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AUTOMOTIVE STYLING: SUPPORTING ENGINEERING-STYLING CONVERGENCE THROUGH SURFACE-CENTRIC KNOWLEDGE BASED ENGINEERING

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Abstract

The emotional impression a car imprints on a potential buyer is as equally important for its commercial success as fulfilling functional requirements. Hence, to create a positive emotional impression of a vehicle, great effort is put into a car's styling process. One of the key aspects during the early stages of the automotive design process is the convergence of styling and engineering design. While requirements stemming from engineering design are usually characterised by quantitative values, styling requirements are rather qualitative in nature. Converging these two requirement types is laborious. The present publication focuses on supporting this process through Knowledge Based Engineering. This is achieved by introducing a method which enables the designer to intuitively regard functional requirements during the styling phase. Moreover, the method improves the process of technical requirement checks regarding the shape and orientation of styling surfaces which exceed conventional package verifications.

Keywords: Computer Aided Design (CAD), Design engineering, Requirements, Knowledge management, Styling

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1 INTRODUCTION

Passenger cars are highly complex products which must incorporate many functional features. However, the emotional impression a car imprints on a potential buyer is as equally important for its commercial success as fulfilling functional requirements. Hence, to create a positive emotional impression of a vehicle, great effort is put into a car's styling process (Stadler and Hirz, 2016). In that regard, developing a passenger vehicle has been compared to solving a very large equation system. As a deduction, Nehuis (2014) quotes an example stated by Clark and Fujimoto (1992) that stylists aspire to lower the bonnet for visual reasons, while engine developers strife for the opposite. Moreover, the body development claims additional package space for mechanical structures, which in turn also influences the height of the bonnet. This example is characteristic for opposing development goals in the interdisciplinary automotive development process. As stated by Hacker (2002), finding a solution for conflicting development goals is effort-intense for complex products. Hence, a billion Euro investment is required to develop a vehicle from scratch (Aust *et al.*, 2012). This resource investment justifies expenditures as well as any additional development efforts to elaborate a customer appealing styling (Braess and Seiffert, 2013).

Styling a vehicle takes place during the conceptual and early series development phases of the automotive design process. Elaborating the finalised styling can be interpreted as an iterative process of synthesis and analysis, as is depicted in Figure 1 and summarised by Brüdek (2015) and Kurz (2007). Starting with the initial styling intention, the stylist uses various methods and modelling tools to further develop the shape, i.e. the styling of the vehicle. The stylist then evaluates the new iteration's aesthetics and uses this impression as an input for the next styling iteration. Concurrently, the styling is also evaluated from a functional point of view. Among other things, Engineering Design checks for package conformity and legislative rules. Any considerable divergent aspects between the checked styling iteration and the functional requirements are listed up. These aspects then act as a basis for discussion between engineering and styling to find a compromise. The stylist uses this compromise as an additional input parameter for the next styling iteration. At the end of the styling process, a required level of convergence between the styling model and functional requirements must be achieved to finalise the styling.

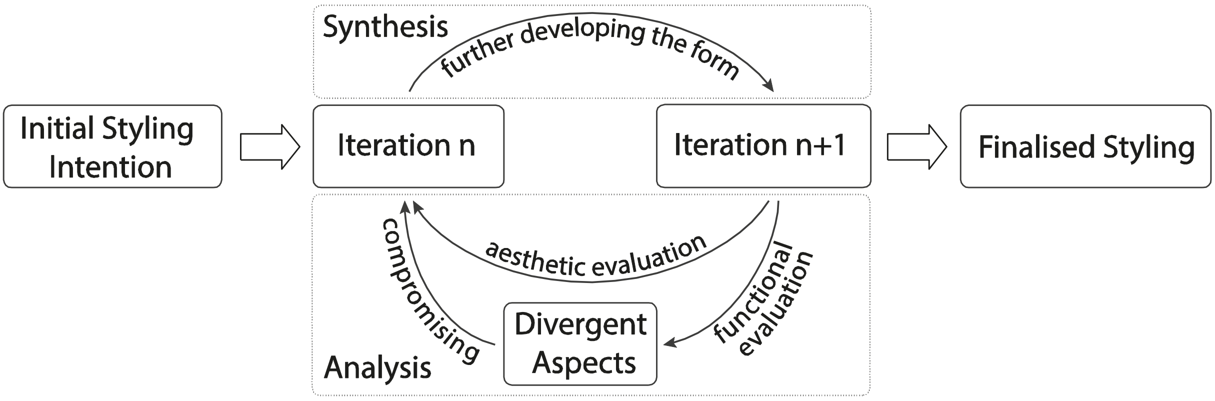


Figure 1. Converging process of technical aspects and styling

The continuous evaluation of styling models from an engineering design point of view is laborious. Yet it is necessary to ensure the progressive convergence of technical aspects and styling models starting from the early concept stages on. The above mentioned styling process is not sequential but rather parallel in nature (Braess and Seiffert, 2013). Moreover, it is characterised by dynamic behaviour, which is why several problems arise. In the industrial practice, the engineering design snapshots one styling iteration as a basis for the functional evaluation. However, as the functional evaluation is being conducted by the engineering design, work on the styling continues. This leads to a comprehensive functional evaluation which refers to an already outdated styling iteration. Evidently, this results in avoidable overhead during the vehicles concept development phase, where styling and engineering design must be interconnected to work efficiently (Braess and Seiffert, 2007).

This raises the question on how to improve the interdisciplinary collaboration process during the concept and early series development phase. This means in particular the convergence between the subjective requirements towards a vehicle's styling and its respective quantitative requirements stemming from engineering design.

Several approaches have been made to support the automotive design process during above-mentioned phases by using Knowledge Based Engineering (KBE). KBE aims at formalising product knowledge in order to automate repetitive tasks. Therefore, it accelerates product development. One approach towards KBE are KBE-Templates. KBE-Templates are parametric CAD assemblies, which contain formalised knowledge, for instance packaging information and manufacturing restrictions. Hirz (2013) describes the necessity for a close connection of the different disciplines involved in the concept creation of a vehicle. In order to do so, the approach of *ConceptCar* is illustrated. It is as an example of a parametric 3D-CAD model, which integrates ergonomics, packaging and legal requirements, as well as simplified styling data. Amongst other things, the approach features concept checks for A-Pillar Covering and fields of view. Similar checks are also available in state of the art commercial systems like *CAVA*. Additionally, functions to check for vehicle dimensions, legal requirements and fields of view are available (TechniaTranscat, 2016).

Despite the fact that these methodically aided package checks and package creators are nowadays indispensable, the thorough check of styling surfaces regarding functional fulfilment is still time-consuming. This is due to the fact, that current approaches focus on the creation of parametric vehicle concepts regarding ergonomics, installation space of components and legislative aspects. However, several functional requirements of the styling surface cannot be verified with mentioned approaches. In fact, analyses regarding more profound characteristics, like styling surface orientation, styling features or designated openings are required (Lender, 2016). The aim of this article is to present a time-effective KBE approach which also supports verifying mentioned styling surface characteristics. These go beyond conventional package checks. In this context, special attention is paid to the interconnected nature of styling surface requirements, as applying KBE methods have proven to greatly support optimising solutions with interdependent parameter ranges (Kuchenbuch, 2012).

As an introduction to the approach, an outline of the challenge to incorporate both functional and emotional requirements into a vehicle's styling will be given in section 2. Next, the basics of the chosen KBE approach will be illustrated. After briefly summarising these fundamentals, section 3 discusses the methodology to capture and formalise the required knowledge. Following, the implementation of the KBE approach will be laid out. This will be achieved by showcasing a problem resulting from the current research gap and applying the presented methodology to approach it in section 4. Lastly, the results of the approach will be discussed and an outlook for further developments will be given in section 5.

2 FUNDAMENTALS

The aim of this section is to illustrate the theoretical background of the presented approach. To this end, a brief introduction of the difficulties to incorporate emotional and functional aspects into the styling of vehicles will be given. Moreover, the elementals of the Knowledge Based Engineering approach will be laid out.

2.1 The Challenge of converging emotion and function into a vehicle's shape

In contrast to functional vehicle's characteristics such as the drag coefficient, styling is not a quantifiable variable (Kurz, 2007). As mentioned above, finding a satisfactory holistic solution can only be achieved by close and permanent collaboration between engineers and stylists (Beier, 2013). However, this close cooperation is complicated by differing educations and mind-sets, as well as dissimilar approaches of problems (Guden *et al.*, 2011). As a consequence, the process of shaping the surface of a vehicle requires the stylist to mentally incorporate a significant interdisciplinary amount of conflicting emotional and functional requirements. Balancing conflicting goals and, in turn, their influence on the process of shaping the vehicles surface, is depicted in Figure 2.

On the one hand, balancing quantitative goal conflicts resulting from interconnected functional requirements is a common task of engineering design (Feldhusen and Grote, 2013). In this regard, stylists face a very similar task. Analogous to solving goal conflicts between quantitative interconnected functional requirements, the qualitative requirements towards the styling must be balanced as well. For instance, a vehicle's styling must give its observer pleasure and should imprint desire to own it (Braess and Seiffert, 2007). Simultaneously, both the quality and the technical characteristics must be communicated as well as the value and purpose of the vehicle. As incorporating these aspects is already demanding, a stylist must also consider the expected lifetime of a vehicle. Including facelifts, the average production time of a vehicle is approximately eight years (Braess and Seiffert, 2013). Adding its development time and average lifespan, a stylist must keep in mind that the created vehicle shape will be visible on the streets for approximately the next twenty years. Hence, a distinct formal design language is needed - without making the vehicle's predecessor look old. Furthermore, the stylist must consider the design freedom implied by the customer's desire for consistency which constitutes towards brand recognition as stated both by Krasteva, Inkermann and Vietor (2016) as well as Burnap (2016). Loewy (1992, p. 1) phrases this correlation towards the shape as ‘most advanced, yet acceptable’.

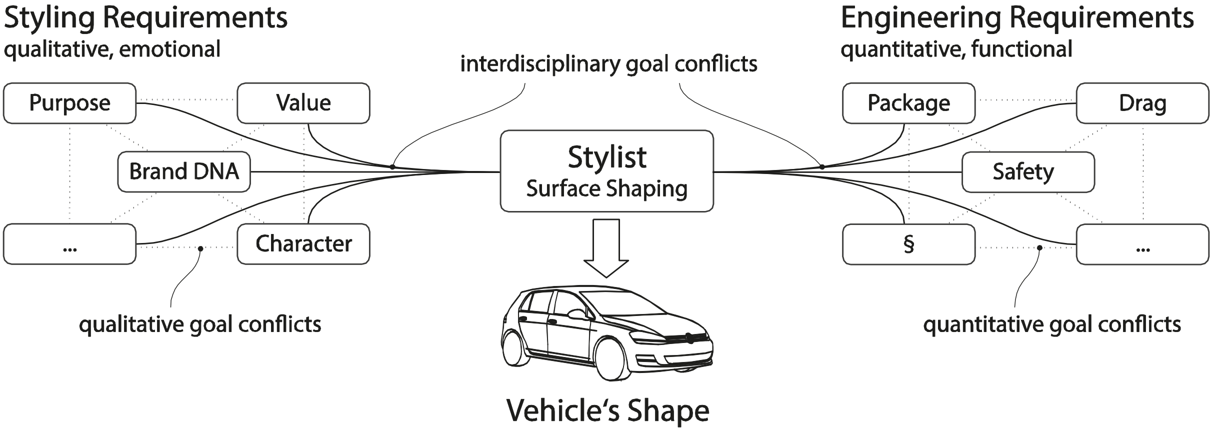


Figure 2. Converging emotional and functional requirements

Evidently, working out the quantitative emotional goal conflicts and the qualitative functional goal conflicts separately is demanding. It is a challenge for the stylist to regard both factors simultaneously while elaborating the vehicle's shape (Sareh and Rowson, 2009). Chandra (2015, p. 2) characterises this harmonisation process as ‘a divide between emotional and functional’, while Braess and Seiffert (2007, p. 5) refer to it as ‘the quadrature of the circle’.

2.2 Knowledge Based Engineering

The objective of Knowledge Based Engineering (KBE) is to reduce time and costs of product development. This is primarily achieved by automation of repetitive design tasks while capturing, retaining and re-using product and process knowledge (Liese, 2004). Collecting knowledge of products, processes and organisational requirements in a knowledge management system facilitates the development of new and innovative products (Vajna *et al.*, 2009). La Rocca (2012) gives a review on Knowledge Based Engineering and the related topics Knowledge Management (KM) and Knowledge Engineering (KE) (Figure 3).

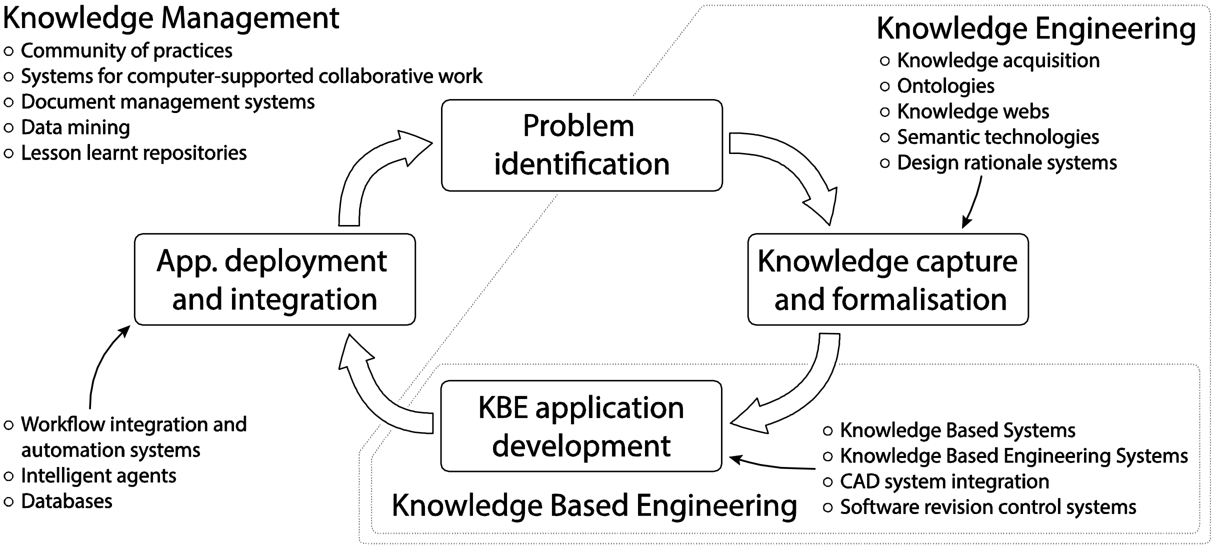


Figure 3. Correlation of KBE, KM and KE (La Rocca, 2012)

KM focuses on the overall goal of promoting and supporting initiatives which may enable a more efficient and effective use of knowledge assets in the organisation. The research discipline of KE can be seen as a subset of KM. It concentrates on the acquisition and formalisation of knowledge to support the development, implementation and maintenance of Knowledge Based Systems (KBS). There are various KE methodologies, e.g. model-based and incremental knowledge engineering (MIKE) and Protégé-II (Kuhn *et al.*, 2011). Ideally, the KBS capabilities regarding knowledge capture, knowledge representation and reasoning are to be merged with computer-aided design (CAD) and computer-aided analysis (CAA) capabilities to provide engineers with automated assistance in geometry manipulation, data processing and analysis (Stjepandić *et al.*, 2015).

Based on KBS and its identified and formalised knowledge, KBE is an extension which enables the manipulation of geometry or assemblies in CAD. There are ‘KBE-like’ functionalities available for every major CAD system. A KBE template consists of one or more CAD models. Templates and user-defined features offer an acceleration of the development task and a reduction of repetitive modelling tasks by automation of engineering tasks (La Rocca, 2012).

3 IDENTIFYING AND PROCESSING RELEVANT KNOWLEGE

As mentioned in the previous section, several prerequisites must be met in the course of developing a KBE application. This section deals with the acquisition and formalisation of the relevant knowledge. Firstly, the relevant knowledge sources will be discussed, followed by outlining how to capture and filter the relevant knowledge. As a conclusion, evaluating and processing the knowledge will be clarified.

3.1 Sourcing and filtering the knowledge

Considering the complexity of modern passenger vehicles, an important task was to choose the relevant sources and to refine the acquired knowledge to an appropriate level. The aim was to acquire knowledge regarding requirements with direct impact towards the shape of the exterior styling surface. Figure 4 illustrates the distinct steps from analysis towards synthesis and finally the use of the acquired knowledge.

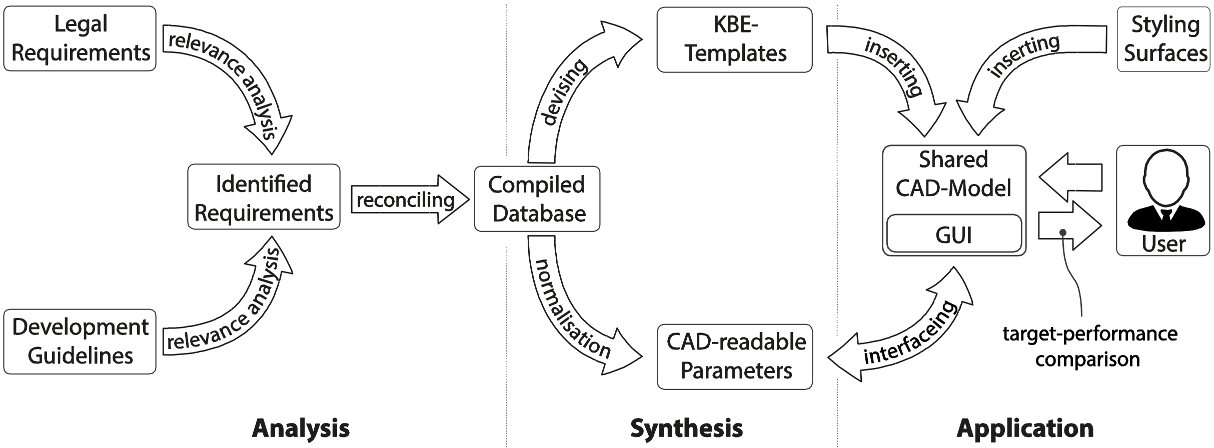


Figure 4. Processing requirements with direct impact on the styling surface shape

Starting with the analysis, a dualistic approach was applied to source relevant data for the method at hand. Firstly, requirements deriving from legislative bodies, such as *Federal Motor Vehicle Safety Standards (FMVSS)* and *Economic Commission for Europe (ECE)* were examined, as well as requirements stemming from consumer tests such as *Euro NCAP* or *RCAR*. The examined requirements were evaluated regarding their direct impact on the shape of the styling surface. Afterwards, relevant requirements were compiled. They were also allocated to common exterior parts of a vehicle such as bumpers or headlights as several of these requirements directly determine the shape and orientation of the styling surface. For instance, position, size, curvature and mounting angle of the licence plate carrier. However, most quantitative requirements towards the shape of the styling surface are not directly specified by the aforementioned regulations. They are rather derived by the engineering design choices towards the vehicle to fulfil regulations as well as the engineering design guidelines of the distinct vehicle manufacturer. For instance, while *FMVSS §571.108* (2016) clearly specifies the acceptable mounting height of the lower beam headlights of a vehicle to be registered in the United States, it also specifies several illumination characteristics which have to be met. However, the document does define the headlamp design to fulfil these illumination requirements. It is up to the engineering design to embody a headlamp which fulfils all regulations and internal guidelines. Evidently, the design choice of a headlamp with its distinct characteristics has its own requirements towards the shape of the styling surface, such as the required opening size for the headlamp in the front of the vehicle. Therefore, development guidelines must also be considered, even though most of this engineering design knowledge is undisclosed intellectual property of the respective manufacturers and their technological suppliers. This leads to the second part of the dualistic analysis approach, where unpublished reference guidelines regarding common exterior parts were analysed and relevant specifications towards the shape of the styling surface were reconciled with the previously collected data.

3.2 Formalisation and application of the knowledge

Using the compiled data as a basis, two distinct steps were made during the synthesis phase. Firstly, the requirements were entered into an expandable database while their specific attributes were normalised to quantifiable, geometric features like angles or lengths. Secondly, the requirements were aptly grouped into requirement complexes and combined to be represented by geometrical KBE-templates. This procedure is exemplified in Figure 5 by representing the set beam angles of the low beam headlights by a truncated pyramid. These geometrical representations are hereafter referred to as styling guidance geometries.

Name	Value
beam angle, upwards	5°
beam angle, downwards	5°
beam angle, inwards	5°
beam angle, outwards	5°

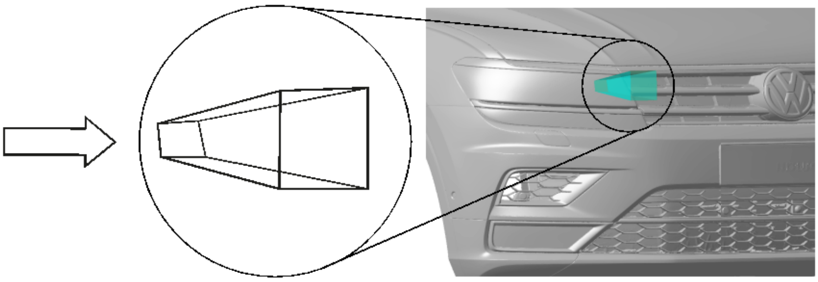


Figure 5. Transforming quantitative requirements into geometrical representations

Concluding with the synthesis phase of the approach, the elaborated database was linked with the conceived geometrical templates inside a CAD system. Combining the geometrical templates and styling data inside a shared CAD model enables the engineer to verify requirement fulfilment of the styling surfaces. In order to do so, a graphical user interface (GUI) was implemented to control the geometrical requirement representations. Furthermore, functional checks for the compliance of the styling surface with the elaborated technical requirements were devised.

4 SHOWCASE: FLUSH PARK DISTANCE CONTROL COVER

This section outlines the results of the proposed approach by showcasing a commonly encountered obstacle during the styling and engineering convergence process. At first, the exemplified problem will be described. Afterwards, the results of approaching the problem according to the previously presented course of action will be laid out. Lastly, an implemented KBE application will be illustrated to address the problem.

4.1 Problem Identification

Park Distance Control (PDC) is a driver assistance system which indicates obstacles in front of the vehicle while parking. In general, the system uses several ultra-sonic distance measurement sensors. Depending on the vehicle size, usually four to six interconnected sensors are installed into a vehicle's front. If the sensors are to be embedded into the bumper cover, a flush transition from the bumper cover to each distinct sensor cover is desirable from the aesthetic point of view. This shaping is illustrated in Figure 6 (A). However, in order to ensure reliable system operation, requirements towards the position and orientation of the sensors must be met as well. If the orientations of a sensor and the styling surface at its installation position do not match due to these requirements, an undesired funnel must be used, as depicted in Figure 6 (B).

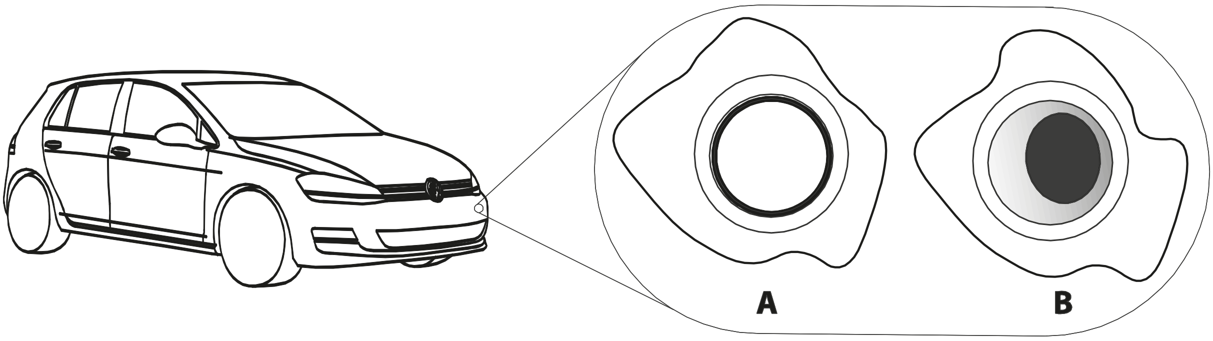


Figure 6. Desired Flushness of Park Distance Control Sensor Covers

4.2 Knowledge Analysis and Formalization

The definition of the flush transition of the two components is formalised in Equation (1). It states that the normal vector of the PDC sensor cover and the normal vector of the styling surface must match at the given installation position.

$$n_{surface}(x,y,z) = n_{PDC\ cover}(x,y,z) \tag{1}$$

Additionally, two side conditions do apply as well. These are directly related to the sensor inclinations α and β as illustrated in Figure 7. The side conditions originate from the working principle of the ultrasonic sensor. It detects obstacles in a cone shaped detection area by using the reflection of emitted ultrasonic pulses. On the one hand, there is a minimal inclination angle β in order to avoid range limiting reflections by the road surface. On the other hand, there is also a maximum inclination angle, because the system could fail to detect narrow obstacles right in front of the vehicle. The acceptable value range of sensor inclination β is also dependent on the sensor installation height relative to the road surface, as depicted in Equation (2).

$$\beta_{max}(z) \geq \beta > \beta_{min}(z) \tag{2}$$

The mutual alignment of the sensors must be regarded as well, as illustrated in Figure 7 (B). As mentioned before, the detection range of each distinct sensor is cone shaped. In order to avoid gaps in the coverage between the distinct sensor detection areas, a specific overlap of the detection cones must be ensured. This results in the relative alignment angle Δα between two sensors. The acceptable range for the angle Δα is determined by the relative distance of two sensors which is formalised in Equation (3). Using the sum of the distinct angles Δα, the absolute horizontal sensor orientation of each sensor can be determined. Concluding, the angle α is depicted in Equation (4) as the second side condition.

$$\Delta\alpha_{max}(l_\mathrm{n}) \geq \Delta\alpha > \Delta\alpha_{min}(l_\mathrm{n}) \tag{3}$$

$$\alpha_n = \frac{\Delta\alpha_1}{2} + \sum_{i=2}^{n} \Delta\alpha_i \tag{4}$$

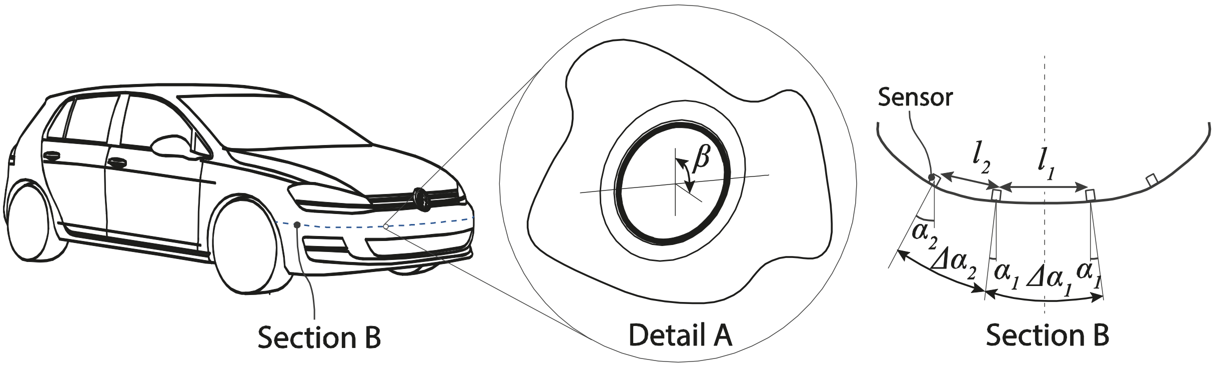
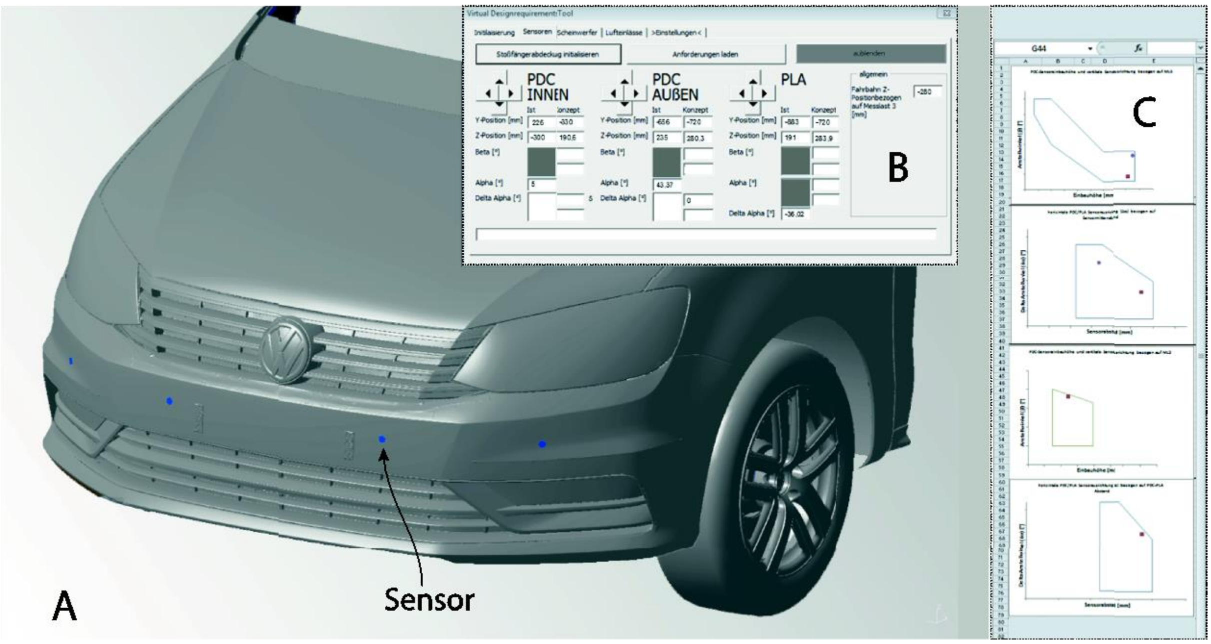


Figure 7. Functional side conditions of a flush transition between PDC and bumper cover

4.3 KBE Synthesis and Application

As mentioned earlier, a geometrical template has to be conceived to represent requirements graphically. In this use case, a circular shaped plane with the diameter of a PDC cover was chosen to customarily represent the installation position of a sensor. By applying the side condition (2) with its respective acceptable value range to this geometry, an initial template was created. By combining the styling surface and the created template inside a shared CAD model, an initial graphical representation of the styling proposal and the technical requirements was achieved. This is illustrated in Figure 8 (A). Additionally, the distinct graphical templates for each sensor were mutually linked inside the shared model by applying side condition (4). Moreover, the templates were constrained onto the referenced styling surface. Lastly, the primary condition for a flush transition between the sensor cover and the bumper cover was applied to the template.



PDC INNEN: Y-Position [mm] Ist 226, Konzept -330; Z-Position [mm] Ist -300, Konzept 190.6; Beta [°]; Alpha [°] 5; Delta Alpha [°] 5

PDC AUßEN: Y-Position [mm] Ist -656, Konzept -720; Z-Position [mm] Ist 235, Konzept 280.3; Beta [°]; Alpha [°] 43.37; Delta Alpha [°] 0

PLA: Y-Position [mm] Ist -683, Konzept -720; Z-Position [mm] Ist 191, Konzept 283.9; Beta [°]; Alpha [°]; Delta Alpha [°] -36.02

Fahrbahn Z-Positionbezogen auf Messlast 3 [mm] -280

Figure 8. Combined styling model and graphical requirement representation

Figure 8 (B) illustrates a graphical user interface created to check the styling surface of the functional requirements. It enables the user to individually vary the sensors' position on the styling surface, while automatically considering the primary condition (1). In case of violating side conditions (2) and (4), the user is notified by the GUI. Moreover, the aforementioned range of values for the side conditions are displayed individually as qualitatively depicted in Figure 8 (C). For each sensor, the value inside the range is displayed and updated according to the user input.

5 CONCLUSIONS AND OUTLOOK

The functionality of state of the art CAx methods is limited regarding technical requirement checks of the shape of styling surfaces which exceed conventional package verifications. This, in turn, leads to error-prone and time-consuming manual checks of the styling surface. By depicting the generally applied automotive styling process with its dynamic interaction between its interdisciplinary stakeholders, the need to supplement current CAx methods has been further clarified. To address the need for mentioned CAx support, a process scheme was presented to source and analyse requirements with direct impact on styling surfaces in the automotive industry. Due to this process scheme, the gathered data could be formalised into intuitive, graphical representations which were applied to the styling process. The approach was demonstrated by showcasing a common challenge during the convergence of engineering design and styling which resulted in formalised requirements towards the shape of the styling surface. In this context, a KBE application was presented to apply the formalised data.

It becomes immediately apparent that the presented application enables to intuitively check the shape of the styling surface regarding its technical requirements. This has also been proven by applying the approach to further use cases other than the one presented here. Moreover, it is apparent that the combination of intuitive, graphical requirement representations in combination with a styling model not only supports regular checks of already existing solutions. It also supports the process of finding new ones. This was demonstrated by the presented graphical user interface (GUI). In the presented example, the user may simply vary the horizontal and vertical position of each sensor on the styling surface by using the GUI. The application, on the other hand, lightens the users' workload to manage the interconnected variables and reduces error probability by dynamically checking the interconnected primary and side conditions of the proposed solution. As the original proceeding to find an alternative installation position is characterised by iterative trial and test, the approach enables to quickly check the existing styling surface for alternative installation positions rather than requiring to change the styling surface to comply with technical requirements. This, in turn, helps to hasten the styling process and further improve the aesthetic quality of the styling.

As mentioned earlier, the approach was meant to supplement current methods for checking the convergence of styling and engineering design models. The presented approach focuses on checking the shape of the styling surface regarding the installation position of components. It becomes immediately apparent that this proceeding does not make conventional package checks obsolete. In contrast, combining the proposed styling surface verification with a state of the art package check would imply a great design process improvement. Using the presented showcase as an example, the knowledge template of the PDC sensor would also need to incorporate its distinct geometrical package model and its side conditions such as clearings and wiring. With these perquisites, a proposed sensor installation position could be dynamically checked against an underlying package model of the vehicle and its implications towards the styling surface at the same time.

The proposed approach uses geometrical representations for requirement complexes which are otherwise hard to grasp by the human mind (Hacker, 2002). As geometric bodies and shapes have the same abstraction level which stylists use to shape a products surface, the approach is especially suitable to communicate complex requirements in interdisciplinary development teams.

As computer and visualisation technology evolves ever quicker as before, new possibilities arise for this approach. Apart from virtual styling models, physical styling models are still being used to elaborate and evaluate surfaces. However, as Radkowski and Linnemann (2009) stated that a seamless integration of physical and virtual styling models is desirable, further research should aim to incorporate the presented approach to be used in physical styling models as well.

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