Title:

A Knowledge-Based Framework for Integration of Computer Aided Styling and Computer Aided Engineering

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Keywords:
KBE, Computer-Aided Styling, Class-A, Product Data Quality

DOI: 10.14733/cadconfP.2015.368-373

Introduction:

The appearance of a product for example in electronic or automotive industry is one of the main reasons for customers' buying decision. Looking at automotive industry the styling of a new car still states an important aspect besides costs, reliability, safety and fuel consumption. New mobility concepts and propulsion systems provide more degrees of freedom for new shapes and appearances of future vehicles. The styling development is part of initial phases of product development and therefore it is characterized by a dynamic behavior. Fig. 1 gives a coarse overview of the main disciplines in early automotive development with focus on the styling integration. Based on initial specifications, a prospective vehicle outline is developed, until a styling concept is found. In general, there are different procedural methods that are performed simultaneously during styling development. After creation of two-dimensional drawings - physically as well as on virtual way - the three-dimensional styling development is continued using computer-aided industrial design (CAID) software. This technology can be seen as a subset of CAD, but offers more conceptual and aesthetic tools instead of manufacturing-oriented ones like in technology-oriented CAD [10]. In the following, several computer-aided systems like CAD, CAID and CAE are combined under the term CAx. Particularly direct geometric modelling of curves and surfaces and the possibility of including specific analysis tools, e.g. continuity and optical reflection assessment, are main reason for using specific CAID tools. Simultaneously to virtual modelling in CAID a physical mock-up, a so-called clay model, is built up and modified manually with scrapers. In some projects, the physical model is built up by milling machines, using already developed 3D-CAID data. These hardware models are optimized by hand, and brought back into virtual environment by use of 3D-scanners, e.g. laser-scanners. This hardware-based method delivers just raw data of vehicle surfaces in form of point clouds. The quality, content, structure and format of raw data are often inapplicable for downstream performed process tasks, like engineering-oriented development or even virtual reality (VR) representation. In this way, raw data which serve as a proposal in view of vehicle styling have to be built up new to reach harmonious freeform surfaces with a high quality in terms of mathematical accuracy and geometrical continuity. These so-called Class-A surfaces are created within modelling tasks including periodic fairing or smoothing processes in so-called "Class-A Surfacing", as seen in the Fig. 1. A main challenge in Class-A Surfacing is the conversion of styling inputs into producible shapes that simultaneously consider several requirements from engineering points of view. These intensive and iterative alignment processes in initial phases between aesthetic requirements of styling and technical boundaries from engineering point of view can be summarized as "Styling-Technology-Convergence". The consecutive status of these convergence processes is represented by the corresponding Class-A surface data. Class-A data are manually checked for quality in the CAID author system and are forwarded to the downstream disciplines like engineering design and simulation, as well as high performance visualization. The engineering design for example uses these data as boundary conditional outer surfaces for the creation of technical parts within CAD, e.g. vehicle fender incl. wall thickness, flanges and flared tube ends. It's important to emphasize that downstream disciplines are prohibited to do changes on released Class-A data.

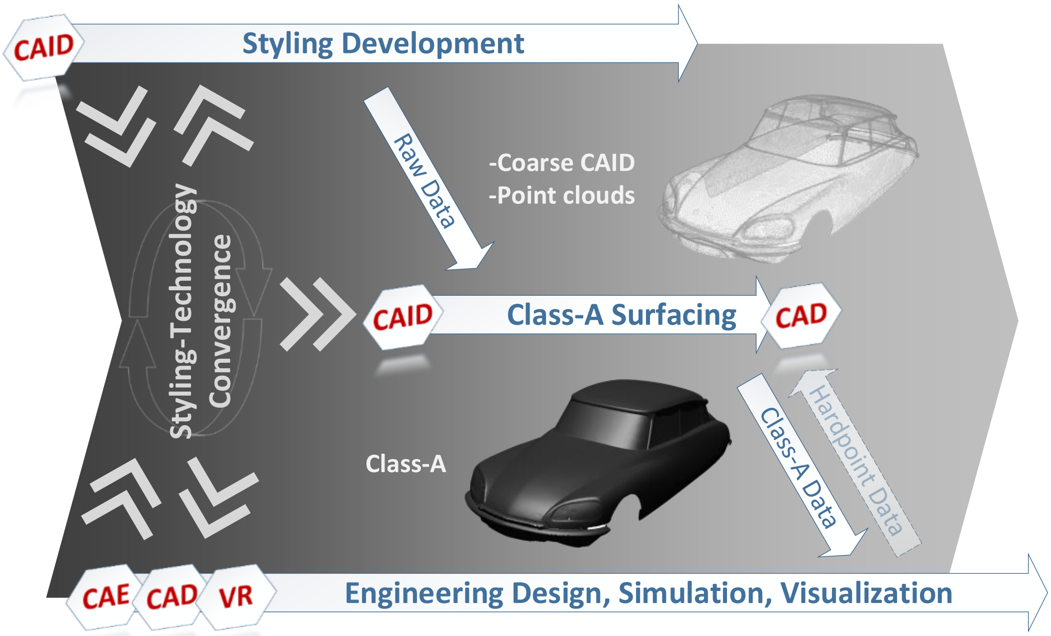

Fig. 1: Styling integration process and different virtual environments.

As part of the research work, state of the art styling-technology-convergence processes were analyzed regarding effectivity and efficiency within virtual development. Due to the facts, that Class-A surfacing works with the same virtual technology (CAID) as styling development and Class-A surfacing uses the raw data and drafts from styling just as requirements, the interoperability between styling and surfacing disciplines state no serious problems. Considerable potential for improvement can be detected in the creation, administration, check and transition of Class-A data between surfacing-processes and engineering & visualization disciplines. Before Class-A data are released to downstream, the surfaces are checked in the CAID system according to prescribed requirements, like geometric continuity, gaps or draft angles. A conversion of surface data from CAID to CAD induces changes in data structure and geometric representation in the target system, especially when using neutral geometry exchange formats like IGES. The degree of freedom in CAID, which allows an explicitly creation of geometry by definition of the spline order, the direction of u- and v-parameters, the orientation of the surface normal or even the tolerances for connection continuities between surfaces, may lead to profoundly problems after conversion into CAD. Practice in industry shows that, based on those reasons, converted Class-A data from CAID are often not applicable within CAD. Despite of a prohibition of changing Class-A data in downstream disciplines, they have to be prepared manually before they can be considered in engineering-related works, which may result in different derivations of one release Class-A status. In this context, the creation of essential topological surface compounds of not parameterized surfaces states a precondition for several technical-oriented design steps in CAD.

As already mentioned, the geometrical surface quality is checked manually in CAID environment with a relatively high effort so far. Besides problems with geometrical and topological data quality, another challenge appears concerning data structuring in terms of product data arrangement. In engineering design, CAD-based assemblies of modules and components are state of the art representation techniques on module- and full vehicle-level enabling complex product structure-oriented processes. In contrast to accurate and deep structures in engineering design, styling development does not consider an adaptable data structuring. One reason therefore is, that CAID systems are not able to build up surface assemblies out of surface parts. In addition, surfaces are drawn on the whole for a bigger region before they are separated by gaps to surface sets that cover specific areas. These surface sets allow structuring within a CAID document, but the technology is strongly limited to one or two layers. Thus, one question is how to get a transition of raw styling data to dynamical structured surface data including a part wise separation of the geometry. A second topic includes the definition and storage of technology-related attributes in CAID systems as it is commonly used in engineering design.

A review of the state-of-the-art shows, that the interaction of styling and technology demands for new methods. In literature, some information about the general processes in this area can be found [2], but there is only marginal information available which discusses the topic process-oriented in view of the required level of detail, e.g. surface quality and data structuring. On the other side a lot of research is done focusing on data exchange between CAD and CAD [9] or CAD and CAE (computer-aided simulation) [6], [8] systems. Furthermore, there are several works in the area of quality assessment of freeform surfaces like [4]. There are also contributions related to new methods in CAD for fairing or surfacing functions to improve the freeform surface quality for styling applications: e.g. [5]. Regarding the aesthetic evaluation of freeform surfaces and contours in car styling, Bluntzer et. al. [1] introduces a knowledge-based CAD approach to automatically identify, extract and interpret characteristic lines of styling. However, the process view from styling creation until integration to modern strongly structured PDM-oriented engineering disciplines including fairing processes for Class-A data in not considered sufficiently until now.

Main Idea:

The goal is to reach an effective and efficient integration of styling and Class-A surfacing disciplines into structured engineering processes. The main idea includes a knowledge-based engineering (KBE) framework which provides several methods and procedures to face these specific challenges. An overview of KBE including different levels of knowledge integration is discussed in [3]. Fig. 2 gives a schematic overview of this framework, which is separated into a problem-oriented KBE system to control and administrate processes and data and a predefined CAx/PDM system environment, which contains the required system to be controlled. Furthermore, the framework is divided into a system level in the background and an application level for user accessibility. As a key aspect of this framework, the strongly limited application level allows the user to work in a primary CAID system by applying specific expert knowledge. In this way, time-consuming and non-creative work, like data conversion or preparation is not part of the user’s work anymore. For example, a Class-A surface engineer is then enabled to keep its focus on the creation and modification of Class-A data, while data conversion, check and preparation tasks including the storage in global engineering PDM databases are performed by the framework system in background.

Besides support for work within CAx systems, an additional problem-oriented KBE architecture manages process-oriented tasks efficiently. As core elements, this KBE architecture contains methods to manage data from three different views, as shown in Fig. 2. First, there is the quality management of Class-A data in terms of surface quality and data applicability. Second, the management of structures during the transition from styling is provided to enable compatibility to downstream engineering master-structures and their detailed degree of resolution. Third, the enrichment, consistent definition and maintenance of meta-data for Class-A surfaces are also parts of the KBE environment.

Besides these main functionalities, the KBE system approach provides further operations to administrate and control processes and data. As there are process-related methods included, which support the time-consuming release procedure of Class-A data conversion to downstream-ready data. An information monitoring and preparation unit enables the engineer to monitor the actual status of Class-A data on demand; e.g. in view of data quality in relation to a selected predefined milestone criteria of the development process. So, the system also contains functionalities for project-management to view actual development status with required meta-information. Several geometry-related results, meta-data and additional information as well as documents are stored in a coupled relational KBE database (e.g. SQL) which is controlled by a specific database interface. The KBE system contains additional interfaces to handle CAID and CAD data, to connect application programming interfaces (API) of CAD and PDM systems, as well as an interface for export and import of status, templates or even the history documentation of specific CAID and CAD processes. While APIs have become standard for many CAD and PDM systems to enable high professional knowledge-based engineering methods, today's CAID software do not support this potential opportunity. Nevertheless, the presented KBE framework is able to process the CAID data efficiently by an efficient interface structure.

The introduced framework management leans on three main pillars: the organization of data quality, of structure and of meta-data, which are described shortly in the following. The data quality management of the framework focuses on the quality of Class-A surface data. This includes checks in view of the described traditional tasks, like geometric continuity, but also the applicability in downstream disciplines. Here, CAD technology, which reflects the highest sensitivity on CAID data quality. This sensitivity mainly derives from the characteristics of geometry description in CAD systems, which are based on topological relations to create compounds of geometric elements. Small gaps in surfaces, overlaps or self-intersections of geometry can appear by working in CAID systems. After conversion into CAD, these failures lead to incompatible surface elements, which furthermore conduct problems within CAD environment, e.g. merging errors, topological errors. Creating compounds (e.g. surface of engine hood) is necessary in engineering-related design to apply technical features, e.g. wall thicknesses of a sheet metal.

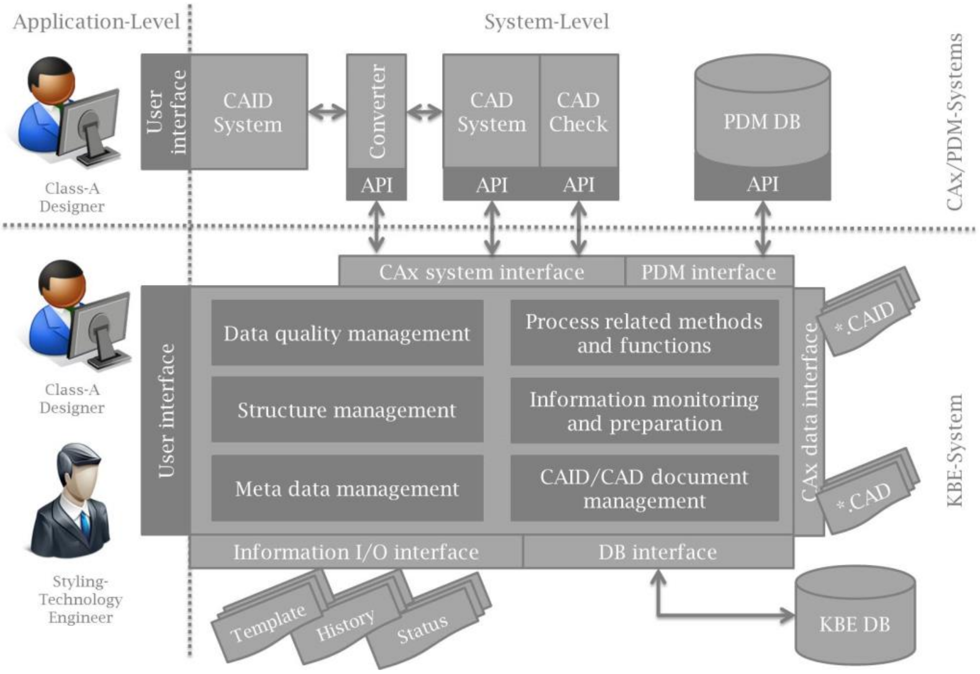

Fig. 2: Scheme of KBE framework for integration of CAID into engineering processes.

In course of the present research work, the data exchange between CAID and CAD systems was analyzed in detail. As a result, the introduced quality control method is able to check the creation of topological compounds in the target CAD system. If a topological compound can be created, different values of thickness of surface compounds are checked and stored in the KBE database. Besides the check for downstream applicability, a configuration of check criteria for surface quality was elaborated, especially for Class-A data in different maturities according to product development progress. As a basis for the development of new methods, the present paper includes an extract of relevant criteria with regards to product data quality guidelines, e.g. SASIG [7]. Considering these guidelines, a Class-A engineer is able to check data in the target system while working in CAID environment. In addition, documentation of results is enabled by use of the KBE systems' user interface. As a result, Class-A data can be approved and prepared in the target system and stored in the PDM system for further use in design and simulation processes, as well as in VR applications. The KBE system informs the user with the results of data quality in a prepared way and provides a detailed documentation of checks.

The scope of one CAID document contains bigger areas, like the half exterior of a car. The conversion to a CAD part-document leads to extensive CAD data, which may lead to structural and granularity problems. The idea of the framework's structure management is to define and administrate a master-structure for Class-A data in the KBE system. This master-structure enables a disassembling of CAID data to single CAD models including grouped geometry. As a key aspect, the elements of this structure can be connected to the further technical pendants of the engineering structure, which enables an adoption of the Class-A structure to the engineering structure in traditional PDM system. Furthermore, the KBE system allows the definition of structures in a more detailed granularity as on part level, which may be advantageous for downstream visualization disciplines or for check operations of specific elements.

A new introduced meta-data management within the KBE system enables the assignment of information to the specific entity of the defined master-structure. This approach provides an important step forward due to the fact, that today's CAID data do not support user-specific attributes. Now, CAD data, which are created and uploaded to the PDM database, are able to include meta-data added to the CAD attributes. Further meta-data, like an assignment of variant, the definition of mirror-parts, carry-over parts, engineering material, shading information, work effort for cost-estimation, etc. are now part of the styling integration framework.

For a better understanding and illustration, the journal paper describes the main functionalities of the framework in detail. Furthermore, it contains a comprehensive application of the framework by an exemplary surface release process in automotive industry. For that purpose, the framework is implemented into a software prototype which is introduced by use of the previous example and the applicability and practicality in automotive industry processes is discussed.

Conclusions:

The paper points out the challenges of styling-technology integration processes in view of the involvement of different computer-aided styling, design and engineering systems. The presented KBE framework is able to face these challenges of styling integration into engineering processes. Actually, a prototype solution of the framework is applied in automotive full vehicle body development projects, where it first of all has led to transparent and documented representation of Class-A data. A continuous view on the actual status of maturity and quality regarding specific development milestones states a key issue of the solution. Integrated automation procedures, like an automated Class-A release procedure, which provides data conversion, disassembling, checking, documentation as well as storage in PDM database, lead to a tremendous time-reduction. In this way, the framework supports styling-engineering change-management and shortens the duration of technical validation loops of styling data. The KBE solution is able to check the quality of data, but reparation of Class-A data or the evaluation of harmonious surface reflection by use of isophote technology has still to be done interactively or physically by the responsible designers. In this way, the presented approach is able to support the styling-technology convergence efficiently, but of course, the creative tasks of vehicle design remain in the charge of stylists and engineers.

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