Modular Car Design for Reuse

Justus von Freeden, Jesper de Wit, Stefan Caba, Carsten Lies, and Oliver Huxdorf

Abstract The design of reusable composite structures for cars needs high constructional effort. The car must be divided into separable modules meeting ecologic and economic requirements. Here, a battery containing platform and a seating structure were selected as large components with high potential for reuse. In a first step the desired car is described setting the basic scenario. A carsharing vehicle shows perfect conditions due to low logistics effort and the business model of the owner. This sets the boundary conditions for the design of the platform. Two different approaches were tested and merged into a concept ready for reuse. Simulations of the stiffness and the crash performance show good values. First large CFRP profiles were produced in a complex pultrusion process. An associated seating structure following similar design principles was constructed using profiles and nods. All load-cases that can occur during the utilization phase could be beared. Both modules together can form the basis of a reusable car. The design principles like detachable joints—in particular the utilization of detachable adhesive connections—can be adapted for any other technical composite product.

Keywords Fiber reinforced plastics · Reuse of composite components · Non-destructive testing methods · Composite repair · Detachable adhesive · Laser-based remanufacturing processes

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1 Introduction: The Idea of a Reusable Car Structure

Todays cars are in use for only about 200,000 km [1]. This represents about 4000 h of utilization. A such short time is not common for machines with comparable costs. The use-phase of the car in majority consists of the time in parking spaces. Thus about 12–16 years for a privately owned car is common [2]. For business applications the value of the car sinks rapidly due to costs for inspection and repair. Thus about 160,000 km or 4 years usually lead to a sell-of of the car. The car is then owned privately or directly shipped to developing countries. When customized vehicles are produced this low time or distance will mean an even shorter utilization.

Carbon fiber reinforced plastics on the other hand show a very high durability [3]. This means they will always exceed the lifetime of the cars they are used in. The comparatively high emissions for their production raises the carbon footprint while the low weight reduces the footprint during the use-phase [4].

Taking these facts into account, it seems a good idea to enlarge the lifespan of composites to enable them to play out their benefits. Thus, a possibility should be found to enlarge the use-phases of composite parts. Here the idea of recovering the structural carbon parts comes into the game. If it is possible to regain the large CFRP components from used cars—in particular from customized cars—a lower carbon footprint and reduced costs over lifecycle can be expected. For that purpose, two large parts of a car were chosen as demonstrating objects. A platform structure that is invisible for the customer and a seating structure hidden behind the cushions. Both provide high mechanical performance and can reduce the weight of the car. To enable the idea of reuse, the platform and the seating structure must be redesigned.

1.1 Basic Requirements of the Car

The car is planned as a car for the coming years (Fig. 1). During the last years a steady trend is an increase in mobility as a service (MaaS) [5]. The most important type of MaaS is Carsharing which was selected as the main purpose. Cars will not be owned by the drivers any more. They will be owned by companies renting them for short times and distances. Passengers will rent the car via app and the car will have many different drivers during the day. The car will drive in the city for most of the time. It must cover multi purposes like people transport or shopping. At least 4 seats must be included. During the long use phase technologies will change. Autonomous driving is an example for the technologies that should be updateable into the concept and not be impeded.

The car must take into account that the drivers will not clean the car after renting it. So in particular the interior design must enable a simple cleaning, e.g. via vacuum cleaning. A flat floor design is a possible design element to support this. Also the cushions must be designed in accordance to this.

Fig. 1 Possible design of a car including the reusable parts

The future drives electric. It is clear that the car must be a battery electric car to take the change of the propulsion into account [5]. The energy storage is usually placed in the bottom of the car, because it is heavy. Due to better drive dynamics it should be placed between the axles. Thus it can only be placed in the platform. Electric drives do not need a gearbox. This also supports the idea of the flat floor design. The battery capacity is today part of numerous discussions. The range of the car is defined by the capacity of the battery. For the car sharing car, it is important that the car needs not to be useable for long distance travelling. On the other hand the users do not want to recharge the batteries after every rental. Thus a range of more than 450 km is seen as a good compromise between cost, weight and range today [6]. It is clear that updateability must be given since the research on new battery systems is still ongoing. The battery compartment must be exchangeable and repairable.

The powertrain of electric cars can be located next to the wheels. Thus the concept should include drive either in the axles or directly in the wheel. This is also a possible factor of improving the updateability by a modular design. The possibility to mount different drives with high or low power.

The weight of the platform is decisive. Only a lightweight vehicle can save energy in comparison to a steel or aluminium car. The reusability over a long time span will only be possible, if carbon fiber reinforced plastics are used. Only this material can provide the aimed high durability. On the other hand, these materials are expensive and their production emits high amounts of CO_2. This backpack must be equalized by low emissions during the use phase. It is also clear that the platform must be affordable. So a cost objective of < 3500€ is set. The production rates are estimated as 10,000/year.

Table 1 Basic dimensions of the car

Wheelbase	2670 mm
Length	4371 mm
Width	1830 mm
Height	1600 mm
Curb weight	1100–1600 kg

The basic requirements for reuse are a use phase of > 25 years. During this time more than 1,000,000 km will be driven. At least 5 reuse procedures must be covered. After the first use phases a remanufacturing procedure must be possible causing less than 7% weight increase. The overall cost reduction by using the reusable platform instead of 6 single platforms should be more than 50%. As well the energy consumption during production should be decreased also by at least 50%. This should be provided by a decrease in CF use of 70%.

Dimensions

The car must be ready for any type of use. However the platform must be designed for a particular car as a starting point to fulfil all requirements and to test the performance. Thus the dimensions will be fixed, but they must be chosen in a manner that other vehicle dimensions will be possible. The dimensions are derived from numerous multi-purpose cars (Table 1).

The dimensions fulfil the aspect of multi-purpose use. Also the new possibilities with autonomous driving are included. The dimensions of the platform and the seat are defined by the external dimension. The selected medium class vehicle dimensions with a height slightly above average enables many different variants of a car (Fig. 2).

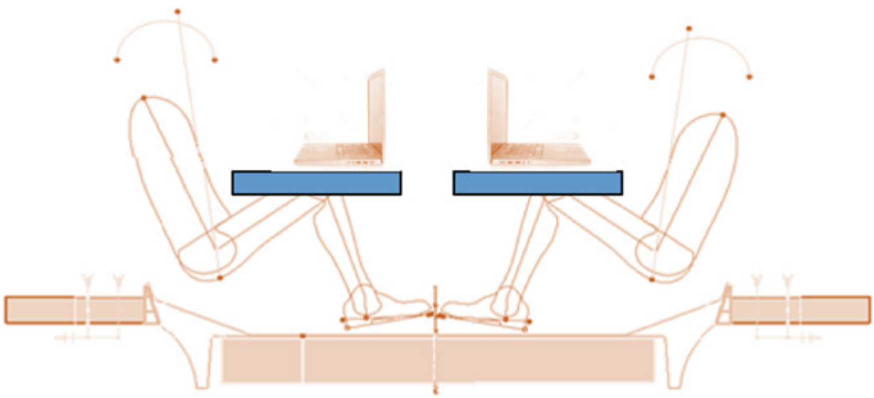

Fig. 2 Possible use-cases of the interior

1.2 *Basic Requirements of the Platform*

The selection of the part to be designed for reuse was influenced by the knowledge that logistics and rework processes will require cost intensive manual work. Hence a large part of the car body had to be chosen. The mechanical properties of CFRP enable high performance parts. Thus a part with high stiffness requirements could be provided. The platform fulfils these basic requirements. The CFRP section of the platform does not provides the basic functions of the platform like the safety function of the battery compartment. It is the basis for a whole car. The name of this element was chosen to be CFRP foundation.

Boundary Conditions

The platform provides all basic mechanical properties of the car. The whole drivability but also the crash safety and the ergonomics for the passenger are mandatory. Car design usually begins with the ergonomics. Based on the EDAG Light Car, a former show car, the ergonomics and the construction was set up. The car was stretched into the defined dimensions (Fig. 3).

Also the legal requirements must be fulfilled. This covers the visibility of other cars in traffic. The mirrors must be placed and the windows must be dimensioned and positioned. The wheels must be spring-mounted to achieve a high level of comfort and the steering must be possible. Thus the wheels need space. The auxiliary units also need a suitable design space. Again the spaces must be large enough to position any future auxiliary unit (Fig. 4).

The reusability is the main innovation of the platform. The long utilization phase and a changeable design means that the platform will be totally invisible to the customer. The crash safety is the main driver for the construction of the body in

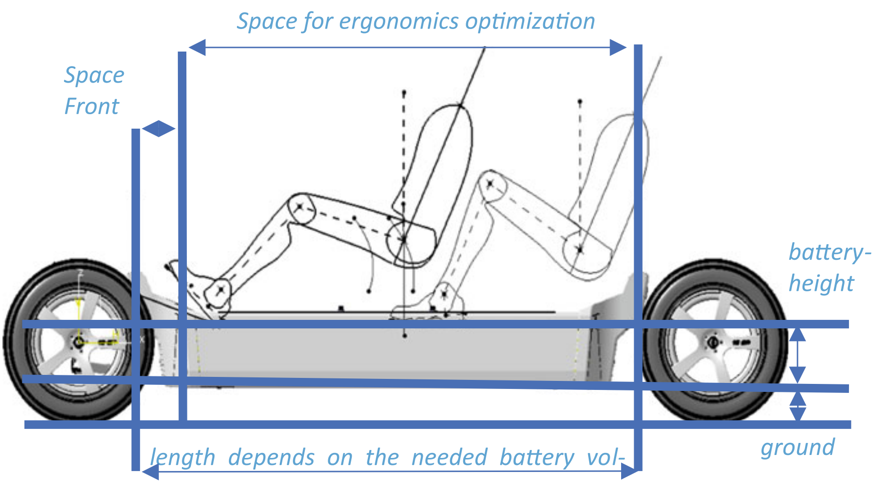

Fig. 3 Basic dimensions for the ergonomics optimization

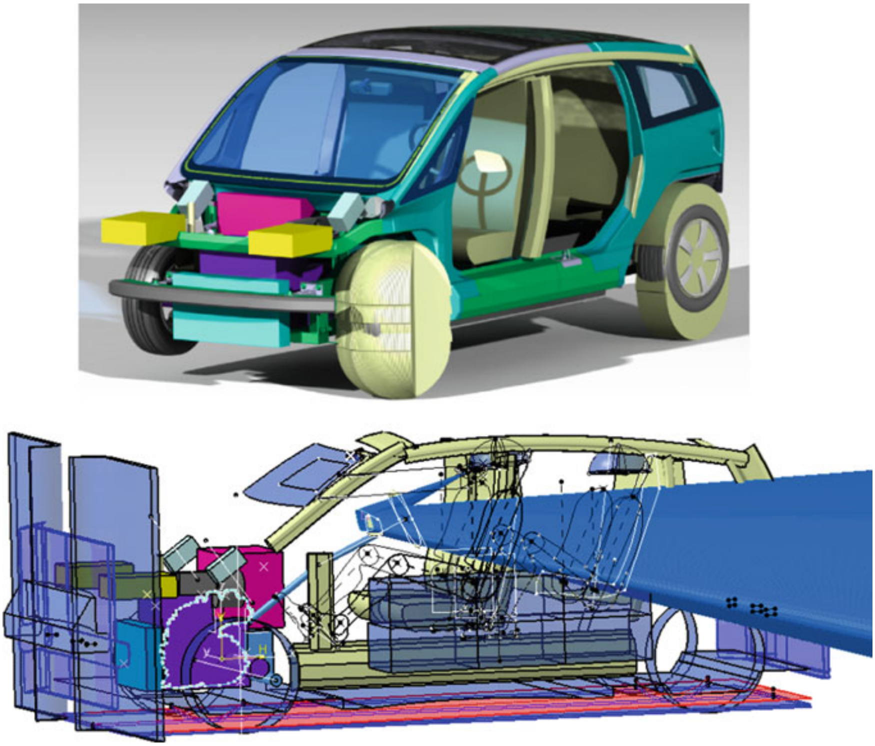

Fig. 4 Ergonomics, legal and space investigation of the basic car model

white. The platform must be able to fulfil the EURO NCAP requirements. This means a front crash and a side pole crash are the most important scenarios.

1.3 Basic Requirements of the Seating Structure

For demonstrating a further component within automotive engineering, an interior component was selected in addition to the platform. In order to be able to demonstrate the variety, the interior should be represented by a seating structure. A seating structure is available for all models in a wide variety of variations, from a simple seat to a bus seat to a bench seat. This is how the potential of a modular design can be exploited.

The clear main objective of the seating concept is the reusability of the individual components. In order to receive as high a degree of utilization of the resources as possible, as many exchangeable components as possible are to be represented. Only so it is possible to accomplish a re-use of individual components. In order to reach this, it is necessary to ensure a fast assembly as well as disassembly. Attachment

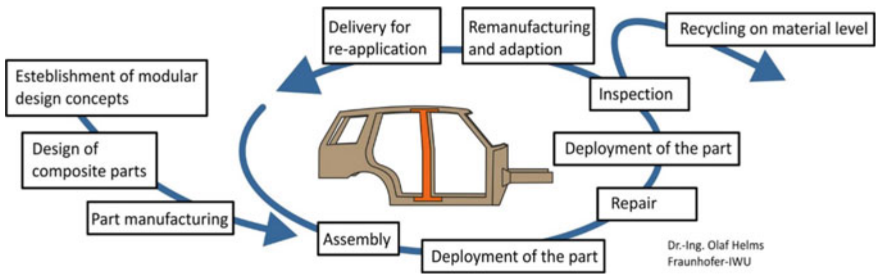

Fig. 5 Concept for reusing an automotive component

elements must be separable and/or removable beyond that. If these requirements are possible, it can be assumed that the seat structure has a life expectancy of at least 30 years. This period includes at least three life cycles or reuse scenarios. Inspection and repair scenarios are also included here.

Requirements beyond life expectancy concern functionality. For example, a corresponding structure should be movable on the platform to be fastened and the seat itself should be adjustable. Since repairs may be required in the event of reuse, the weight of a reused seat structure may be 110% of that of a new seat. The cost of a new seat may be 150% compared to a reference seat structure. Since this seat structure is largely reused in a further life cycle, the cost of such a reused seat must be only 50% compared to a new seat.

With these requirements and boundary conditions, the scenario of use-case 3, an application for a car sharing fleet, is possible (Fig. 5).

2 Design of the Platform

The design of the platform using CFRP in the foundation is possible using different construction methods and manufacturing processes. The processes must be mass productive and create a very high strength laminate. Thus resin transfer molding and pultrusion processes are seen as the most promising. Molded parts can be very complex but require an expensive mold while pultruded profiles can provide high stiffness but the connection of sill requires node elements. The conception stage was divided by these two basic processing ideas between IWU and EDAG. Both worked on the same basis of dimensions and requirements to compare these technologies.

2.1 New Concepts for Reusable Platform Structures

(a) Profile concept

The profile concept is based on the idea of creating a framework with profiles and connecting elements as the basic structure of the platform. The pultrusion process is used to produce the profiles. Pultrusion is very well suited for the cost-effective and continuous production of fiber-reinforced profiles with high lightweight potential. The use of profiles and connecting elements makes the vehicle platform scalable. Thus, different vehicle sizes can be easily developed by using shorter or longer profiles.

For the design of the connecting elements two different variants were developed: shell structures and node elements. The first design concepts are shown in Fig. 6.

The left design in Fig. 6 shows the front and rear side members, which are joined to two big shell structures (front and rear wall). The shell structures are connected through the left and right outer sills. In comparison to the shell structure concept the right design shows another solution to connect the profiles by nodes. The nodes connect the front and rear side members with the left and right outer sills by using some crossbeams. The advantages of the shell structure compared to the node elements are the lower number of interfaces and the resulting improved stability. However, the large and complex shaped front and rear wall have a high production costs and tooling. On the contrary, the nodes have significantly lower production

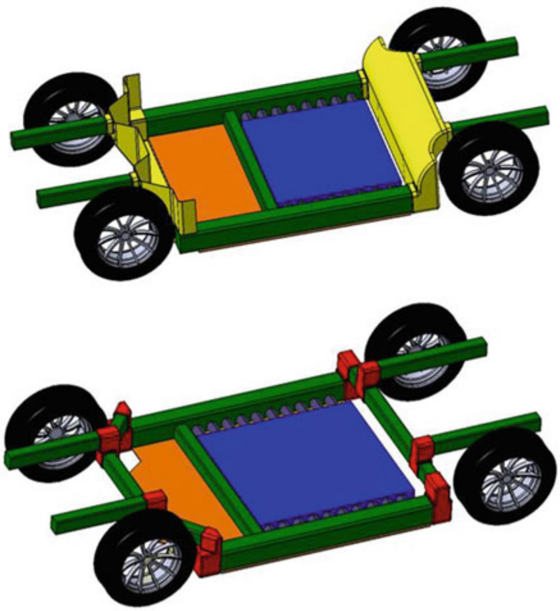

Fig. 6 Design concept for platform with profiles and connecting elements (left: shell structures, right: node elements)

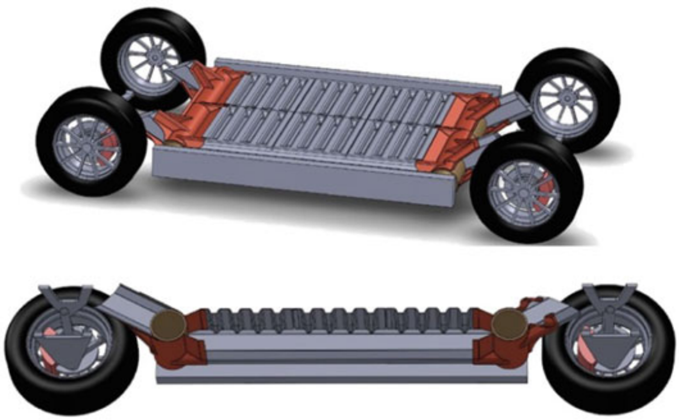

Fig. 7 Advanced concept of reusable platform using profiles

costs and tooling costs. Nevertheless, the load transfer over the many interfaces is a challenge, especially in case of a crash.

For these reasons a new design for the platform using profiles was developed. This design is shown in Fig. 7.

The new design concept is a combination from the previous ones. To connect the different profiles smaller shells are used, which means lower production and tool costs. The interfaces between the profiles and connecting elements are designed with large surfaces to ensure optimum load transfer. In addition, two large crossbeams in the form of tubes to accommodate crash loads were inserted at the front and rear. On these crossbeams, the front and rear side members are supported. Two shells enclose the cross member and the longitudinal members and thus ensure the connection and fixation. An adhesive bond is planned to use as the joining technique at this point. The sills of the vehicle platform are divided into an inner profile, which together with the crossbeams forms the battery box, and an outer profile for the absorption of crash energies. Moreover, the platform was designed symmetrically to save costs by using the same parts in the front and rear area.

The second platform design also has weak points and challenges that need to be solved. Complex geometries can only be realized with great effort and peak loads in critical areas can only be achieved using massive elements. However, this leads to a strong increase in weight of the vehicle.

(b) Molded concept

The molded concept is based on former cars already on the road just like BMW i3 or monocoque cars like the McLaren models. The basic idea is that all fiber reinforcement sheets are combined in a mold and after hardening the injected resin combines these sheets into a single part with all functions. The design is seamless and a high flexibility in fiber layup is possible.

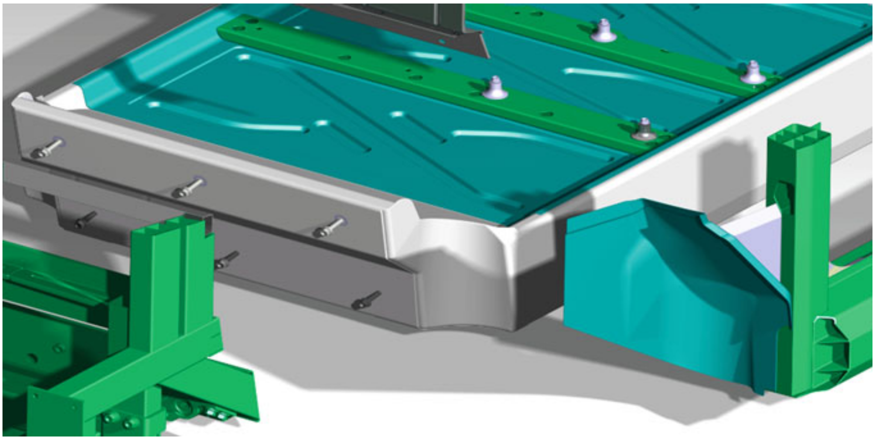

Fig. 8 Design of the platform with a molded foundation

In the molded concept the side beams are formed by a sandwich element consisting of a foam core and CRFP sheets. The front and the rear part of the car are constructed in a similar manner. The combination forms a frame similar to the profile design containing the batteries (Fig. 8).

The preforms needed to form the part play an important role to lower costs. Cut-off is one of the major factors to optimize the product. Material costs for carbon fibers are high. On the other hand the recycling needs high effort and the mechanical properties of the waste are usually worse than with the virgin material. Thus a concept reducing the cut-off during preforming was developed. It takes into account the foam cores in the side bars. These can be used to wrap the fabric. The profile parts are connected via simple geometries with only few single preform geometries (Fig. 9).

The top is closed via aluminium formed sheet. The reason to use aluminium is not the stiffness, but the electric shielding and flame retardancy requirements. The bottom is also formed using a sandwich part. So the stone chipping as well as the bollard test can be passed without any damage to the battery (Fig. 10).

(c) Merged Design

The two presented concepts show individual strengths and weaknesses. Even though both can provide a technical feasibility, the economic and ecologic assessment would differ. While the profile concept shows lower cost in particular for the profiles, the molded concept can provide all functions in one part. These functions are mainly connected to the joining technologies necessary for reuse.

Thus both concepts were evaluated and combined to the final design of the platform. The advantages of the profile should be used. In addition Fraunhofer IWU researches bended profiles that could be useful in the front and the back of the car to lead the forces from a crash into the sill. The profiles used for the sill were too simple. To provide more functions and a higher crash performance, they will become more complex. The possibility to produce hollow profiles will be used to replace the

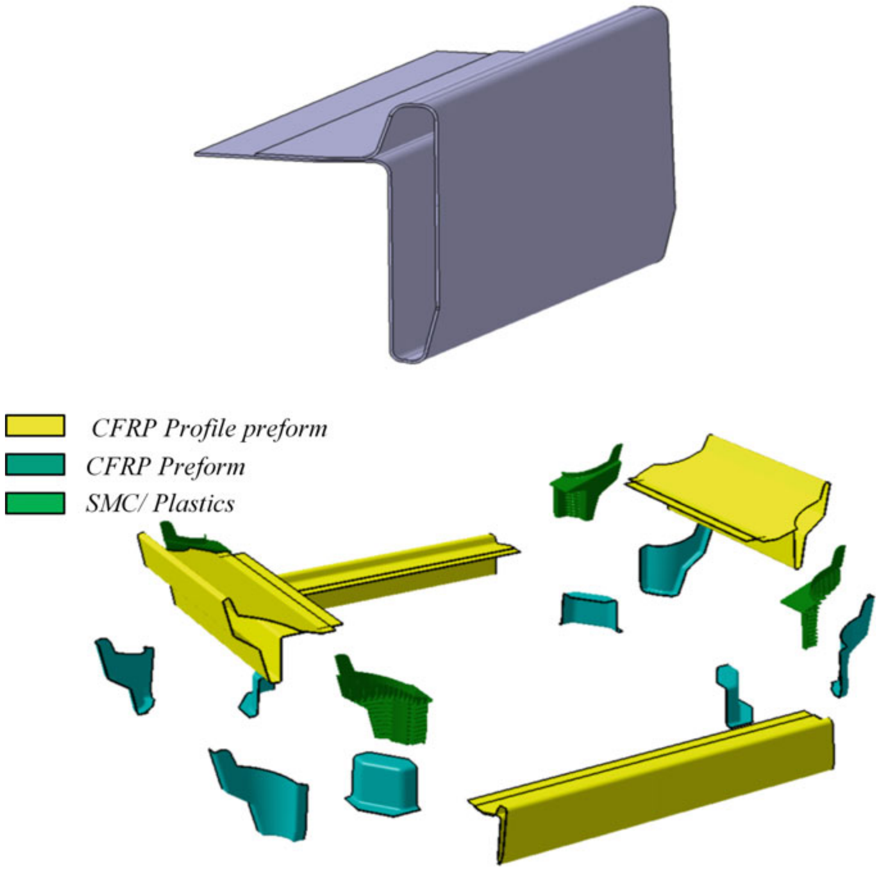

Fig. 9 Preform concept of the molded design of the foundation part

foam cores with bars. The connection of the profiles is critical, because the forces must be lead into the profile. The profiles can only be constructed using a single geometry over the whole length. So the loads must be transferred softly. On the other hand the thickness of the hollow profile is hard to translate to a molded part. Thus a 2 component connection was designed. Large areas with an adhesive will be used to provide a large cross section. The parts are designed demoldable (Fig. 11). The main component will be joined from outside of the battery compartment. It will be produced with SMC/BMC. Recycled fibers could be used. To connect the bars the profiles will be cut in this area to achieve more surface for the adhesive. From inside of the battery compartment a formed sheet will be used that can be molded easily.

In an earlier version it was planned to close the corners by putting the profiles into a molding process. But it was shown that it will be too complex to close the profile to prevent the resin from flowing inside the profiles.

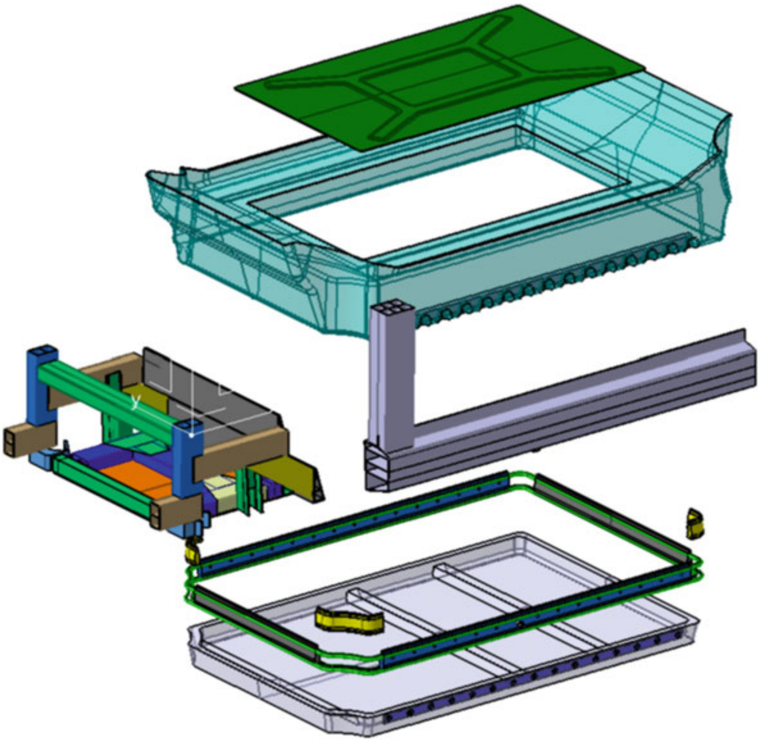

Fig. 10 Basic design of the battery compartment and the molded platform

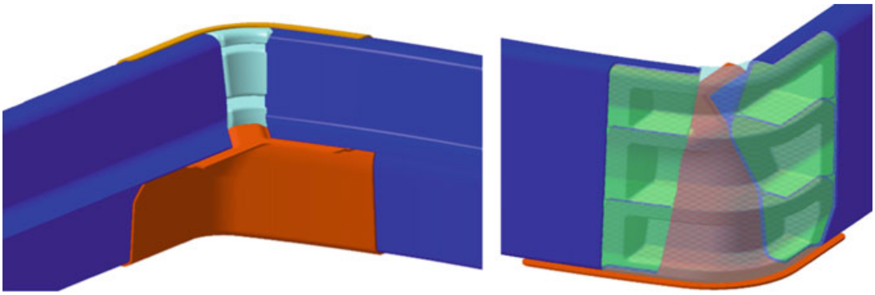

Fig. 11 Demoldable design of the corner elements

The whole design of the foundation is now aligned to the profiles and the weaknesses of profile constructions are addressed. This is the basis for further developments concerning reuse and safety of the concept (Fig. 12).

The front and the back of the car will be made of metals due to a shorter life-cycle and the higher requirements for crash. Here, a design proposal was made taking into

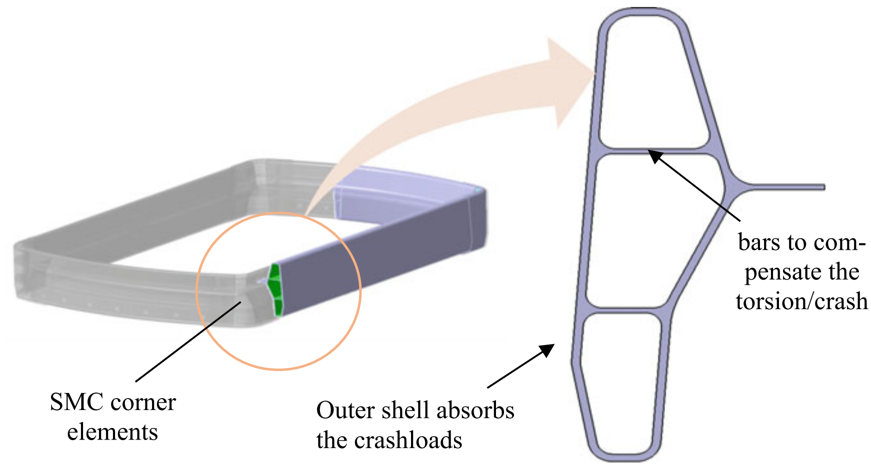

Fig. 12 Final basic design of the foundation

account reuse, safety and functionality. The basic idea is that the CRFP foundation is covered by metallic crash elements to form the platform.

2.2 *Crash Simulation*

The basic design can provide stiffness and strength for the platform. The crash loads require a high energy absorption during the deformation of the parts. Here, composites show lower values in comparison to metals. Hence, crash elements are designed for this special purpose. A material providing crash performance as well as a low density is aluminium. Thus all parts of the platform that are not intended to be reused can be produced using this metal.

The design is based on experiences made with previous vehicles. The crash load paths are defined to lead the loads around the passengers and the battery. No intrusion of the battery compartment or the passenger cell is allowed.

The most important crash cases are the front crash and the side pole crash. Both must be passed and the intrusion must be prevented. For the front crash after the Euro NCAP the car must be able to withstand a crash against a steady wall with 50 km/h. Thus the kinetic energy of the car must be transformed into the deformation of the aluminium crash elements.

The simulation showed that no intrusion could be detected, but in a first step the accelerations were too high. Usually a human can stand 30 g, but in the first version for a very short time more than 50 g could be measured. So the crash elements behind the bumper were reinforced and the beams in the subframe were shortened. The effect was a higher acceleration at the beginning of the crash and the deletion of the peak. The bended profiles around the battery were able to lead the loads into

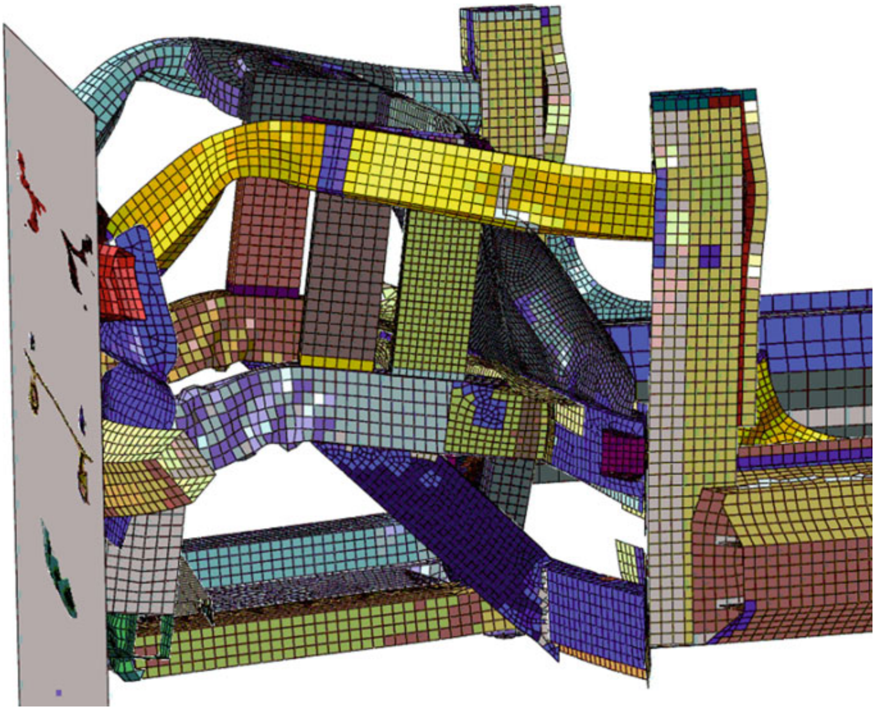

Fig. 13 Crash simulation of the front crash

the sills. The CFRP profiles were connected directly to an aluminium profile. The combination showed good performance (Fig. 13).

The side pole crash after Euro NCAP requires a crash into a steady pole of 254 mm. The speed is 32 km/h. Again no intrusion of the battery is allowed and the accelerations of the driver must be reduced under 30 g. The side pole crash is more critical, because the car must be stopped in a very short time and a short deceleration length. The maximum intrusion is a very good measure for a comparison. It is not possible to measure the acceleration of the passenger directly because the platform is only one part of the car. Thus the criterion was the intrusion into the sill.

In a first version an aluminium profile with bars was defined. It will be attached to the CFRP profile via an adhesive. Both profiles were dimensioned during the crash simulation. While the CFRP profile should not be destroyed during the crash, the aluminium profile should show as much deformation as possible to take up the crash energy. The battery compartment was also constructed using a wet pressed sandwich floor element. It can contain up to 28 battery modules. During the side pole crash the deformation will be high. Thus two aluminium profiles were placed right under the seat carriers. They transfer the loads to the other side of the car and improve the stiffness of the platform. The seat carriers also provide the connection between the seat system from INVENT and the platform. The connection between the aluminium profiles and the pultruded profile was achieved using a very simple molded element. It provides stiffness and carries the loads from the CFRP into the profile (Fig. 14).

In 5 iteration steps the dimensions of the profiles were defined. The aluminium material was selected as a high ductility material with high energy absorption. This enabled the reduction of the bar thicknesses. On the other hand the directions of the bars were adapted to strengthen the profile for the first contact with the pole. With this procedure the weight of the sill could be lowered by 30 kg. The pultruded profile could be designed with feasible fiber directions and wall thicknesses. The idea behind

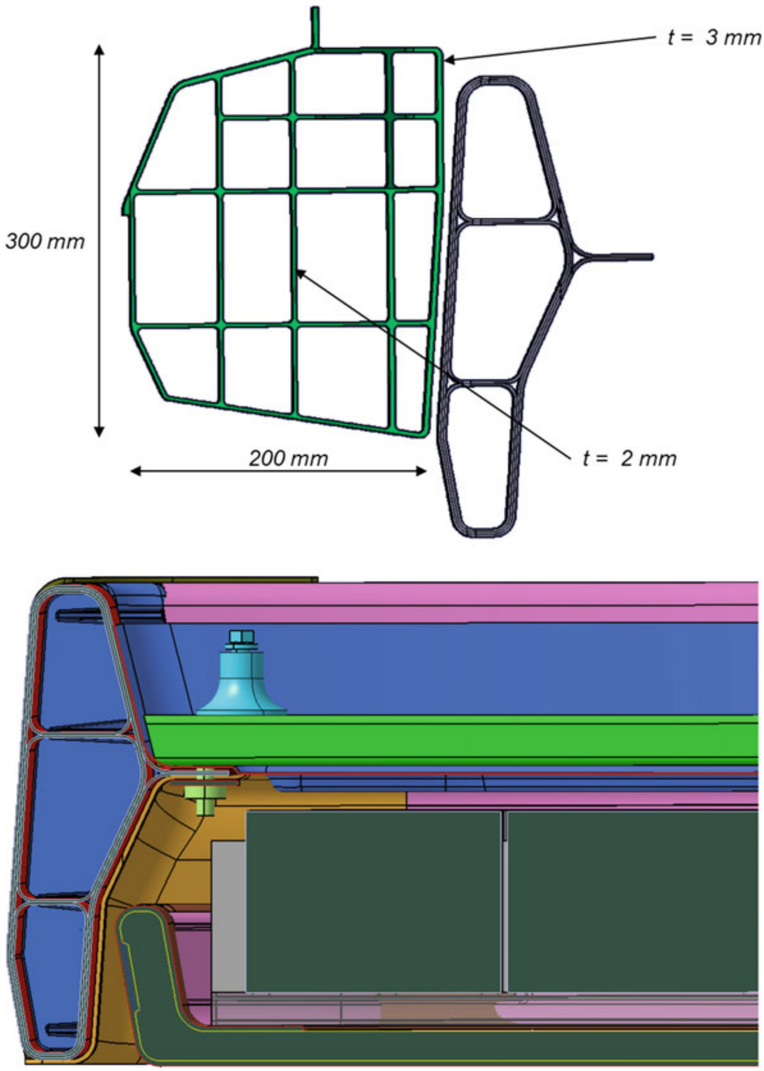

Fig. 14 Concept of the sill and the battery compartment

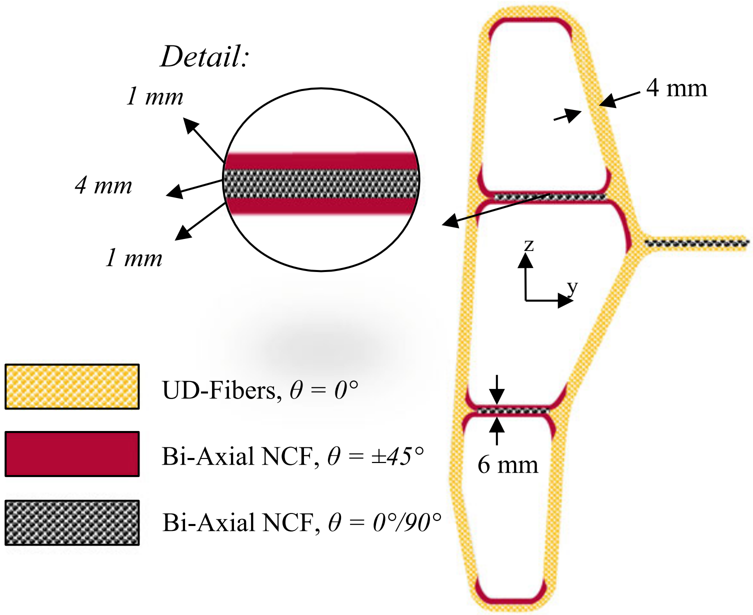

Fig. 15 Dimensions of the pultruded profile in the sill

the fiber lay-up was to achieve two objectives. On the one hand, the platform must provide much stiffness for a high driving comfort on the other hand the crash loads must be withstand. The main fiber direction is 0° in x-direction. This maximises the bending stiffness of the platform. The fibers in the bars provide stiffness in the crash load case. A simple 90° lay-up is not possible due to manufacturing restrictions. The fibers must be pulled into the mold. This is only possible for fabrics in combination with fibers in 0° direction or symmetric ± 45° (Fig. 15).

The crash simulation of the final set-up shows the expected result. The maximum intrusion into the sill is 173 mm. This is 77 mm less than the comparison vehicle. The intrusion does not affect the battery. The acceleration of the battery after a strong slope stays on a steady level of 30 g. This means that the deceleration of the vehicle works as desired (Figs. 16 and 17).

2.3 *Manufacturing Technologies*

The platform design consists decisively of four profiles (aluminium and CFRP), four connecting elements on the platforms corners and the floor of the battery compartment. For these components, low-cost and mass-production methods are necessary to fulfil the economic requirements of vehicle production.

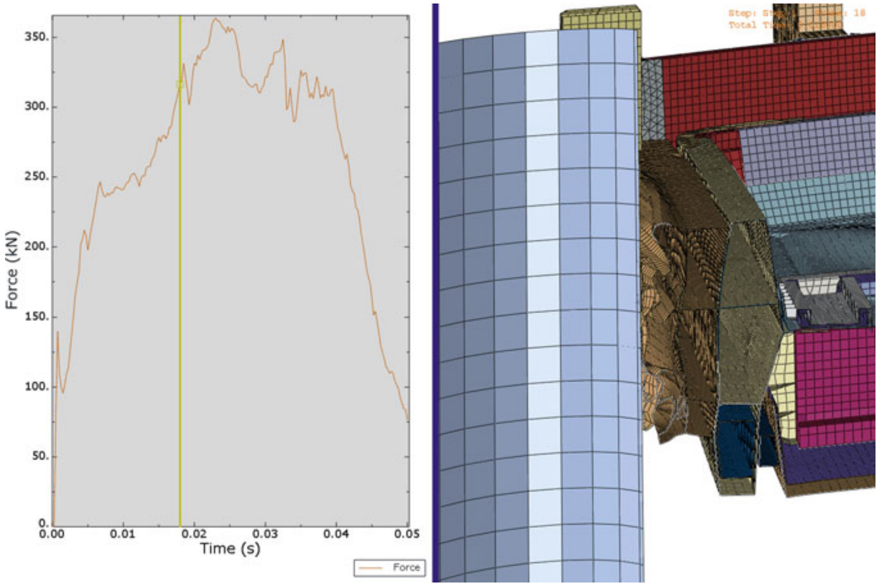

Fig. 16 Crash simulation after 17.5 ms

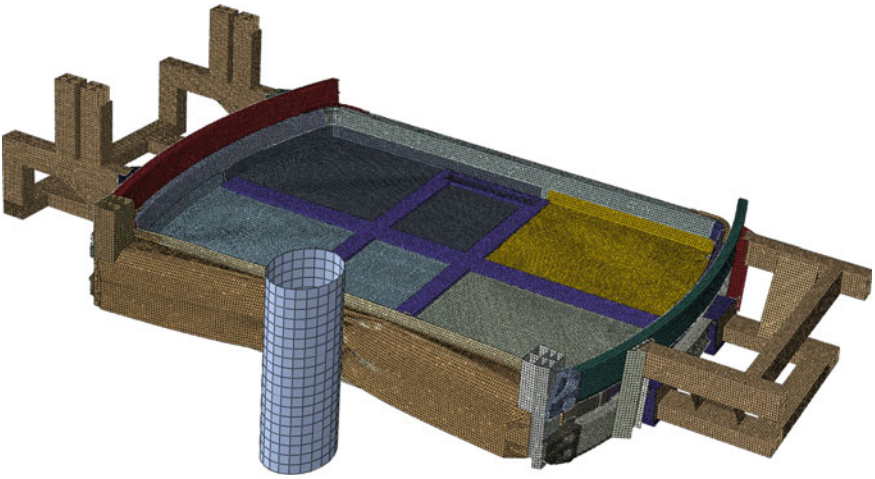

Fig. 17 Crash simulation at maximum intrusion

Pultrusion is such an economic and continuous process for the production of straight and low weight profiles made of fiber-reinforced plastic. Therefore, fibers and additional fabrics are pulled from bobbins and impregnated with the thermosetting resin. The wet reinforced fibers are pulled through a heated tool where the curing process of the plastics starts. By increasing the temperature in different heating zones of the tool, the thermosetting plastic cures completely within seconds. Two alternate working puller which grasp and forward the cured fiber-reinforced plastic profile are after the tool. A special set-up of the pultrusion process also allows the production of curved profiles with a constant radius (Fig. 18).

The geometry of the profile and the calculated lay-up for the reusable platform is very complex and represents a challenge for the pultrusion process. To produce this profile in the pultrusion process, a multipart shaping tool with three cores and panels for a reliable fiber guidance had to be developed (Fig. 19).

Based on the CAD data the three-part tool including the three cores and the fiber guidance panels were manufactured and installed in the pultrusion line.

The calculated fiber set-up of the platform profiles was converted into a pultrusion-compatible lay-up. As shown in XXX specific semi-finished fiber products as unidirectional fabrics (0°, green), triaxle fabrics (+45°/0°/−45°, blue) and woven fabrics (0°/90°, orange) with different fiber weights and dimensions were used for the pultrusion process. In total almost 100 semi-finished fiber products and nearly 140 fiber roving were required (Fig. 20).

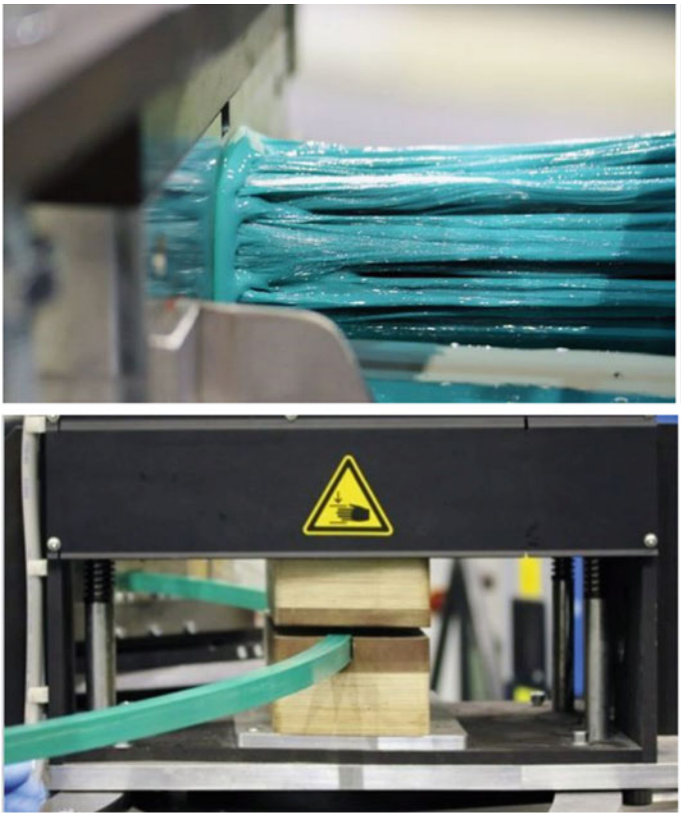

Fig. 18 Pultrusion process

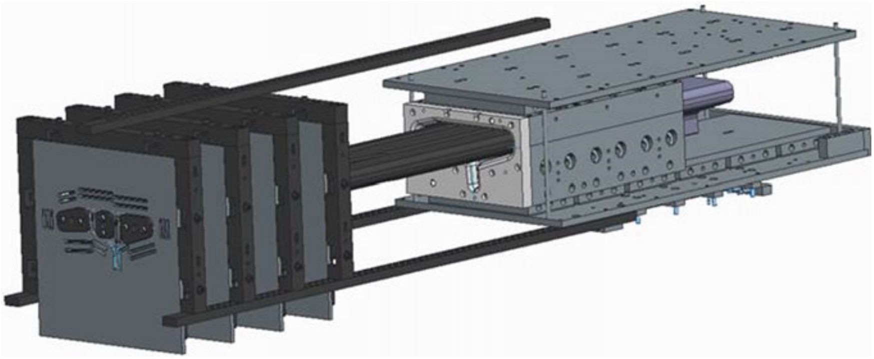

Fig. 19 Pultusion tool for the platform profiles

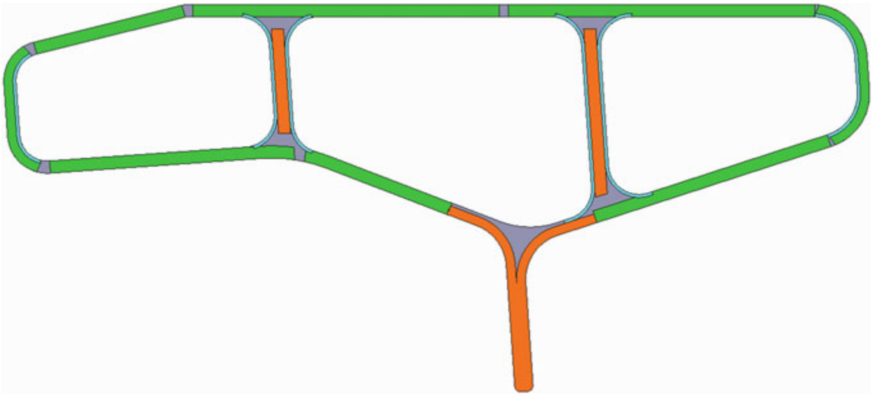

Fig. 20 Fiber lay-up suitable for pultrusion process

The pultrusion process was prepared using the semi-finished products. The fibers and fabrics were positioned in the bobbins stock and passed separately through all fiber guidance panels. The fibers were pulled through the tool and led to the pullers. These pullers were equipped with contour-specific hardwood fittings for gripping the profile. In the next step the resin system (unsatured polyester) were mixed and filled into the resin bath.

The semi-finished products were impregnated with the resin and pulled through the specific heated tool (including the cores). The resin systems reacts and the profile is formed because of the heat treatment in the tool. With this installment a few meters of the profile could be pulled. Further optimization loops regarding the fiber guidance and the resin formulation were done. As result requirement-specific profiles were produced for the platform and part of the further demonstrator production (Fig. 21).

The aluminium profiles will be produced using extrusion. The heated melt will be pressed through the dies and cooled down. This technology is predestined to produce

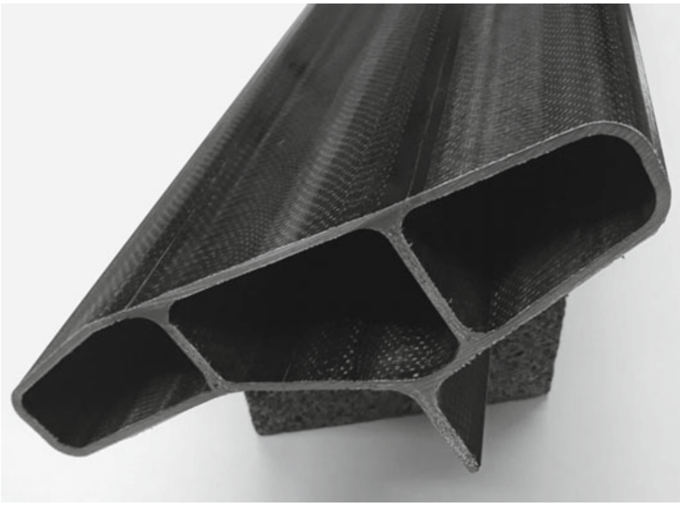

Fig. 21 Demonstrator—pultrusion profile

profiles. It offers low costs for medium part numbers and gives good mechanical properties. The materials are usually wrought alloys perfectly fitting to the purpose of high crash performance. The floor of the passenger cell is produced using aluminium sheets. They are necessary to fulfil the requirements for the reaction to fire.

The corner elements of the platform are made of a bulk molding compound (BMC). BMC is a composite material, which consists of reinforcing fibers, (mostly) polyester resin, fillers and additives. The mineral content is often very high, including glass fibers, the mineral content can rise to over 80%. So it is a comparatively small amount of resin necessary. The recipes are easy to adapt to customer requirements. The material is one of the simplest materials to process, is suitable for mass production and allows short cycle times. Since heat must be supplied during processing, the cycle times are in the minutes range and not in the seconds range. The compound is put into the open mold, pressed and heated. It contains fibers with a length of up to 30 mm to achieve high stiffness and strength. High impact strength combined with inherent corrosion resistance of this material ensure good appearance even at high mileages, which is important for the longlife platform. The technology is capable to produce more than 10,000 parts per year. The same manufacturing technology can be used to produce the connection element between the pultruded profile and the aluminium profile in the battery compartment. In Task 4.2 the use of thermal recyceled carbon fibers is investigated. If the mechanical properties are sufficient, a BMC material with these rCF can be used.

The floor of the battery compartment will be produced as a wet pressing part. The geometry is quite simple and the fibers will not be formed in small radii. The preforms are wet out with the resin and transferred to the mold. Thus the impregnation is very simple through the thickness of the fabrics. A higher performance is reached by

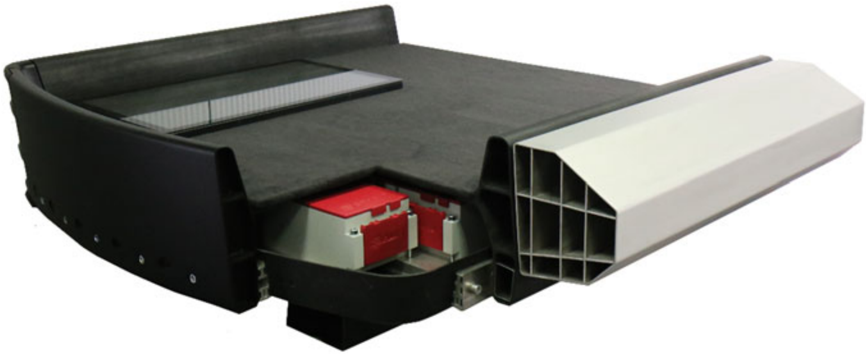

Fig. 22 Demonstrator of the reusable vehicle platform

implementing a sandwich core into the part. This maximises the stiffness by adding just few weight. A very simple foam sheet can be implemented directly into the press. It must be taken care of the pressure inside the mold to assure that the core is not crushed during the process.

For showcasing the use-case of the reusable platform a demonstrator was manufactured using prototyping technologies. It is used to represent the idea of reusing structures. It is shown in Fig. 22 and includes a touch screen giving information about reuse.

3 Design of the Seating Structure

The starting point of the development of a reuseable seating system was a concept survey, asking about the aspects of the relative target segments of the automotive sector inter alia: pricing, seat arrangements, and user profiles. The survey result assessment helped to reveal that cheap and minimalistic city-cars have the biggest potential for circular reusable seating applications in (shared) car fleets in urban environments. These cars should be used by individuals as well as families. The result of the survey and the following concept-freeze is visible in Fig. 23.

The above described concept was the starting point to design a manufacturable seating structure assessing possible technologies and materials. The first step in a detailed design of the seating structure is to split the described frames of backrest and seat shell into different parts. In this way an easy manufacturing and demanufacturing of these parts is possible. Figure 24 shows this early design stage.

To get a modular seat structure, the backrest has an identical design as the seat shell. If the individual segments are designed as profiles, only two different types are needed, which must be connected to each other: Longer lateral profiles as well as short horizontal profiles. As the backrest has the same geometry as the seat shell, a middle element must be included to reach the correct height of the headrest. As

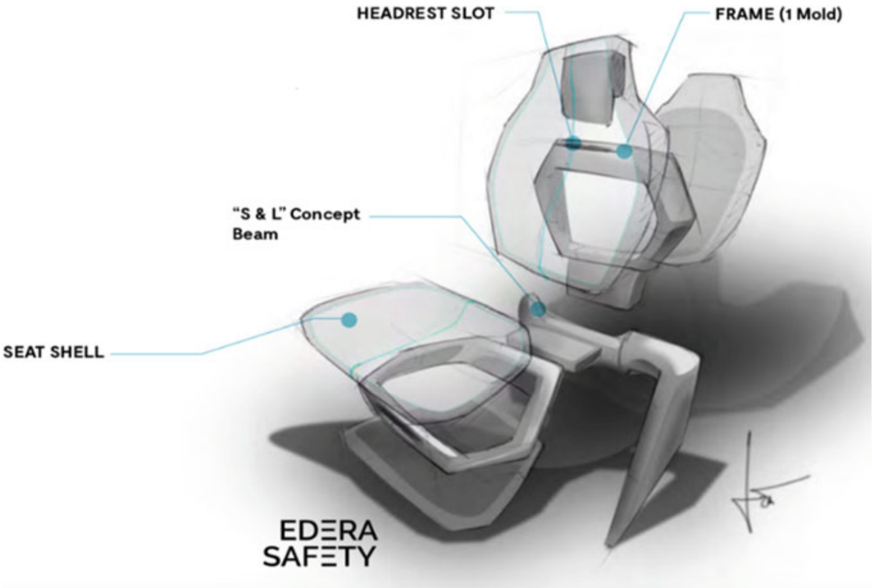

Fig. 23 Final concept for seating structure

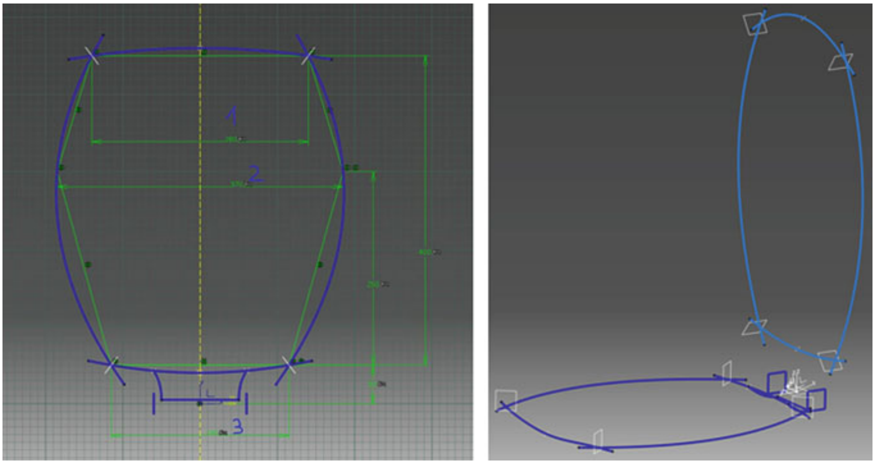

Fig. 24 Skeleton design of backrest and seat shell

shown in the final concept (Fig. 25), the seat is mounted only on one side to the platform.

For this early model a first FEM analysis was performed to verify that the design of the seating structure meets the deformation requirements for all load cases. The applied load cases are mainly loads caused by misuse or static deflections (Table 2).

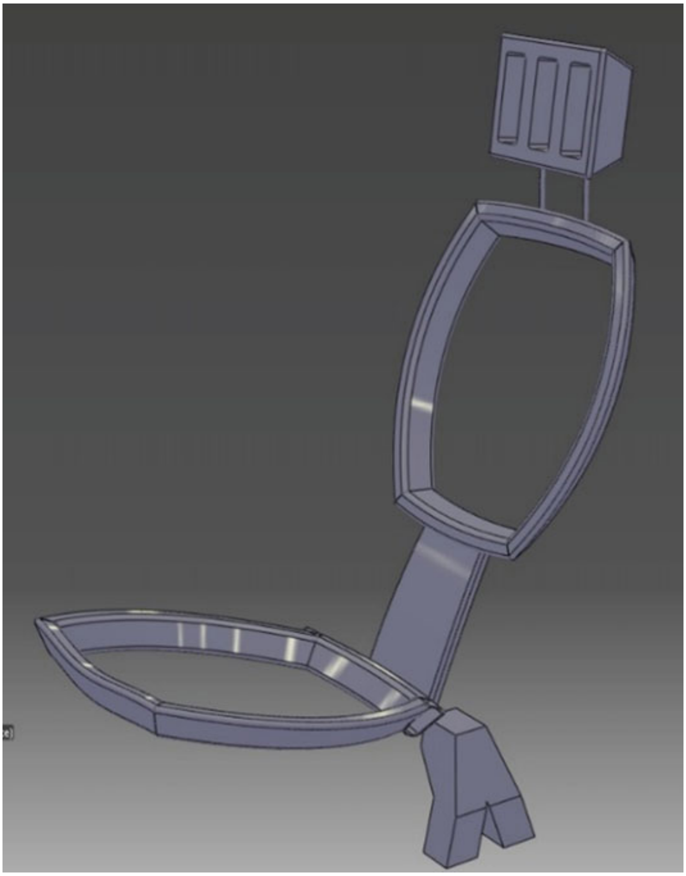

Fig. 25 First draft of design of seat structure

Load cases caused by a crash are not considered due to the fact, that the platform will absorb these loads mainly. In Fig. 26 it is visible that the seat area between the seat carriers is not affected during crash. The seat only has to carry the loads caused by the passenger. Figure 27 shows the positions of the applied loads.

Unfortunately, this first FEM-analysis showed too high deformations which means that the initial design of the seat structure had not the required stiffness. The design had to be optimized for fulfilling the given requirements and tolerances in deflections. In order to increase the stiffness, several changes were implemented:

- The wall thickness of the CFRP-profiles was increased.
- A foam core was implemented for all CFRP-profiles.
- The intermediate element between backrest and seat shell was removed.
- This causes a necessary extension of the profiles towards the middle cylinder.

Table 2 Applied load cases [7]

ID	Load case	Force [N]
1	Static deflection (load which the entire seating structure shall withstand)	1.600
2	Submarining	4.000
3	Unrestrained cargo impact	6.250
4	Passenger pushing against seat back	3.600
5	Driver throwing weight against seat rest while sitting down	7.000
6	Rearend car-crash	8.320

Fig. 26 Top view of the seat area during side pole crash

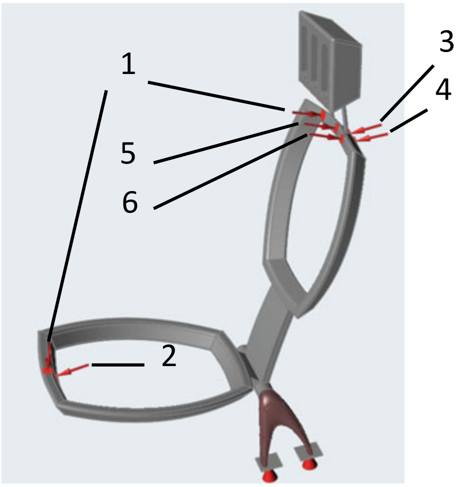

Fig. 27 Positions of applied load cases

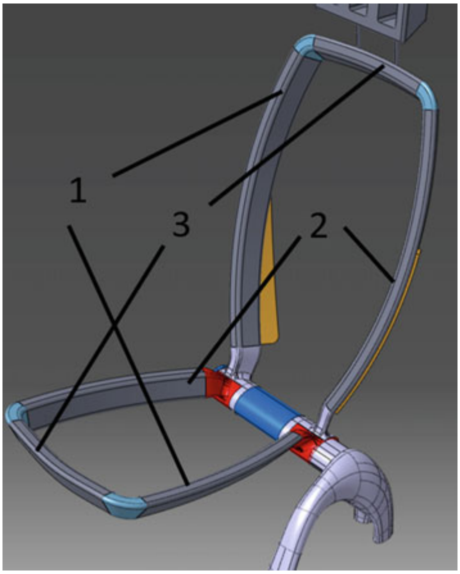

Fig. 28 Optimized design

- Shear panels were implemented to increase the stiffness additionally, visible in Fig. 28 (brown-coloured parts).

Due to this design, the geometries of backrest and seat shell are not identical anymore. The initial idea of only two different kinds of profiles is no longer feasible. But a small amount of identical profiles is possible: Regarding the curvature and cross-section, only three pairs of profiles are sufficient for the manufacturing of this seating structure. The numbers in Fig. 28 are marking the three kinds of profiles with same curvature and cross-section. A FEM-analysis of this design showed that the deflections for the described load cases (Table 2) are small enough to proceed with this design.

In addition to the profiles, the following subchapters describe in detail other necessary components.

Corner elements

The CFRP-profiles will be connected by these elements. The corner elements are inserted into the hollow ends of the profiles. An adhesive is injected which will bond the parts together. As material a sheet moulding compound (SMC) or aluminum is chosen (Fig. 29).

Middle cylinder

The concept for a middle connecting element has been developed. This part is a metallic component, to which the profiles of backrest and seat shell will be mounted. Aluminum was chosen due to the complex geometry. The space is large enough to implement possible adjustment mechanisms. The middle element is subdivided into

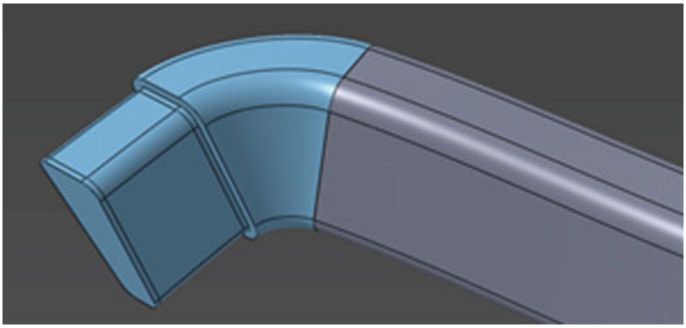

Fig. 29 Corner element (blue)

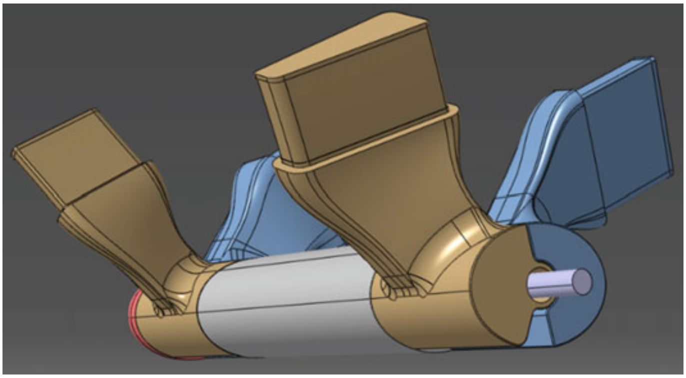

Fig. 30 Middle element (grey)

five parts for a simplification of the design for a cheaper and easier manufacturing. Additionally, changing the position of the sidearms (connection area of the profiles) to each other makes a smooth adjustment of the seat possible (Fig. 30).

Mounting element

The mounting element is the part which connects the seating structure to the platform. The element is designed by using a topology optimization software (TO). This part is a CFRP element with included foam-cores. The TO showed, that a single element in the middle area of the platform is sufficient, as shown in the early concept-phase. The mounting area for the element on the platform includes appropriate slides for a slidable seating structure (Fig. 31).

After describing all the single parts of the seating structure, the final design is visible in Fig. 32. It represents a novel styling supporting the requirement of a car sharing vehicle as well as the option for reuse. The seating structure was manufactured in prototyping processes. The mounting element was realized using bearing

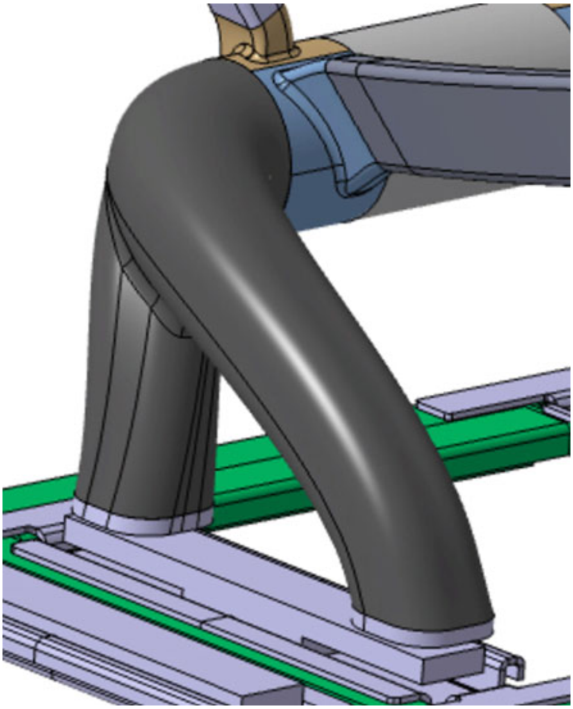

Fig. 31 Mounting element (black)

for machine constructions. It is movable and bears the loads for passengers in use and crash.

4 Conclusions

The change of the boundary conditions for the design of cars to reuse of mechanically highly loaded lightweight design structures requires new concepts. The structures on the one hand must be light and cost effective, but on the other hand durable and reusable. Taking these ideas into account, new designs of a platform and a seating structure were found.

4.1 Platform

The platform must provide stiffness and crash safety. It bears all major loads during driving and saves the battery compartment from intrusions that would lead to a catastrophic developments. Two basic concepts were designed with different construction philosophies. A profile based solution with as many pultruded profiles as possible

Fig. 32 Final design

showed low costs for molds and good lightweight performance, but a the connection to other components and the reduced design space for the batteries were negative aspects. A molded concept providing all connection possibilities and complex structures was the second concept. Here, the stiffness was found to be very high, but the costs for molds and the resulting high investment costs reduced the possibilities in particular for medium series production rates that are expected to be the starting point.

With the experiences made with both concepts a merged concept was derived providing the lightweight and low investment cost design of the pultruded profiles in combination with the simplified connection and the high design freedom of the molded concept. The merged concept uses profiles for the rocker panels and the major beams while the corner elements are molded with a SMC/BMC. Here, also recycled fibers could be applied to lower the carbon footprint. Crash simulations showed good results, thus the concept is seen as ready for detailed developments and first prototypes.

4.2 Seating Structure

Besides the platform the design of a seating structure was presented. The seating structure is designed with the main targets reusability and remanufacturability. The design was optimized regarding highest possible strength with sufficient small deflections. It was shown that an easy separation process is feasible. By these measures the scenario of reusing the parts at least three times becomes realistic. The functionalities described above are implemented in the presented design, so that these requirements are fulfilled as well.

In addition to the design shown, a detailed FEM analysis was carried out to optimize the profiles regarding wall thickness and manufacturability. It could be shown which materials for which components are necessary to bear the loads.

References

1. Heycar Magazin, Was ist die typische Lebensdauer eines Autos (2020). [online], Available: www.hey.car/magazine/was-ist-die-durchschnittliche-lebensdauer-eines-autos
2. Statista.com, Typische Lebensdauer von Autos in Deutschland nach Automarken (2014), [Online], Available: http://de.statista.com/statistik/daten/studie/316498/umfrage/lebensdauer-von-autos-deutschland/
3. Szabo, R., Szabo, L.: The cars need lightweight composites to reduce the CO_2 emissions ToT improve the fuel efficiency. Express (2018)
4. Al-Lami, A., Hilmer, P., Sinapius, M.: Eco-efficiency assessment of manufacturing carbon fiber reinforced polymers (CFRP) in aerospace industry. Aerosp. Sci. Technol. **79** (2018)
5. Bundesverband Carsharing, Fact sheet car sharing in Germany (2022)
6. Horvath & Partners, Faktencheck E-Mobilität: Status quo der E-Mobilität in Deutschland—Update 2020 (2020)
7. Steinwall, J., Viippola, P.: Concept Development of a Lightweight Driver's Seat Structure and Adjustment System, Combining Optimization and Modern Product Development—Methods to Achieve a Lightweight Design. Master's thesis in product development, Chalmers University of Technology, Gothenburg, Sweden (2014)