Advanced 3D-CAD Design Methods in Education and Research

Dr. Mario Hirz
Dipl.-Ing.(FH) Alexander Harrich
Dipl.-Ing. Patrick Rossbacher
Institute of Automotive Engineering
Graz University of Technology, Austria

ABSTRACT

The integration of advanced virtual engineering methods into 3D-CAD based development processes leads to increased requirements, concerning the software packages as well as regarding the applied procedures and strategies. Modern IT-based engineering tools offer much more than the conventional development methodologies in component creation and digital mock-up processes. The trend definitely goes into the direction of simultaneous CAE - support during the layout and design phases, attendant quality and structural management and the implementation of external data sources and receivers into the product development. It is up to the engineers to tap the full potential of virtual engineering processes regarding time reduction, error prevention in early phases and through technical modifications, whereas the applied methods and strategies represent a key factor on the way to efficient progresses.

The present publication includes an assessment and evaluation of modern 3D-CAD based development processes and discusses future prospects in the field of virtual engineering. On the basis of parametric geometry generation, different methods and tools, which are able to increase the efficiency in virtual development processes, will be introduced and compared.

Keywords: virtual vehicle development, 3D-CAD design methods, parametric – associative design strategies, process optimization

1. INTRODUCTION

Especially in automotive engineering processes 3D-CAD design offers a wide spread working field for the geometry creation as well as for the linkage of numerous simulation procedures, customer demands and legislation tasks (Fig. 1). A significantly reduced design and time effort for packaging studies, vehicle safety concepts, feasibility studies and other tasks result in a quick generation of basic data for customer discussions at a very early phase. In this way different strategies of parameterized associative vehicle design in combination with the possibilities of external data or application implementation, are essential to support geometry creation and digital mock-up processes in state of the art automotive engineering.

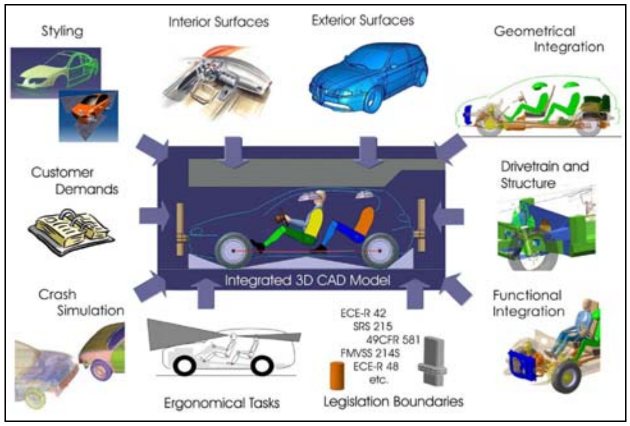

Fig. 1: Integrated 3D-CAD vehicle modeling (selection)

2. INTEGRATED 3D-CAD DESIGN STRATEGIES

Beside various design relevant functionalities, modern CAD systems offer enhanced modules to support the entire development process. The efficiency of simultaneous engineering procedures often depends on a close integration of the applied software packages, whereas a smart data transfer structure between geometry generation processes and simulation processes can reduce time and engineering effort. The trend goes into the direction of integrated 3D-CAD systems, which include an integration of (former) stand alone simulation software tools, as there are finite element programs, multi body simulation software and CFD-applications. In the next years, more and more software packages applied in the automotive industry will be available as add-ons of CAD programs. Beside the optimized data flow between design and simulation processes, modern automotive design and development methods and strategies require a number of principal demands on the applied CAD software.

2.1 Parametric-associative design

Characteristic for parametric design is a separation of the geometry elements of the CAD model and the corresponding parameters [4]. A geometry variation is accomplished by changing the input data of the corresponding dimensional constraint associated with a new computation cycle (ref. to Fig. 2). 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.

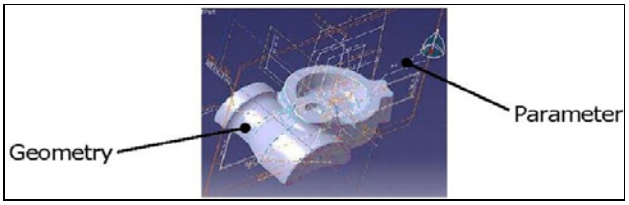

Fig. 2: Parametric – associative design

The degrees of freedom of associative models are only in part ascertained by direct input of specifications, whereas the remaining requirements for an unambiguous determination are defined by means of relations to geometrical elements, for instance a sketch. 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. The geometry creation process has to consider a universal usability, in a way that a variation of lengths or distances has no negative influence on the stability of the model. When generating template models, it is essential, that the range of possible parameter values as well as the flexibility of the created geometry fulfill the requirements of the projected application. Mathematical connections of parameters and restrictions of input values to reasonable rates support the definition of expansible templates for several standard components. In engineering based development processes, the functionalities of template models support variant studies, packaging optimization or geometry improvement. Every variant of a template based component states 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 [7].

2.2 Parametric design on assembly level

State of the art CAD processes are based on the assembling of numerous components, units and groups in digital mock ups (DMUs). In this way, it is important that parametric 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 the 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 a superordinated system (multi-model design) [4].

2.3 Possibility of external parameter control

For realizing user friendly and highly automatic work routines, it is vitally important that the CAD software features the possibility of externally controlling the parameters used in the virtual model [1]. The applied CAD software features an interface to a spread-sheet or text processor enabling the external control of parameters driving the geometry within the CAD model (ref to Fig. 3). These features enable the possibility to define design relevant parameters in a user friendly database. The database is implemented into the 3D-CAD model and accomplishes a control function of geometry relevant parameters. The CAD internal data base can be linked with an external data collector, in a manner that a definition of values in the external data collector controls the geometry of the CAD model (ref. to Fig. 4).

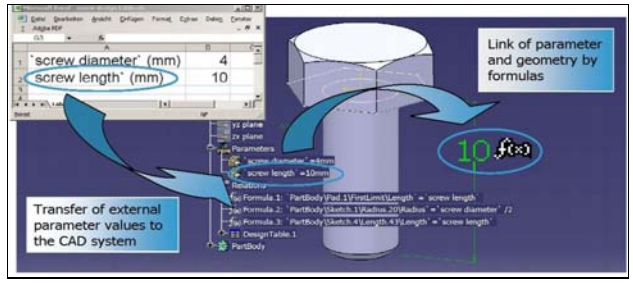

Fig. 3: External parameter control of a simple geometry

The CAD – independent character of external databases opens a wide field of possibilities for the implementation of additional applications. Geometry based data storages of existing components without connection to a CAD system (e.g. wheel- or tire databases) can be linked with the external data collector. During the design process, the required data will be selected in time and implemented into the 3D-CAD model. All geometry data of the virtual model, which are not controlled by an external data link, can be currently modified in the design process.

If the external data collector is performed in a commercially available spreadsheet software package, additional mathematical connections and functions can be performed beyond the CAD system to prepare the data flow for the geometrical parameter control in the virtual model.

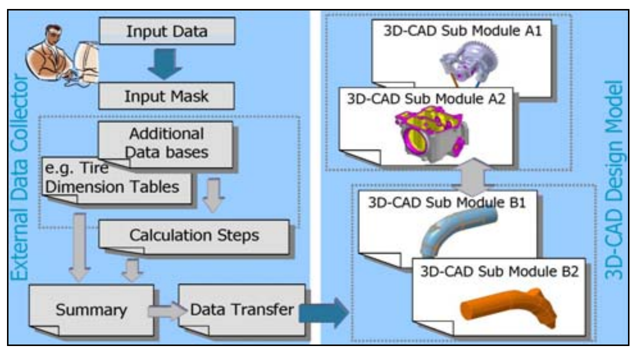

Fig. 4: Procedure of an external parameter controlled virtual model

2.4 Possibility of programming routines (macros)

In order to enable an automatic sequence of features and actions, the opportunity of programming macros can be very helpful. Most of the advanced CAD software packages offer Visual Basic based programming languages, enabling the creation of effective and versatile routines [6]. In this way, macros can control recurrent operations in virtual development processes (ref. to Fig. 5). The implementation of the program into the CAD software enables its integration into the virtual model, whereas the data flow in assembling structures and between other types of CAD files support the generation of efficient tools. As an example a macro controlled generation of 2D section drawings from a 3D digital mock up (DMU) model can automatically perform the sectioning processes, the completion of title blocks or bills of material, numbering of components and others [3].

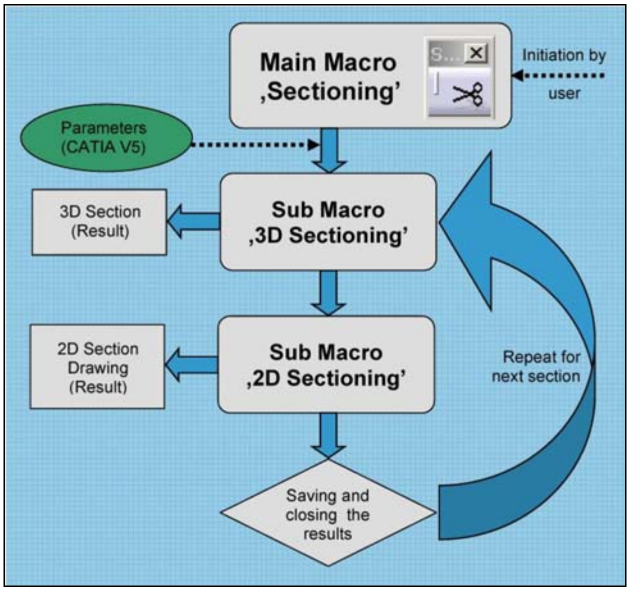

Fig. 5: Example of an automatically performed CAD model sectioning process [3]

2.5 Implementation of non CAD data

Modern 3D CAD software packages enable the implementation of pictures, 2D studies, sketches or drawings into the 3D vehicle model (ref. to Fig. 6). This possibility moves the engineering based construction and DMU development close to the styling process. Based on an open architecture, 2D based studies can be implemented into the virtual car model to perform different checks regarding ergonomic viewpoints (passengers), packaging boundaries (drive train or chassis components) or legislation based influences (safety and crash regulations, etc.).

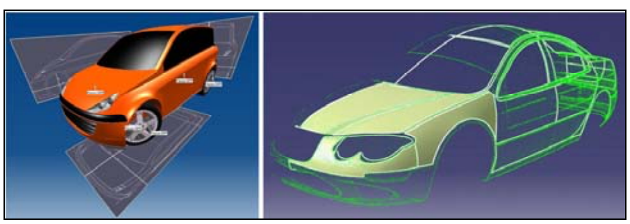
Fig. 6: Sketch based and measurement point based surface creation [2]

Advanced design software packages offer an additional possibility to generate 3D surfaces from 2D sketches, which allow a direct implementation of studies into the automotive 3D-CAD model. In case of provided 3D hardware (style studies, clay models or scaled detail models), scan or measurement data can directly be imported into the CAD software to serve as a basis for surface generation processes.

3. STRUCTURED 3D-CAD DESIGN METHODS

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 structures in so called start up models. These start up models include various definitions related to the design process of the components and can also include additional functionalities regarding design check features, DMU relevant information or basic calculations. Different kinds of parts in automotive development processes call for different requirements. Therefore the content of start up models varies according to the required components. Depending on the applied CAD software, the start up model can separate reference geometries, supporting geometries, executive surfaces, uncircumcised surfaces and the final geometry. A main function is to predefine the order of each element of the geometry creation process to support modifications, check operations or upgrade processes. Start up models of components of the same category (e.g. sheet metal parts, plastic parts, cast parts, etc.) should keep the same structure during the entire development project to guarantee a good compatibility.

3.1 Component design

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 accomplished 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. As an example, Fig. 7 displays a general structure of a cast metal part. The presented small cylinder head is made of aluminum with steel molds and sand cores. In case of the cylinder head, the manufacturing processes significantly influence the structure of the geometry creation process. The principle structure of the start up 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. In this way, the node "Geometry Definition in SOLID" is accomplished as logical connection of several bodies. Each body can consist of numerous solid based functions and describes a solitary result. A logical interaction of these bodies in a logical order results in the final geometry.

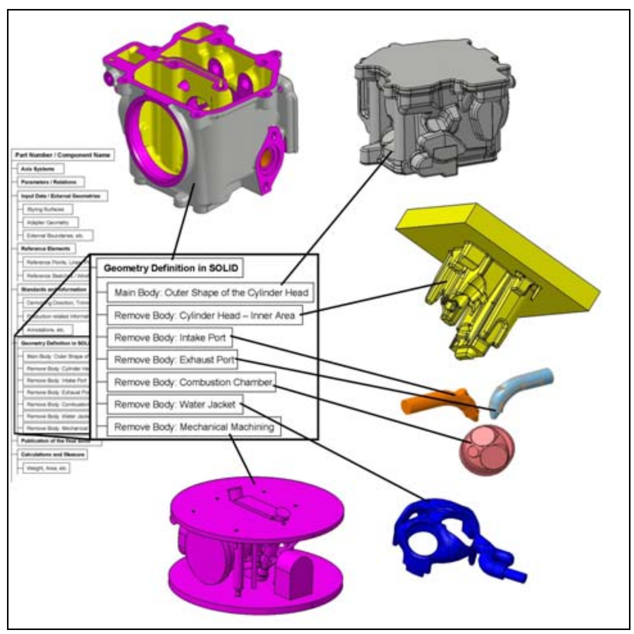

Fig. 7: Structure of a 3D-CAD cylinder head model

The exemplary cylinder head model in Fig. 7 is composed of seven single elements (bodies), whereas each element includes all the required information regarding its geometry as well as the production process. The body "Outer Shape of the Cylinder Head" contains geometry data for the mold manufacturing process including the parting surfaces, the draft angles and the fillets. In this way, the manufacturer is able to produce the mold directly from the 3D-CAD model by separation of the body “Outer Shape of the Cylinder Head” from the cylinder head model. The second body “Cylinder Head – Inner Area” also includes the production related information and is defined as a negative volume. After removing the second body from the first one with a Boolean operation, the geometry of the cylinder head in the upper area is created. In the production process, the intake and the exhaust port are defined as sand core parts, fixed in the iron mold. The corresponding bodies in the virtual geometry creation process include all the required information for the production and the positioning of the core parts. The last body describes the mechanical machining of the cylinder head. This component represents the basis for the programming of NC controlled working machines and can also include 3D tolerancing related data.

The parametric associative structure of the virtual models states the basis for highly flexible development processes. The parameterized design modules of a part can be linked with each other or linked with modules of external geometries, supporting automatic update functions during optimization cycles. The presented design method enables a relatively simple exchange of single modules. In this way, results of simulation processes (e.g. finite element optimization, CFD- calculations and others) of specific areas can be currently implemented. In the presented cylinder head, the geometry of the intake and the exhaust port as well as the geometry of the water jacket were built into the 3D-CAD model as a rough estimation first. In the course of CFD based optimization processes, the dummies of the initial phase were replaced by actual results from the simulation. Virtual optimization phases are periodic processes, whereas geometry generation sections and simulation steps are linked via the 3D-CAD data. Fig. 8 shows the interactions of a virtual CAE engineering process exemplified by a cylinder head development. The parametric associative design process is divided into several sections, which are simultaneously linked with corresponding CAE processes.

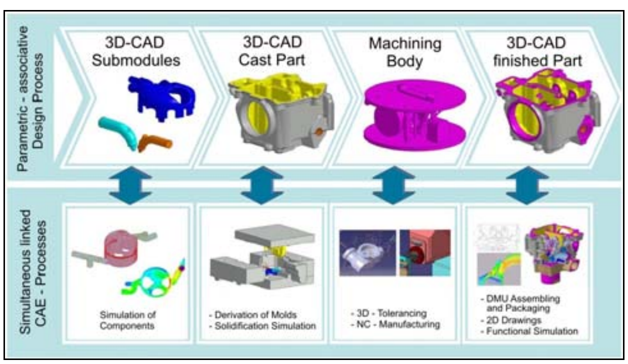

Fig. 8: Parametric associative design and simulation CAE processes

3.2 Assembling

The assembling of components in 3D-CAD is carried out in a specific assembly design environment. The product structure contains links to the single components and their relations to each other. An assembly orientated 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 a vehicle-DMU could represent the body including all movable and fixed parts.

The sub-assembling of an automotive body itself consists of several sub-assemblies, e.g. side panel modules, the roof module, doors and some other products and parts. Sectioning of complex structures into sub-assemblies consisting of multiple components provides a basis for a simultaneous design process considering functional and space requirements (ref. to Fig. 9). The positioning of the components within a product can be carried out in different ways. In case of small assemblies, it makes sense to define constraints directly between the components. Typical constraints are distances, coincidences or angles.

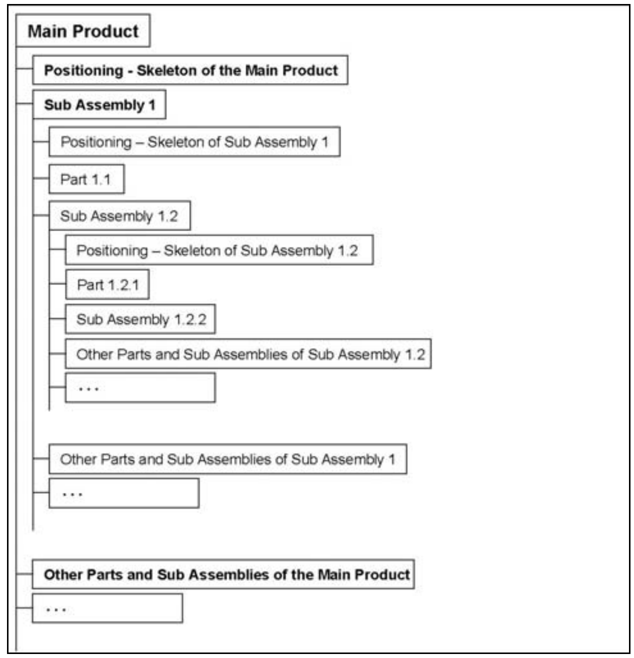

Fig. 9: Exemplary assembling structure including skeletons

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, such as a product of a complete virtual engine, can be built up by use of dedicated positioning components within the product structure. The so called skeleton method does not use constraints between the components, but 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. Tall assemblies use several sub-products logically combined with the help of a number of skeletons, thus realizing a modular design. In addition to the two positioning strategies mentioned above, a different method has been established in automotive assembling and design methods. This strategy consists in the positioning of each component relative to a main coordinate system. The positioning is performed in the course of the part design process using a start up model, which includes the main coordinate system.

To avoid problems during the design process, it is essential to clearly predefine the component positioning strategies in the course of the project planning development. DMU processes include several functional checks of single components and of sub-assemblies. Common applications are collision examination, minimum distance checks and fitting simulations. Kinematic simulation processes support the optimization of movable functionalities e.g. door opening mechanism, wheel suspensions, movable components in engines and others. All the results of DMU based analysis and optimization steps can directly influence the design processes of components. Based on a parametric associative structure of the virtual models, modifications are considered simultaneously.

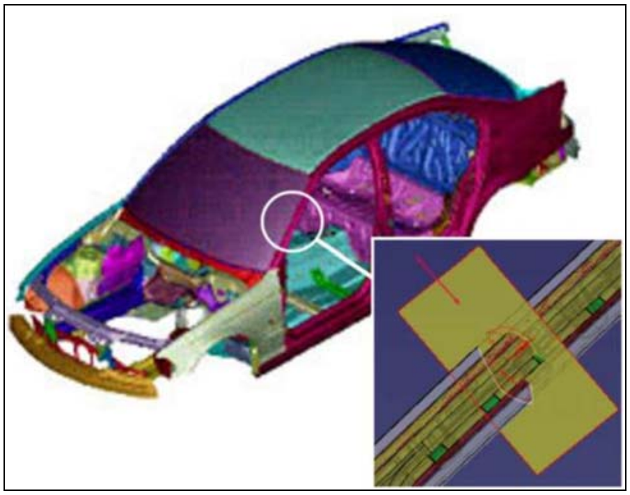

Fig. 10: Sectioning analysis in an automotive DMU - model

4. CONCLUSION

The high potential of state of the art CAD software packages to support and optimize development processes states the basis for a continuous reduction of time and cost effort. Integrated 3D-CAD design strategies in vehicle and engine development processes are based on the application of parametric-associative methods in geometry creation procedures at component as well as at assembling levels. Shortened project phases in combination with increasing numbers of product variants call for highly flexible virtual models across the entire development phase. The functionalities of external parameter control in combination with smartly designed only spreadsheet non CAD based data collectors enable the generation of easy to handle virtual models for concept studies, for the assessment of variants and for a quick generation of geometry based components for further development steps. Programming macro based routines within the CAD models gives the possibility to automatically execute repeatable standard functionalities.

Parametric-associative design methods only work with a high efficiency, when they are well structured and planned. It is essential to predefine start up models for all components of the construction, considering the requirements of different types of parts regarding their geometry creation and their manufacturing characteristics. All these structure related tasks form the basis of an effective work within the boundaries of modern product lifecycle management (PLM) systems.

The far reaching possibilities of state of the art CAD software packages can only be utilized with a high efficiency, if the applied design methods and strategies consider the requirements of modern parametric development cycles. In this way, the presented approaches are able to support virtual engineering processes right from the initial stage.

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