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Reverse Engineering and Rapid Prototyping in the Process of Developing Prototypes of Automotive Parts

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The presented article deals with the application of Reverse Engineering and Rapid Prototyping processes in the development process in the automotive industry. In our case, we will focus on the design of the exterior rear view mirror. We obtained the information about the shape and as well as the data used to model the part in a virtual CAD computer environment by scanning it with a Leica laser scanner. The obtained point cloud was imported into CATIA V5 software, which is often used in the automotive industry. In the CATIA software modules, section curves were translated into cloud points. Based on these curves, free shaped surfaces of the mirror body and its holder on the car door were created. After creating the mirror body-mirror mount assembly, print data of these parts were generated for production by Rapid Prototyping technology. The printing method based on ABS material using the FDM (Fused Deposition Modeling) method was chosen.

Keywords: CAD, Reverse Engineering, Rapid Prototyping, 3D modeling, 3D printing

1 Introduction

Reverse engineering and rapid prototyping processes have been used in the automotive industry since the beginning of automotive development and production (Fig. 1), although they have not been called by the terms mentioned above. Reverse Engineering and Rapid Prototyping began to take shape in the form we know them today with the introduction of computer technology into the automotive design and manufacturing process (Fig. 2). Thanks to the digitalization established in design and manufacturing activities, these technologies have become common tools that have been able to shorten all stages of car development (design, simulation, testing) as well as manufacturing processes (CNC machining, welding robots, assembly and handling robots, paint shop processes).

Without the use of CAx systems, the deployment of these processes would not have been possible to the extent that it is today. The philosophy of CAD (Computer Aided Design) and CAM (Computer Aided Manufactur-ing) approaches has become an integral part of the automotive industry. These technologies have shortened the innovation cycle in car model lines to 6 to 8 years. In the middle of this cycle, the so-called facelift of the model range takes place, when certain changes are made to the exterior and interior of the vehicle, or the equipment is extended with new or improved features. CAx systems make it possible to make changes in such a short space of time.

The digitisation process is supported by 3D scanners (Fig. 3, Fig. 5). Scanning is used to acquire data in the form of "point clouds", which are later processed and digitised in CAD systems. Based on these surfaces, data is generated for 3D printing to produce prototypes of the designed components. 3D printing methods using 'Fused Deposition Modelling' technology are used from ABS or liquid-based materials using stereolithography, where a phospho-sensitive liquid material is exposed to laser light to harden it.

Várady et al. already in 1997 in [1] describe the digitization of free form surfaces, where he gives an example of creating a surface model of a car fender. Vinesh and Kiran in [2] describe the use of Reverse Engineering approaches in automotive, aerospace, and medical engineering. Sansoni and Docchio in [3] deal with the issue of three-dimensional optical measurements and reverse engineering for automotive applications. Carbone et al. in [4] describes a novel methodology for the reverse engineering of complex, free form surfaces, based on the integration of the measurement information from a 3D vision sensor and a coordinate measuring machine (CMM). Scanning free form surfaces requires certain skills and sometimes it is good to automate it robotically. Son et al. in [5] describe a new method for scanning a complex surface model with multiple patches. Li et al. in [6] present a reverse engineering system for rapid modeling and manufacturing of products with complex surfaces. The system consists of three main components: a 3D optical digitizing system, a surface reconstruction software and a rapid prototyping machine. This set of devices and the sequence of data processing also form the basis for Reverse Engineering and Rapid Prototyping in the development process in automotive (Fig. 2). Rapid Prototyping and Additive Manufacturing technology is discussed by Groover in [8]. Describes the principles of prototyping activities according to the principle of operation of individual devices for 3D printing and according to the used printing materials. Rapid prototyping is also used in the field of biomaterials and medicine. Hosic et al. in [9]. Svane. et al. in [10] deals with the use of additive technologies in the pharmaceutical industry. Developments show that Reverse Engineering and Rapid Prototyping technologies have quickly found their way into industries other than the engineering industry [11]. Pralay and Ballav in [12] deals with the reconstruction of the shape of the scanned object through the interpolation of the NURBS surface. Fabian et al. in [13] deals with the principles of digitization based on 2D drawing documentation and in [14] deals with the use of the intuitive tool Imagine & Shape CATIA V5 in the process of digitization of shapes. In [15] Fabian et al. deals with the parameterization of 3D models with the connection of parameters to spreadsheets. Daneshjo et al. in [16] deals with the issue of utilization of Modern Software Systems for Design and Realization of Prototype of Three-dimensional Model. Ponikelsky et al. in [17] deals with the issue of the influence of production technologies on selected properties of polymers. Nevertheless, we will focus on the use of these approaches in the design process of the car component, specifically the creation of a rear view mirror model based on scanning the real body of the ŠKODA Fabia (Fig. 5).

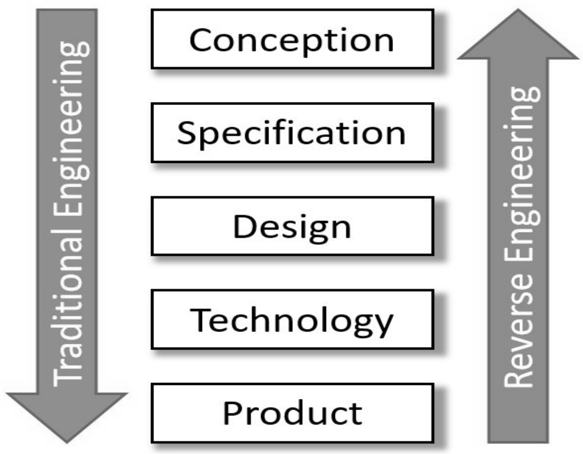

Fig. 1 *Comparison of traditional design and reverse engineering design*

2 Scanning

The technology of scanning a 3D object, its digitization, modifications in a CAD modeler and subsequent production are comparable to scanning, digitizing, editing and printing a 2D paper document, with which everyone has personal experience. A comparison of the digitization process of a 2D document and a 3D object is shown in Fig. 2. The ŠKODA Fabia I. was scanned by a Leica laser scanner (Fig. 3). The data scanned by the hand-held scanning head emitting a beam onto the scanned surface and scanning the reflected profile of the object is sent to the computer. The software allows us to monitor the scanning process in real time. The coordinate system standardly used in the automotive industry is shown in Fig. 4.

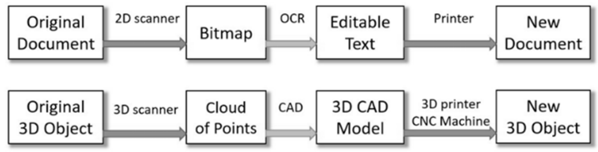

Fig. 2 *Comparison of activities with 2D document and RE/RP 3D object*

Fig. 3 *Scanning the shape of a car body with a laser scanner and the principle of scanning based on the transmission of a laser beam to the surface, its scanning by a camera (bottom right)*

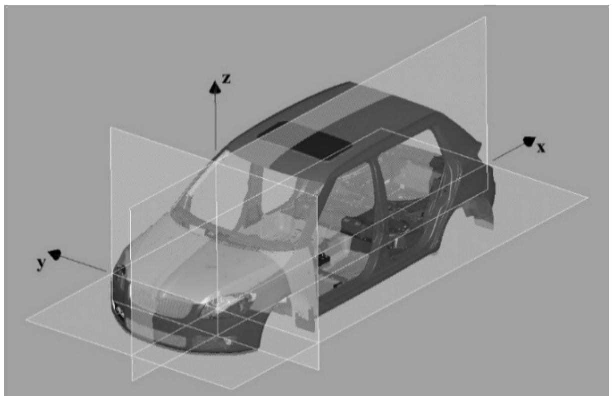

Fig. 4 *Coordinate system used in the automotive industry*

The output of the ŠKODA Fabia scanning process was a point cloud, which was imported into the CATIA V5 CAD software environment. This software will be used to digitize the model. The point cloud scan of approximately half the shape of the vehicle contained 1 305 016 points, file size was 123 MB. [11]

Fig. 5 *Scanning the shape of the ŠKODA Fabia I. with a Leica AT 901 scanner*

The remaining missing part of the shape was subsequently reflected relative to the XZ plane. The cloud of points in ASCII free format was imported in the Digitized Shape Editor module of CATIA V5 software (Fig. 6 left).

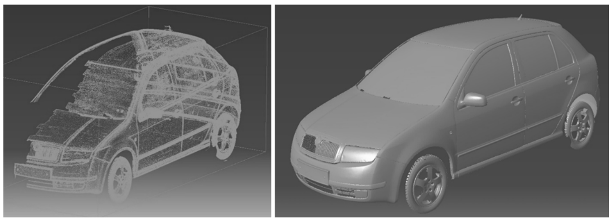

Fig. 6 *Scan half the shape of the vehicle (left) anf full scan (right)*

3 Cloud of points processing

The imported cloud of points (Fig. 7-left) was approximated by a triangulation network (Fig. 7-right). A feature of the triangulation network is the ability to make cuts through planes, thus obtaining cutting curves that can be further worked with. The triangulation network of the car body can also be displayed in the so-called shaded mode (Fig. 6 right).

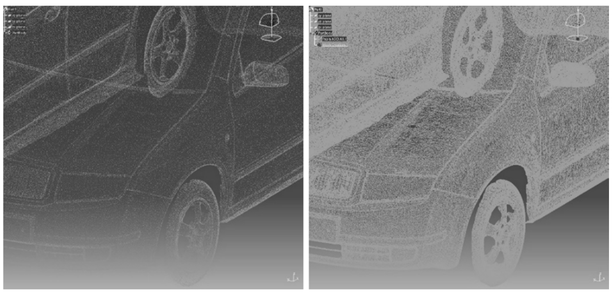

Fig. 7 *Scanned cloud of points (left) and created triangulation network (right)*

The object we decided to digitize was selected from the imported cloud of points in the CATIA Digitized Shape Editor environment.

This article will point out the approaches to digitization of sheet metal and plastic components of the car. Specifically, these will be the front and rear doors of the automobile, which are made of sheet metal by stamping technology, and the plastic rear view mirror, which is made by plastic injection technology.

Due to the complexity of the shape of the rear view mirror, the process of its creation will be described first. The mirror will be created by digitizing a scanned point cloud obtained by scanning a real car.

The front and rear doors will also be created on the basis of a scanned point cloud and, as an example, the possibility of extracting the geometry of the shape based on the imported and calibrated dimension of the 2D drawing documentation to the CAD system environment will be pointed out.

The left rear view mirror with a handle on the door window was chosen (Fig. 8). A triangulation network created with the condition of a maximum distance of two adjacent points at 20 mm was translated through our cloud of points. This value proved to be in-sufficient, due to which several unfilled areas were created on the mirror. (Fig. 9 left) By entering a higher value of the point distance, this defect has been corrected (Fig. 9 right).

Nevertheless, discontinuous surfaces and deformations on the triangulation network are visible. Some defects had to be removed "manually" using the Fill command to obtain the final version of the triangulation network, which appears to be a smooth surface (Fig. 9 right). Therefore, it is necessary to create cutting curves (Fig. 10) and fold smooth surfaces over them (Fig. 11 right). The quality of this triangulation network is fully sufficient for us to create the cutting curves of the mirror body profile.

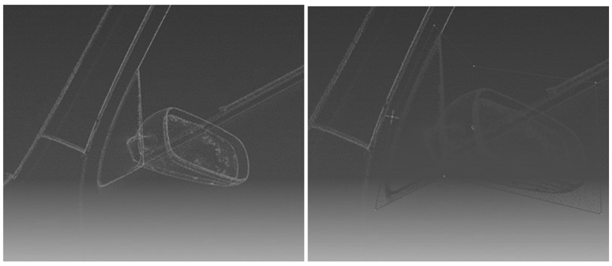

Fig. 8 *Cloud of points selection*

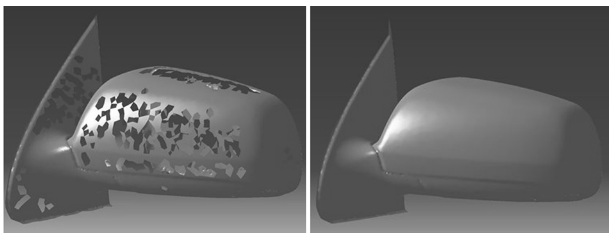

Fig. 9 *Approximation of a cloud of points by a triangulation network and final shape of the triangulation network*

4 Digitization of the shape of the rear view mirror

There are several types of point cloud digitization and triangulation network approaches. In automotive practice, only two programs are used for surfacing, namely ICEM Surf and Autodesk Alias, which create so-called A-Class Surfaces. We will digitize the prototype quality in the modules Digitized Shape Editor, Quick Surface Reconstruction and Generative Shape Design 3D system CATIA V5.

First, we create section curves through the mirror body in planes parallel to the ZX plane of the model coordinate system (Fig. 10). Since the triangulation network is a grouping of triangular planar elements, the cutting curves are also considerably "rough". It is possible to translate surfaces with cutting curves. By smoothing the cutting curves, we get the opportunity to create better surfaces that will be optimally smooth (Fig. 11-left).

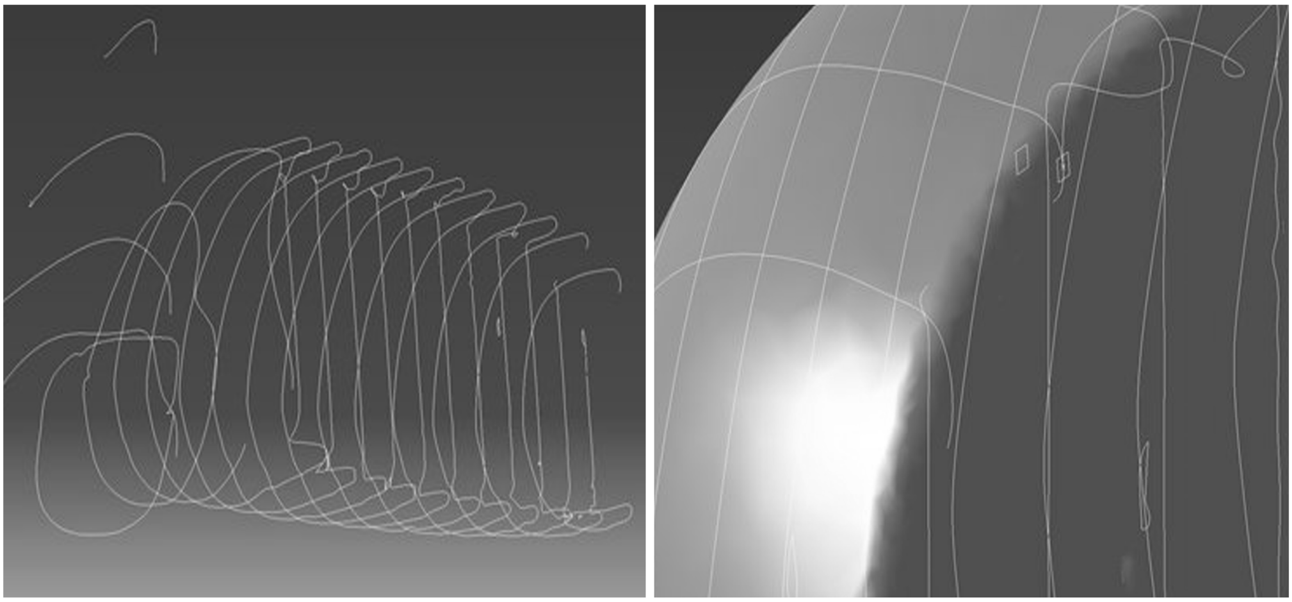

***Fig. 10** Cutting curves created by the penetration of cutting planes and the triangulation network*

Cutting curves must first be approximated by curves of a certain order of polynomials, which creates smoothed curves. With such approximated - smoothed curves (Fig. 11-right) it is possible to translate the so-called Multi-section surface. The surface created in this way is fully editable in the CAD system and it is possible to make adjustments or use these areas for further modelling.

In our case, after creating the main "body" of the mirror, we completed the shape of the mirror mount with a cylindrical hole on the pivot pin. After creating the shape of the handle surface, we closed the surface model in Volume and created a solid model from it (Fig. 12).

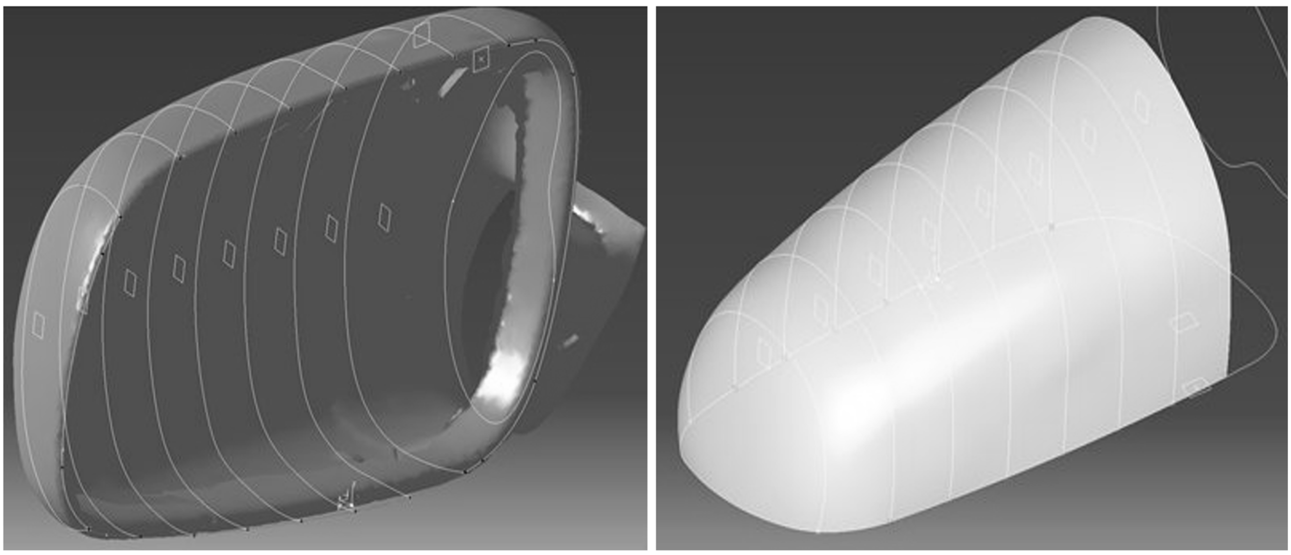

***Fig. 11** Smoothed cut curves (left) and interleaving surfaces with approximated mirror cutting curves (right)*

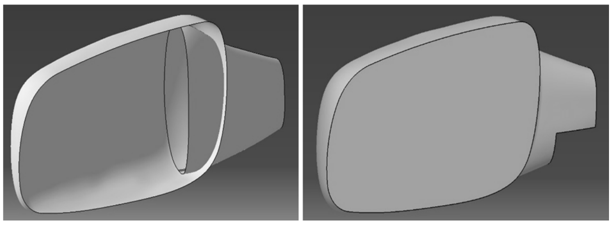

Fig. 12 *Mirror mount modelling*

Subsequently, a thickness was added to the surface model, thus creating a shell model of the mirror body shape (Fig. 13). The hinged part of the mirror body holder to the body, which will be fixed to the door frame, was also modeled.

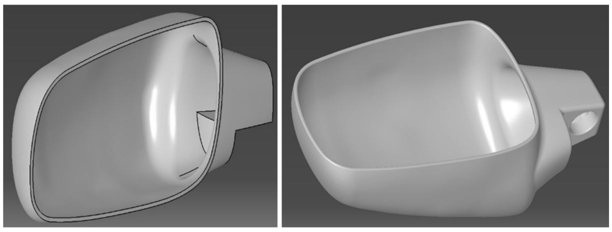

Fig. 13 *Creating a shell model of the mirror body*

In a similar way, the second part of the mirror was created on the basis of the cutting curves by the triangulation network (Fig. 14).

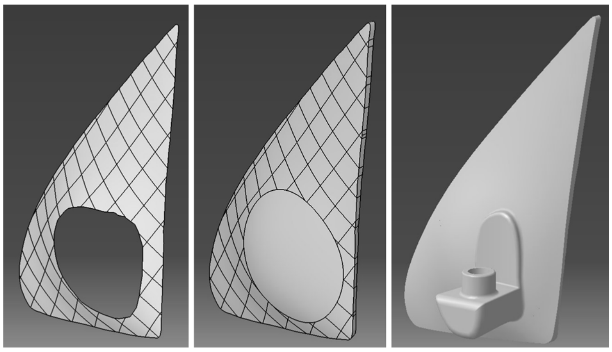

Fig. 14 *A model of the mirror mount, which is located on the vehicle door*

5 Part assembly creation, material assignment and visualization

An assembly was created in the Assembly design module from the created models of the mirror body and the mirror holder integrated into the front door side glass space. The assembly is connected by the Coincidence bond, the two contacting planar surfaces, and the Coincidence bond of the axis of rotation of the pin of the grip and the cylindrical surface of the mirror body. The functionality of the mirror tilt was verified in the Assembly environment. The mirror was assigned the material Plastic in black. The assembly was supplemented by the area of the mirror part, to which the material with the mirror properties was assigned. The resulting assembly is shown in Fig. 15.

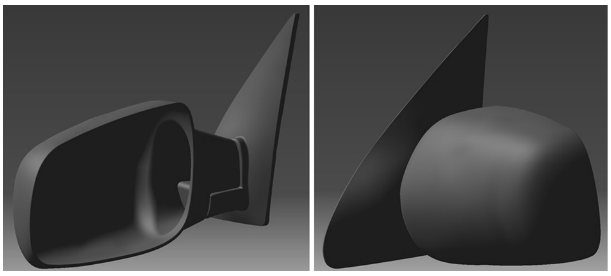

Fig. 15 *Mirror body and mounting bracket assembly*

6 Digitization of the shape of the rear and front doors

We will show the procedure of digitizing the shape of the door on the basis of a point cloud on the back door. The geometry of the rear door from the triangulation network will be the first to be selected in the Digitized Shape Editor environment (Fig. 16). [18]

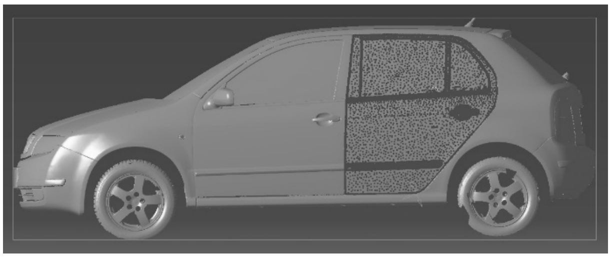

Fig. 16 *Rear door triangulation net geometry selection*

In order to be able to obtain the profile curves of the door, it will be necessary to create planar sections of the selected cloud points of the door geometry. The section planes will be parallel to the YZ plane of the car's basic coordinate system (Fig. 17 left). The view of the door profile curves is on (Fig. 17 middle). Based on the cloud of the triangulation network, the side profile curves of the door perimeter and the side window perimeter were also created (Fig. 17 right). Due to the possibility of shape tuning, some dimensions of the curves were parameterized.

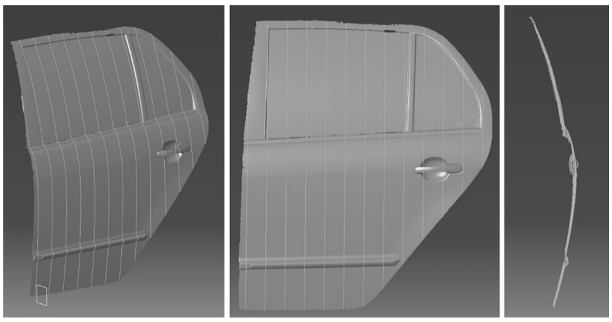

Fig. 17 *Creating profile curves by cutting a point cloud with Planar Sections and Profile curves displayed in the ZX and YZ planes*

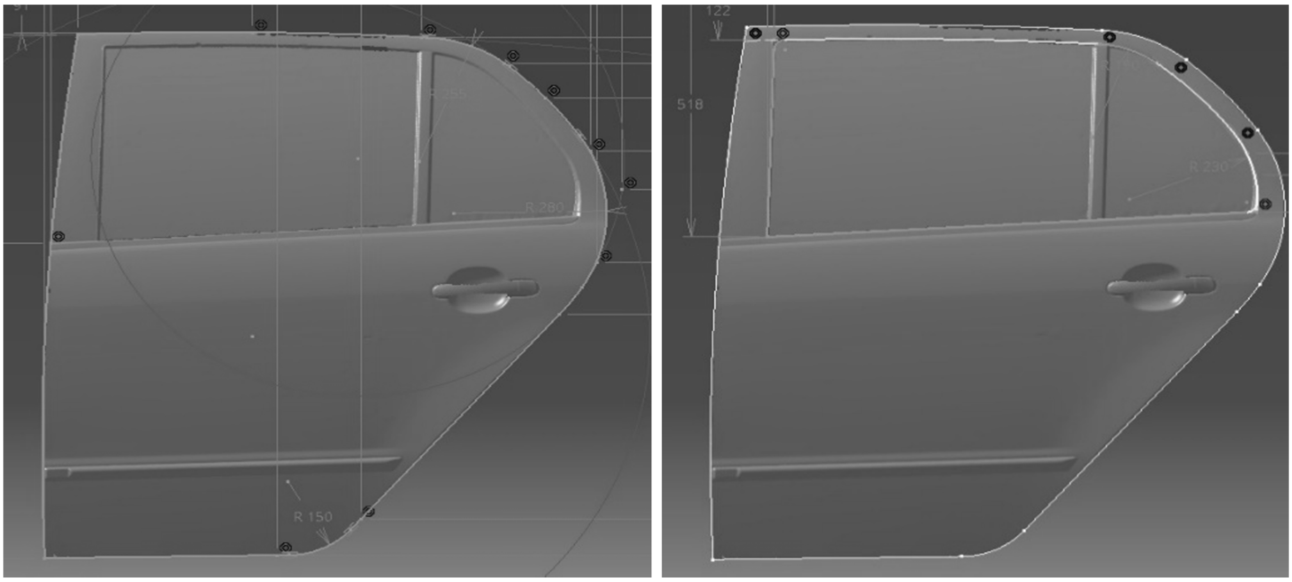

Fig. 18 *Side profile sketch of the outer perimeter of the door and Side profile sketch of a door window*

From the profile curves created by the YZ section planes, the surface area of the door was created, on which the curves of the sketch of the perimeter of the door and windows were projected (Fig. 19 left). Subsequently, the shape of the door perimeter and the window opening were cut into the surface (Fig. 19 right). Subsequently, the surfaces of the interior of the door and the removal on the handle were modeled. The completely modeled rear door is shown in Fig. 20.

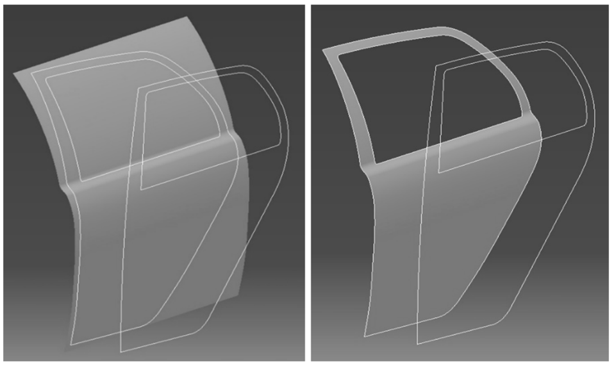

Fig. 19 *Creating the shape of the door surface and trimming the perimeter shape of the door and cutting out window*

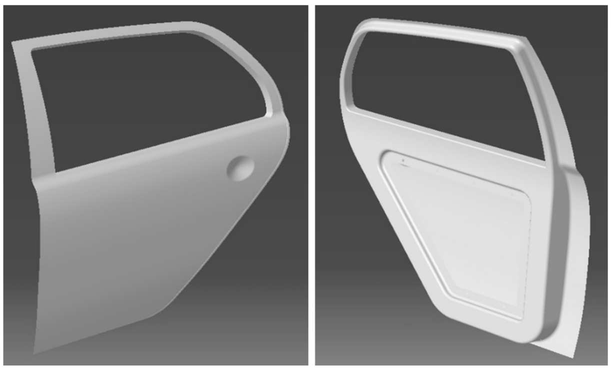

Fig. 20 *The final shape of the exterior and interior of the rear door*

The front doors were modeled on the basis of the rear door profile curve, as the rear and front door profiles are the same. The perimeter curves of the door and the window profile were derived based on the geometry of the blueprint (Fig. 21), which was imported into Sketch Tracer. This module allows us to import bitmaps into the modeling environment of a CAD system. We defined the size of the blueprint based on determining the size of the wheelbase. The distance between the axles of the front and rear axles was defined by the size of 2462 mm (Fig. 21).

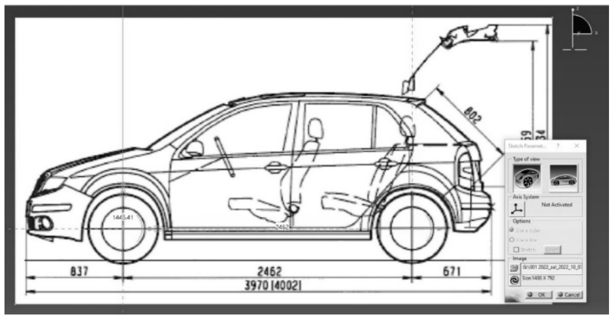

Fig. 21 *Import and define blueprint size in Sketch Tracer*

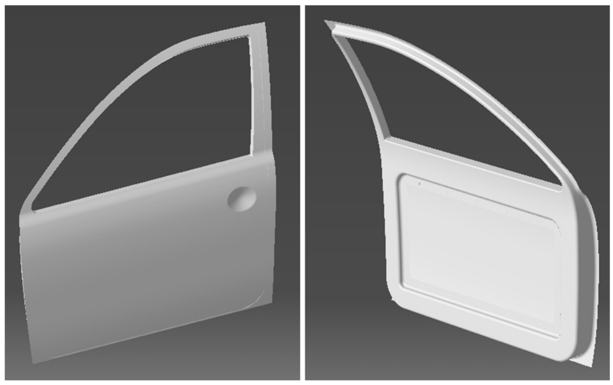

Fig. 22 *Surface model of the outer and inner shape of the front door*

Subsequently, a previously created surface model of the rear door was imported into the assembly. The outer contour of the door and the opening for the window were designed on the basis of a blueprint of the side view of the car. The final shape of the front door surface model is at Fig. 22 and assembly of front and rear doors is shown in Fig. 23.

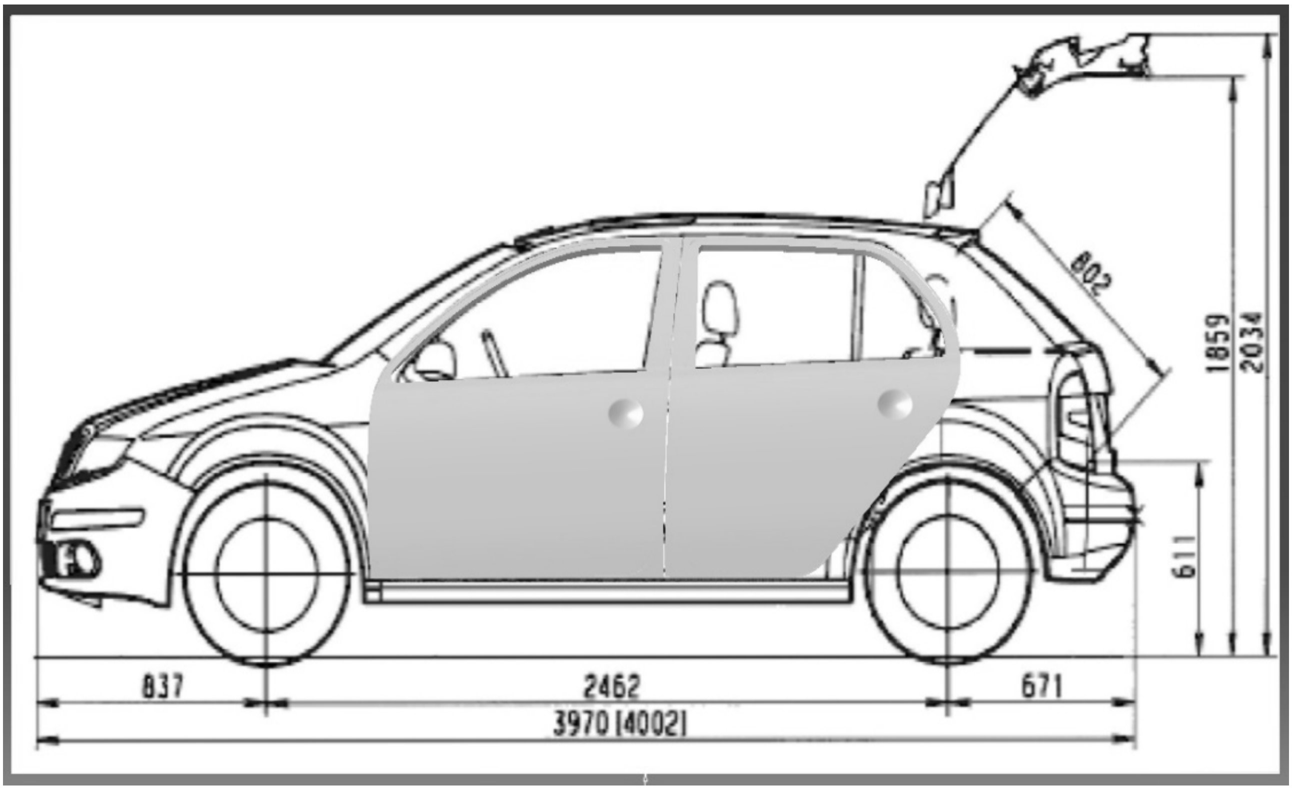

Fig. 23 *Front and rear door assembly*

7 STL data generation and production using 3D printing technology

The created 3D virtual model was printed by Fused Deposition Modeling technology on a ZORTRAX M200 single-jet printer. The model created in CATIA was exported to STL format. Furthermore, this format was processed in the Z-Suite environment, which supports the generation of print data for printers from the manufacturer Zortrax. Both parts were extruded from ABS material. The diameter of the print nozzle was D = 0.4 mm and the print layer was set at 0.19 mm and 30% material fill was chosen. The program optimized the support material in automatic mode (Fig. 24, Fig. 25). The final printout of the assembly is shown in Fig. 26.

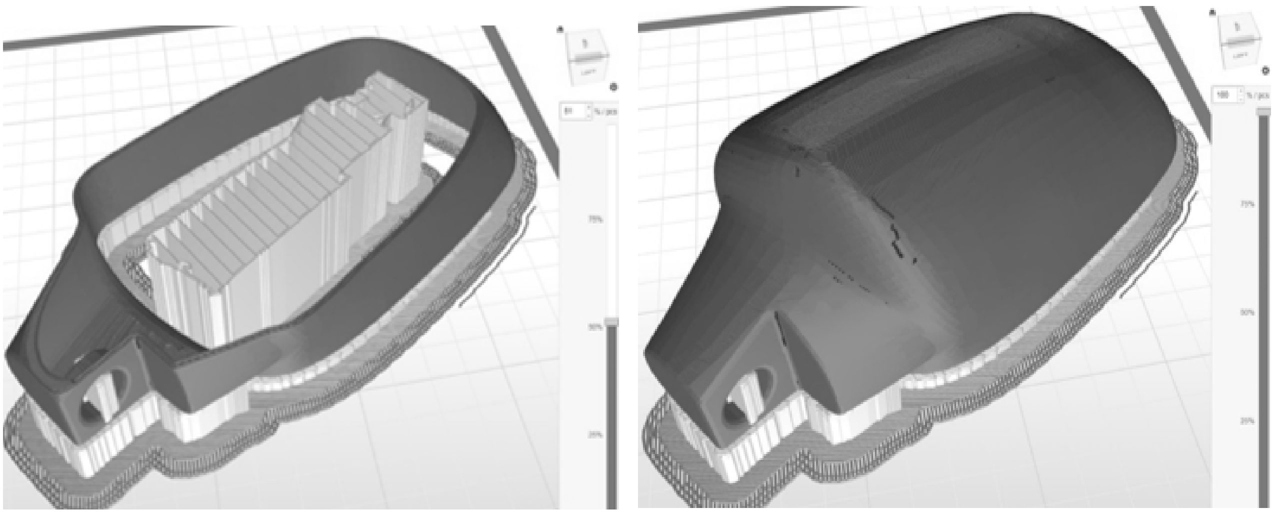

Fig. 24 *Mirror shell printing process with support material (left) and extruded mirror shell*

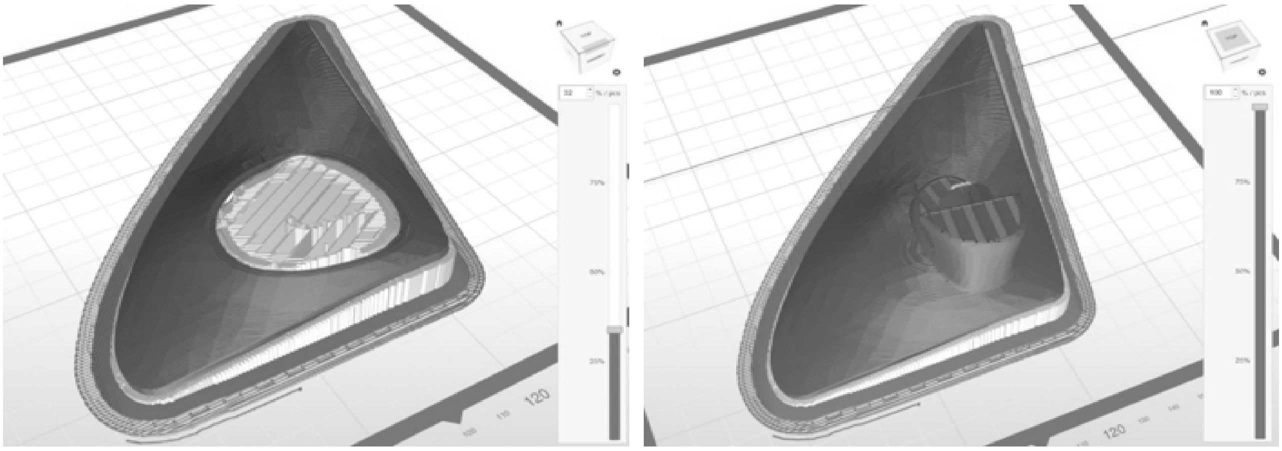

Fig. 25 *The process of printing the mirror mount on the car door*

Fig. 26 *3D printout of the mirror body assembly and the integrated mirror holder in the front door window area*

Similarly, the front and rear doors were printed on a 3D printer. The door model has been scaled down to fit in the printer's press area (Fig. 27 left). The inner recess of the door and the upper edge of the door frame required the printing of the support material (Fig. 27 right). Printed scale models of front and rear doors, see in Fig. 28.

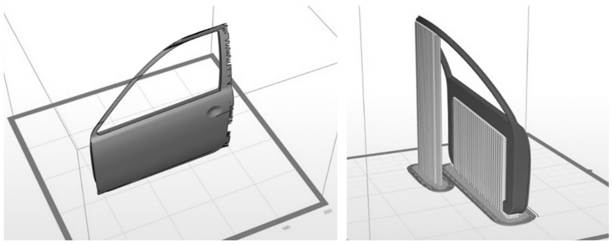

Fig. 27 *Reduced model of the front door in the printing space of the printer and printing of the door with supporting material*

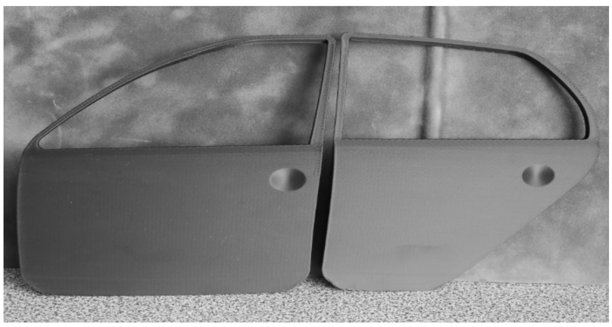

Fig. 28 *Printed scale models of front and rear doors*

8 Visualization

Finally, a set of doors with a rear view mirror was created and the door was assigned a color. Visualization of the detail of the front door with the rear view mirror is shown in Fig. 29 and an overall view of the assembly is shown in Fig. 30.

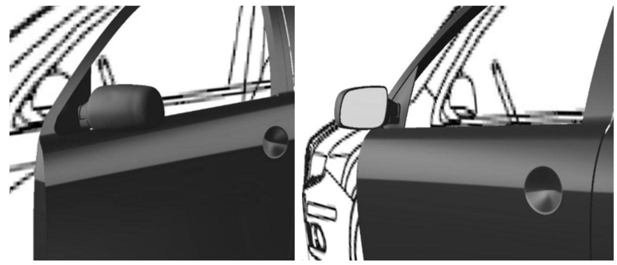

Fig. 29 *Mirror mounted in the front door frame*

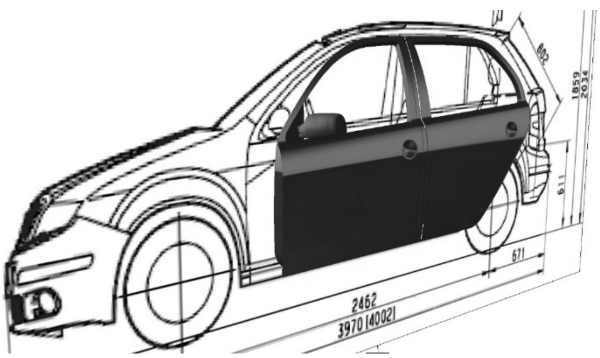

Fig. 30 *Assembly visualization – perspective view*

9 Results

This document demonstrated the digitization of a scanned cloud of car rear view mirror points using a reverse engineering approach. Subsequently, the shape of the front and rear doors was digitized, and in addition to the scanned point cloud, a side view of the 2D drawing documentation was used. This approach is widely used in the automotive development process, where scanned material models are designed and manufactured by a design team. By further processing the point cloud and its digitization in the CAD system, we obtain an editable virtual model, which we can further optimize or rather subject to analysis. Finally, print data for a 3D printer were generated from the created digital model, when we obtained a material model using the Rapid Prototyping approach. In addition to developments in the automotive industry, the Reverse Engineering and Rapid Prototyping process is also widely used in the so-called restoration industry resp. renovation of many technical works.

The article presents the Reverse engineering and Rapid Prototyping technologies and their applications on a model of the 1999-2007 model range ŠKODA Fabia vehicle. The data obtained by scanning and production of scaled down components has been used solely to explain the individual procedures and for the purposes of this article only.

Acknowledgement

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