ARCHITECTING NEW VEHICLE CONCEPTS: VIRTUAL DESIGN AND PERFORMANCE BASED ASSESSMENT



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Abstract

This paper focuses on the concept design of commercial vehicles in the early concept phase when manufacturers strive for an efficient balance between highly customized special vehicles and the greatest possible degree of standardization in their product portfolio. In this context, modularity and standardization strategies are crucial success factors for manufacturers and have to be considered in the very beginning of the vehicle concept phase in order to achieve not only sporadic but overall synergetic effects throughout the complete vehicle portfolio.
Accordingly, the presented approach and integrated tool concept allow for solving this conflict systematically by focusing on architectural standards and standardized vehicle layouts as guide rails and aiming points for the engineering departments planning new vehicle concepts. The tools chain allows for developing concepts referring to customer profiles using parametric base geometry and simultaneously concept relevant vehicle characteristics are measured. Having added several single vehicles a KPI analysis for the vehicle portfolio shows strengths and weaknesses concerning the overall degree of standardization and gives starting points to revise poor standardized concepts. Subsequently, package and layout analyses can be performed within the Architecture Digital Mock-up, an early 3D representation of vehicle concepts.

Keywords: commercial vehicles, concept design tool, vehicle architecture**,** early concept phase

1. Introduction & problem description

Profoundly new commercial vehicle concepts for improved transport efficiency, better TCO (Total Cost of Ownership) and decreasing environmental impact are the key issues in current research. Although being showcased more and more as first concept studies and prototypes by OEM these new concepts do hardly find their way into the market. Beside their non-conformance to today’s legislation another reason is that manufacturers are cautious and reserved when it comes to new concepts that require far-reaching changes in engineering and methods of production. In the context of sensitive markets manufactures cannot afford low volume vehicle concepts that in addition include a lot of exclusive components and interfaces i.e. extra investment and engineering effort. In order to pave the way for radical innovation in commercial vehicle concepts, manufacturers need to be able to analyze new concepts on their compatibility with the existing product portfolio and if necessary redesign their product architecture to avoid unmanageable overflow of variance. Already in the early concept phase manufactures have to succeed in anticipating characteristics and performance factors of new vehicle concepts and their impact and implication on engineering and production methods and processes as well as the existing product portfolio. By this means the most efficient and economical trade-off between optimized customer vehicles and over-standardized all-round vehicles can be found. The former provide best characteristics at a high degree of extra efforts and exclusive components. The latter are indeed efficient in development and production but do not meet crucial performance factor for specific applications due to their high degree of standard components.

2. Background MAN & modular vehicle design

MAN Truck & Bus AG (short: MAN) focuses on mass customization for specialized markets. To keep up necessary synergetic effects, vehicles are based on a highly modular architecture forced to support an increasing spectrum of different vehicle variants. For this reason, over the past four years a more purposeful and elaborate product architecture planning process (as part of the concept design phase) was established [8], especially targeted on developing and documenting only variance needed from a customer’s point of view [7]. For this, several processes were introduced and refined: a specification phase generating a set of product specifications in a formal way, a product architecture phase translating functional specifications into a consistent vehicle architecture and a package planning phase to assure the product architecture being clash-free for each planned variant. In this context, vehicle architecture can be interpreted as mapping of the features of the product (its "behavior") to its components [11]. The physical arrangement of elements in a structure and the definition of the interfaces between them and their system environment are incorporated as well [6, 1, 12]. An architectural approach for efficient design of versatile products is given by modular development [2]: Synergies and modularity are the key enablers for new vehicle concepts and they are managed at the company at two levels, through the overall modular kit and through modular design at the component level (described in detail in [10]). This multilevel modular development [10] is based on architectural standards [9] constituting mandatory rules and guidelines for routing the geometrical and functional structure of products. They aim at high intrinsic architectural commonality and transparency coping with the essential challenges in commercial vehicle design [9]: High variance at comparatively low production volumes, many package-related special customer requests, need for adaptability at external bodyworkers, long life cycle periods involving substantial changes and innovations for the basic architecture.

3. Virtual architecting of new vehicle concepts: Overview tool chain concept

To give consideration to the above mentioned challenges in commercial vehicle design a design methodology for the early concept phase of particular concepts and whole vehicle portfolios was developed and implemented in an integrated tool chain (Figure 1). It combines mathematical vehicle design (“NuKET”, Figure 1 left) and 3D buildup of a digital mock-up (“A-DMU”, Figure 1 right). At first, early vehicle concepts are configured (using abstracted base geometry provided by a database, Figure 1 center) targeted on associated customer profiles and operational scenarios, respectively. Having linked a designed vehicle concept and a customer profile essential complete vehicle characteristics and performance factors are measured and related to a customer-specific rating system (relevance and utility value of criteria). A subsequent KPI analysis of the vehicle portfolio including the new concept measures the degree of commonality within the portfolio and allows for decisions on the need of revision in favor of more standardization [5]. Every completed vehicle concept is finally stored in the vehicle design table (Figure 1 bottom) and transferred to the architecture digital mock-up (Figure 1 right). Within the Architecture DMU the vehicle concept specification provided by NuKET is converted in a 3D mock-up for detailed package analysis: component integration, possible clashes and potential standard packaging spaces and vehicle layouts are investigated. Applicable standardized vehicle layouts [4] are documented and set compulsory as preferred choice when creating the following new vehicle concepts in NuKET. This closed loop portfolio development enforces communality and synergetic effects within the vehicle portfolio.

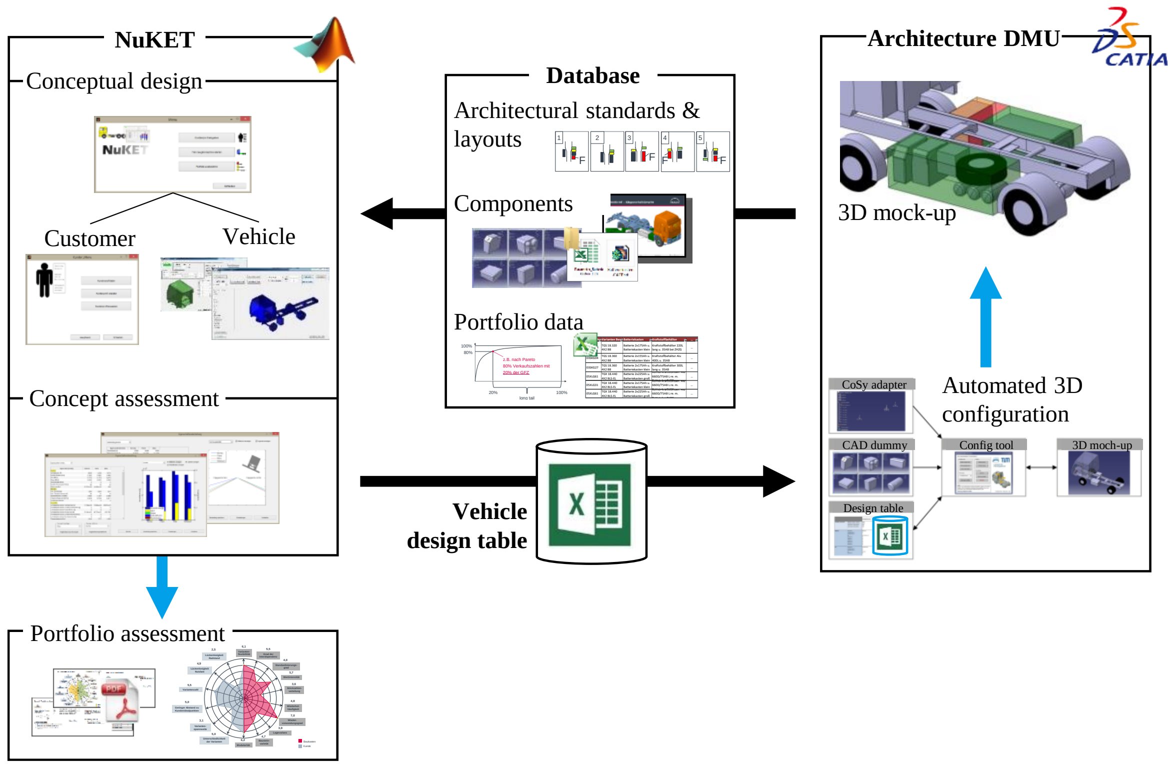

Figure 1: Integrated tool chain for commercial vehicle concept design and assessment [cf. 5]

4. Vehicle design tool NuKET

The design tool NuKET (German acronym for "**Nu**tzfahrzeug**K**onzept**E**ntwicklungs**T**ool" = commercial vehicle concept design tool) enables concept engineers to develop commercial vehicle concepts referring to customers' requirements and considering OEM's strategic alignment in terms of standardization and modularity. In the following, the basic tool building blocks are described.

4.1. Customer profiles

Customer profiles collect desired vehicle characteristics (e.g. range, TCO, emissions, axle loads, ramp angles etc.), usage and payload characteristics (standard loading equipment, load balancing, tonnage, road class split etc.) and additional components of bodyworkers (Figure 2). Each profile represents a comprehensively described customer or customer group (e.g. branch with same requirements) and serves as a design aiming point for vehicle concepts to be developed. To evaluate the degree of fulfilment of a final vehicle concept the desired vehicle characteristics are supplemented by customer-specific criteria weightings and evaluation parameters (e.g. value functions, Figure 2 down right).

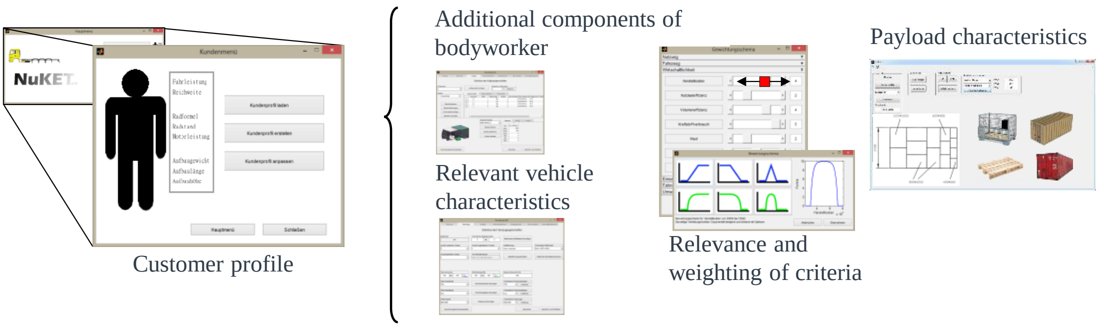

Figure 2: Defining customer profile and operational scenarios [cf. 5]

4.2. Conceptual vehicle design

Commercial vehicle concepts can currently be configured based on 30 main components (e.g. fuel tank, cabin) including up to 108 geometrical variants each (i.e. different material, length and cross-sections). Every component variant is described by relevant characteristics (e.g. mass, center of gravity, material, etc.) and abstracted base geometry stored in a database (chapter 5). This degree of abstraction allows for performant buildup and visualization.
Complete vehicles are successively developed by either starting a concept fully anew or using existing concepts to revise them: component variants are added (e.g. additional fuel tank), displaced (e.g. repositioning fuel tank), replaced (e.g. 550l replaces 400l fuel tank) or removed. That way, the vehicle buildup description is generated that is used later on to create a 3D digital mock-up of the vehicle within the Architecture-DMU (chapter 6).
If necessary for special and ambitious complete vehicle characteristics, not only preassigned stored component variants can be chosen: Within the borders of the particular component's parameters new component variants with individual geometry and properties can be added.

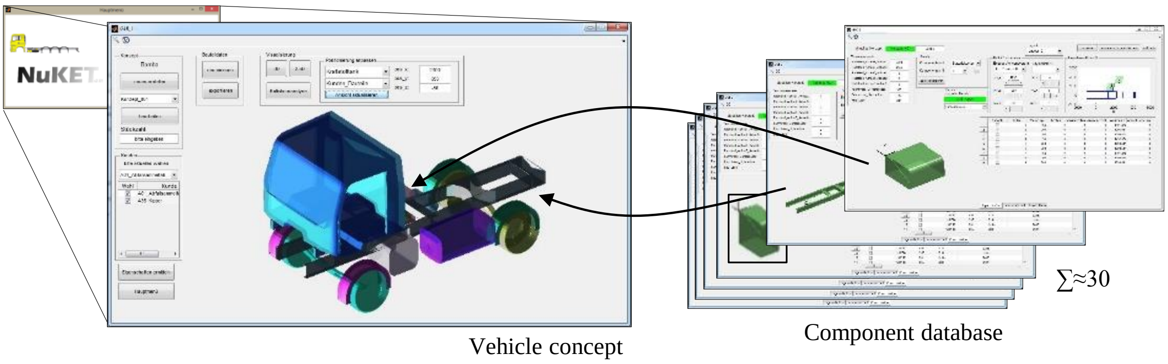

Figure 3: Development of vehicle concept based on abstracted component geometry and basic characteristics [cf. 5]

4.3. Performance-based assessment

Developing a vehicle concept is always targeted on achieving compliance with the requirements defined in customer profiles. The first step to evaluate a concept's fitness is to calculate current 35 important complete vehicle characteristics (e.g. fuel efficiency, road wear, turn radius etc.). Different alternative concepts can be compared and visualized using polar diagrams (Figure 4). The second step is to link the vehicle concept to a designated customer profile for customer-specific evaluation of its applicability (using the relevance and utility rating).
If in the rating a vehicle concept appears to be deficient, it can be revised in the concept design area (chapter 4.2).
These two steps are carried out iteratively until the developed concept meets the requirements satisfactorily.

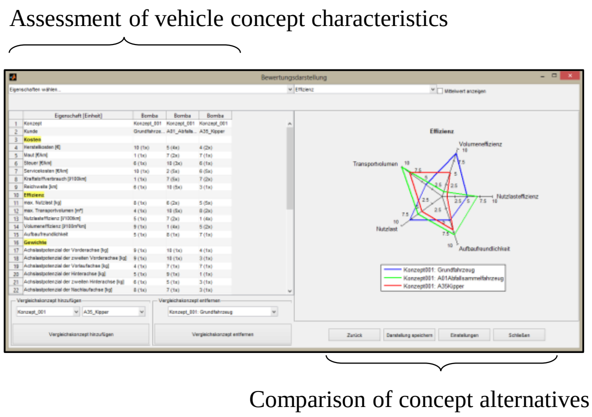

Figure 4: Concept assessment and comparison [cf. 5]

4.4. Vehicle Portfolio Analysis

Successively designing more vehicle concepts according to costumer profiles results in developing a vehicle portfolio. In doing so, OEM strive for the best possible degree of standardization instead of accumulating perfectly customized unique vehicles without synergies within the portfolio. To support this, a revision loop is created between an optimized individual vehicle and the vehicle portfolio (Figure 5). The first step is to

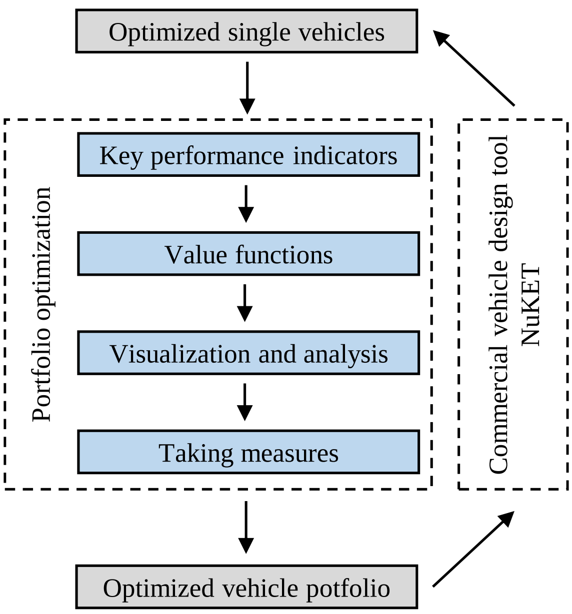

Figure 5: Methodical approach portfolio optimization [cf. 5]

analyze the whole vehicle portfolio (stored in the vehicle design table, Figure 1 middle) evaluating 15 key performance indicators (KPI) related to modular design (e.g. reutilization ratio) and customer perception (e.g. relative diversity of product variants). To compare all KPIs they are related to a uniform data scale (using value functions). Finally a PDF portfolio analysis report is compiled automatically to show potentials for improvements (e.g. to many different fuel tank variants applied). Based on that report several particular vehicle concept can be revised in favor of a higher degree of standardization, the impact of these measures on vehicle characteristics can be tracked simultaneously in NuKET. The portfolio optimization approach is presented separately and in-depth in [5].

5. Data backbone for vehicle concept phase

As part of the tool chain (Figure 1) the *Database* is the knowledgebase and input source for NuKET (chapter 4) and the A-DMU (chapter 6). It has to covers a range of about 30 different components and their corresponding component variants documented in Excel files. Most components affect the architectural layouts of the frame and aim for customer-specific solutions such as 20 variants included in the component “trailer”. In summary, so far the *Database* stores an amount of around 350 component variants (Figure 6) and is extended continuously. Theoretically the actual quantity allows combinatorial for at least 10^{15} possible combinations.

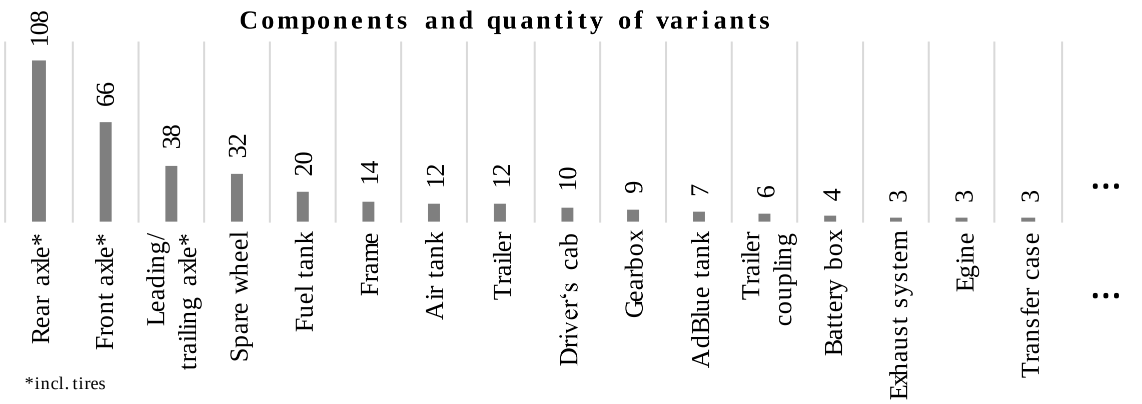

Figure 6: Included components and quantity thereof

5.1. Derivation of relevant components and corresponding component variants

The component database is based on the MAN generic product decomposition (also referred to as “Green Structure”, [9]). In several discussions with specialists with expertise in vehicle concepts the most important components for the early concept phase were identified and modeled as abstracted base geometry. In a subsequent evaluation the concerned components were reviewed with respect to their influence on the frame design and the attachment parts layout giving 10 promising components as a starting point. The database is upgraded successively with components prioritized in terms of their functional contribution and their amount of mass and volume input to the complete vehicle.

5.2. Setup of components

In general, components are represented by CATIA CAD Parts (CATParts) either as real CAD geometry (e.g. carry-over parts) or as parametrical, abstracted base geometry (e.g. components with high variant spectrum) or as parametric-associative elements adapting to the particular vehicle context (e.g. drive shafts, mud guards).

Most components are implemented as parametrical, abstracted base geometry: The variance spectrum of a real component is analyzed in order to derive consistent parameters to create and parameterize a simplified CATPart representing every real variant by means of different parameter settings (stored as rows in each corresponding Excel file in sheet "Construction").
The size and the complexity of parameter sets are specific for each component: Simple components such as the battery box can be realized using only three basic parameters whereas complex components such as axles or cabs need significantly more parameters to build up geometry for every component variant. For visualization of components within NuKET also simple package boxes and STL files ("Surface Tesselation Language", surface description of 3D bodies using triangles) are compiled for every component variant.

5.3. Component variant tables

The *Database* is stored and accessible as easy to edit Excel files. The tool chain is able to import all information out of the *Database* via an automated workflow. This means data is processes automatically whereby adding new components and additional information is possible without adapting the workflow (adding rows for additional variants or adding columns for extra attributes within the Excel files).
Each Excel file consists of three different sheets: *Construction*, *Packaging Space*, *Attributes* (Figure 7). The *Construction* sheets lists identifiers and short description of each variant and stores the parameter sets for the parametrical CATParts. These parameter sets depend specifically on the component and include all information for the construction in CATIA. The sheet *Attributes* specifies additional information like mass, service costs, drag coefficient, material etc. The characteristics vary in this sheet depending on the specific component and are needed for the later vehicle properties analysis. Finally the sheet *Packaging Space* provides all data defining the dummy box. The sheet contains the boundary box information, which defines the outmost borders of each variant, the position of the local coordinate system within the boundary box and coordinates of the center of gravity.

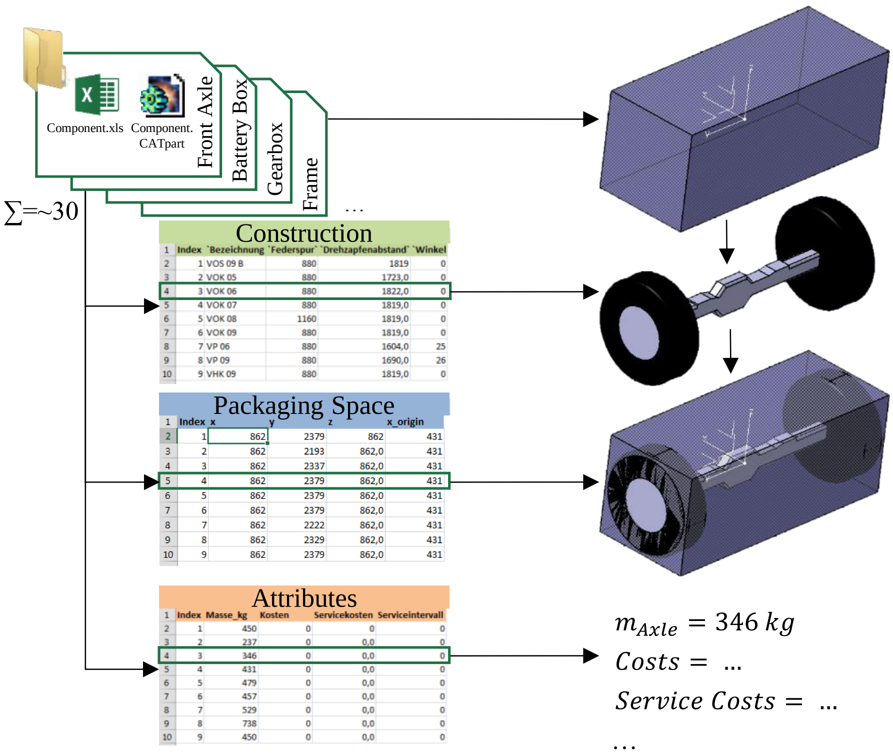

Figure 7: Structure of database with Excel tables and CATIA part

6. Architecture Digital Mock-up

The Architecture Digital Mock-up (also referred to as Architecture DMU or A-DMU) represents a seamless follow-on to NuKET: It converts the vehicle concept buildup description of NuKET into an early three-dimensional CAD mock-up. Within this mock-up several DMU function allow for analyzing promising architectural standards [4] and it serves as a CAD placeholder model for the later series development.

6.1. General concept

The purpose of this tool is to provide visualization and geometrical analysis of the vehicle architecture in the early concept phase. Following the principle of frontloading in the early concept phase [8], the A-DMU provides for gaining as much information as possible in an early stage which is important as costs and complexity of changes increase significantly during the development stage [cf. 3]. To ensure efficiency and performance abstracted base geometry derived from real vehicle components is implemented. The operating concept is to provide a simple and intuitive graphical user interface (GUI) enabling even non-CAD experts to conduct analyses and concept manipulations. All component variant and positioning information is provided by NuKET and smooth data exchange is assured by a standardized Excel interface. In the end, an exported version of the A-DMU is used in series development to gradually replace all abstracted geometry by real CAD parts.

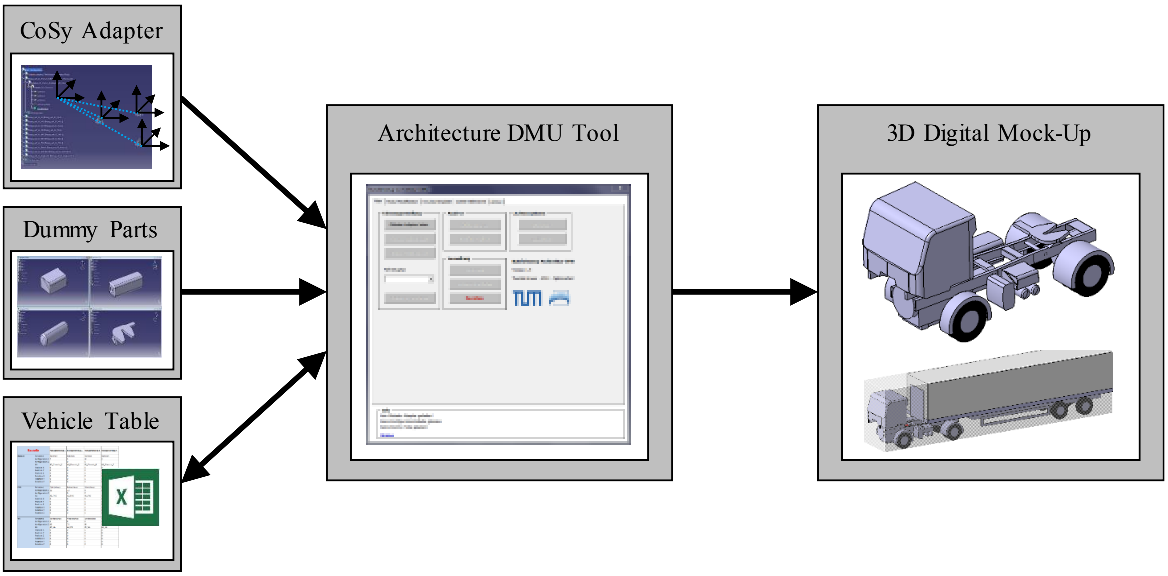

Figure 8: Tool structure of the Architecture Digital Mock-up (A-DMU)

6.2. Tool structure

The A-DMU incorporates 4 main building blocks (
Figure 8): CoSy adapter, CAD dummy parts, the vehicle design table and the configuration tool itself.

The CoSy adapter

The CoSy adapter is the central part of the truck model. It represents a CATPart with several systems of coordinates for main components of the truck. These systems are positioned by template parameters (wheel base, ride height, etc.) which are given in the design table.

Afterwards dummy parts can be attached to the appropriate axis system. The simple positioning and replacement of parts is advantageous adopting this approach. The positioning is given explicitly by the coordinates and there are no complex relations between parts which had to be considered when changing parts. As the systems of coordinates are the same as during the series construction phase, the dummy parts can be replaced by original CAD parts afterwards. Furthermore, changes in the template parameters are considered automatically for attached parts (e.g. if the wheel base between the front axle and the first rear axle is extended, the trailing axle is moved consequently).

Parametric dummy parts
Instead of detailed geometry of real parts the A-DMU uses parametrical dummy parts, i.e. abstracted base geometry, which provide an adequate representation of the components' package space requirements. These dummy parts are designed parametrical in CATIA with configuration tables (Figure 7). By switching the configuration index of the component the geometry is changed. Therefore only one CATPart is needed for representing all real parts of a type (e.g. the change of the capacity of a fuel tank from 400l to 500l is realized by extending the length of the body automatically). The benefits of this procedure are reduced loading time of a model and high performance when adding or replacing elements.

The vehicle design table
All information about the configuration of a vehicle concept is given by the vehicle design table (Figure 1 middle). In the vehicle template the positions of the axis systems of the CoSy adapter are saved. All parts of a vehicle concept are specified by the relevant dummy part, a configuration index to attract the right geometrical variant, an axis system they are attached to and a translational and rotational offset in six dimensions to this axis system.

The A-DMU configuration tool
The configuration tool itself is based on a VBA script (Visual Basic for Applications) and provides a graphical user interface for all necessary functions. Within this tool the actual buildup of a 3D model is performed. Therefore it loads the global adapter, adapts all axis systems depending on the parameters from the vehicle template, configures all parts (attracting the right parameter set for geometrical variant) and positions all parts of the model (offset according to vehicle design table).

6.3. A-DMU functionalities

After successful configuration and visualization of the truck concept it can be manipulated easily if changes are necessary: in Figure 9, first of all, the frame variant is changed by editing the configuration index of this component to allow for a longer vehicle bodywork. Afterwards due to the required payload center of gravity the wheel base is adapted additionally (change in vehicle template parameters). These changes can be saved in the design table and effects on vehicle characteristics can be reviewed in NuKET.

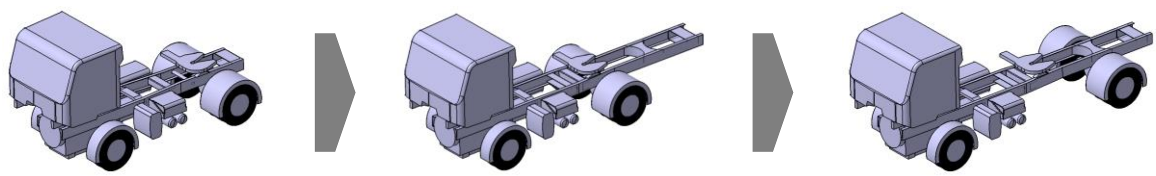

Figure 9: Exemplary vehicle concept manipulation (frame variant and wheel base)

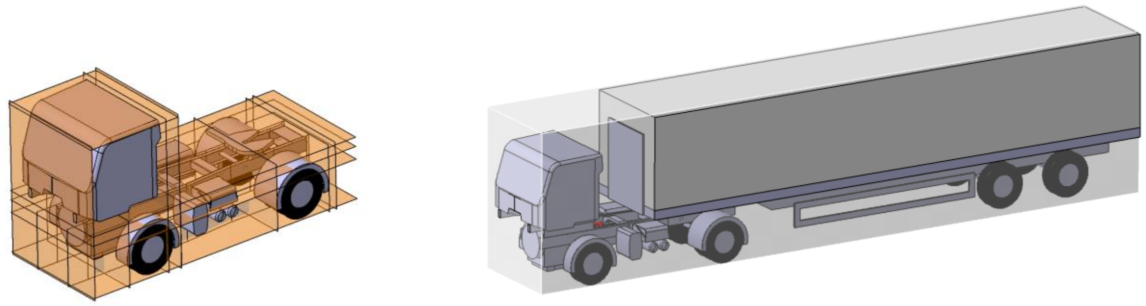

Figure 10: Section model (left) and legal boundary layers (right)

A further functionality of the A-DMU is the clash analysis. It uses the CATIA implemented operation triggered from the GUI: Every part is checked for clashes and all detected conflicts are reported to the user with a coloration of involved parts. For detailed analysis of the truck layout sectional views can be generated. The user has to choose a plane for the section and can additionally enter an offset. Afterwards the sectional view can be analyzed. Furthermore a parametrical sectional model [9, 4] is implemented (Figure 10 left). It structures the vehicle and defines explicit areas, which is the basis for the development and definition of vehicle layouts. The recommended positions (or other package space related restrictions) for a part (e.g. fuel tank) can be displayed by colored boxes in this model. Other sections such as legal boundary layers (Figure 10 right) help to keep a concept within the legal limits when experimenting with new component variants and vehicle layouts.

7. Conclusion

Consistently, improvements and radical innovations in commercial vehicle concepts are presented in the industrial field as well as in academia. However, a lot of these showcases do not come into effect on the market and the logistics system. Amongst others this is due to manufactures being cautious and reserved. They try to avoid the risk of deficient market success and monetary failures when radically new concepts require intensive engineering and production efforts by reason of too many exclusive components and technologies, incompatibility to the existing modular system and thus lacking synergetic effects.
The presented virtual design approach for commercial vehicle concepts – not neglecting manufacture's portfolio requirements – allows for purposeful design and integration of new concepts and technologies on component level in an existing product portfolio. The integrated tool chain helps to bring trade-offs to a head that exist in balancing between dedicated vehicles with best customer-relevant characteristics and standardized vehicles with highest degree of communality.

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