

7.3 Design Appeal

7.3.1 Legal and Customer Requirements

Perception of a new car by a potential customer usually happens from the outside to the inside and along different levels of detail: The first look catches the vehicle's body style and proportions. Is it a classic roadster? A dynamic coupe? A luxury sedan? As the customer gets closer to the car, surfaces come into focus. The shape of the hood, characteristic swage lines in outer body panels, the door. Eventually, details such as door handles, front- and rear lights or exterior trim parts are experienced. Opening the trunk lid gives a first impression of practicality and eventually entering the car allows the potential customer a first experience of ergonomics by means of the ease of access.

Then, from inside, the vehicle's interior can be explored – again starting with proportions: Does the interior feel spacious or restricted? Is the dashboard a piece of modern art furniture or rather a rack for vehicle equipment? Are the seats sofas rather than stools? Next, interior surfaces like trim parts or upholstery give an impression of value. The details of interior design such as control elements, displays or package trays allow further experience of ergonomics and value perceived. Figure 7.4 illustrates this process of experiencing a vehicle's design.

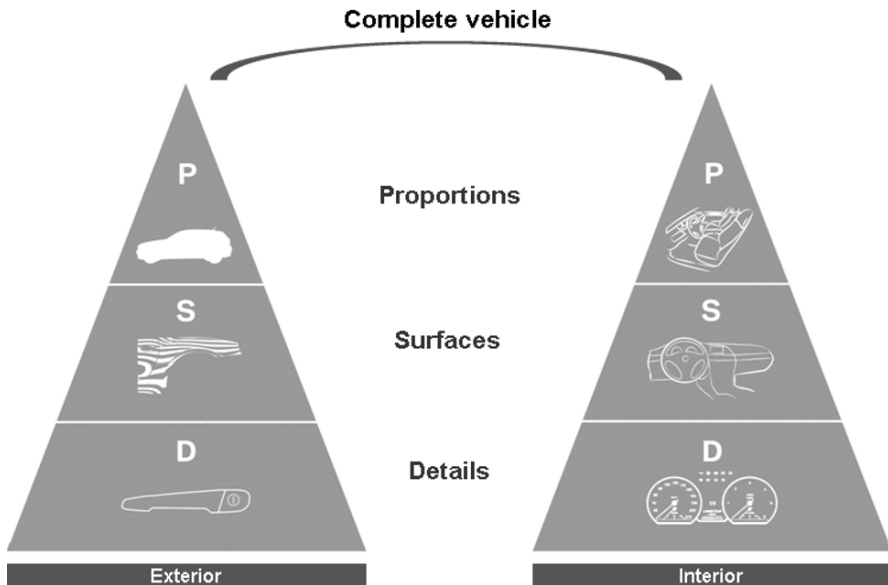


Fig. 7.4 Levels of vehicle design perception (Source: BMW)

Out of this process of perception, three main customer relevant properties can be deduced which are determined by the vehicle's conceptual design: Styling, ergonomics and practicality.

7.3.1.1 Styling

As discussed above: The first characteristic of a car that should catch a potential customer's attention, ignite his emotional perception and eventually draw him to the showroom is the aesthetic appearance of its exterior styling [9]. Typical features that determine a vehicle's exterior styling are: Overall dimensions, wheel base, wheel size, track, front and rear overhang, hood line, windscreen line, windows, pillars, belt line, doors, wheel house size, color etc. Brand specific styling features differentiate the vehicle from its competitors.

Both from the customer's and society's viewpoint, styling carries an important statement about a vehicle's owner's character. And even if this statement is understatement: For most customers, the message sent out by their vehicle's styling is as important as its objective technical features (such as performance or acoustics etc.). This message can be rather weak or strong. Figure 7.5 shows four cars with a distinctive exterior styling that send very strong (though very different) messages to its environment, e.g. provocation and radicality by a Lamborghini Reventon (top left), ultimate exclusivity by a Rolls Royce Phantom (top right), emotion and fun by a MINI Cooper (bottom left), or power and sportiness by a Porsche 911 Turbo (bottom right).

The fact that styling is as important for a vehicle's market success as its technical properties has been known since the 1930s. Until then, the sole driver for a vehicle's body style was optimization of technical parameters such as aerodynamic drag or stiffness – resulting in cars which consequently all looked more and more the same. Alfred Sloan, GM's chairman at this time, realized that the car had changed from a pure means of transportation to an article of fashion, and that it made sense to sacrifice a certain amount of its technical performance in order to obtain a distinctive and emotional styling. GM started offering an annual revisions of their models exterior style – and subsequently surpassed their big rival Ford in sales.

A more recent example for the importance of styling is Toyota's launch of its youth-oriented and U.S.-exclusive Scion brand in 2004. Two cars were brought to the market: The subcompact xA and the compact station wagon xB, both based on the Echo/Yaris platform. Planned sales volume for the xA was significantly higher than for the xB, but due to its distinctive styling and body concept the xB outsold the xA 2 to 1.



Fig. 7.5 Cars with strong exterior styling messages
(Sources: Lamborghini, BMW, BMW, Porsche)

While exterior styling is said to be responsible for “love at first sight”, interior styling and value perceived should make this love everlasting. The fact that many people spend more time in their car than in their living room is one of the reasons for the current market trend towards premium-quality and distinctive vehicle interiors. As an example, Fig. 7.6 shows four completely different design approaches: Luxurious and comfortable in a Bentley Arnage Final Series 9, (top left), elegant and sporty in a BMW Concept CS concept car (top right), young and extroverted in a MINI Cooper S (bottom left), puristic and sporty in a Lotus Exige.

Aside from the exterior and interior, the engine and baggage compartments are also styled. The customer should experience the design language of the vehicle even when opening hood or trunk.



Fig. 7.6 Distinctive dashboard styles (Sources: Bentley, BMW, BMW, Group Lotus Plc.)

7.3.1.2 Ergonomics

A commonly accepted but very general definition of the widespread term ergonomics was adopted by the IEA Council in August 2000: “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, ...” [10].

The central target of ergonomic vehicle design is the realization of both a spatial geometry and a man-machine-interface that allows driver and passengers to safely and comfortably operate all vehicle functions in all relevant situations – of course with the primary focus on the driver driving the car. Customer relevant properties regarding ergonomics are e.g.:

- Seating: Position, adjustability, variability, dimensions of the seats; static and dynamic seat comfort; foot well size; seat belt comfort.
- Dimensions: Leg room, knee room, hip room, elbow room, shoulder room, head room. Subjective feeling of spaciousness.
- Driving operations: Steering effort; pedal characteristics; handbrake, gear selector operation; accessibility of control elements; visibility of displays.

- Non-driving operations: Ease of entry and exit; passenger comfort; ease of loading and unloading; ease of refueling; ease of equipment installation (e.g. roof rack, trailer etc.).
- User interfaces for information, communication and entertainment systems: Intuitivity of operations, readability of displays, general management of the complexity caused by the increasing amount of information technology within cars.

Together with dynamic, acoustic and thermal comfort (see Sects. 7.4.1, 7.4.2 and 7.4.3), ergonomics contribute to the minimization of the driver's fatigue and discomfort and thus significantly influences his or her alertness and active safety. For this reason, many vehicle characteristics concerning ergonomics are subject to legal regulations (compare Sect. 7.1.1).

When optimizing vehicular ergonomics, one has to keep in mind that the occupants' physiognomy varies from market to market. Typically, Scandinavian men being among the tallest and far eastern women being among the shortest represent the extremes of anthropometrical height. Similar variations appear in factors such as width, waist line, hand size, reach, and weight. Achieving the same level of customer satisfaction worldwide is a big challenge for international car makers.

Another challenge to vehicle ergonomics arises from the fact, that people nowadays live longer and also drive their cars at an ever older age. These senior drivers have very high requirements concerning ease of operations whilst still expecting to use the full spectrum of its functions.

7.3.1.3 Practicality

Another customer relevant aspect of a vehicle determined by its design is its practicality, including both the vehicle's capability to store luggage and personal items and the dimensional practicality of the vehicle as a whole. Typical requirements from a customer's point of view are e.g.:

- General load space: Width, length, height; open / closed; total volume (e.g. number of VDA standard boxes)
- Load space for standard items: SAE standard luggage set; bicycles, golf bags, skis etc.
- Additional load space: Roof rack availability / capacity; towing hitch availability
- Size and position of trays, pockets, holders etc. for stowage of personal items
- Dimensional practicality: Overall length, width, height (especially in relation to e.g. maximum dimensions and weights of streets, garages, trailers, auto-trains etc.)

Practicality is one of the vehicle characteristics that are typically only perceived when not provided in certain situations: When the luggage for holiday travel does

just not fit in the trunk, when there is not enough space to store a cell phone and sunglasses in the center console or when the car hardly fits in the customer's garage.

During the development process, the customer's requirements concerning practicality are represented by a *list of personal items* that indicates the items such as suitcases, sunglasses, sports equipment etc. for which storage space should be provided in a car. There are different lists with a growing number of personal items, representing different levels of practicality. The lowest level could e.g. be valid for a small two-seater roadster, the highest level to a multifunctional van. At the target agreement milestone, each new vehicle will be assigned a list of personal items that must be accommodated.

7.3.1.4 Sound Design

In addition to visual and haptic characteristics, a vehicle is also – and very directly – perceived by its acoustic properties, both in the cabin and the vehicle's environment. From a customer's point of view, vehicle acoustics have three different aspects:

- Vehicle sound as a differentiating design element (discussed in this section)
- Interior noise as an element of cabin comfort (discussed in Sect. 7.4)
- Exterior noise as a form of vehicle emissions (discussed in Sect. 7.10)

Particularly in the premium market segment, customers expect their car to have a distinct engine sound profile that fits the overall character of the brand and the vehicle type – naturally within the legal limits discussed in Sect. 7.10.4.1 [4]. Such consistent sound design comprises:

- Suppression of unwanted noises
- Acoustic feedback of driving dynamics (engine load, tire-road-friction)
- Permeability for external acoustic warning signals (horns, sirens etc.)
- Provision of an optimum acoustic environment for on-board entertainment and operation signals

Figure 7.7 depicts the preferred combinations of the general engine sound characteristic and the engine loudness during acceleration for different vehicle types. For cabin comfort reasons, the engine should not be audible at all in the cabin at constant speed. When under load, the engine should provide appropriate acoustic feedback to the driver.

In addition to engine sound, customer requirements also include appropriate sound design for all operations such as closing doors and flaps, lifting and lowering windows, actuating power seats, or operating switches. The sound should give clear feedback and reflect quality. Lowering a window e.g. should create a uniform, sovereign operating sound without any load related frequency fluctuation.

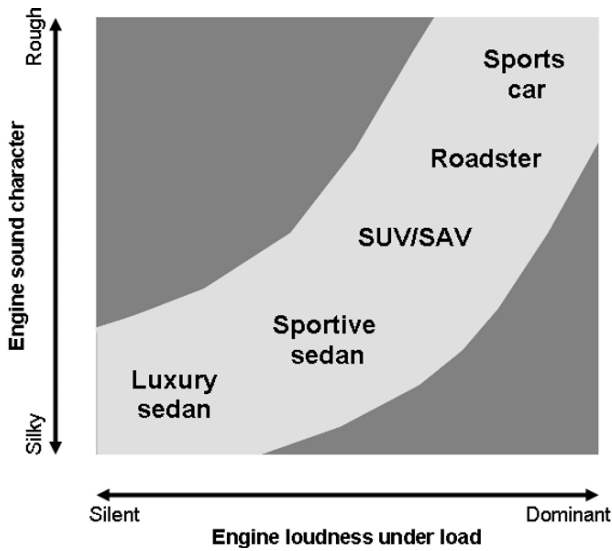


Fig. 7.7 Engine sound characteristics (Source: BMW)

7.3.2 Component and System Design

The ways and methods by which a new vehicle's design is worked out, evaluated and eventually determined, differ vastly among OEMs. As they reflect differing levels of emphasis placed on various product characteristics and functions, they are essentially a major factor of differentiation among the specific brands and OEMs. Even though this makes a generic model for automotive design processes difficult to create, there are elements and sequences that can be considered as general. For this book, the BMW Group automotive design process is taken as a specific example. A comprehensive description of this process is given in [9] and [11].

The design process is an integral part of the general PEP (see Chap. 1). BMW Group (BMW, MINI, Rolls Royce) designers use particular names for the phases of the PEP – according to the emphasis the design process has during the respective phase: During the project-independent product strategy, *advanced design* creates design visions for the future. As the main design focus during the early concept phase lies on understanding the design task agreement on proportions, this phase is called *understanding phase*. During the following *believing phase* (which is parallel to the late concept phase), the final exterior and interior design are selected. Eventually, the *seeing phase* incorporates detailing and realization of the design concept – as part of series development.

A special characteristic of the BMW Group automotive design process is internal competition. To obtain a very high level of design quality, up to eight different design teams work out different exterior and interior concepts – both during the understanding phase and the believing phase. In a gradual selection process, each concept proposal is evaluated. Eventually, a winning design is selected by the board of management. The upper level of the BMW Group automotive design process is illustrated in Fig. 7.8.



Fig. 7.8 BMW Group automotive design process (Source: BMW)

7.3.2.1 Advanced Design

As discussed in Sect. 3.1, corporate strategy and brand image represent the book-ends between which project-independent advanced design takes place – the creative exploration of concepts for potential new vehicles. Stimulated by current customer trends, ideas, competition analysis, innovative materials and technologies, internationally distributed design studios create visionary exterior and interior design themes which eventually are incorporated in concept cars. As the rendering and the picture of the 2006 BMW Concept Coupé Mille Miglia¹⁷ in Fig. 7.9 demonstrate, new or distinctive styling elements are particularly highlighted or even exaggerated on concept cars. But even if a concept car is never brought to series production, the public reaction it gets when displayed at international auto shows

¹⁷ The BMW Concept Coupé Mille Miglia 2006 was revealed by BMW at the opening of the 2006 Mille Miglia oldtimer race in Brescia, Italy. Its design is inspired by the legendary BMW Mille Miglia Touring Coupé that won the Mille Miglia in 1940.

provides valuable feedback to management on whether the revealed design or function features will appeal to future customers or not.

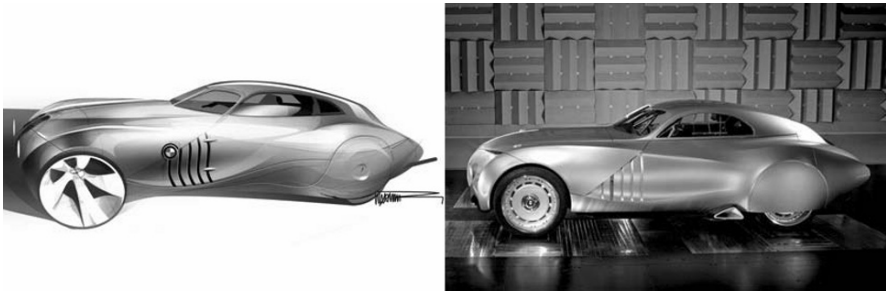


Fig. 7.9 Concept car: Design sketch and drivable model (Source: BMW)

7.3.2.2 Understanding Phase

As a vehicle project starts, the innovations and design concepts identified during the advanced design stage are consolidated with the requirements of marketing (including the customer requirements stated above) and engineering in order to understand the design task and come to a consistent vehicle specification. During this phase, the specification is converted into sketches, *computer aided styling* (CAS) models and package plans that incorporate the general proportions of the vehicle as well as the position of the major components and occupants' seating positions.

Also, the major conceptual dimensional chains of the complete vehicle (e.g. right wheelhouse – right engine carrier – engine – left engine carrier – left wheelhouse) are determined by exterior and interior styling and are checked for feasibility during the initial phase (compare Sect. 3.1.1).

In parallel to the hand-made sketches, 2D and 3D CAS drafts are created. Usage of CAS systems allows the designer to develop rough surface geometries within a short period of time and to share this geometry data with all partners involved in the PEP.

To allow exterior and interior styling and packaging to work in parallel, *dimensional limit points* are stipulated. These points show e.g. the exterior designer how steep his roofline may descend without affecting the required rear passenger space.

The understanding phase can take up to one year. The results of the competing teams are typically represented by means of 2D sketches, 1:1 foam models or even 1:2.5 clay models. With the selection of one interior and one exterior proportion model at the end of this phase, proportions and character of the new vehicle are confirmed.

7.3.2.3 Believing Phase

Based on the selected proportions, the main focus of the believing phase is on the aesthetics of the vehicle, especially represented by means of surfaces and design lines. At the beginning of this phase, each design team expresses their idea of a design language with sketches and manual renderings like the one of a BMW 3 Series coupe depicted in Fig. 7.10).

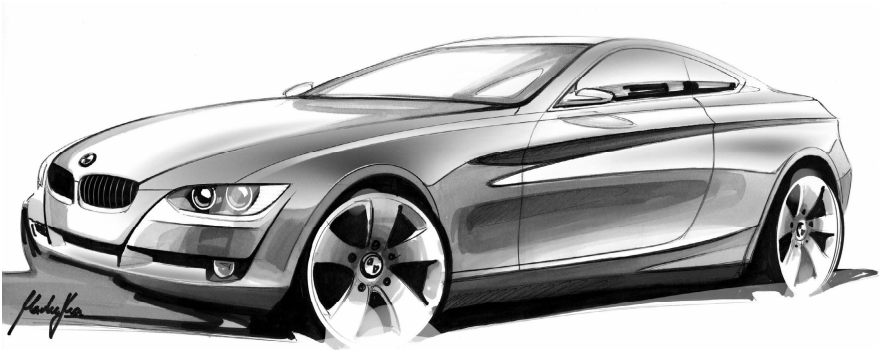


Fig. 7.10 Manual exterior rendering (Source: BMW)

Next, contour lines are honed to perfection by applying adhesive tape of different width to 1:1 tape plans (see Fig. 7.11). This method allows a high flexibility to changes within the design concept, e.g. adding extra headroom or changing the dynamic appearance of contour lines.

As a next step, a clay model is derived from the tape drawings, marking the transition from 2D to 3D representation. Highly skilled specialists transfer the vehicle geometry meticulously from the 2D drawings to the clay, using high-precision 3D measuring devices and putty knives. Covered with resilient foil, clay models give a first but very realistic impression of the new vehicles' – exterior and interior – visual and ergonomic appearance (see Fig. 7.12). In a way that would never be possible with CAS models, the 1:1 clay models widen the sensory perception and are the central platform for design work during the believing phase.

Interior design is followed correspondingly, only with a higher focus on materials and textures. Figure 7.13 shows different realization levels of an interior design concept.



Fig. 7.11 Taping of exterior contour lines (Source: BMW)

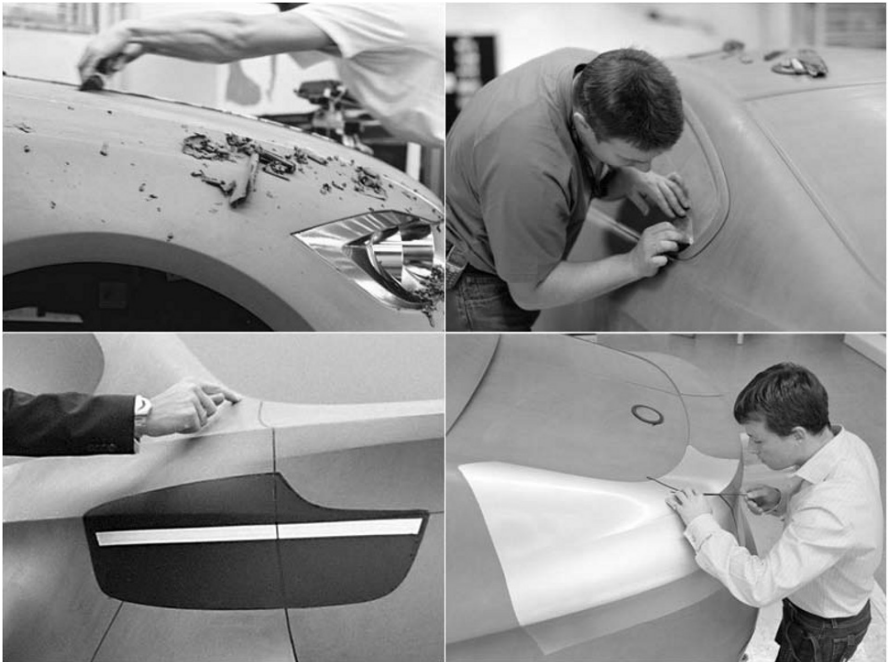


Fig. 7.12 Manufacturing of 1:1 exterior clay models (Source: BMW)

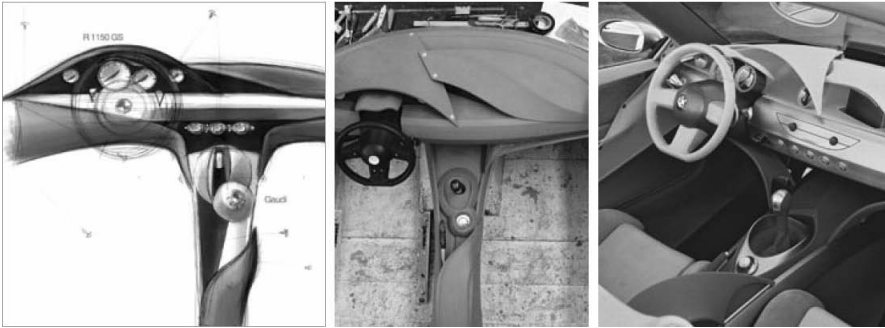


Fig. 7.13 Development stages of an interior design concept (Source: BMW)

In a process that is both intuitive and methodical at the same time, up to eight competing design teams are honing their 1:1 models through multiple try-test-discard loops, until they represent what the designer perceives as the perfect equilibrium between form and function. At the end of the believing phase, the final exterior and interior design models are carefully chosen by the board of management in a stepwise selection process [9].

7.3.2.4 Seeing Phase

The seeing phase is about “turning a sculpture that was refined by human hands into a product that can be reproduced by machines”. Designers focus on getting the selected design concept realized as exactly as possible by series development and negotiate fractions of millimeters with their partners from engineering and production, e.g. whether the 2 mm bending radius of the trunk lid can be changed to 3 mm in order to improve manufacturability. This “fight for design” concerns all the changes that occur to vehicle development until its production is launched.

To make the design data available for all partners involved in the series development, the selected clay model is laser-scanned and in this way converted into a precise 3D CAD surface representation. This model is then used as the binding data reference for all following development [9].

7.3.2.5 Sound Design

Legal noise emission limits and cabin comfort requirements are the borderlines between which a vehicle’s sound as an element of its design can be “styled”. At the relevant low vehicle speeds, rolling noise and wind noise only play a minor role. The two sound sources that have potential for sound design are the engine and auxiliary actuators such as window lifters etc. (compare Sect. 7.4.2).

Sound design must start at an early stage in the development process. The relevant components that need to be optimized are:

- Engine/gearbox combination
- Exhaust system
- Electric actuators

The acoustic characteristics of these components are initially analyzed during the concept phase. After respective measures have been derived, these components will be pre-qualified when they are brought into complete vehicle integration in series development. Design measures taken for sound design must be in line with the often conflicting objectives concerning interior acoustics and vibrations as well as noise emission.

An approach to suit an engine's sound to the required vehicle characteristic is acoustic accentuation of engine orders. In an engine's sound spectrum indicating the sound level over frequency and engine rotating speed, the engine orders can be seen as characteristic lines through the origin. Figure 7.14 exemplifies how different sound characteristics can be achieved for a BMW six cylinder in-line through targeted modifications of the exhaust system: To create a cultivated, silky sound that suits a sedan, emphasis is placed on the main engine order (red line in the left picture); to create the sportive, sonorous, speed avaricious sound that suits a sports car, lower and higher level engine orders are accentuated (red lines in the right picture).

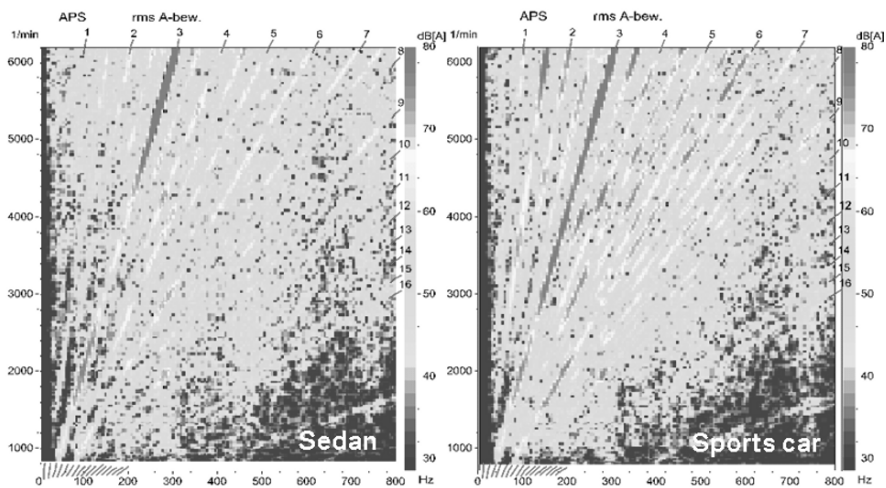


Fig. 7.14 Sound design through accentuation of engine orders (Source: BMW)

Selectable driving modes (such as *comfort* or *sport*) which are available in certain premium vehicles may – in addition to different suspension settings and

gear-change-patterns – also offer different sound patterns. In this case, sound design elements such as resonators can be switched on and off according to the required sound characteristic.

7.3.3 System Integration and Validation

As stated above, design validation is an integral part of the design process, and different tools and methods are applied during the different stages.

7.3.3.1 Styling

For intermediate results and qualitative decisions, exterior and interior styling can be validated using rendered CAS models, visualized as pictures, 1:1 projections or virtual reality environments. Smoothness and harmony of surfaces are checked by means of computer aided tools (see Fig. 7.15).



Fig. 7.15 Surface evaluation on virtual surface models (Source: BMW)

Photo-realistic representation of surfaces, materials and textures allow a very lifelike perception of exterior and interior design appearance without the necessity of expensive physical prototypes. Figure 7.16 shows a photorealistic exterior representation of the BMW Concept CS, Fig. 7.40 an interior detail.



Fig. 7.16 Photo-realistic exterior representation (Source: BMW)

When eventually decisions of consequence are made concerning exterior and interior design, it always relies on 1:1 models. Only realistic hardware allows the highly multi-sensual process of validating a car's proportions, surfaces, colors, odors, touch and feel etc. The number of 1:1 models used during this optimization and selection process directly influences the quality of the final design. Figure 7.17 shows the assessment of an early design model.



Fig. 7.17 Evaluation of an early design model (Source: BMW)

As styling strongly affects other complete vehicle characteristics, (e.g. manufacturing costs through manufacturability of body surfaces, acoustic comfort through aerodynamic drag, ride comfort through the space provided for suspension elements), it is developed in close cooperation between designers and engineers [12].

7.3.3.2 Ergonomics

Basic ergonomics criteria such as the adoption of healthy and efficient postures for the complete range of future users must be taken care of and validated in the design process as early as possible to prevent late and costly alterations [12]. In contrast to styling, conformity with ergonomics requirements can be thoroughly assessed at a very early design stage. Advanced simulation tools like RAMSIS or SAMMIE CAD allow precise investigations of driver and passenger ergonomics using virtual cars and scalable virtual manekins. Figure 3.5 shows a simulation to assess a ergonomics of the driver environment.

As vehicle ergonomics highly depends on individual physiognomy, validation must include a broad bandwidth of representatives of the future users. One method are *fitting trials*, during which seating positions, the position of displays and control elements etc. are evaluated by 20 to 30 individuals in an experimental driving rig [12]. A common method to evaluate ergonomics for the largest possible variety of occupants and make these data available for future vehicle projects are questionnaires that are sent out to vehicle owners several weeks after purchase.

7.3.3.3 Practicality

To ensure that a vehicle concept provides the required space to store the items specified in the list of personal items at locations convenient for driver and passengers, virtual representations of these items are positioned in the virtual car and included in the virtual car process (compare Sect. 4.2). The complete set of virtual personal items is shown in Fig. 7.18.

While virtual validation can ensure the basic possibility of storing the required items, realistic fitment of e.g. non-rigid items such as golf bags can only be checked using hardware representations of the respective storage area. As these requirements can determine concept-critical dimensions (such as e.g. the maximum width of the rear trunk opening), their fulfillment must be confirmed as early as possible in the project. For this purpose, concept mock-ups as shown in Fig. 7.19 are used, embodying the storage area as well as critical borders (in this case the rubber sealing of the rear trunk lid). Based on concept CAD data, these concept mock-ups can be quickly built at low cost and allow realistic evaluation of fitment, ergonomics and space.

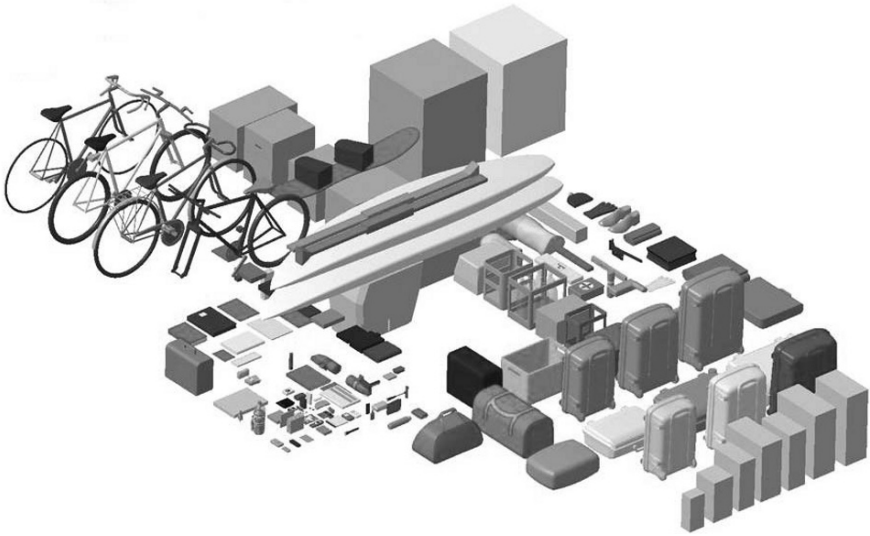


Fig. 7.18 Virtualized personal items (Source: BMW)



Fig. 7.19 Early concept mock-up for trunk practicality evaluation (Source: BMW)

Figure 7.20 shows the validation of standardized trunk capacity in simulation (left) and reality (right) according to VDA directive 210.



Fig. 7.20 Measurement of formal trunk capacity (Source: BMW)

7.3.3.4 Sound Design

One of the challenges in evaluating the individual perception of the interior sound of a given vehicle is, that the human acoustic memory only lasts for about 20 sec – which makes direct comparison of competing models or conceptual alternatives close to impossible. To make the acoustic perception of driver and passenger reproducible and thus enable time-independent evaluation, the binaural sound experience in question is recorded via an artificial head – an acoustic measuring system consisting of auditory canals and microphones disposed in a human torso (see Fig. 7.21). The recorded sound sample then can be replayed in a studio situation equalized by correction filters and be precisely evaluated by one or more sound engineers [13]. A comprehensive sound library allows direct comparison with former models or competition vehicles.

In order to make the subjective human perception of sound measurable and comparable, three psychoacoustic qualities of sound perception are identified which then can be measured by physical variables [14]:

- **Loudness:** Describes the perception of a sound by an occupant. Depends on the pressure level, the frequency and the duration of the sound. Measured variables are e.g. sound pressure level [dB] or speech comprehensibility / logatom comprehensibility [%].
- **Dynamics:** Describes the dynamic behavior of the sound, such as development of the engine sound when increasing the engine speed or load. Measured variables are e.g. frequency change over time [Hz/s] or sound pressure level increase over time [dB/s].
- **Timbre:** Perceived quality and color of a sound, depending primarily upon the sound spectrum (overtones) and waveform. The measured variable is e.g. the maximum sound pressure levels for each engine order [dB].



Fig. 7.21 Vehicle sound recording using an artificial head (Source: BMW)

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