dankwort [1]. The complex configurations can lead to inhomogeneous product model structures in terms of parameterization and model history. Of course, the technological requirements are fulfilled from all participating development departments, but the various working methods can lead to incompatibilities in terms of process automation and modification.

The creation of integrated model structures for the supply of design, calculation and simulation throughout the entire development process requires the application of enhanced modeling functionalities. In the present approach, the product model definition and its parameterization is carried out within the same software environment. Besides the geometry creation and the geometrical parameterization, enhanced methods of modeling come to use.

The application of parametric-associative design enables an integration of knowledge-based features and methods with the target, in order to reduce engineering effort and increase data quality at the same time. The wide field of functionalities in knowledge-based design can be divided into two main groups. The first group offers a reuse of 3D-CAD models in subsequent product creation processes through variable template geometries. These templates can include standardized components or flexible models. In either case, they transform both geometry and design knowledge from former projects or libraries into new applications. The second group includes the implementation of routines, reactions and algorithms into the 3D-CAD process with the aim of supporting geometry creation through automated calculation and optimization procedures. Both approaches have to be planned carefully to tap the full potential throughout their application in virtual product development. An important basis for the creation of efficient model structures is the application of predefined model structures throughout the entire development process chain by use of startup models.

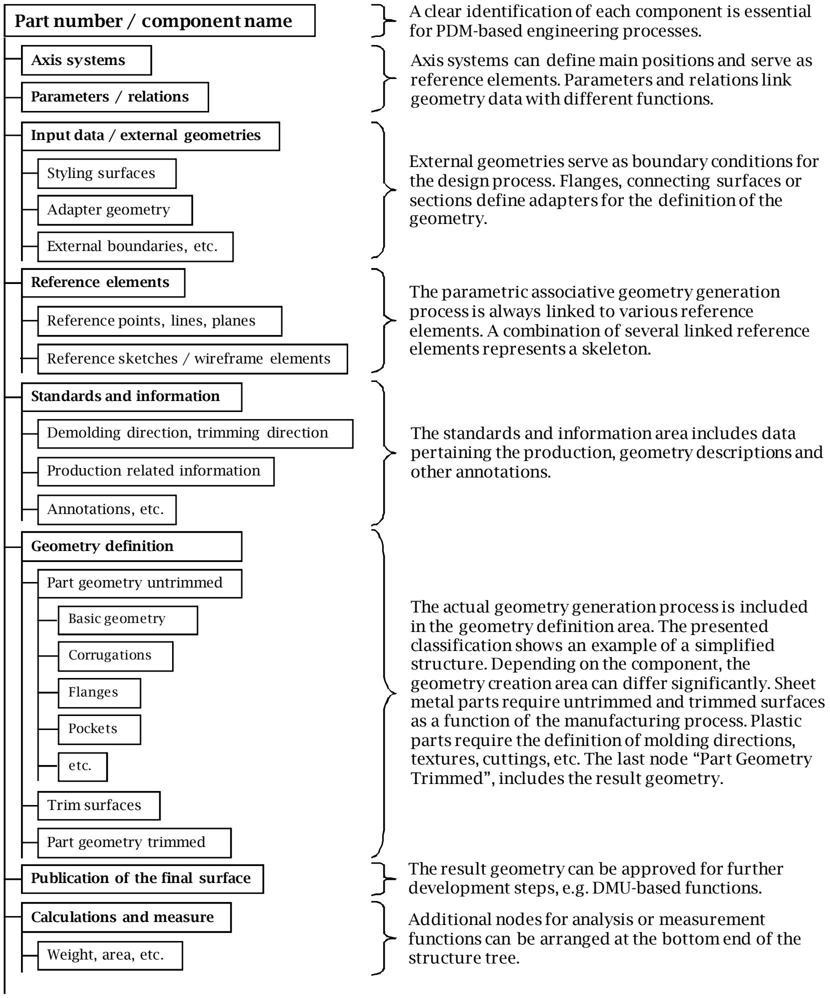
3.1 Design Structure Predefinition by Use of Startup Models

3D-CAD models are configured in a logical order of geometrical elements. In state-of-the-art design software, the history-based construction of parametric-associative geometry models is represented in specification trees, which include a detailed description of all geometrical elements and parametric relations. In modern development processes, the 3D-CAD geometry generation is based on parametric-associative structures, whereas the virtual models are built up according to predefined orders in so-called startup models. These startup models include various definitions related to the design process of the components and can also include additional functionalities related to design check features, calculations or DMU relevant information. Different kinds of parts in virtual product development processes call for different design-related boundary conditions. Therefore, the setup of startup models varies according to the requirements of each type of component to be created.

Surface-based models, which exemplary occur in car body development require a predefinition of the sheet metal design process. Depending on which CAD software is applied, startup models of surface based parts separate reference geometries, supporting geometries, executive surfaces, green surfaces and the final geometry. A startup model predefines the order of each element of the geometry creation process to support modifications, check operations or upgrade processes. Startup models of components of the same category (e.g. sheet metal parts, plastic parts, cast parts) unify the model structure during the entire development project to guarantee a good compatibility.

Figure 1 displays a generic model structure for sheet metal design processes, which has been created as a result of detailed body in white startup model configuration studies in the automotive industry. The generic start model shows the segmentation of a parametric model structure into different modules, which contain specific types of components, functions and relations required for the model generation. Each component is identified by its part number and/or its component name. Unambiguous notations are the basis for the integration of CAD models into product data management systems, which control the data flow during the development processes. Reference elements serve to orient geometrical relations within the entire product structure. There are different types of reference elements, which are organized in prescribed folders of the specification tree. Axis systems define main positions in the design process. External geometry elements serve as input data and boundary conditions for the design process. In this way, styling data, adapter geometries and other external geometry-related aspects are imported into the model environment and stored in a predefined folder of the specification tree.

Design-related standards and information enable the implementation of production-related aspects, such as demolding and trimming directions, annotations, specifications for programming mechanical machining procedures and others. This information is provided as geometry elements or in the form of information and parameter. The folder “Parameters/relations” includes user-defined parameters and formulas, which control several integrated functions, such as embedded calculation algorithms, geometry control or data exchange procedures. The geometry creation process itself is accomplished in the “Geometry definition” area, which is divided into different folders based on the requirements of the model which has to be created. In many cases, the operational sequences of geometry creation are not prescribed and give the essential creative freedom for the generation of appropriate geometries. In this area, engineers produce their models based on their knowledge and experience. Finally, the resulting geometry is marked as final component and checked for further processes. The approved geometry is placed in a specific area of the structure tree, for example in the folder “Publication of the final surface”. Supporting calculations and measurement operations are organized in the last folder of the specification tree.



A clear identification of each component is essential for PDM-based engineering processes.

Axis systems can define main positions and serve as reference elements. Parameters and relations link geometry data with different functions.

External geometries serve as boundary conditions for the design process. Flanges, connecting surfaces or sections define adapters for the definition of the geometry.

The parametric associative geometry generation process is always linked to various reference elements. A combination of several linked reference elements represents a skeleton.

The standards and information area includes data pertaining the production, geometry descriptions and other annotations.

The actual geometry generation process is included in the geometry definition area. The presented classification shows an example of a simplified structure. Depending on the component, the geometry creation area can differ significantly. Sheet metal parts require untrimmed and trimmed surfaces as a function of the manufacturing process. Plastic parts require the definition of molding directions, textures, cuttings, etc. The last node "Part Geometry Trimmed", includes the result geometry.

The result geometry can be approved for further development steps, e.g. DMU-based functions.

Additional nodes for analysis or measurement functions can be arranged at the bottom end of the structure tree.

Fig. 1: Example of a startup model configuration for sheet-metal-based geometry creation [6].

Unlike sheet metal parts, cast metal components are mainly designed in solid structures. Solid structures define the geometry with the help of volume-based functionalities. The main body design is generated with the help of solid-based features and so-called Boolean operations. If required, surfaces are integrated as boundary conditions, reference elements or splitting components. The general structure of the startup model corresponds to that of the sheet-metal-based geometry creation. Axis systems, boundary conditions, annotations and reference elements are arranged in the same order, but the geometry creation itself follows the rules of solid-based operations.

3.2 Knowledge Integration by Use of Template Libraries

The separation of geometry and underlying parameters enables the definition of flexible models, which can be modified by simply changing the values of parameters. These highly variable templates include all structural and geometric information and are controlled by input parameters. Koschorrek and Forsen have introduced basics of template-related design methods for the application in automotive body-in-white development [2, 8]. The geometry creation process of these templates has to offer a universal usability, so that varying lengths or distances has no negative influence on the stability of the model. When generating template models, it is essential that both the range of possible parameter values and the flexibility of the created geometry fulfill the requirements of the intended application. Mathematical connections of parameters and restrictions of input values to reasonable rates support the definition of expandable templates for several standard components. Every variant of a template component represents a variation of the basic model, including the same design methods and rules. In this way, the template method samples expert knowledge and integrates know-how into the design processes.

As an advancement of conventional template methods, library based design methods facilitate the configuration of knowledge related models, which are composed of different preselected parametric modules, imported from a 3D-CAD model data base. This method supports a quick and efficient generation of conceptual geometries that takes into account a wide range of influencing factors. Besides the use of complete predefined models as templates, an enhanced application supports the generation of new geometries using predefined modules, which are selected by the user and assembled with automated functions. Due to the remarkable advantages of library-based geometry creation methods this approach has a high potential for a further increase of efficiency in modern design processes.

The product geometry is divided into several modules, which are saved in a data base. During the design process, these modules are loaded in a predefined sequence and implemented into the 3D-CAD model. After a user selection of desired components from the library, the geometry is built up step by step by application of automated loading and assembling procedures. Figure 2 shows an example of a semi-automated design process by use of a modular template library. In the present example, the library includes several modules for the design of a complex product, which includes different levels of detail. A predefinition of production related features (e.g. mould configuration, draft direction, draft angles and rounding characteristics) considers the requirements of mass production processes from initial design phases on. Each parametric-associative geometry template module is available in a number of choices with different characteristics and details, so that a broad combination variety enables the generation of numerous different concept geometries.

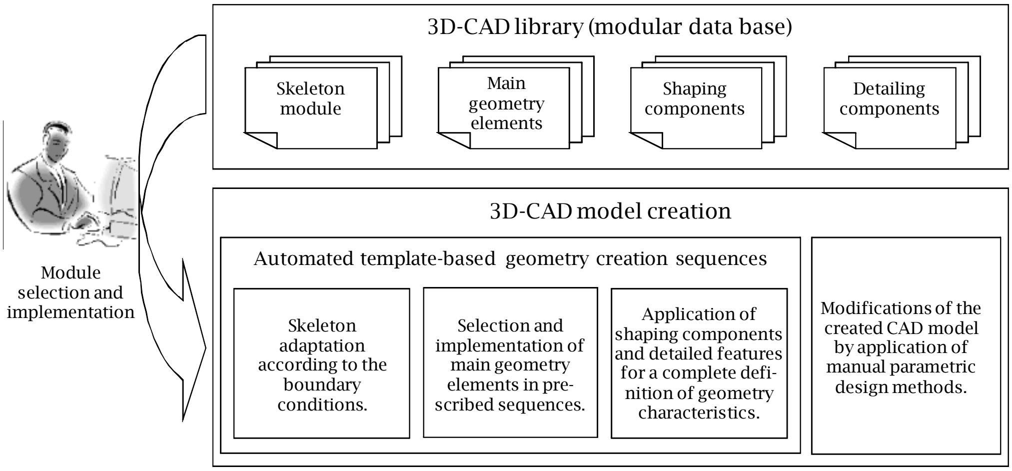


Fig. 2: Semi-automated design process by use of a modular template library.

Figure 2 displays the general strategy of a library based design procedure. The data base structure of the library includes a skeleton module, a module with main geometry elements, a module with shaping components and finally a module with detailing components. The first step of semi automated geometry creation includes an adaptation of a variable skeleton module onto geometric boundary conditions. The variable skeleton serves as a reference for the following positioning process of geometry templates. In the next steps, the main geometry modules are user selected and implemented in prescribed sequences. All main modules include sub-elements, which are available in the data base as parametric-associative template geometries. The automated assembling process of geometry templates can include Boolean operations, split and trim operations as well as the application of fillets and draft angles.

The entire geometry generation process is fully implemented into a commercial 3D-CAD environment, so that all standard functionalities of geometry generation and modification can be combined within the automated design process enabling subsequent manual modifications. Adjustments and optimization cycles are supported by a direct linking of the skeleton module onto boundary conditions, e.g. geometries of surrounding components or imported styling surfaces. In case of replacements of these boundary conditions during the development process, the existing references are exchanged and the geometry model is reconnected automatically. In this way, the application of template based geometry modules for the generation of parametric-associative concept geometries supports an easy to handle definition of flexible 3D-CAD models. A high level of detail is achieved by use of a hierarchical model architecture, which includes rough geometry templates for initial steps as well as detailed models for the creation of connecting surfaces, punches, flanges and trims.

A stepwise creation of the product geometry in combination with a continuously increasing share of verified data leads to an increase of product maturity during the entire development process. The product maturity itself is defined by a fulfillment of clearly prescribed milestones, which enables a reporting and observation procedure regarding the achievement of objectives. Every optimization step in the workflow is accomplished by a coupled reaction of the 3D-CAD model, which leads to a successive increase of knowledge in all involved areas. This is achieved by an increasing level of detail in geometry creation and growing information content in the technology concept definition. Besides the pure technical oriented procedures in virtual product development, the integrated architecture of the presented approach supports a communication of all involved parties and the required knowledge transfer. This is achieved by an easy to handle product representation via 3D-CAD geometry data as well as by the universal parameterization strategy and a data based parameter management.

3.3 Implementation of Mathematical and Logical Relations

The definition of mathematical connections between parameters enables the implementation of logical geometrical dependencies. In this way, formulas, relations, rules and reactions can be applied into the 3D-CAD model environment and support automated geometry definition processes. This can lead to a reduction of design effort in case of variant studies or re-use of parametric models. Besides purely geometry-related characteristics, these enhanced parametric models are able to include additional knowledge about dependencies and relations between different design related aspects.

Figure 3 shows an example of function oriented geometry creation within a common 3D-CAD environment. The definition of mathematical connections between parameters states the basis for the creation of rules, which can be used to control geometric functionalities in the applied CAD system. In the present example, the equation $x_2=A \cdot \sin(k \cdot x_1)$, with $[0 \leq x_1 \leq k \cdot \pi]$ and the real parameter A (amplitude) defines the progression of a curve in a Cartesian coordinate system. The application of this curve progression onto a user-defined curve in space as leading element leads to the corresponding three dimensional spline, which can be used for the creation of complex technical surfaces, e.g. sine based tubes.

Parameter-based rule definition

Application on a centre curve as leading element

Further usage of the rule-based geometry for the creation of technical surfaces

Fig. 3: Exemplary function-based geometry creation.

Besides standard functionalities for the implementation of mathematical and logical coherences, the integration of (internal or external) problem-oriented solving procedures into the design process enables supporting recurrent operations in the course of development and optimization cycles. In the case of internal calculation procedures, the mathematical algorithms are embedded in the CAD environment, which facilitates a direct access to the implemented functionalities. Internal solving algorithms use the functionalities of the CAD system to define user-defined procedures and calculations. These can be simple linear calculations of dimensional values or enhanced mathematical algorithms, which are embedded in macro-controlled software sequences.

External solving algorithms use specific programs and/or simulation procedures for the computation of complex tasks. The transmission of parameter values required for the calculation is performed by bi-directional data transfer between the design software and the simulation programs. For this purpose, specific parameter sets are defined in the CAD software and handed over to the simulation program. The subsequent external computation procedures can include different procedures, such as complex calculations of dimensional characteristics, optimization cycles or the simulation of influencing physical processes.

3.4 Programming of Automated Routines and Business-Oriented Software Applications

In order to enable automatic sequences of features and actions, the ability to create macros can be very helpful. Most of the advanced CAD software packages offer programming languages, which support the creation of effective and versatile routines. Macros can control recurrent operations in virtual development processes. The implementation of these programs into the CAD software enables their integration into the virtual model, while the data flow in assembling structures and between other types of CAD files supports the generation of efficient tools for specific problems in the development process. An automated handling of problem-oriented mathematical connections, formulas, rules and algorithms can be implemented into the corresponding product model to support the layout and design phase significantly. In addition, the creation of graphical user interfaces and macro-specific toolbars in the design environment supports a user-friendly operation.

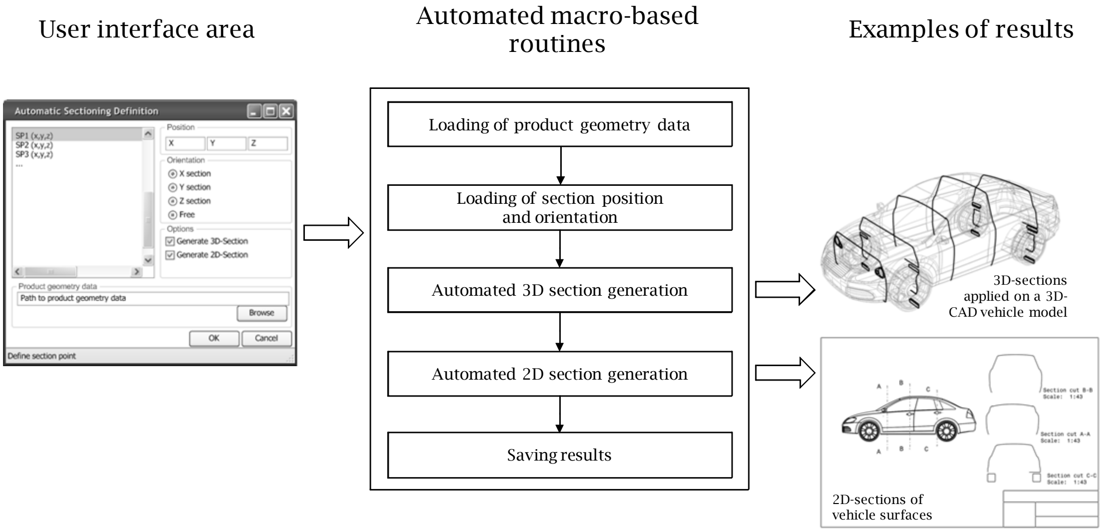


Fig. 4: Example of a CAD system integrated, automated sectioning application.

Figure 4 shows the general architecture of a macro-based business-oriented software application for the automated generation of sections in 3D-CAD product models. A sample of graphical user interfaces enables an easy to handle data input. In case of the present example, the path to the concerning product geometry as well as the positions and orientations of sections are prompted in prescribed boxes. After that, the program loads the specified geometry models and accomplishes the operations required for the sectioning process automatically. Finally, the produced 3D and 2D sections are saved in predefined folders. Based on the automated functionality, a big number of sections can be created with a low charge of manpower, e.g. as autonomous overnight-work package.

3.5 Assemblies

The assembling of components in 3D-CAD is carried out in a specific assembly-design environment. The product structure contains links to individual components and their relations to each other. An assembly-oriented design strategy enables an easy examination of component positions and collisions; therefore, the entire product can be divided into several sub-assemblies. As an example, a sub-assembly of an automotive full-vehicle DMU can represent the body, including all movable and fixed parts. The sub-assembly of the automotive body itself consists of several sub-assemblies (e.g. components of automotive body-in-white structures, such as side panel modules, the roof module, doors and several other products and parts). Stripping down complex structures into sub-assemblies consisting of multiple components provides a basis for simultaneous design processes that take functional and space requirements into account.

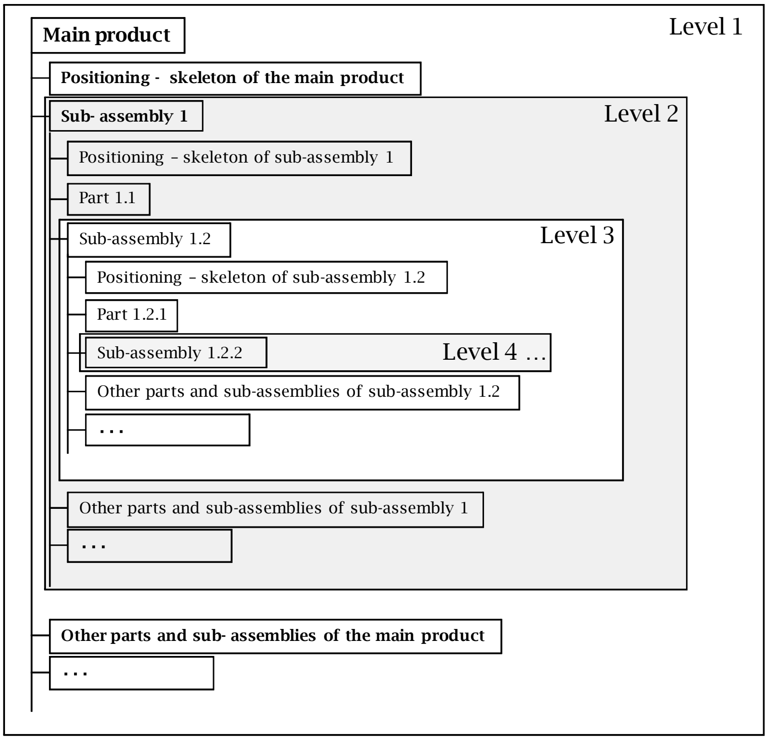


Fig. 5: Sample assembly structure, including skeletons.

The positioning of the components within a product can be carried out in different ways. In the case of small assemblies, it makes sense to define constraints directly between the components. Typical constraints are distances, coincidences or angles. Thus, the components of a product can be positioned with reference to each other, with the constraints being subject to parametric-associative laws. More complex assemblies can be built up by using dedicated positioning components within the product structure. The so-called skeleton method does not use constraints between the components. Instead, they are defined relative to an auxiliary construction, the skeleton. The geometrical elements of the skeleton model therefore define the positions of each component in space and relative to each other. The reference elements of skeletons are typically lines, planes or points. Tall assemblies use several sub-products logically combined with the help of a number of skeletons, thus generating a modular design (Figure 5). The modular structure of assemblies enables (linked) modularities in data configuration, which support an efficient data management.

In addition to the two positioning strategies mentioned above, a different method has been established in assembling and design of complex products. This strategy consists of arranging each component relative to a main coordinate system. The definition of position is performed in the course of the part design process using a startup model, which includes the main coordinate system. Sub-modules can be placed by the definition of sub-coordinate systems, which are referenced to the main coordinate system. Of course, it is possible to combine the different positioning methods. To avoid problems during the design process, it is essential to clearly predefine the component positioning strategies in the course of the project planning.

3.6 Integrated Virtual Product Development by Use of Centralized Master Models

One key to an effective coupling of design related aspects and simulation related tasks can be the use of a centralized master model, which contains the product geometry, as well as additional information. In principle, the components to be developed are the point of intersection between all engineering disciplines. On the one hand, the design department has to develop the product geometry including the component structure under consideration of several design related aspects. This development must be done within manifold boundary conditions from calculation, simulation and under consideration of production requirements to guarantee an efficient industrialization process. On the other hand, the production engineering has to consider the product characteristics, meaning that the product is the focal point of several processes. In this way, it must be optimum to use a master geometry model as centre of development. This master geometry model can be managed in a superordinated product data management structure, which takes into account all required data flows.

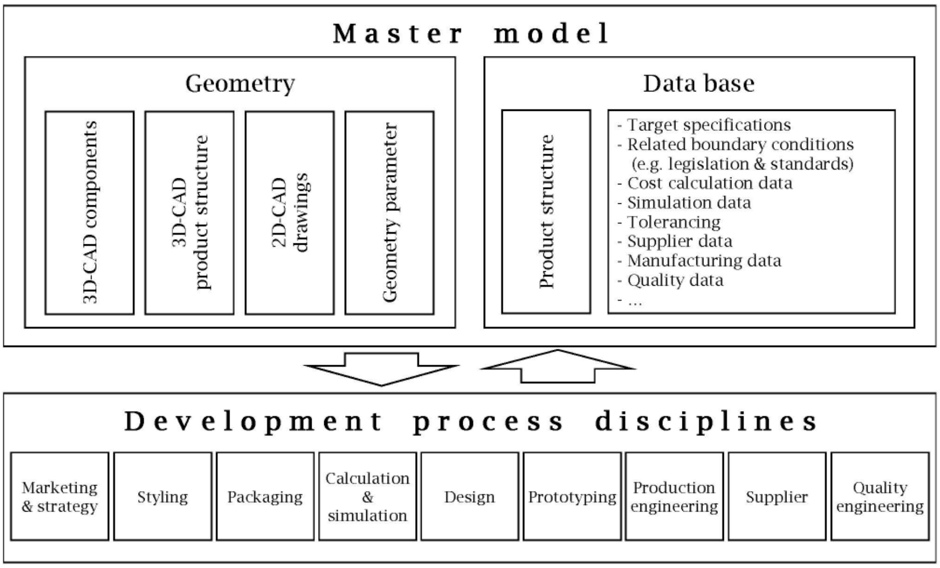


Fig. 6: Configuration of an exemplary integrated master model.

Figure 6 shows the configuration of an integrated master model, which can be used for the development of complex mechanical products. The geometry section includes all components and modules of the product as 3D-CAD components. The product structure is arranged and managed in an assembly structure. Besides tasks of positioning, packaging and functional development (e.g. kinematics), the assembling includes a hierarchical configuration of the sub-modules and components. For archival purposes and the support of production engineering, parametric derived two dimensional (2D) drawings are created and administrated. An important feature is the organization of geometry parameter in a predefined order, which includes a consistent parameter structure in each component and assembly level as well as a centralized parameter structure in the main level of the product assembly. This centralized parameter structure is used for direct information exchange with an associated data base.

The data base section also contains the product structure to enable a thorough organization of different types of product data. These data are stored in different areas of the data base and supply a broad field of development disciplines with required information. Besides this role, the data base serves as central unit for storage and tracking functionalities through the entire virtual product development process. Depending on the type of product to be developed, different disciplines are taken into account. The exemplary configuration in Figure 6 shows a selection of main working tasks and data groups in an automotive full vehicle development process.

In many cases, the product development starts with a design process within a CAD environment. In the initial phase, the model structure has to be adapted to the requirements of development status and is displayed in separate prescribed configurations. Product data management (PDM) systems for series production apply their management strategy in relatively rigid structures, created to fulfill the demands of design, simulation, production and administration, whereas PDM configurations for concept phase and pre-development have to consider the highly flexible processes and requirements of initial engineering. It is a challenge for the engineers of new development processes and strategies to create methods which are able to combine the flexible work during concept phases and the rigid, manpower-intensive work in series development. The target is to transfer the knowledge from concept phases directly into the series development process. A direct adoption of geometry models coming from the concept phase as start up models in the series development cycle could lead to a data flow integration of both phases. This method has to meet the subsequent challenges.

The use of the same parametric-associative geometry model structure in both pre-development and series development requires a flexible model architecture which is able to fulfill the requirements of both process phases. Currently, different start models are used to respond to the different necessities. The different demands related to geometry creation are mainly based on a high flexibility during the concept phase and a high degree of detailing during series development. Normally, the degree of parameterization is much higher in initial development phases and decreases significantly in series development. On the other hand, the level of detail in component geometry is relatively low in the early phases, but has to be high in the production-related development of the final geometry creation process. The development of future design processes has to solve this contradiction by implementing flexible geometry model structures for both phases. First, two things must be clarified: what degree of parameterization is reasonable for each process step and how a changing level of model parameterization can be handled in the same environment to ensure an effective data and knowledge transfer between the different disciplines and departments. In this way, research work in upcoming years will make use of the increasing abilities of CAD software combined with rising hardware performance to enable a high degree of parameterization of the 3D-CAD models across the entire development process.

4 EXAMPLE OF APPLICATION: ADVANCED CAD METHODS IN AUTOMOTIVE DEVELOPMENT

The present application shows an actual challenge for the development of integrated, business specific design methods by use of advanced CAD technique in automotive development. A master model includes a full vehicle configuration and serves as a central development platform. Within this configuration, a conceptual vehicle model “Concept Car” covers all full vehicle related boundary conditions and requirements, as there are legislative prescriptions, requirement specifications, ergonomic demands, packaging relevant aspects, styling data, etc. This conceptual vehicle model is composed of several parametric CAD templates and supports the entire full vehicle layout phase of a new car model. The setup and the possibilities of application of the integrated vehicle model for conceptual automotive development are introduced in [4, 5, 11]. In addition, the master model DMU contains different design related modules for the development of a full vehicle model, including assembly groups and meta-data (e.g. technological requirements). The entire master model structure is linked with a CAD external data base, which accomplishes the management of the product structure as well as the implementation and organization of simultaneously performed workflows. For an improved user handling, macro based program routines and graphic user interfaces are implemented.

Figure 7 shows the workflow of an exemplary bumper system development as a part of the full vehicle development process. Specific requirements and boundary conditions for the development of a front end crash structure, as there are packaging relevant data, limitations due to standardized crash tests and legislation instructions, styling demands and others, are transferred from the master model structure into the targeted module level. The layout of the front end crash system is performed in a module level by use of specific layout algorithms, which are implemented in an integrated CAD template model. Within this model, dimensions of bumper and deformation elements are conceptual calculated by use of empirical determined experienced values and integrated computation routines. The possibilities of a conceptual front end crash structure pre-calculation within a CAD template model is discussed by Harrich in [3]. As a result, the main dimensions of the bumper system are transferred to a parametric-associative skeleton model, which displays the packaging relevant space requirements of this module. The verified design space stands the basis for a subsequent conceptual geometry creation process of the respective components.

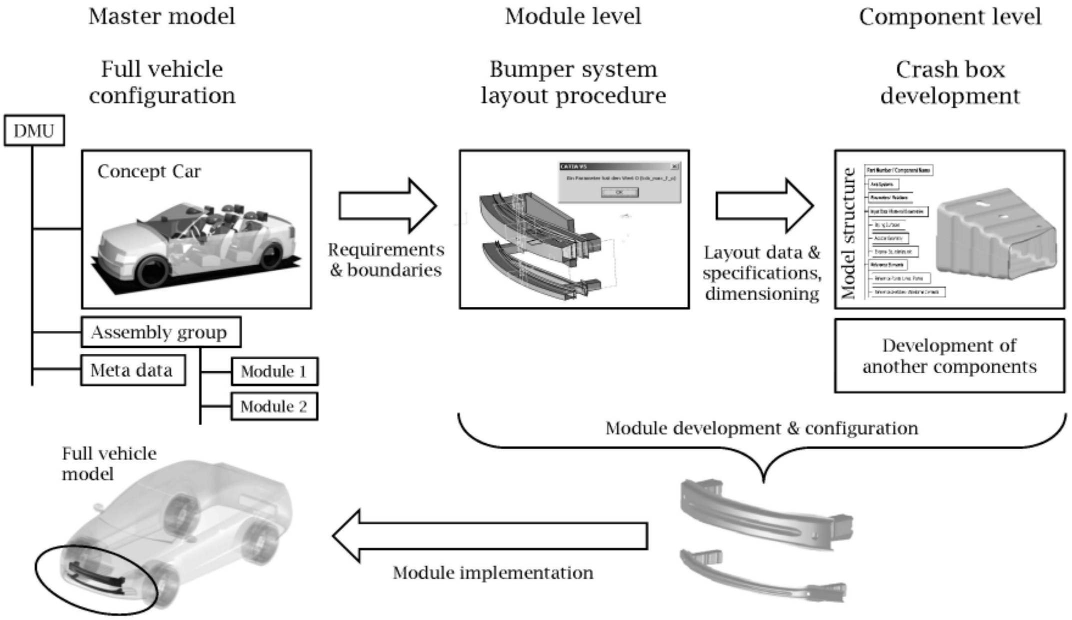


Fig. 7: Workflow of an automotive bumper system development by use of integrated design methods.

The geometry creation is accomplished at component level using parametric templates of each component, which are included in start-up model configurations. The advantages of the start-up model approach consist in a predefined component structure, which force predefined geometry creation methods and facilitate the reuse of template models and different automation functionalities. Thus, adaptations and changes of the geometry can be arranged flexible and within short durations. Furthermore, the prescribed model structure enables geometry creation procedures using library based geometry creation features. In this way, a predefined geometry, for example of a crash box, is implemented and automatically adjusted to the embedded module skeleton. The components are assembled on the module level and parametrical associated to the module skeleton model. Finally, the conceptual bumper system geometry is implemented into the full vehicle configuration of the master model.

This procedure enables an efficient and quickly creation of conceptual component and module geometries in initial product development phases. The early concept geometries are used for initial investigations and simulation procedures; so they are continuously improved or exchanged by models with higher maturity. The flexible data configuration of a centralized master model makes an efficient handling of product related data possible, which is not restricted to the design process, but covers many surrounding working fields.

5 CONCLUSION

Besides geometry creation, modern design processes include the development of several additional product characteristics, such as functional layout, materials, process-relevant data (e.g. for production), product structure, and others. Thus, the geometry creation represents an important working area in the development of complex products. The present publication introduces knowledge-based parametric-associative design and development methods and gives short examples of application. The use of parametric-controlled design enables an integration of business-specific solving procedures into the design process, with the goal of supporting recurrent operations in the course of development and optimization cycles. A main topic represents an integrated centralized approach, which links the entire workflow of virtual product development to a virtual product master model. During all task of product definition, the geometry-based master model is able to represent the current state of development and to interact with the simultaneously performed workflows. The present approach of an integrated master model enables a comprehensive product description based on object-oriented parameters, which are transferred into different attending processes. The extended consideration of numerous working fields in initial development processes, in combination with a detailed parameterization of a product model itself and its influencing boundary conditions, enables the application of knowledge-oriented methods for the step-by-step creation, all that within a virtual environment. In this way, advanced parametric-associative design methods open up a wide range of possibilities for a further improvement of virtual product development processes.

REFERENCES

[1] Dankwort, C.W.; Ovtcharova, J.; Weidlich, R.: A Concept of Engineering Objects for Collaborative Virtual Engineering: Automotive Case Study, ProSTEP iViP Science Days 2003, Dresden 2003.

[2] Forsen, J.: Ein systemtechnischer Ansatz zur methodisch parametrisch-assoziativen Konstruktion am Beispiel von Karosseriebauteilen, doctoral thesis at the Universität Duisburg-Essen, Shaker Verlag, Aachen, 2003, ISBN: 3-8322-1862-9.

[3] Harrich, A.; Sinz, W.; Hirz, M.; Lorenzer, M.: CAD basiertes Werkzeug zur Vorauslegung der Crashstruktur eines Frontenmoduls, VDI Report 2107, 2010, 569-585, ISBN 978-3-18-092107-5.

[4] Hirz, M.: An approach of multi disciplinary collaboration in conceptual automotive development International Journal of Collaborative Enterprise (IJCEnt), in press, 2011, ISSN (Online): 1740-2093, ISSN (Print): 1740-2085.

[5] Hirz, M.; Hirschberg W.; Dietrich W.: Integrated 3D-CAD design methods in early automotive development processes, FISITA World Congress 2008, Munich, Germany.

[6] Hirz, M.; Göber, T.; Lang, M.: Integrated 3D-CAD Design Strategies in Vehicle and Engine Development Processes, 8th International Symposium in Stuttgart, Germany, 2008.

[7] Hoffmann, Ch.M.; Hopcroft, J.E.; Karasick, M.S.: Towards Implementing Robust Geometric Computations, Annual Symposium on Computational Geometry 1988, ISBN: 0-89791-270-5.

[8] Koschorrek, R.: Systematisches Konzipieren mittels Ähnlichkeitsmethoden am Beispiel von PKW-Karosserien, doctoral thesis at the Institut für Konstruktionslehre, Technische Universität Baunschweig, 2007, Logos Verlag Berlin, ISBN 978-3-8325-1784-7.

[9] Lee, K.: Principles of CAD / CAM / CAE Systems, Addison-Wesley Longman Inc., USA 1999, ISBN 0-201-38036-6.

[10] Meywerk, M.: CAE-Methoden in der Fahrzeugtechnik, Springer, 2007, ISBN 978-3-540-49866-7.

[11] Rossbacher, P.; Hirz, M.; Harrich, A.; Dietrich, W.; Theiss, N.: The potential of 3D-CAD based process –optimization in the automotive concept phase, SAE International Journal of Materials and Manufacturing 2, 2009, 250–257, ISSN: 1946-3987.

[12] Salehi, V.; McMahon, C.: Development and Evaluation of an Integrated Approach for Parametric Associative Design in an Industrial Context; Journal Computer Aided Design and Applications, DOI: 10.3722/cadaps.2010.07-14

[13] Shea, K.; Wölkl, S.; Helms, B.: Computer-Aided Concept Models and Methods for Vehicle Design, 2nd Grazer Symposium Virtuelles Fahrzeug (GSVF), 2009, Austria.

[14] Weissberg, D.E.: The Engineering Design Revolution: The People, Companies and Computer Systems That Changed Forever the Practice of Engineering, Cyon Research Corporation, online book http://www.cadhistory.net, USA, 2008.