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In partial fulfillment of the requirements for the

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Specialty: Mechanical Design & Innovation

Reverse Engineering, Inspection, and Optimization of Peugeot 308's Front Fender

Submitted by:

AAZI Hamza* & *KHALDI Mohammed

Supervised by:

Pr. ABOUTAJEDDINE Ahmed (FST FES)

Mr. EL HAMMOUDI Mouhcine (MG2 Engineering)

Mr. NAMIR El Mehdi (MG2 Engineering)

Defended on 20/07/ 2022, In front of the jury:

Pr. ABOUTAJEDDINE Ahmed	**Supervisor**
Pr. EL MAJDOUBI Mohammed	**FST FES**
Pr. BELATIK Mourad	**FST FES**

Submitted to the Graduate the
Faculty of Science and Technology of Fez

Mechanical Engineering Department
July 2022

بسم الله الرحمن الرحيم

وَقُل رَّبِّ زِدْنِي عِلْمًا

صدق الله العظيم

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A Thesis Submitted by

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DEDICATON

To Mom Latifa,

To Dad Mohammed,

As always and forever, Source of living

To my little brother Rayan, Source of happiness and hope

To all my family, Source of joy and motivation

To all my professors, especially Mr. Ahmed ABOUTAJDDINE

To my friends, Source of trust and loyalty

To my colleague KHALDI,

Hamza

À ma mère Latifa,

A ma famille,

D'avoir été mon soutien,

À mes professeurs et mes amis,

Étant source d'inspiration,

A mes superviseurs du MG2,

Etant mon aide à chaque instant,

A mon cher ami AAZI,

Merci.

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Abstract

Today, industrial growth has made it necessary to improve design and manufacturing processes from the ground up, especially in terms of time and material. This has significantly increased the demand for computer-based user interfaces that would exploit existing applications in an efficient and cost-effective manner and make the design and engineering process more green-industry oriented. Since reverse engineering has been heralded as one of the most promising technologies to combat this legacy systems problem, large companies have begun to integrate reverse engineering tools into their design and manufacturing processes.

The work presented in this thesis is part of our graduation project as Mechanical Design and Innovation engineers at MG2 Engineering. This latter is a collaboration between Capgemini Engineering, a global leader in applied research and advanced engineering, and Magna, a Canadian company specializing in mobility technologies for automotive manufacturers, known for its expertise and know-how in vehicle.MG2 Engineering is a subcontractor for world's largest car manufacturers such as Audi, Rolls Royce, BMW, Volkswagen, Peugeot, Citroen, etc. The current project is part of their collaboration with Peugeot.

The first objective of this project is to evaluate the integration of a reverse engineering process into the design of car parts, the front fender of the Peugeot 308 in our case. The rationale behind this objective is to establish the differences between the use of conventional design methods and the RE methodology.

The second objective is to evaluate the post-production errors that occurred on the front fender of the Peugeot using inspection tools while keeping in mind the efficiency and the tolerance zone of our scanner (Creaform HandySCAN 3) and to evaluate the use of laser 3D scanning methods as a post-production inspection tool.

The third objective is to evaluate and improve the design of the front fender of Peugeot 308 by taking into account the results of MEF simulation and manufacturing feasibility. The improvement effort is focused on the technical zones (attachment points) because the style of the fender is a client constraint.

The fourth objective of this project is to reform the process followed in this project so that it can be used as a course study for future engineers.

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Glossary of Terms

3D scanner – A device that capture data on the shape and colors of a real-world environment for processing in the digital world, such as construction of 3D models.

CMM – Coordinate measurement machine that uses a point or ball probe on an articulating arm, allowing users to collect individual 3D data points from a physical object.

Optical CMM scanner – A 3D scanner tracked by optical CMMs. Optical CMM cameras track passive or active reflectors affixed to the 3D scanner itself and to dynamically reference them in 3D space.

CAD – Computer-aided design; the act of creating a digital model for design, engineering, and manufacturing. The model is based on various geometric entities such as triangles, lines and curved surfaces. Typical formats for CAD models are .stp and. igs.

CAE – Computer-aided engineering; the act of digitally simulating performance of objects and assemblies. CAE encompasses simulations such as finite-elements analysis and computational fluid dynamics.

CFD – Computational fluid dynamics; computational fluid dynamics; a digital process by which engineers can simulate how fluids such as air, water and gas behave within different design, engineering and natural environments.

CAI – Computer-aided inspection; the act of comparing an as-manufactured part to its CAD equivalent or ideal specifications for quality control, wear-and-tear assessment, and other forms of analysis.

FEA – Finite element analysis; a digital process by which engineers can simulate how the structure of an object or assembly performs under different environmental stresses.

STL – Stands for stereolithography or standard tessellation language; a file format native to stereolithography CAD software created by 3D systems Inc. and supported by many other software packages. STL files are used widely for rapid prototyping and computer-aided manufacturing.

PLM – Product Life-cycle Management is the strategic process of managing the complete journey of a product from initial ideation, development, service, and disposal.

CATIA – Computer Aided Three-Dimensional Interactive Application.

RE – Reverse Engineering.

SOD – Standard of Development.

BIW – Body in White.

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General Introduction

Figure 1: Carl Benz's Motorwagen patent

The first introduction of a car fender into the automotive industry was made as early as 1984 by Carl Benz with his world renowned Motorwagen patent, and it hasn't stopped developing since. Carl wanted his design to be a rudimentary appendage to his car concepts, only to see it evolve into a major styling element with specific purposes. The fenders defined the era in which the car was built.

The fender design evolved from simple curves to a functional piece protecting the car and passengers from dust and rocks, and its purpose rose after the official introduction of aerodynamics in the automotive industry.

The fender's style has grown to add to the handling and safety of the car. Lately, taking into consideration the considerable impact of the car's weight on its CO2 emissions, car manufacturers are looking to reduce every last bit of weight they can deduct without sacrificing any function. With today's advanced and forged manufacturing methods such as cold stamping, laser spot welding, hemming, and with more appropriate materials, car manufacturers do not, by no means, sacrifice the huge role that a fender plays, but rather work to make it even larger. As shown in today's car models, the fender takes up a part in the global production process, and it is constantly studied to be advanced while maintaining the same level of safety and reducing the overall weight of the car and production cost.

the use of the reverse engineering process in this improvement phase is a big step, especially the 3D scanning process. Some big companies have already started to introduce these technologies in some steps of their current process. For example, the Range rover has officially started to use the 3D scanner in its design phase to have fast and accurate CAD parts, and others are continuously following.

Figure 2: Using Creaform HandySCAN 3D to capture style of Range Rover.

In order to evaluate this integration of reverse engineering in the industrial world, MG2 gave us the chance to test the RE method on one of their own products and see if improvements can be made using the RE results.

CHAPTER I

About the Company

This chapter is an overview of the company, with a focus on its history, organizational chart, key figures, and departments.

Introduction

Before starting a project in a company, it seems important to first understand the entity and its field of activity. In this chapter, we will briefly present the MG2 Engineering office, where our internship was carried out. We will specify its history, its numbers, and its organizational structure.

1.1 Capgemini Overview

1.1.1 Group Presentation

Figure 3: Capgemini Logo

Capgemini is a global leader in consulting, Engineering, technology services and digital transformation. Capgemini is at the forefront of innovation to address the entire breadth of clients' opportunities in the evolving world of cloud, digital and platforms.

Building its strong 50-years heritage and deep industry-specific expertise, Capgemini enables organizations to realize their business ambitions through an array of services from strategy to operations. Capgemini is driven by the conviction that the business value of technology comes from and through people. It is a multinational, multicultural company of 200,000 team members in over 40 countries. The Group reported 2016 global revenues of EUR 12.8 billion.

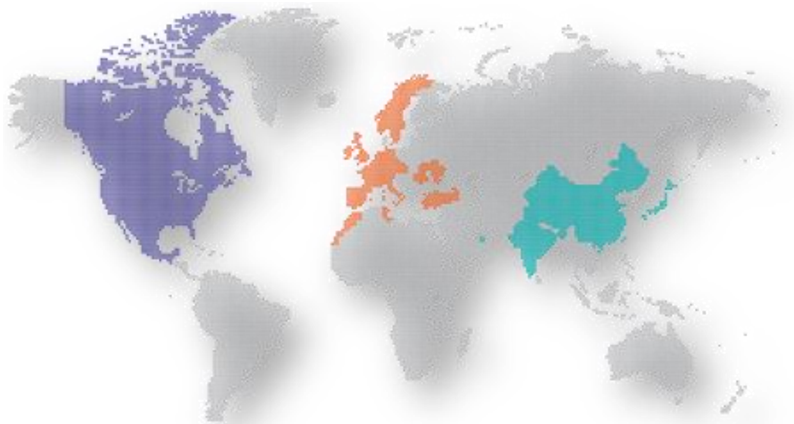


Figure 4: Implantation of Capgemini worldwide.

1.1.2 Capgemini in Numbers

Figure 5: Capgemini's summary.

1.2 Capgemini Engineering

As of April 8, 2021, Capgemini Engineering is the brand of the Capgemini Group bringing together the engineering and R&D services of Capgemini Engineering, the global leader in the sector whose acquisition Capgemini finalized in 2020, and Capgemini's expertise in digital manufacturing.

Capgemini Engineering operates in over 10 industries

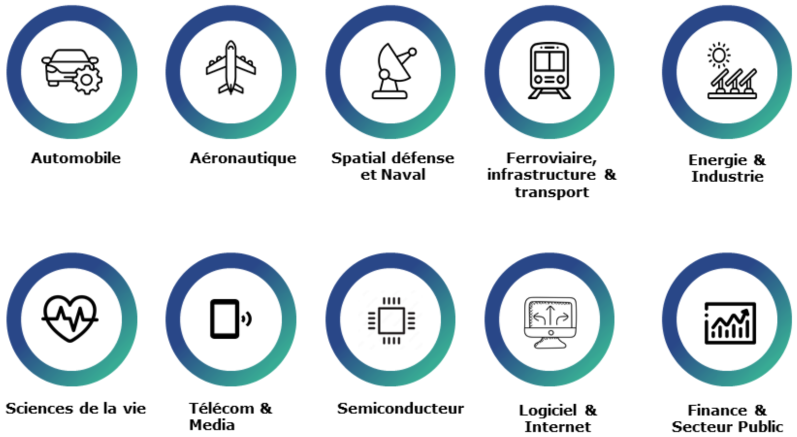


Figure 6: Field operation of Capgemini Engineering.

1.2.1 Capgemini Engineering in Numbers

Figure 7: About Capgemini Engineering.

1.2.2 Capgemini Engineering Morocco (FKA Altran)

Figure 8: Altran's Logo.

Altran (Capgemini Engineering Morocco since 2021) is an engineering consulting company, offering its clients Innovation and Advanced Engineering Consulting to become the preferred partner for higher value-added services and optimizing their R&D costs.

1.2.3 Fields of Activity

The group operates in most sectors of industry, providing integrated services and products to its various clients diversified by sectors as follows:

Figure 9: Major Clients of Altran's group.

1.2.3.1 Summary of Altran's Journey

- **1982:** Alexis Kniazeff and Hubert Martigny launch CGS Informatique.
- **1987:** Creation of Altran /CGS Informatique becomes Altran Technologies and is listed on the Paris Stock Exchange.
- **1989:** Altran acquires Ségur Informatique, a company specializing in structural simulation and calculation for the aerospace industry.
- **1992:** Altran Conseil was created to carry out missions in the automotive, nuclear and consumer electronics industries.
- **1993:** First international division in Belgium.
- **1994:** Opening in Spain.
- **1995:** Opening in Italy, Sweden, Switzerland.
- **1996:** Opening in Germany and Great Britain.
- **1998:** Altran Technologies deploys a telecom network in Portugal.
- **2000:** First division in the USA.
- **2002:** Cambridge Consultants joins Altran's portfolio.
- **2004:** Altran sets up in Asia.
- **2012:** Stellantis (ex. PSA) chooses Altran as strategic partner.
- **2013:** Implementation in Morocco.
- **2018:** Collaboration between Altran Group - Magna for the creation of MG2 Engineering in Morocco.
- **2020:** The Capgemini takeover bid for Altran is finalized.
- **2021:** From Altran to Capgemini Engineering Morocco.

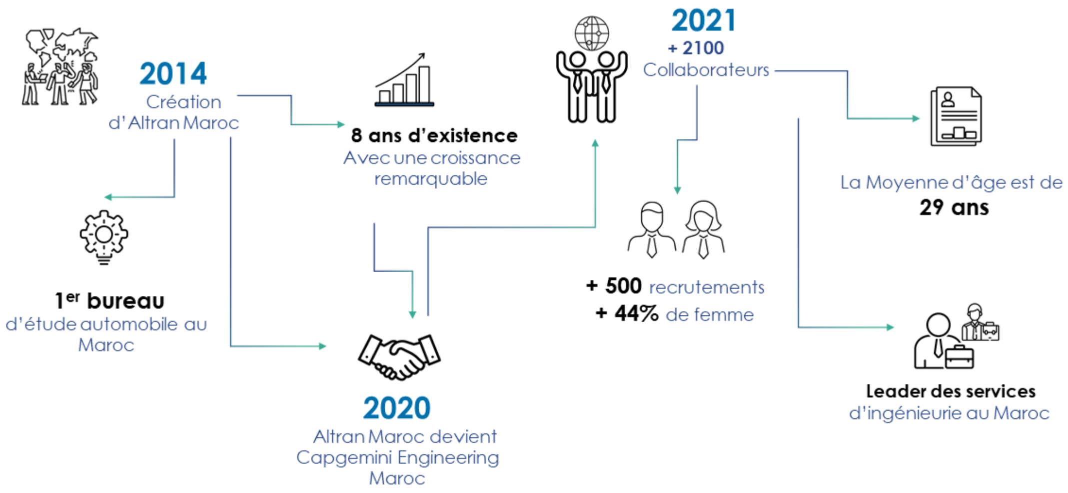


Figure 10: History of Capgemini Engineering Morocco.

1.3 Magna Overview

Figure 11: Magna's Logo.

Magna is one of the world's leading automotive suppliers. It supplies its customers with components and spare parts and supports manufacturers in their industrial projects. Magna International has opened a plant in Kaluga next to the one built by its client Volkswagen AG10.), this plant is for the manufacture of parts for the Russian platforms of Volkswagen, Skoda, Renault and Stellantis. According to Magna's press service, the Kaluga plant will produce bumpers, wheel covers and radiator grills.

MAGNA International Inc.'s network of operations includes more than 347 manufacturing factories and 94 product development, engineering, and sales centers in five continents and 27 countries

Figure 12: Implantation of Magna worldwide.

1.4 MG2 Engineering

MG2 ENGINEERING is a collaborative joint between Capgemini Engineering Morocco (ex. Altran) and MAGNA. It was launched in November 2018. It is considered the leader in engineering services in Morocco in the most complex automotive trades, thanks to its very high level of technical expertise, its contribution in the design, manufacture of the new 208 and the electric AMI and its diversity of customers.

Figure 13: MG2 Engineering.

1.4.1 Organization of the Technical Departments of MG2 Engineering

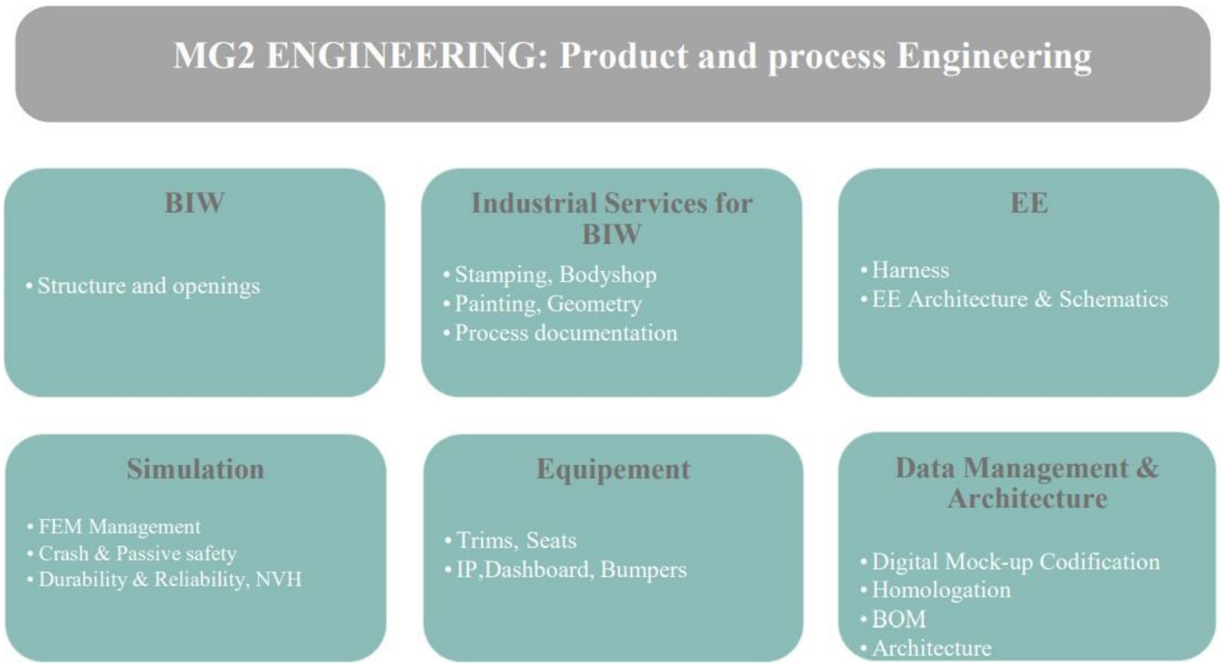


Figure 14:Different department of MG2 Engineering.

1.4.2 MG2 Engineering's Mission

Design and development of vehicles (body, interiors equipment...) in accordance with the client's performance objectives in terms of quality, cost, delivery time and service value.

MG2 Engineering has the possibility to work on major projects on an international scale thanks to its human and material resources. The mastery of the computer tools used is certainly the main characteristic that differentiates the group from other competitors.

MG2 Engineering has unlimited access to a client platform allowing the use of more than 70 professional softwares, whether it is for mechanical design, simulation of mechanical or electronic systems or numerical calculation and simulation of the behavior of mechanical structures.

These tools include: CATIA, AUTOCAD, ARENA, SOLIDWORKS, NX, RobCad, NASTRAN, ABAQUS, RADIOSS, FLUENT, ANSA, VLAB, AMESIM, DesignLife,Hypermesh.

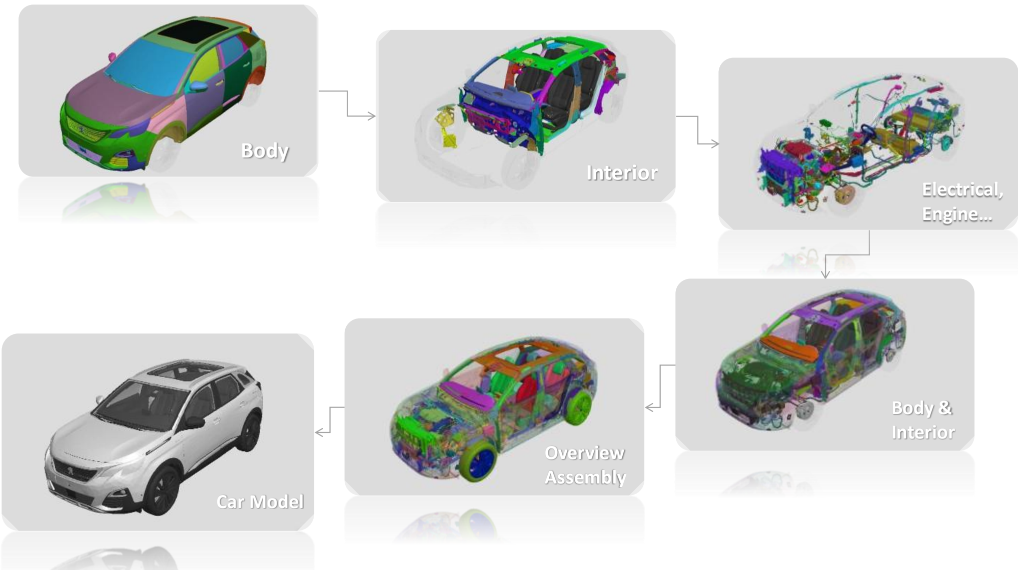


Figure 15:Process of development of Peugeot 3008.

Conclusion

In this chapter we have provided a general overview of the company. We have presented its details, history, departments and objectives. The next chapter will tackle the implementation of the training planning.

Chapter II

Post Planning & Job training

This chapter is dedicated to the Tools and Profession trainings that were conducted during this internship and their planning in time.

Section I: Post Planning

Our internship involved many steps, from the internship training; which included various information that enabled the interns to understand the environment and goals of the company, and to understand the prerequisites to perform the various tasks required from an engineer; to our work directly on the fender, to finally get a better optimized design process.

The figure below shows our initial planning in relation to the actual execution dates:

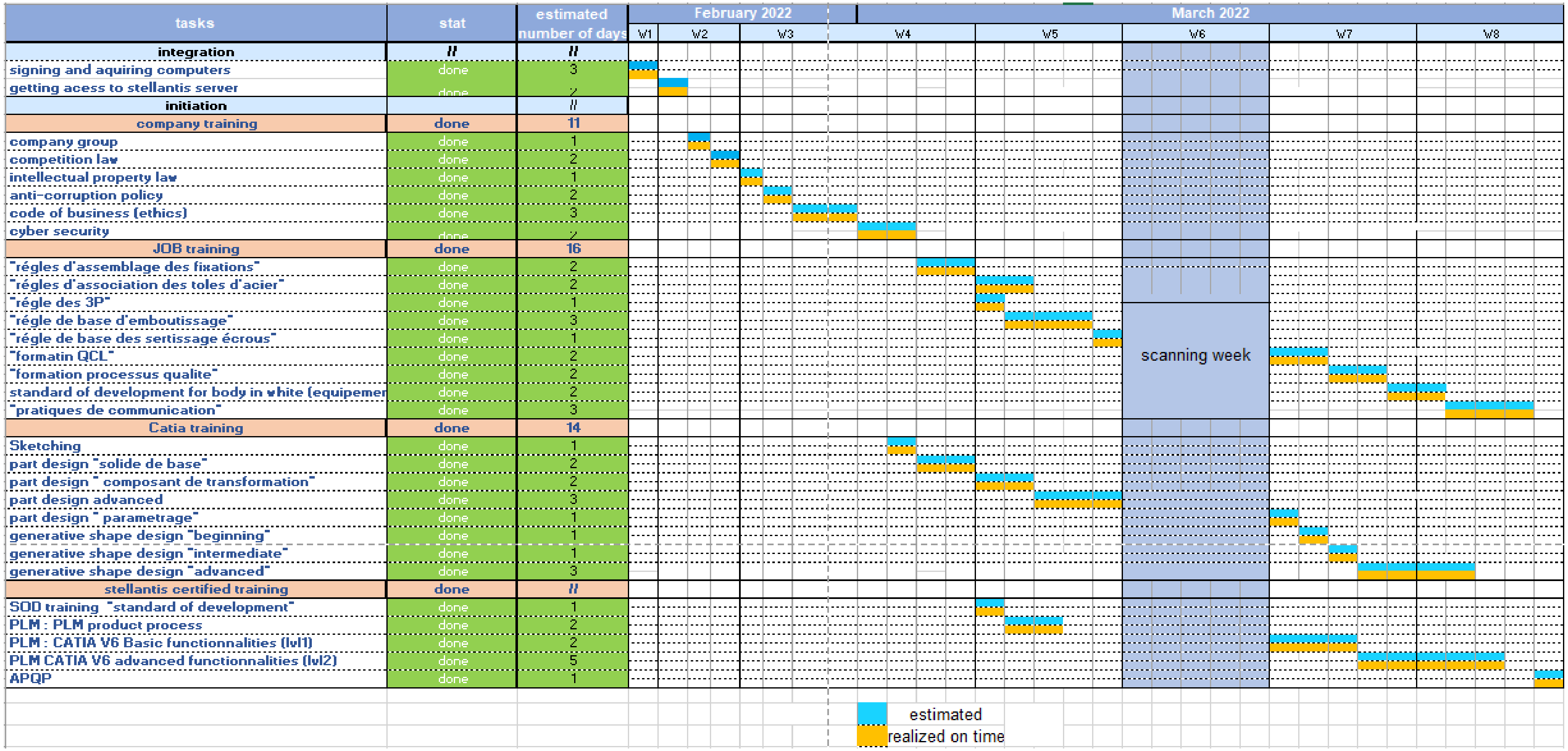


Figure 16: Post Planning.

Integration:

The acquisition of our equipment (computer and accounts, etc.) took almost 3 days due to the arrival of many trainees, the access to the STELLANTIS server took 2 days since the contract must be verified through STELLANTIS.

Initiation:

- Company training: includes all the requirements for a safe and comprehensible environment at MG2.
- Job training: includes all the requirements necessary to fully understand the context of the work performed within the MG2.
- CATIA training: a set of exercises that has helped interns raise their level in the CAD SYSTEM CATIA
- Stellantis certified training: (optional), a series of training courses designed to help interns understand the PLM work process.

Section II: Standard of Development (SOD)

The SOD is the group's guideline describing the project milestones and related expectations, the overall logic and the main stages of the design process, development and industrialization of a new vehicle, module, or component. SODs of the company considered tools for company's competitiveness.

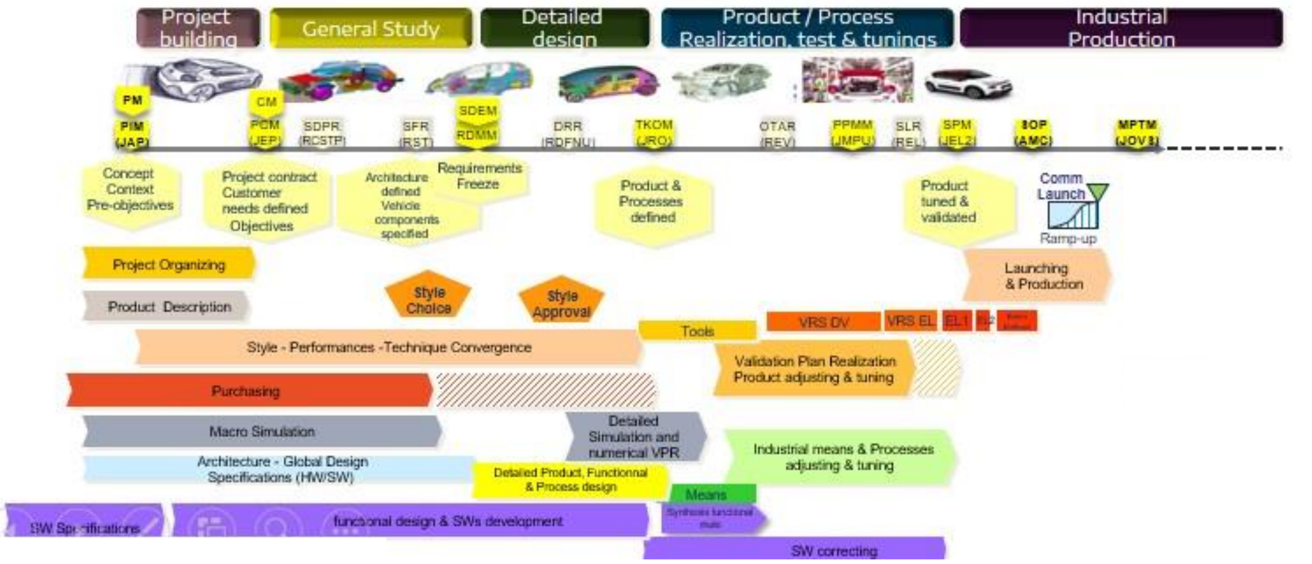


Figure 17: Standard of Development of Stellantis.

Milestones:

- ➢ Each project phase starts or ends with a milestone.
- ➢ A milestone is defined to check project maturity and allow to go on.
- ➢ A milestone is Quality gate (which means that a milestone assessment is required).

Reviews:

- ➢ A review is planned inside a given project phase (at main project events)
- ➢ A review is defined to check project maturity.
- ➢ Quality assessment is optional.

Section II: CATIA Training

The following rules are some of the good practices we learned during this internship. They are set in order to avoid errors in the design process and make it easier for starting engineers to understand the logic of creating the parts.

Organization of the specification tree

-Create several unordered Geometrical Sets. (Input data DE, Design, Finished part).

-To improve the clarity of the tree and help with understanding:

⇒ Explicitly rename elements.
⇒ Create groups of elements.

-Respect design standards and tolerance of surfaces.

-Delete unnecessary elements in the "CATPart".

-Create surfaces with history to ensure traceability of the modifications.

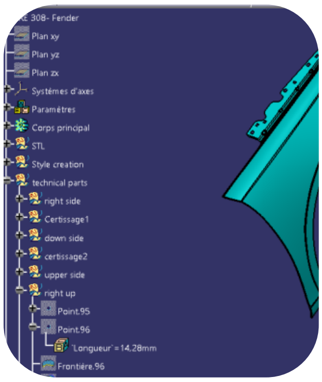


Figure 18: Organization of the specification tree in Catia.

Quality control of the geometry during development

⇒ Create and verify the tangency and curvature continuities.
⇒ Make the drafts and field with the appropriate features and not within the sketch.
⇒ Conformity: smoothing / correcting / organizing (placing prepared input data in "sets").
⇒ Apply the surface analysis tools (Surface Connection Analysis, Curve Connection Analysis, Draft Analysis, Curvature Analysis, Curvature Analysis).
⇒ Run CATDUA on the model.
⇒ Finish by creating a thick surface.

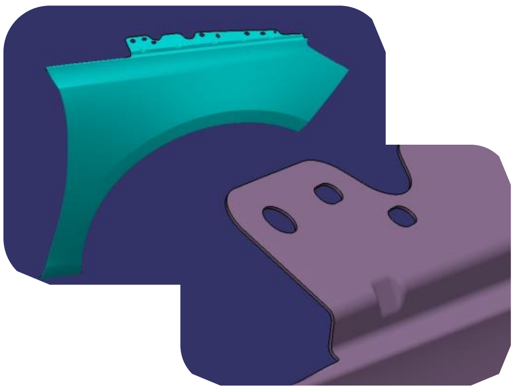


Figure 19: Tangent continuity & tick surface verifications.

Organization of Input data (DE):

To organize and structure the work, each data (input data- process- conception- final surface- surface quality control) should be in a unique geometrical set.

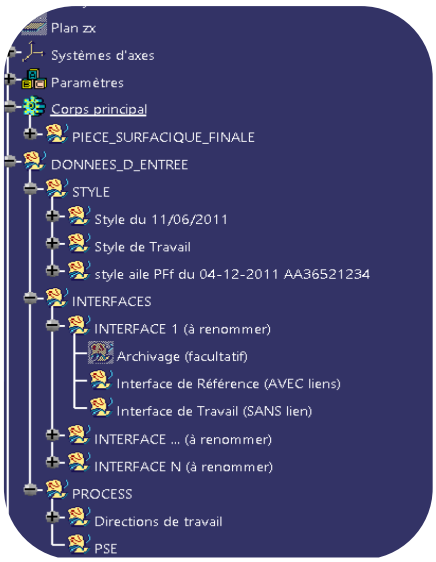


Figure 20: Organization of Input data in Catia.

Basically, the original model is subdivided into 5 subparts, each of which groups construction elements according to their functionality and role for the integrity of the part.

Figure 21: Subparts of a model in Catia.

Conclusion

The focus of the training is to provide the trainees with basic rules of the company and to introduce them to the working environment, which is the context of this chapter. In the following chapter we will detail the general context of the project.

Chapter III

State of the Art

In this chapter we will present bibliographical research on all the information We are going to need to achieve our project.

Introduction

in order to have a comprehensive insight into the environment surrounding our project, state-of-the-art research was necessary, in which we looked for all data that would be relevant to our project, and that could be useful to understand its environment.

This data includes the product development processes that we could follow, an overview of the automotive industry, a thorough research on the BIW, since it is the main components of our department, a thorough examination of the fenders and styling since it is one of the requirements that we have to respect the most in our project, an overview of reverse engineering and 3D scanning, and finally a look on the tools and problems of inspection.

3.1 Product Development Process

The more structured the work on a project is, the more value it will produce and the more comfortable the work on it will be. the development of a product or a project usually follows a certain process that guarantees to some extent its success, depending on the commitment of the project developer to work and follow the chosen process.

The following are some of the processes that have been suggested to us in this project since they relate to our project to some degree.

3.1.1 Ulrich and Eppinger's Process

Starting first with Ulrich and Eppinger's process, which is summarized in 6 major steps as shown in figure 22,

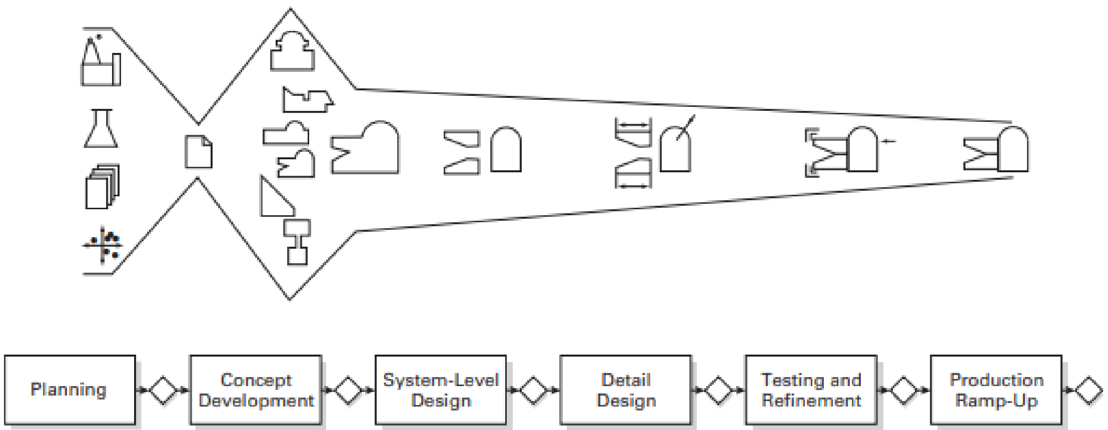


Figure 22: Product design and development process of Ulrich and Eppinger.

3.1.2 RE in Product Development Activities

The process presented in Figure 23 is a part of a PhD thesis presented by Mr. Akerdad, it shows the inclusion of reverse engineering in the product development process.

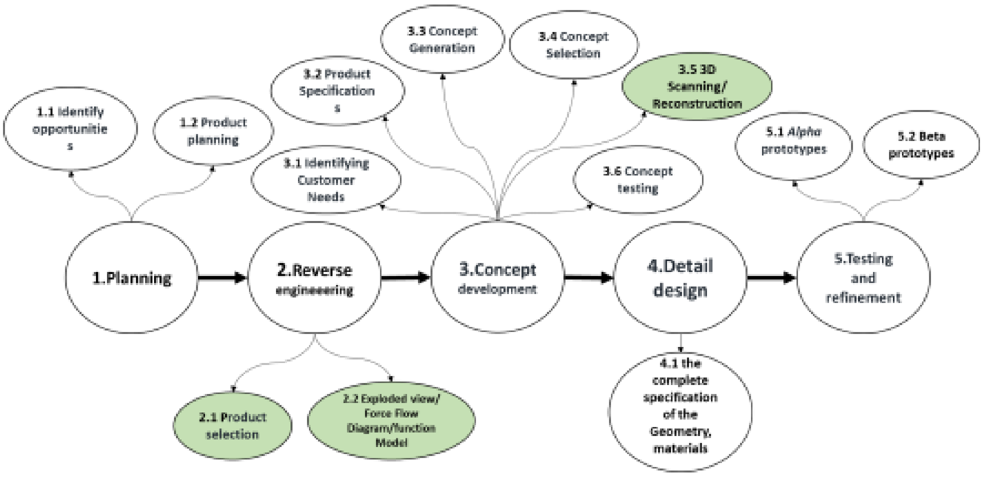


Figure 23: New Product development process including reverse engineering activities. (M. Akerdad)

3.2 Automotive Industry

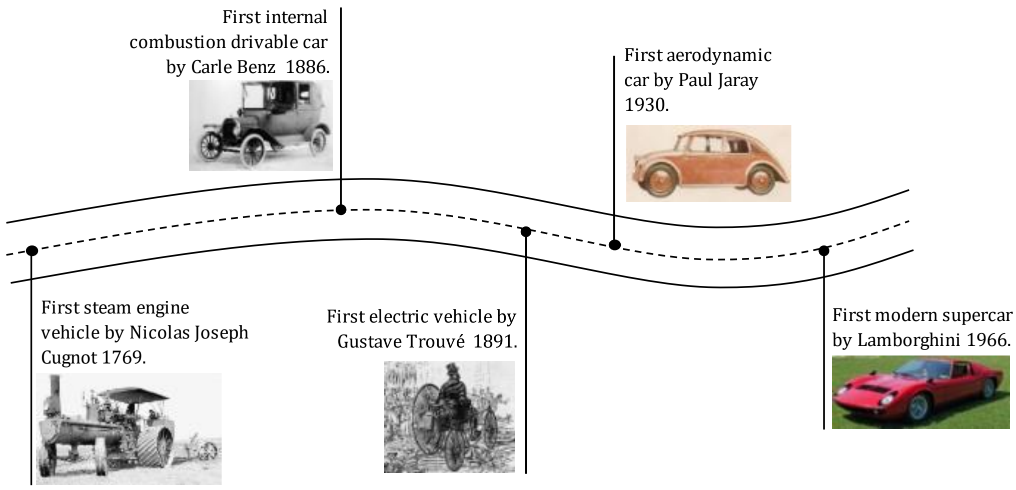
The automobile industry, and in particular the invention of the vehicle, was a world-class invention at the end of the industrial revolution. While many understand the basic function of the car, few know the actual life cycle of this invention provided by the developing company.

3.2.1 What is Automobile?

Automobile, byname auto, also called motorcar or car, a usually four-wheeled vehicle designed primarily for passenger transportation and commonly propelled by an internal-combustion engine using a volatile fuel.

3.2.2 History of Automobile

We note the main landmarks which marked the history of the automobile:



3.2.3 Types of Automobiles (for the general public)

Generally, there are three types of vehicles:

i. passenger vehicles

Vehicles intended for the public, and which are the only ones to bear the name of automobile.

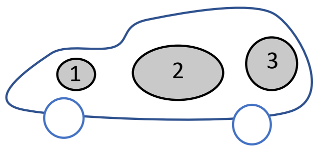


Figure 24:Schematic of passenger's vehicle.

1: engine's compartment

2: Passenger's compartment

3: luggage's compartment

ii. utility vehicles

Vehicles intended to transport goods or many people, or which have an industrial purpose.

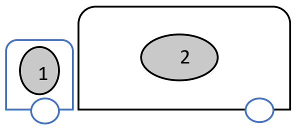


Figure 25: Schematic of utility vehicle.

1: driver's compartment

2: utility specified compartment

iii. light vehicles

vehicles with less than 3 wheels.

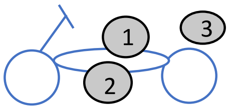


Figure 26: Schematic of light vehicle.

1: driver's compartment

2: engine's compartment

3: luggage's compartment

3.2.4 Principal Function of an Automobile

From the consumer's point of view, the overall function of an automobile is to transport the user from point A to point B while maintaining a certain level of comfort and safety.

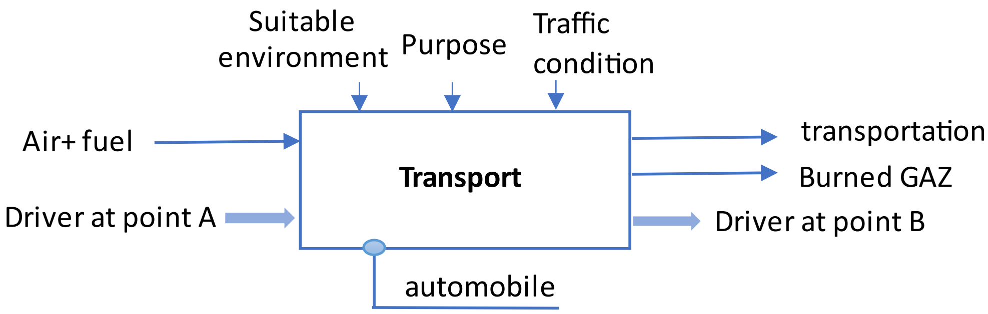


Figure 27: Principal function of an Automobile.

3.2.5 Major Components of Automobile

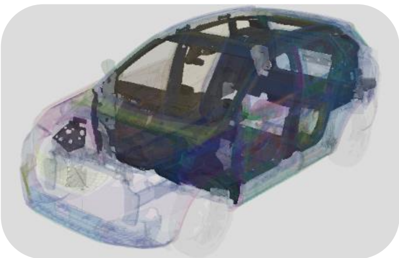


Figure 28: Visualization of frame and body.

The body (BIW + Closures): the use of different and separated frame to which the body structure is attached.

The interior components: englobes dashboard, seats, and variety of accessories.

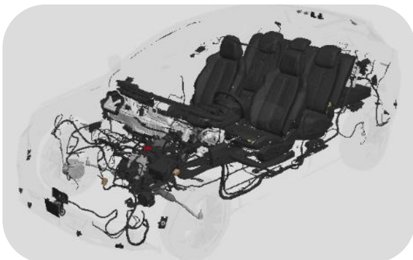


Figure 29: Visualization of interior equipment.

Figure 30: Visualization of the transmission system.

The transmission system + ground contact, transmits power developed by the engine to the wheels of the vehicle.

The engine: the source of the motive power to an automobile. its power determines the working of the automobile, and same its efficiency determines the efficiency of the automobile. it can be a spark-ignition engine consuming petrol or compression ignition engine using diesel.

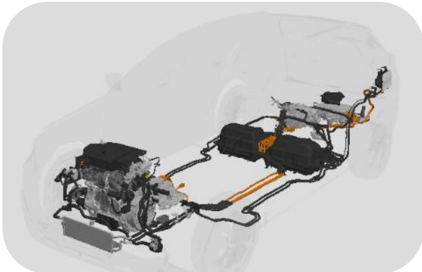


Figure 31: Visualization of engine.

3.2.6 Life Cycle of Automobile Followed by Stellantis

Vehicles and their components at Stellantis follow a life cycle that encompasses the vehicle from its conception to the withdrawal of Stellantis from their repair.

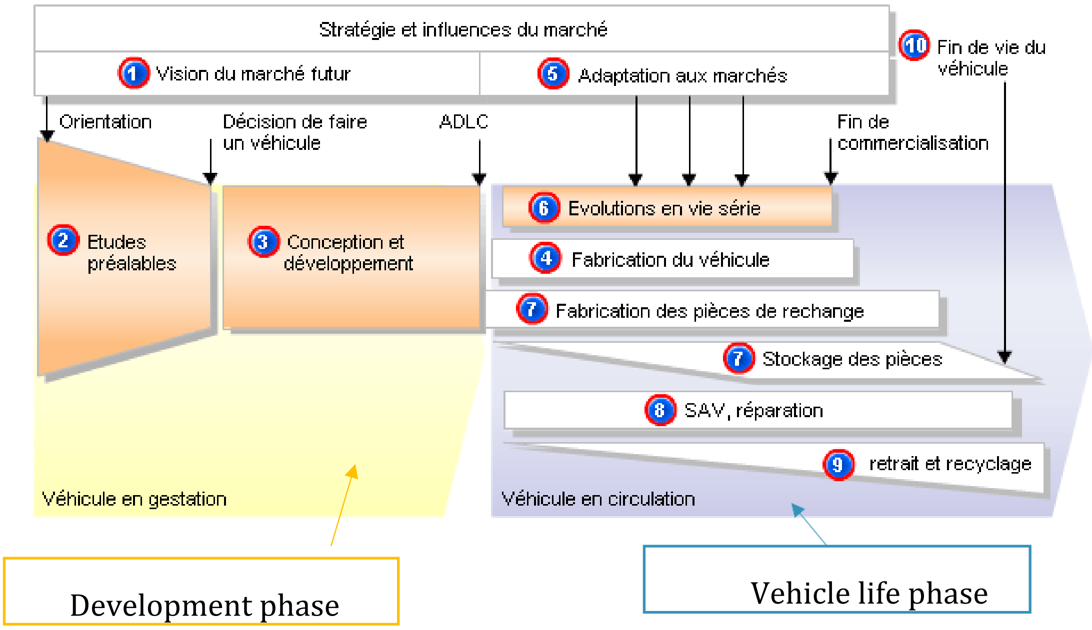


Figure 32: Life cycle of an automobile followed by Stellantis.

This life cycle includes two phases, as shown in Table 1.

Table 1: Steps Automobile Life Cycle Followed by Stellantis.

PHASE	STEPS	DESCRIPTION
Development	Market Strategy	Identification of trends over the past 5 years to better predict the best direction for the preliminary design phase studies.
	Preliminary Study	The identification of innovative concepts that could be incorporated into the vehicle design.
	Design & Development	The first part of this stage is the design of the vehicle, then a detailed definition of the functionality is performed, followed by the manufacturing process, and finally the commercial launch of the vehicle.
	Vehicle Manufacturing	Implementation of a manufacturing line

Vehicle life	Market Adaptation	Market study to better adapt the current design to make it more competitive with the competition and increase its profitability.
	Evolution of usual life	Application of the adaptation found industrially directly to the implementation of the manufacturing
	Manufacturing of spare parts	Manufacture of spare parts to meet the needs of repair shops, even after the end of the production line.
	Customer service, repair	Implementation of an after-sales service to ensure repairs to customers.
	Recycling	In order to respect the standards and constraints, Stellantis group offers several options to get rid of dangerous parts through the GIE inter-construction.
	End of life of the vehicle	After ending the manufacturing line, and ensuring a low number of vehicles in circulation, the group decides to stop the manufacturing of spare parts.

As we have seen before, the car includes many elements, our study will mainly focus on the body of the car, since it represents the environment surrounding the center of our project, namely the fender.

3.3 Body In White

BIW stands for **Body in White**, which is a stage in the automobile industry where the body shell structure of a car and its metal components are wielded together before painting.

The reason it’s called white is because in the early years of car industry, the manufacturers kept the white color before assembling the rest of the components to give the customers the chance to choose the color of their cars themselves, now the term remains the same and refers to the welded sheet metal structure.

Figure 33: Body in white (with paint) of Peugeot 308.

3.3.1 Key Criteria of BIW

- To be strong and stiff.
- To have low weight material.
- To be corrosion resistant.

- To be aerodynamic while having good appealing structure.
- To have sufficient space to support:
    * Interior parts such as seats, dashboard….
    * Exterior parts such as bumper, fenders, mirrors….
- To be able to protect occupants as well as pedestrian in case of an accident or roll over.
- To be as comfortable as possible.

3.3.2 Types of BIW

There are generally two types: the Monocoque structure, and the Body on Frame structure.

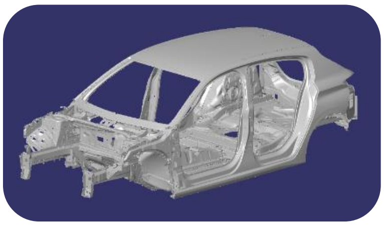


Figure 34: Monocoque BIW.

<u>The Monocoque structure:</u> chassis is inbuilt with BIW itself and there are no separate chassis, it is also used for all passenger cars including our case study; the Peugeot 308; which improve the safety of the passengers.

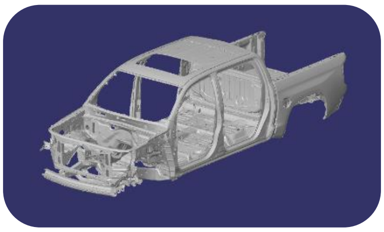


Figure 35: On Frame BIW.

<u>The body on Frame structure:</u> the body is mounted on a separate chassis, it’s generally used in utility vehicles; buses, trucks…

3.3.3 Different Components of BIW

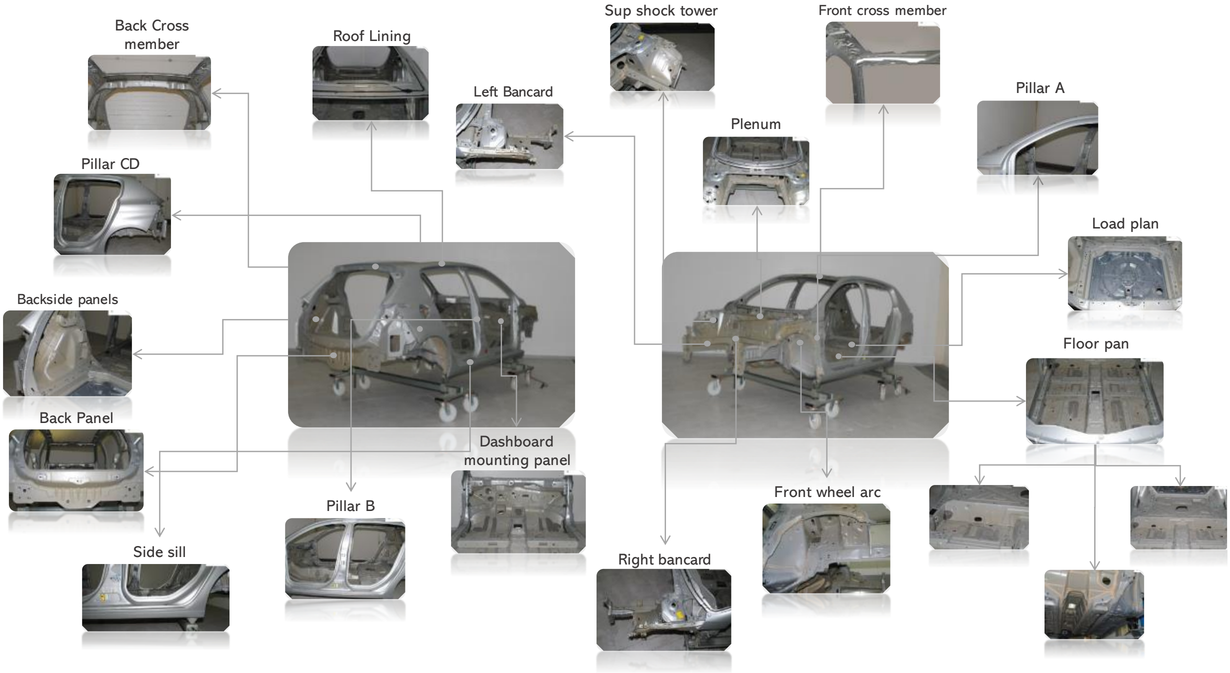


Figure 36: all the Peugeot 308 BIW components. (Stellantis)

3.3.4 BIW Material Properties

Figure 37: Carbon Fiber Monocoque of Hispano Suiza Carmen.

Automotive sector is the most demanding and competitive sector with continuous technological development. This development has led to the introduction of new materials in BIW such as aluminum, carbon fiber, polymers etc.

The steel BIW was generally favored by the industry, but in today ecological awareness, the rising fuel prices and the high cost and scarcity of materials have pushed the automobile industry to become driven by light weighting all their products by using less or alternative materials for their construction; A chassis made of Aluminum could reduce the weight by 30% without reducing the strength. materials such as aluminum, or composite for high end cars, which will become popular for low end vehicles as well in the upcoming years.

Multimaterial Space Frame

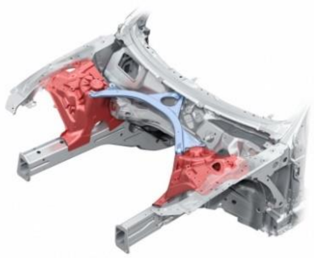


Figure 38: forward section of Audi.

A The Audi, for example, is a great case in point as it has further improved its bodywork by using the multi-material space frame (MSF), which is a combination of many components such as aluminum, steel and fiber reinforced polymers (FRP). This advanced body type has already been introduced in the A7 Sportback, which showed great results in terms of fuel consumption and CO2 emissions.

Another great example is the Audi R8, which weighs only 1454 kg thanks to its MSF structured body, the body weighs only 200 kg, which is incredibly less than older versions and provides a power to weight ratio of 2.55 kg/hp.

Figure 39: Frame of Audi.

Table 2: Material Properties

Properties	Steel ASTM A36	Aluminum 6061	CFPR
Density (g/cm^3)	7.85	2.7	------
Young's Modulus	200	69	220-240
Tensile strength GPa	0.4 to 0.55	0.29	3.5
Elongation %	20%	17%	1.7%

Table 3: Advantage and Disadvantages of Each Material.

materiel	advantages	disadvantages
steel	• Amenable to high-speed fabrication technologies. • Inexpensive material. • Good engineering properties; tailorable • Valuable offal - "Waste" • has market value • Many suppliers, largely indigenous	• Relatively high-density • Corrosion • necessitates expensive processing
aluminum	• Different forming techniques • Less dense Compatible with current steel practice • More recyclable, in principle, than RP/C • Glut on the market • Corrosion resistant	• Different forming techniques • Less stiff • Just different enough to be difficult • Nastier primary extraction processes • Relatively expensive • Incompatible with steel fastening
CFDR	• Parts consolidation opportunities • Primary / secondary weight savings • Low investment costs • Increased design flexibility	• Materials and labor-intensive process • Long cycle times • Non-traditional manufacturing technology

3.3.5 Challengers that Face BIW Designers and Manufactures

3.3.5.1 Lightweight Construction

- The use of lighter materials or composite ones will result in improved fuel efficiency.

- The vehicle body influence its price, both directly and indirectly; directly since it makes almost 40% of the car's cost, indirectly since it influences the life of the vehicle which also influence the price.

3.3.5.2 **Manufacturing Process**

- Minimize the operations steps to obtain the final product.
- Reduce the waste of materials
- To make the process flexible
- Selection and adoption of more new manufacturing technologies for simpler and effective operations

Engine and chassis units are easily replaceable, but serious damage to the body means an end to vehicles life.

3.3.6 Manufacturing Process of BIW

BIW refers to the stage in automobile manufacturing in which the vehicle body sheet has been assembled. This means that the vehicle's body frame has been joined together including doors, hoods, trunk, bumper, and deck lights. At this stage all the chassis assemblies are welded together before painting.

Figure 40: Process of manufacturing for the BIW.

The BIW manufacturing process consists of 5 major steps as shown below. The techniques used in each step may vary from one manufacturer to another, as well as the manufacturing time.

First phase: Creating the Parts:

Starting with a roll of steel sheet and cutting it into small sheets or "blanks", the Manufacturer can start stamping all the parts needed to make a BIW. There are several techniques used to make all different component of the BIW.

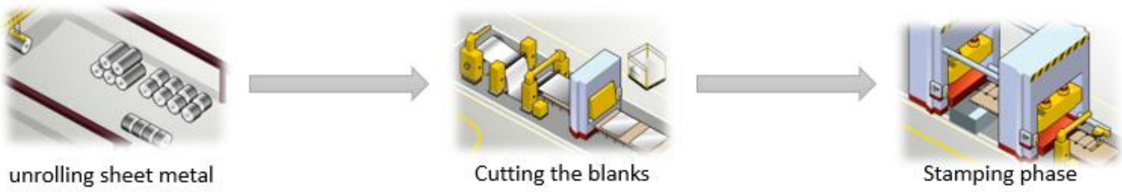


Figure 41: First phase in the manufacturing process.

Stamping:

As previously mentioned, stamping is commonly the first step in the manufacturing of a BIW parts, it consists of 4 phases:

First, **the heating phase,** since BIW parts are manufactured by hot stamping, the blank must be heated to 900/950°C and then quickly placed on the press, in an order not to lose heat.

The blank starts to deform on the blank holder because it can easily be deformed due to its heat, the die presses the blank on the blank holder, to guarantee the shape of the blank. Then the die presses on the blank onto the punch (in this part, the volume and shape are controlled by the die press and the punch).

The phase of spring back and trimming, Spring back should be done first because if it is done after trimming, it can change the shape of the part.

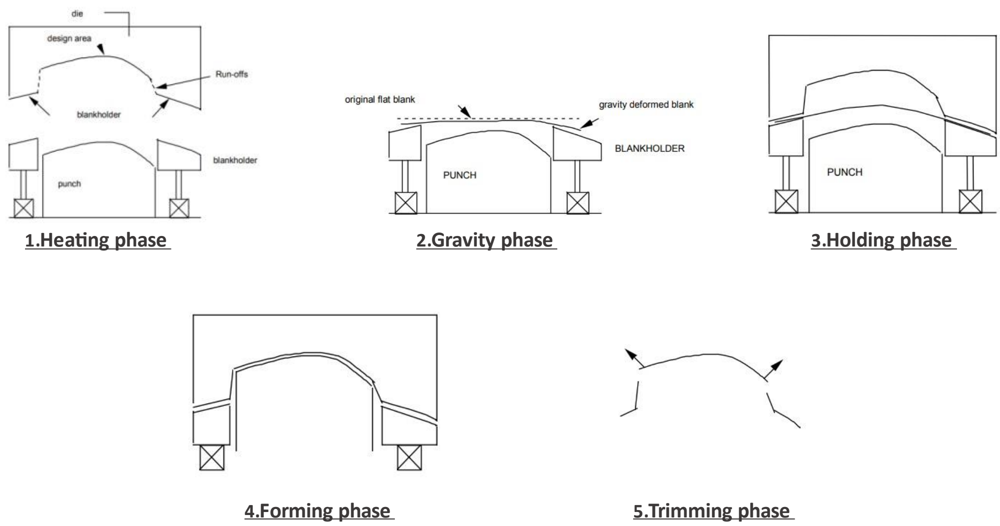


Figure 42: Different phases of Stamping.

The stamping process can be influenced by many variables that affect the result of the procedure,

The Geometry of the Part

In the second stage of forming the geometric details (reverse drawing), some small problems may arise from parts that are far from the die, which are mainly influenced by the design of the part.

The Geometry of the Tools

In contrast to the influence of the parts geometry, the tool geometry can influence the shaping surface.

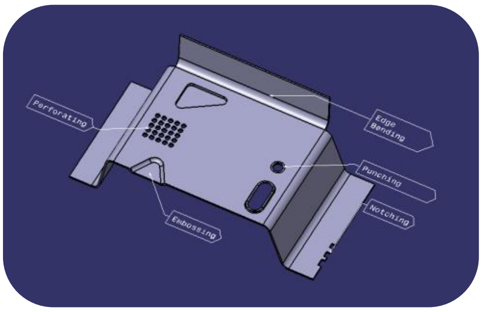


Figure 43: Different operations of Stamping.

Hemming:

In the automotive industry, Hemming is a Manufacturing procedure used to join two sheet metal panels (steel or aluminum) by folding the edge of the outer panel over the inner panel. therefore, hemming is considered by many manufacturers as a joining method, however, it also provides an aesthetic appearance to the sheets and eliminates some of the hazards associated with sharp-edged panels.

the advantage of this method of joining is that it provides a clean, compact joint, although it is not as strong as a welded joint, but it is possible to combine hemming with other assembly methods, such as gluing, which gives the joint additional adhesion and increases its strength.

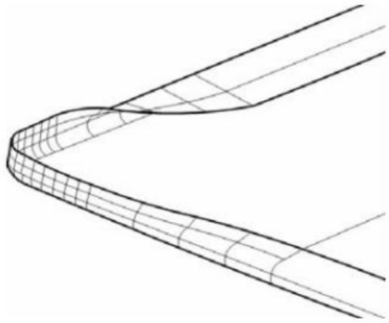


Figure 44: Hemmed edge of the fender.

there are many processes to follow to create a hem, but the most well-known process involves three steps, edge trimming, pre- hemming, and hemming.

The first step occurs in the stamping phase, which involves turning the outer panel at a 90°-degree angle(figure). The pre hemming stage is a sub process that differentiates the different hemming processes, in this stage the panel can be moved in a horizontal, vertical, or linear path, at an angle, in this stage we can shape the overhang of the final stage which means that this stage is a critical stage, the operations done here are irreversible. Finally, the last step is the same for all processes, it depends on the final shape, the final hem steel should be as close as possible to the normal of the final hem surface.

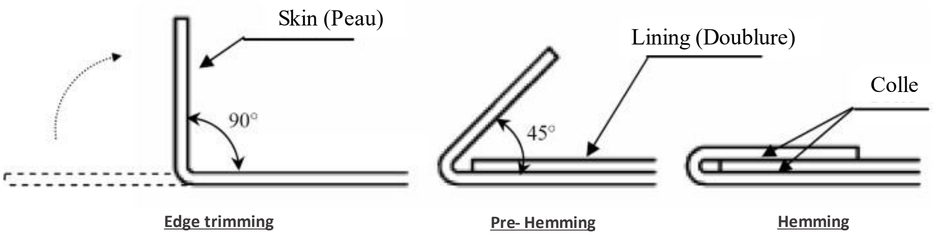


Figure 45: Different operations of hemming.

Second phase: Car fitting

After the stamping stage, the resulting parts are a puzzle waiting to be assembled, in this heavily automated stage, the assembly and overall manufacturing begins.

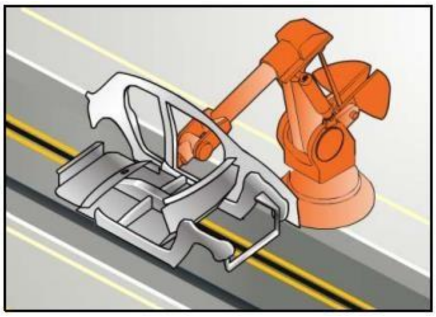


Figure 46: car fitting- assembling the side of the body.

Spot Welding

Generally, the BIW is assembled by resistance spot welding (RSW), Because it is fast, reliable, and economical, however numerous design considerations can affect the quality and cost of the weld, among which is:

- Weld size, number of welds, and their location
- The materiel used (since low carbon is the most suitable (the high carbon steel forms hard welds which are brittle and could crack), and there is aluminum, tin and zinc which all require special preparation inherent to the coating metals.
- Accessibility to adequate spots should be considered.
- Positioning, it is better to choose the same spot weld size and distance between welds.
- The difference of thickness between the sheet metals parts, ideally, the two must have the same thickness, but if two different thickness were to be assembled, a central nugget can be created by using a larger electrode on the thicker member.

*If the ration of thickness goes above 3 to 1, spot welding would become too difficult, and another welding method should be considered.

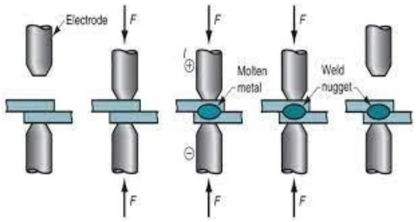


Figure 47: laser welding process.

There are also other welding methods that are considered and used such as:

- MIG and TIG welding (metal inert gas and tungsten inert gas welding).
- Projection Welding.
- Laser welding.

Third phase: Painting

Initially, the BIW receives an anti-corrosion treatment finalized by the joint sealing, then it receives a layer of paint called primer, on which is placed a layer of lacquer, this last layer is what gives the vehicle its final color.

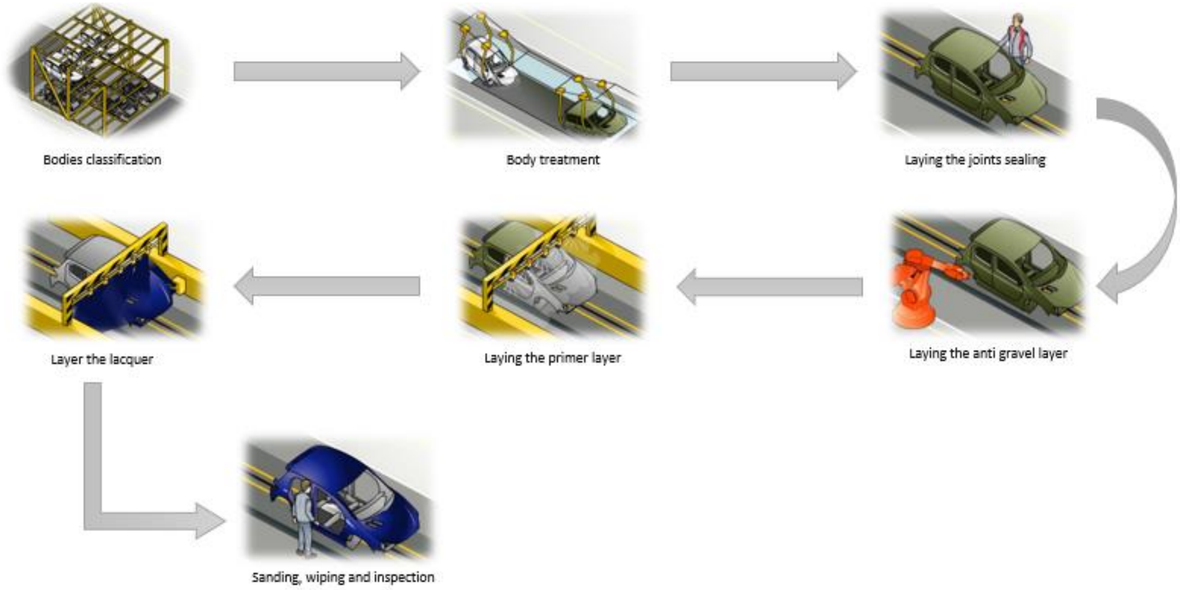


Figure 48: Painting steps of the BIW.

Forth step: Body Assembly

After removing the closures to have easy access to the assembly points, the successive reception of the car's equipment at the BIW is done.

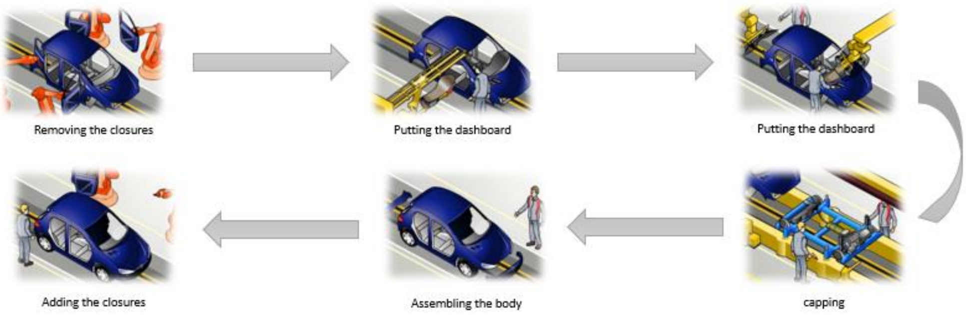


Figure 49: Assembly steps of the BIW.

Fifth step: Control operations

during this stage, the general inspection of the car is carried out to ensure that everything is perfect, the vehicles that comply with the safety margins are out for delivery.

Figure 50: Inspection steps of the BIW.

3.4 Fenders

Fender is the US English term for the part of an automobile (vehicle body) that frames a wheel (the fender side). Its primary purpose is to prevent sand, mud, rocks, liquids, and other road spray from being thrown into the air by the rotating tire.

When the vehicle is moving, tires pick up all sort of things such as dirt, stones and hurl them in all directions. Fenders are basically present to prevent injuring pedestrians and constrain the motion of these particles.

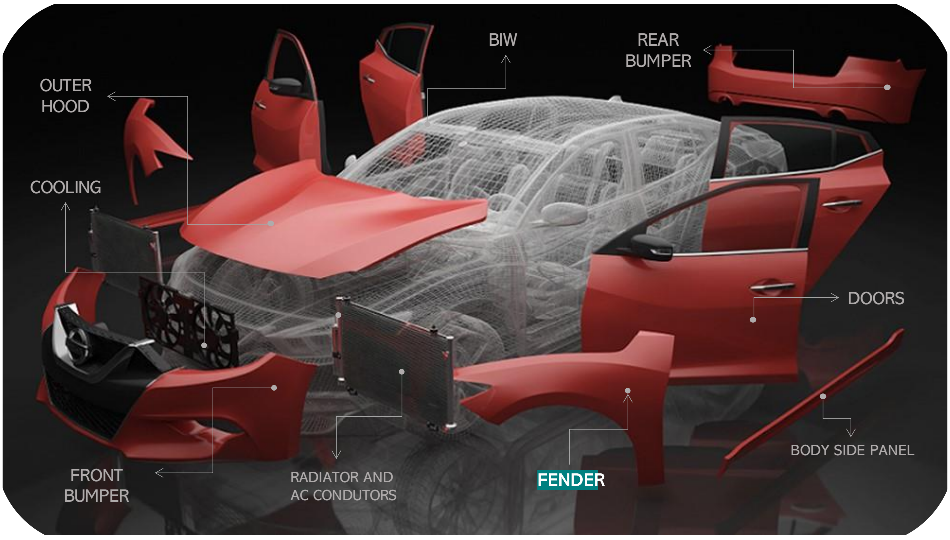


Figure 51: Fender's location in vehicle (Nissan Atima).

3.4.1 Types of Fenders

There are two types of fenders, and they are classified based upon the area covered:

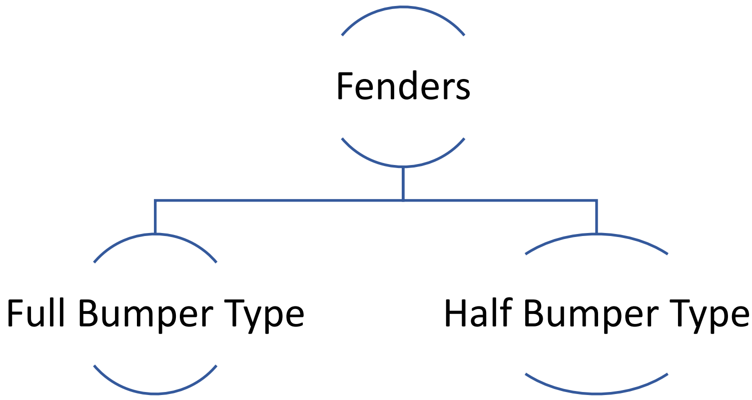


Figure 52: Types of Fenders.

Full Bumper Type

Figure 53: Full Bumper fender.

Full Bumper type is traditional type of fender which is manufactured using more materials. This type is used in old design of automobiles, it has some disadvantages such as increasing the overall weight and thus reducing performance. The manufacturing and treatment is also relatively longer due to it having more surface.

Half Bumper Type

Half Bumper type is the modern design <here less material consumption is observed. So, productivity increases by reducing the size of the blank and thus providing more performance. The treatment is also relatively low compared to the full bumper type.

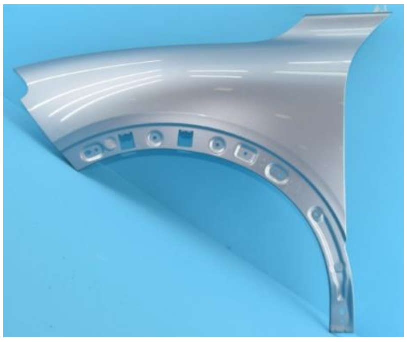


Figure 54: Half bumper fender (DS3).

3.4.2 Aesthetic Appearance

Most people consider fenders to have a strictly aesthetic function; They are a part of the overall construction of the vehicle but only to give it a more finished look. Or are they?

Fenders have a very practical function, which is not that obvious from their name.

The fenders serve one main purpose – to prevent the tires from spreading dirt, mud, little stones, and other road debris. Without the fenders, a small stone could easily be thrown back at another car and crack its windshield. And your car will get completely messy from all the road spray. So, this is another spin to their aesthetic function, is it not?

Back in the day the wheels stood more to the side of the car, and without the fenders, all the mud would get all over the car and over the people in there as well because most vehicles back then didn't have roofs.

With time, the build of the vehicle got a bit wider overall, and the fender became an integral part of the overall frame. It does not stick to the side any longer, but its function is largely the same. However, due to its nature, it can get rusty, especially if the paintjob is not done properly. Small cracks here and there can have water in them and then rust develops.

It also contributes to the overall style of the car; many new models have incorporated many designs to further include the fender in the impression of the car.

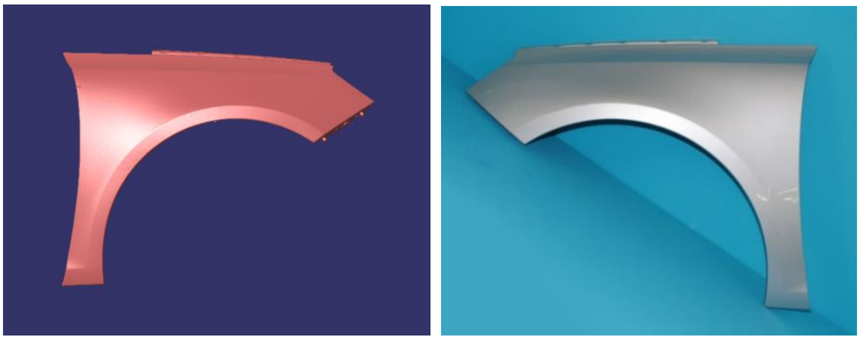


Figure 55: Style of the front fender (scan- physical).

Styling

Although many people have regularly seen stylists' sketches appear as a new car concept is launched, the work of the automotive stylist is still little understood. As Armi said in 1988, who had an interesting insight into how stylists think and what they do, "automotive styling is among the least understood of the commercial arts."

- **Their Purpose:**

The emotional impression due to the shape of the car makes as great an impression on the buyer as the fulfillment of the functional requirements, which greatly contributes to its commercial success, therefore, to succeed in the stage of creating this positive emotional impression, the stylist must demonstrate great efforts. from 2D sketch to 3D modeling, the job of the stylist is to create quality.

- **Their Challenges**

as said before, the work of the stylist is very important, in this regard, the development of a vehicle is as difficult as solving a very large equation system.

While the stylist's work is purely qualitative, engineers have a purely quantitative work that frequently opposes the stylist's work, for example, the stylist aspires to lower the bonnet of the car for visual reasons, while engine developers think the opposite, moreover, the development of the body always requires additional packing space for the interior, Which would also make it difficult for stylists, these contradictions that cannot be quantitative for the stylist, make their work more difficult, the opposite development goals in the interdisciplinary process of automotive development have their own impact on the styling process.

- **Inspiration**

Stylists are often inspired by certain principles; we present here a selection of the main ones:

  - Interpretation of human emotions:

Figure 56: Nissan townpod

This first principle is the most difficult to implement, it involves using human emotions to create a style.

if you force yourself to smile when you are unhappy, you will feel happier, stylists exploit this phenomenon, creating cars that have a kind of human expression, the Nissan Townpod perfectly represents this interpretation since their design is the reflection of a smiling face.

- Imitation of living organisms

Figure 57: Volkswagen Beetle.

This principle is by far the most well-known.

The term Bionics, which is a combination of biology and technology, is the interdisciplinary study of the surrounding nature for technological improvement, engineers seeking to improve their prototypes often find solutions to specific technical problems in nature, by comparing the shape, structure, engineers can adopt certain features if the design is compatible with their development goals.

- Branding and stylistic unity

Figure 58: Rolls Royce phantom.

also, great principles that reflect a certain respect for the brand's heritage, a company with a good reputation, good product quality and clean style, often respects its brand image, which represents both its best features and also works on the nostalgia of the brand enthusiasts.

- **Styling Phases**

The styling process includes many steps that the stylist must follow, from product planning; where the planning department studies the current market, the performance of the current competition, and whether the current tooling is outdated to either produce newmodels or replace existing ones; to the use of a ready-to-use 3D CAD system that can be utilized in the concept and simulation of the global performance of the model.

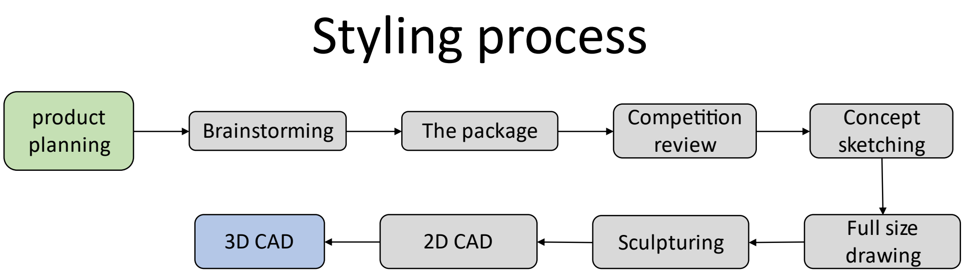


Figure 59: Styling process.

3.5 Reverse Engineering

Reverse engineering (RE) is the process used for discovering the fundamental principles that underlie and enable a device, object, product, substance, material, structure, assembly, or system through the systematic analysis of its structure and, if possible, its function and operation.

Although reverse engineering is most widely used for redesign purposes, it can be used for other reasons as well:

1. The product is no longer manufactured, or a manufacturer cannot be located
2. The original design documentation no longer exists or is inadequate
3. Incorporation
   - New design intent.
   - Additional features.
   - Redesigns for wear or modifications.
   - Updates to obsolete features.
4. To save research and development costs.
5. To better understand competitor products.

But the main object of RE is the analysis of an existing product (which can be software, a mechanical part, etc.) and to *produce a copy* or an *improved version* of it.

3.5.1 RE Process in Industry

In industry, the basic concept of producing a part based on an original or physical model without the use of engineering drawings is called Reverse Engineering (RE). Reverse engineering has changed from a skilled manual process to an engineering tool using sophisticated computer software and modern measuring instruments (VX Model, Catia V5, Geomagic Design X, 3D scanners …). So, the base criterion for choosing RE as a creation method is the absence of a digital 3D CAD model.

In this context, RE is the process of capturing geometric data from another object. These data are usually initially available in what is termed “points cloud” form, meaning an unconnected set of points representing the object surfaces. These points need to be connected together using RE software like Geomagic Design X, which may also be used to combine points cloud from different scans and to perform other functions like hole-filling and smoothing and repairing. in other terms RE goes from a physical product or system to a digital model convertible to computer-aided design (CAD) file (Figure 60-b), And that by utilizing the possibilities that lie within 3D scanning technologies.

Figure 60: 3D scan vs CAD model. (Creaform)

The Generic RE Process

Reverse engineering process is used to extract the data generation pattern, remanufactured products from the parts or raw mode. The following requirements need to be considered; the software structure, object-oriented development tools, data model, intelligent design, product data management, quality control and the application of multimedia technology; to achieve new breakthroughs, which truly enable the process of product design and development (PDP) to provide better and more efficient designs, analysis, management control, manufacturing methods, and other aspects of the environment and tools from the whole product (The reverse engineering process is shown in Figure 61).

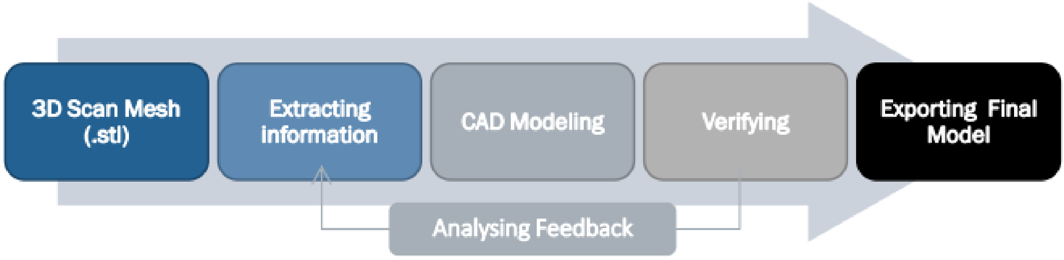


Figure 61: The Reverse Engineering Process. (Creaform)

These steps shown in the figure 8 illustrate the different phases in which the engineer takes the object from its physical state to a point cloud and transforms it into a CAD model.

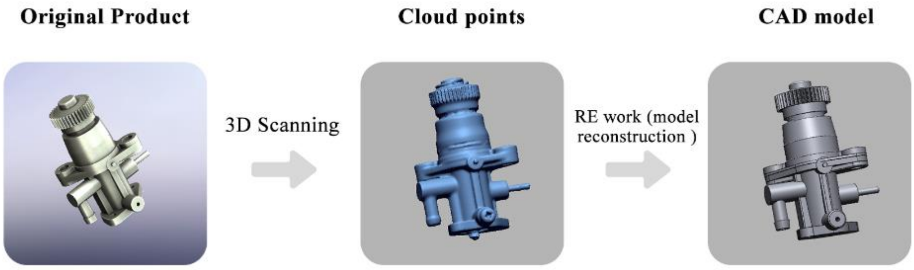


Figure 62: Physical-to-digital process. (Our source)

3.6 3D Scanning

The scanning phase consists of choosing the scanning techniques, preparing the part, and performing the actual scanning. The output is a 3D point cloud. 3D scanning is between the main types of digitizing processes which allow us to transfer real part surfaces to digital form.

Figure 63: The use of HandySCAN 3d for production of prototypes and samples of custom bike accessories. (Abm motorradteile)

The principle of digitizing is to scan points in space and having an output in RE software. There are several types of digitizing techniques that allow this transfer (Figure 60). Main types are:

- Optical
- Laser
- Contact
- Destructive

In machine industry, the fastest and most used are laser and optical 3D scan devices. These devices allow us to scan the shapes of the real parts with machine industry precision demands.

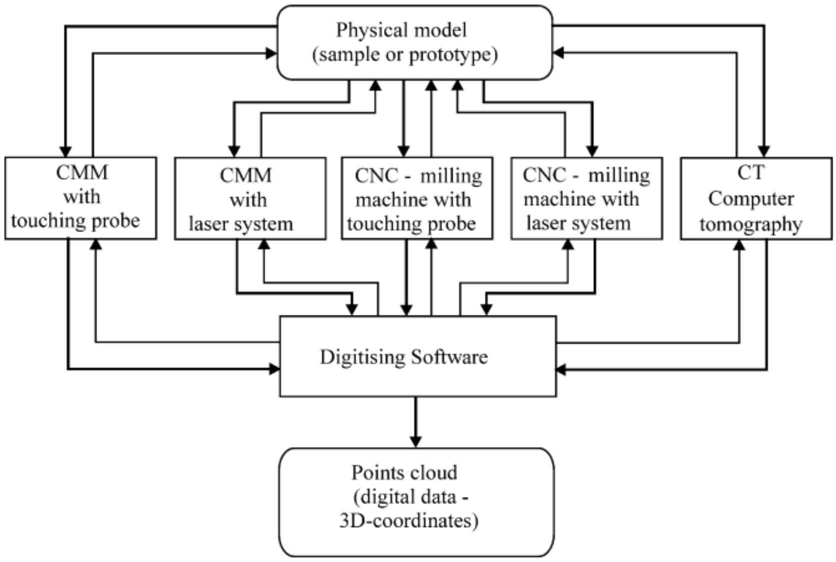


Figure 64: Digitizing techniques for the 3D-geometries and generated data.

The process of RE decrease to minimum with the help of 3D scanner technologies and the designer can transfer his design in few minutes to RE software (VX Model, Geomagic Design X, Geomagic for Solideworks, Solide Edge, Catia V5 …).

Engineered objects would normally be scanned using laser scanning or touch probe technology.

Contact Scanners

These devices employ contact probes that automatically follow the contours of a physical surface (Figure 65). In the current marketplace, contact probe scanning devices are based on CMM technologies, with a tolerance range of +0.01 to 0.02 mm. However, depending on the size of the part scanned, contact methods can be slow because each point is generated sequentially at the tip of the probe. the contact pressure limits the use of the contact scanners because soft, tactile materials such as rubber cannot be easily or accurately scanned.

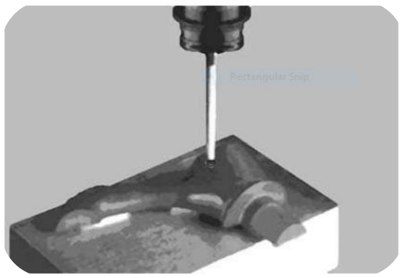


Figure 65: Contact scanning touch probe.

Non-Contact Scanners

A variety of noncontact scanning technologies are available on the market, which are technologies used for capturing data with no physical contact.

Noncontact devices use lasers, optics, and charge-coupled device sensors (CCD) to capture points data, as shown in Figure 67. Although these devices capture large amounts of data in a relatively short time, there are a number of issues related to this scanning technology.

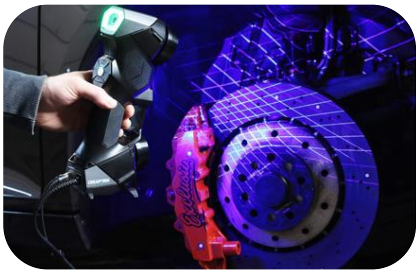


Figure 66: Optical scanning device process.

- The typical tolerance of noncontact scanning is within ±0.025 to 0.2mm.
- Some noncontact systems have problems generating data or describing surfaces which are parallel to the axis of the laser.
- Noncontact devices employ light within the data capture process. This creates problems when the light impinges on shiny surfaces, and hence some surfaces must be prepared with a temporary coating of fine powder before scanning.

3.6.1 3D Scanning Process

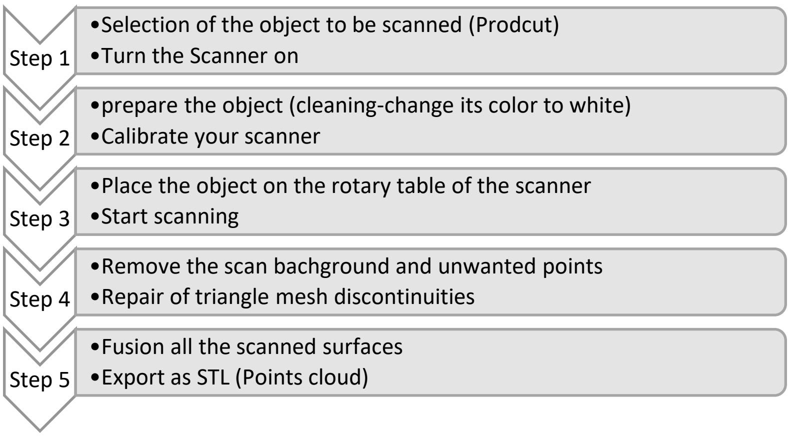


Figure 67: 3D scanning process.

3.7 Quality Control: Inspection (CAI)

Most companies are required to produce high quality products to survive and make their mark in the extremely competitive market. Quality control is not only a solution to produce defect-free products, but also a way to meet customer requirements, which enables the company to better respond to customer expectations and improve its profit perspectives.

Manufacturers of manufactured products need to adapt quality control applications in the manufacturing industry to achieve better quality.

While many manufacturing industries have already successfully implemented this practice, many still struggle to implement it effectively.

an inspection is one of the many steps in quality control, which links the final product directly to the first concept, here are some defects that should be checked while inspecting:

Table 4: Types of Checking and Defects

Types of checking	Defect type
Exterior inspection	• Alignment • Parts Gap • Fitting • Flushness • Part Mismatch • Model Mismatch • Missing Bolts/Clips • Scratches • Looseness
Interior inspection	• Parts Fitting • Parts Gap • Part-Model Mismatch
Paint inspection	• Dents • Lines • Air Bubbles • Chip off • Paint peel off • Under paint • Dust • Thin Paint • Tool Mark • Color Mismatch • Missing Paint
Functions inspection	• Lights • Door Glasses • Central and Remote locking
Engine Room Inspection	• Fitting of Engine parts • Oil Leakage
Physical Functions Inspection	• Wheel turning angle error • Speedometer reading error
Under-body Testing	• Looseness of parts
Track/Road Test	• Low Reliability and Robustness on rigorous road conditions
Shower Test	• Leakage in cabin or hood or boot

Our work will focus on the exterior inspection to verify alignment with the environment and model mismatch.

The use of 3D scanning technologies RE is certainly a big step forward, especially in additive manufacturing that relies on a CAD part for inputs, which is a result of the 3D scanning process. Ultimately, our idea is to use the scanner to inspect the post-production results and compare them to the actual design,

however, tolerance design, without which the geometric design can deteriorate the utility and functionality of the product, must be carefully observed throughout the process.

The consensus is that manufacturing parts that are exactly the same size as the design is impossible; thus, manufacturing two parts that are exactly the same is infeasible. In our case, we will compare the CAD of the scanned fender with an existing CAD (if available) and see how many points have exceeded the tolerance that we will determine.

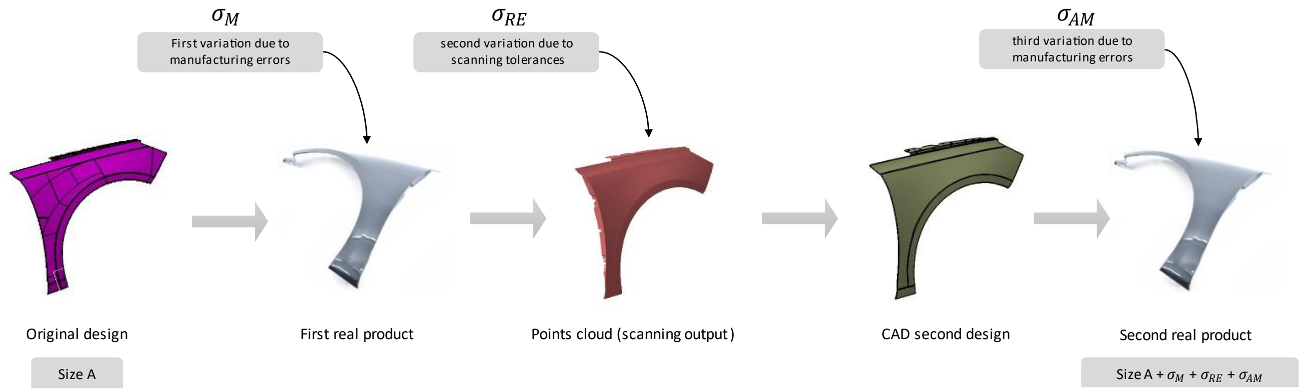


Figure 68: Process flow for product reproduction with error superposition. (Our source)

The anticipated problem with our inspection method is that we should take into consideration the different errors that occur during the application of the RE process, as can be seen in the figure above, if we take a fender with a size A mm, after manufacturing there will be some errors that will change the original size, moreover after scanning additional errors could occur plus the tolerance of our scanner, and finally other errors of the second manufacturing could occurs in prototyping.

which means that our margin of safety must be the sum of all the error limits, and our goal is to minimize these errors as much as possible

RE Workflow- SCAN to CAD to INCPECT

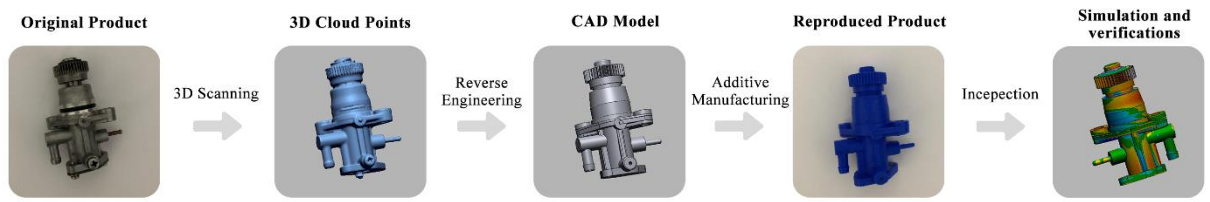


Figure 69:Reverse Engineering workflow. (Our source)

Conclusion

Using the research conducted in the state of the art, we shall create a database on which we will begin our project, in the next chapter we will introduce our project in detail and its planning and process.

Chapter IV

Project Description

This chapter focuses on describing the project in general and presenting the main goals as well as the process we were intended to follow to achieve these goals.

Introduction

In this chapter, a thorough and in-depth inspection of the project's objective is carried out in order to fully understand and take in consideration the purpose of this process,

we first established the retro planning of our work, then the process we will follow, and the different phases of our project as well as the different expected results of each phase.

4.1 Project Post Planning

In this step, we made a prediction of the amount of time required for each step of the process, while taking into consideration the side projects and training periods required for the work.

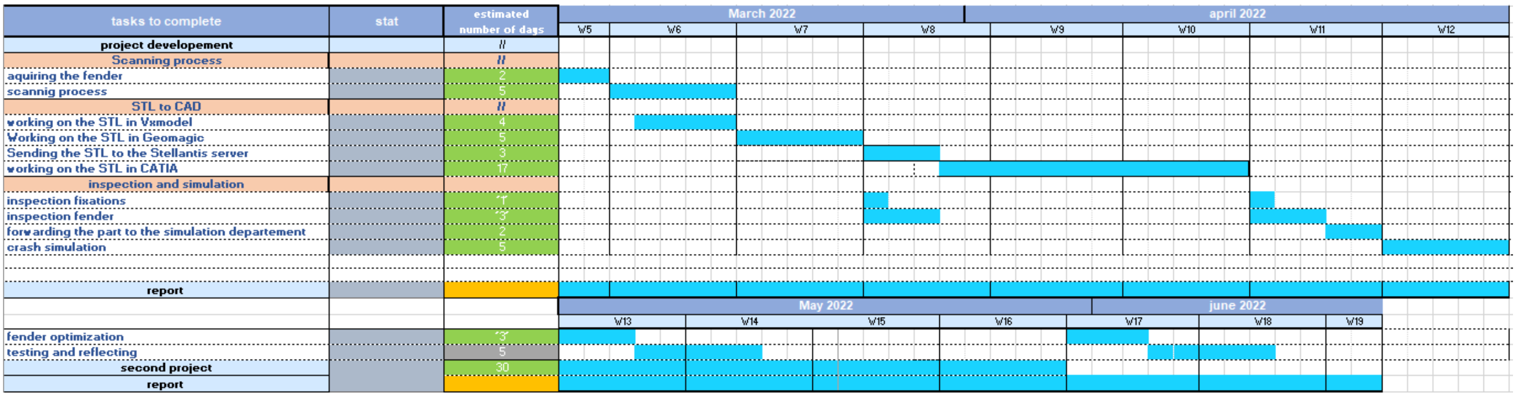


Figure 70: project post planning.

Our post planning includes all the necessary steps to carry out our project.

The actual deadlines are given in the appendix 1 where we explain the difficulty of the execution of each step.

4.2 Development Process

Based on the two processes we saw in stat of the art, and due to the fact that those processes are more effective in case of working on a product that requires a dismantling step and also includes different models such as the force flow diagram which would be difficult to apply to our case considering the large environment surrounding our fender. we proposed a new process as shown in figure below.

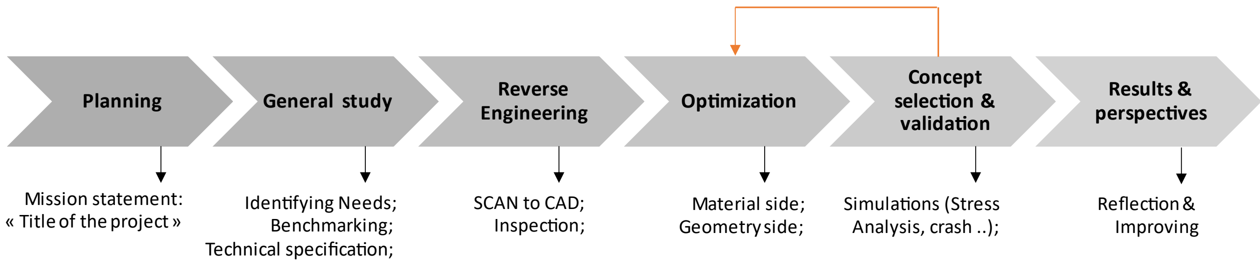


Figure 71: project development process.

4.2.1 Planning

The planning phase is the gate to the process. It precedes the project approval and launch of the actual process. In this phase we formulate the basis of the project and its goals. The output of this phase is a well formulated problematic, project title.

4.2.2 General Study

In this phase, we identify the customer's specifications and the environmental constraints of our part, the research done on this phase is critical since it determines the orientation of the project in general and builds a solid information base on it.

4.2.3 Reverse Engineering

This phase consists of 3D scanning the product to obtain a 3D cloud point, which can be transformed later to a CAD Model, then validating this CAD model using virtual inspection software, from easy and fast ones like Geomagic's deviation analysis tool or advanced ones like Polyworks inspector.

The goal of this phase is a validated CAD model of the scanned part

4.2.4 Optimization

Concept generation phase begins, having a parametric CAD model gives us the capability to change it easily, this phase is where the weak points of the model are being fixed, either by changing material or geometry of the part, taking into consideration the cost and feasibility.

the development of several concepts is necessary to have at least a diversity of options, (even if the first concept works, another improvement may have better results).

4.2.5 Concept Selection & Validation

After proposing various solutions to the main problematic, the use of CAE software is inevitable to determine the validity of the proposed solutions.

4.2.6 Results & Perspectives

Reflecting on the results of the process and making conclusion for other study version.

4.3 Project Goals

Our project is composed of different objectives, divided in phases. Each phase having to give a result in correlation with the realized experiment, note that this axe is basically the planning phase in our process.

4.3.1 Goal I: Reconstruction of the Front Fender (SCAN To CAD To Inspect) & Optimization of the Technical Zones

Problem Statement

With the increasing expectations of customers regarding the life of their vehicles and the environmental impact of the manufacture and cost of their spare parts, it is out of the question to use parts that are difficult to manufacture or at a high price, especially for a part such as a fender, which has a high probability of deformation considering it is on the outer side of a car, not to mention the competition of our product (the fender of the 2013 Peugeot 308) which have several parts that affect its cost and it availability for the repair shops.

Objective

Our goal is to optimize the technical zones by reducing their size or redesigning them completely in order to decrease material and manufacturing while increasing its resistance.

4.3.2 Goal II: Evaluation of 3D scanning as a post-production inspection tool

Problem Statement

With strong competition and increasing demand for quality control, providing high quality, defect-free products is an important part of the supply chain between the automotive parts manufacturer and the final assembly company. The technologies used in quality control are regularly improved, but finding an innovative method is not a luxury, it is a necessity. With high resolution and the option to make the inspection both physical and digital, scanning systems are an important tool in this stage of manufacturing,

Objective

- ✓ Our goal is to test if the tool used in our project (handy scan) can measure up to the currently used inspection methods, for this purpose, an inspection between the STL recovered by scanning a physical part will be compared to the existing CAD design.

4.3.3 Goal III: Evaluate the integration of RE to the design process

Problem Statement

Today, manufacturing markets have become very active and evolving in the needs of project development, in which 3D CAD modeling has shown great importance. In many cases, manufacturers find it difficult or impossible to reconstruct or reproduce a product whose geometry is lost due to age or different situations, in this case, the reverse engineering tool has been found effective, by scanning a physical part to obtain a virtual part, either manually or automated, the manufacturer can obtain a geometry as close as possible to the real product.

Objective

our goal is to evaluate the reverse engineering process in the automotive industry, and to see if this process has more advantages over the frequently used design and manufacturing methods, our comparison would be based on:

- ✓ development time.
- ✓ cost of the design process.
- ✓ quality of the resulting design.

4.3.4 <u>Goal IV:</u> Transform the project into a course Activity to the engineering student of FSTF

Problem Statement

while engineering courses can be rewarding in terms of technical knowledge, they are not effective in instructing students on how to follow a defined process. at the end of the course, students have a great amount of information but little to no idea on how to apply it in the industry, especially important tools such as reverse engineering.

This phase is proposed by our own supervisor Mr. Aboutajeddine, in order to elevate the engineering curriculum in FST Fes.

Objective

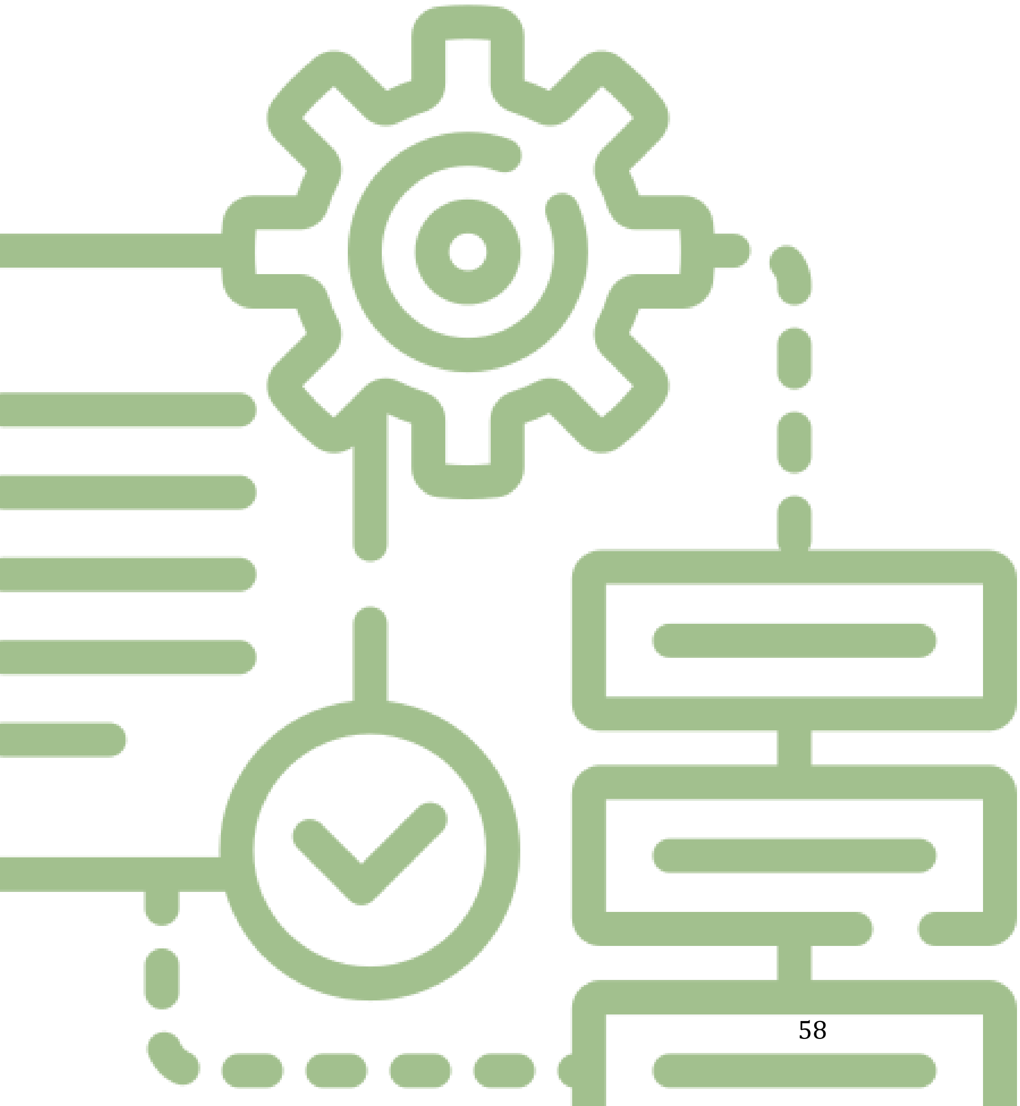
- ✓ Developing activities that uses reverse engineering tools (3D Scanning – rapid prototyping …) in automotive industry.
- ✓ Propose some guidelines that would make teaching the process we have followed much easier for students.

Conclusion

In this chapter, we have presented the different details of our projects, including the process followed and the different objectives sought. The next step would be the introduction to our first research of the stat of the art.

Project Processing

This chapter demonstrates the execution of our process phases towards achieving our goal of reconstructing and optimizing the CAD model of the fender.



Introduction

Following each step of the process that we have presented before, we begin our work on the fender, this phase was performed through the collaboration of MG2 and the Innovation Center.

5.1 Planning

- **Project title**

the first step in our planning is to formulate our project,

- the origins:

we chose to work on this project because of its innovative nature.

since our supervisor Mr. Aboutajeddine has suggested that we work with the RE process, and our MG2 supervisors suggested we work on the front fender of the Peugeot 308/2013 due to the lack of a functioning CAD model, we have been thinking about ways to make it more rewarding, hence the objectives set in the previous chapter, our final project title after discussing and adding what we could work on, is:

Reverse engineering, inspection, and optimization of the Peugeot 308 front fender.

which includes all our steps and objectives, the rest of the planning have been introduced in the previous chapter.

- **Acquiring the fender**

the next step was to acquire a fender to work on, we had several options, either buy one or ask the company for one,

the first option was not ideal because we had to look for one that was still in good conditions, as there aren't any new ones, which would compromise our inspection goal, so we relied on the second option and asked the company for one.

- **Acquiring a scanner**

Thanks to the collaboration of the innovation center (USMBA) with our supervisor Mr. Ahmed Aboutajeddine, we had the opportunity to work with the 3D Creaform HandySCAN, which is an industrial scanner.

5.2 General Study

5.2.1 Benchmarking

Introduction

In order to have a vision of the potential additions to this version of the Peugeot 308 fender, we have compared our data to that of some of the older versions of the same car and to some of the newer versions as well, and in order to have a vision of the competition, we have compared our fender to that of some of the known competing cars with comparatively the least difference in price and the same overall utility.

A2mac1 website:

A2Mac1 is a professional competitive analysis tool that helps its clients keep up with the latest trends and technologies. From its centers around the globe, A2Mac1 provides its clients with a constant supply of carefully curated, unmatched data and reports, expertly evaluating the latest products in terms of design, performance, and cost. Powered by a state-of-the-art platform and applications, and combined with tailored consulting and cost engineering services, A2Mac1 solutions enable its clients to unlock key insights to identify critical opportunities and accelerate innovation.

Figure 72: A2mac1's logo for benchmarking.

why do we need benchmarking?

The goal of benchmarking is to make continuous improvements and implement changes in business products, methods, and services. Therefore, benchmarking practices provide a better understanding of customer wishes and expectations. This is because customers are the most important data source at every stage of comparison.

The different segments:

To better identify the competition; we needed to learn about the different segments that exists to better determine the competing brands and to better identify the overall development that could be achieved.

The European automotive industry has organized the different types of cars into segments, labeled alphabetically. These segments represent the different cars according to their capacity, size, engine, and handling,

These segments are:

- the A segment: Mini cars
- the B segment: Small cars
- the C segment: Medium sized cars
- the D segment: Large cars
- the E segment: Top class cars
- the F segment: Luxury cars
- the J segment (or SUV): SUV vehicles with sports equipment
- the S segment: Sports vehicles
- the M segment: MVP multi-purpose vehicles

each of these segments encompasses a number of different types of cars, but the larger segments such as the C-segment or the M-segment have been further divided to better organize the industry.

We have further explained these segments in the appendix 2.

Our model of Peugeot 308 falls into the c-segment, since it meets all its standards, and as shown in the chart below, which describes the percentage of sales of each segment, the c-segment represents almost 25% of the overall percentage of sales in the automotive industry, which means that it includes a large competition with important and well-known brands such as Volkswagen and Audi.

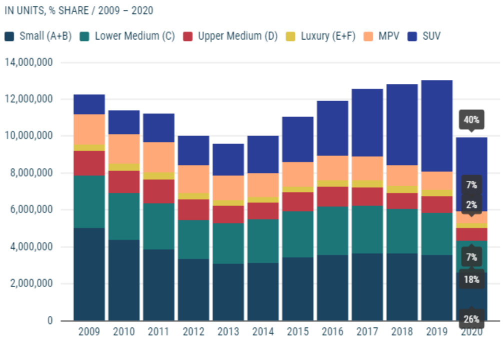


Figure 73: new passenger cars by segments in the EU (data by IHS Markit)

By fully understanding the C-segment market, it is easier to identify competing brands. There were few that were proposed by the team of MG2, and there were some that had relatively the same performance and price range.

The older, newer, comparable versions of the Peugeot 308 2013

Our case study: The Peugeot 308 2013

This model was the shifting point between the old styling of 2008 and the new styling in compact cars, it had a larger interior and a powerful engine, it price ranges from 7500$ to 12000$

Figure 74: Peugeot 308-2013.

Older:

The Peugeot 308 2008 was the launching point for the 308 hatchbacks series. It is apparent that the designers focused on giving this model a large capacity while maintaining a sedan-like interior.

Figure 75: Peugeot 308-2008.

Newer:

This model was a follow-up to the 2013 sportier model, they made some huge styling and capability adjustments, this model was clearly a way for the designers to make a smashing entry into the sportier sedan competition with well-known brands like Ford and Volkswagen.

Figure 76: Peugeot 308-2017.

This is the 2022 model, with even higher performance and styling. Based on the overview description given by the designers, this model would outperform the current competition (which is the Volkswagen Golf) and rival the Audi A4.

Figure 77: Peugeot 308-2022.

Comparable cars

the first equivalent model is the ford focus, which is considered globally as a light car with high performance, and which price is at 8200$ - 10000$.

Figure 78: Figure 71: Ford focus.

the second biggest competitor is the Spanish Seat Leon, with almost the same features but with a well-known brand, the Seat Leon achieves better performance and sales figures, this model is in a price range of $8000-12000.

Figure 79: Seat Leon.

The Volkswagen Golf is the reigning champion of this segment, with advanced German engineering and craftsmanship, this model is a serious contender for compact cars.

The price of this model ranges from $12000~$15000

Figure 80: Volkswagen Golf.

General comparison

Table 5: General comparison

	Peugeot 308 2008	Peugeot 308 2017	Peugeot 308 2022	Ford Focus	Seat Leon	Volkswagen Golf	Peugeot 308 2013
Car segment	C	C	C	C	C	C	C
Year pf production	2008	2017	2022	2012	2014	2013	2013
weight	1382.181	1249.580	1304.938	1380.763 kg	1157.780 kg	1249.168	1332.472
energy	Gasoline	All	All	Gasoline	Gasoline	All	Diesel
Length, width,	4276, 1815, 1496,	4253, 2043, 1457,	4367, 2062, 1441,	4533, 2059, 1465,	4263, 1980, 1459,	4255, 2027, 1452,	4253, 1804, 2043,

Hight, wheelbase	2608.	2620.	2675.	2649	2636	2637.	2620
cylinders	4	3	3	4	4	4	4
Number of doors	5	5	5	5	5	5	5
Destinated market	Europe France	Europe France	Europe France	North America, USA	Europe, Spain	Europe Germany	Europe France

Fender comparison

Peugeot 308's fender comparison between our fender and the 2008's one

As seen in the figure below provided by the benchmarking website, the design or style of the fender was quite different and as a matter of fact for this model they have not placed rear fenders, also one can see that this fender has a lot of supporting points and two of them are parallel to the surface of the BIW, which indicates that they required more parts to cover these supports.

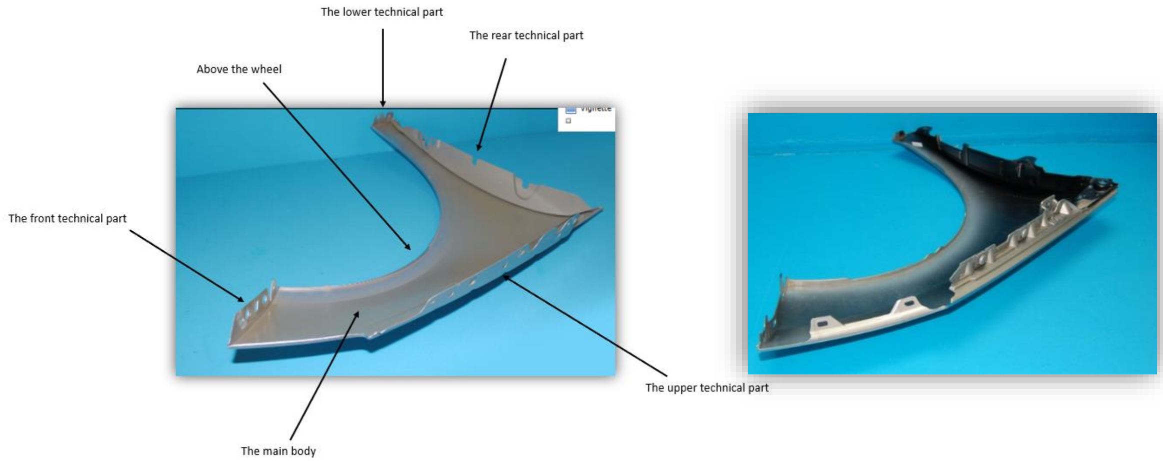


Figure 81: Peugeot 308's fender (a) 2017's version-our case study; (b) 2008's version.

The newer versions (2017/2022)

2017 fender

In this particular version, we can hardly see any difference between it and the 2013 version in regard to the style and design since this model was a follow up on the 2013 model.

Figure 82: Fender of 2017.

2022 fender

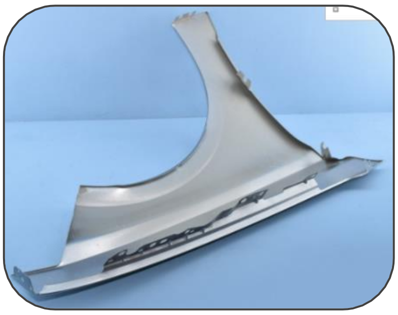


Figure 83: Fender of 2022.

This latest model is significantly different, we can notice that they have abandoned the old style and design and have adopted a new one, they wanted a sportier look, so the fender has a lot of lines, we can also see that they have reduced the surface of the technical parts, the rear technical part has nearly disappeared, on the other hand the upper part has more fixing openings.

Vs the competition

Ford focus

The ford focus is comparably within the same price and utility range as the Peugeot 308, their version of the fender is a little different from the Peugeot's.

For the technical parts they have a lot of attachment points on the upper part but few on the rear, of course the use of the front support part would help in avoiding this issue.

Figure 84: Ford focus fender.

Seat Leon:

Figure 85: Seat Leon fender.

Similar to the ford focus, we can see a big styling difference compared to the Peugeot's fender, we can also notice that its technical parts include the space above the wheel, we can also notice that they used fasteners to fix the upper technical part to the body of the fender, contrary to the Peugeot which uses the hemming method.

Volkswagen Golf

considering that the new model of the Peugeot 308 will be competing with the Volkswagen TDI, we wanted to compare their older versions, especially the 2013 versions that included our fender.

As we can see, the fender of the Volkswagen has a unique design and style, since the designers dropped the technical part in front, and made a triangular cut, we can also notice that it has attachment points on the part above the wheel, and multiple other attachment points distributed around the fender.

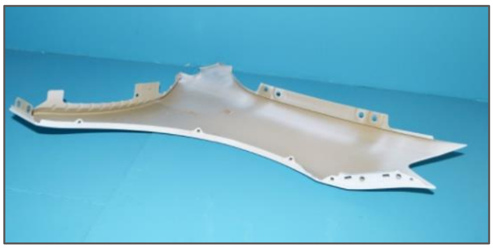


Figure 86: Volkswagen fender.

Technical Characteristics

Table 6: Technical characteristics of each fender.

	Peugeot 308 2008	Peugeot 308 2017	Peugeot 308 2022	Ford Focus	Seat Leon	Volkswagen Golf	Peugeot 308 2013
Quantity	2	2	2	2	2	2	2
Weight (per fender)	2.045 kg	2.064 kg	4.386 kg	3.914 kg	4.025 kg	3.560 kg	1.927 kg
Weight of support (per side)	0.088 kg	0.147 kg	0.146 kg	0.150 kg	0.127 kg	0.127 kg	0.12 kg
Total weight on each side	2.133 kg	2.211kg	4.532kg	4.064kg	4.152 kg	3.687 kg	2.047 kg
Length	920 mm	827 mm	987 mm	909mm	1020mm	955 mm	880 mm
Hight	680 mm	660 mm	760 mm	720mm	670 mm	745 mm	650 mm
Depth	145 mm	145 mm	215 mm	142mm	223 mm	160 mm	140 mm
material	plastic	Steel alloy	Steel	Steel	Steel	Steel	metal

2008: As we can see, this version is heavier than the 2013 version, by 0.086 kg, even though they used steel in the 2013 version, we can also notice a significant size reduction.

2017: We can notice some small but not significant changes in terms of size, the major difference is the weight which has increased by 0.1 kg, even though they used alloy steel, which is lighter, shinier and has better properties.

2022: As we can see, a huge difference in all the specifications, first of all the difference in weight is tremendous, the new model weighs more than twice the weight of the old version, and the size is significantly larger, moreover, we can see that they have dropped the idea of using a metal alloy and returned to the use of steel, all of this is due to the fact that the fenders in the new version of the Peugeot 308 plays a big role in its sportier look.

Ford focus

As the numbers show, there is a large variation in weight, more than twice the weight of the 2013 Peugeot model, and a substantial difference in size as well.

Seat Leon

this model is quite heavy as well as ford focus, and it has an enormous size, especially regarding the length, the motive behind its length of 1020 mm is that developers wanted a fender to extend to the front of the car in a way that it can reach the front lights.

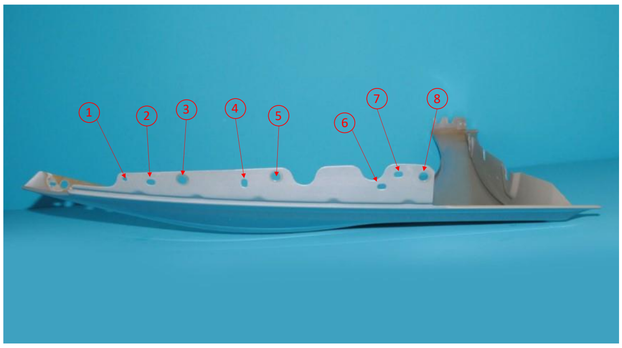
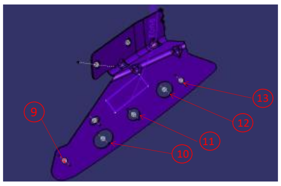
Volkswagen Golf

we can see that considering the size/weight ratio, it is comparable to the Peugeot's, it has a great size, and it is rather heavy, and contrary to the Peugeot, it is made of steel instead of steel alloy.

5.2.2 Technical Specification of Our Fender 308 -2013

- **Punching (poinçonnage)**

Table 7: TS of our fender

<table>
<tr><th>Figure</th><th>index</th><th>description</th></tr>
<tr><td rowspan="8">
Figure 87: Top view of 308 Peugeot's fender.</td><td>1</td><td>Projector attachment (Fixation projecteur)</td></tr>
<tr><td>2</td><td>Pilote Ferrage 2</td></tr>
<tr><td>3</td><td>Passage for screw fastening (Passage vis fixation AV 1)</td></tr>
<tr><td>4</td><td>Pilote ferrage 3</td></tr>
<tr><td>5</td><td>Passage for screw fastening (Passage vis fixation AV 2)</td></tr>
<tr><td>6</td><td>Pilote OS peinture anti-coulure</td></tr>
<tr><td>7</td><td>Pilote Ferrage 1</td></tr>
<tr><td>8</td><td>Rivet passage for front support (Passage vis fixation AV 3)</td></tr>
<tr><td rowspan="5">
Figure 88: Front fastener of the fender.

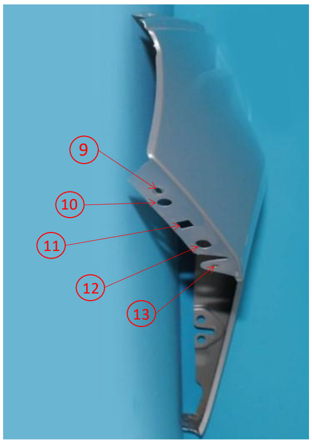



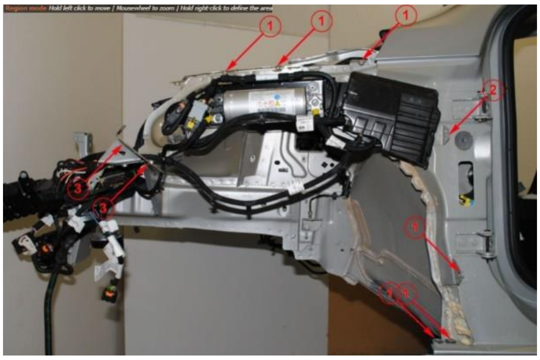
Figure 89: Right view of 308 Peugeot's fender.</td><td>9</td><td>Rivet passage for front support AV1(Passage rivet support avant AV 1)</td></tr>
<tr><td>10</td><td>Front Bumper index (Indexe pare-chocs avant 2)</td></tr>
<tr><td>11</td><td>Front bumpers pull clip (Clippage tirette pare-choc avant)</td></tr>
<tr><td>12</td><td>Front Bumper index (Indexe pare-choc avant 1)</td></tr>
<tr><td>13</td><td>Rivet passage for front support AV2(Passage rivet support avant AV)</td></tr>
<tr><td rowspan="3">
Figure 90: Right view of 308 Peugeot's Chassie.</td><td>1</td><td rowspan="3">Passage for screw fastening</td></tr>
<tr><td>3</td></tr>
<tr><td>2</td></tr>
</table>

Table 8: Technical Specifications used to design technical zones of Fender Peugeot 308-2013

	FP	F	D	L	+-	Zone fonctionnelle	$R_{poiçon}$	$D_{zone\ plan}$	α
2	Pilote	Boutonnière	8.2 mm	12.2 mm	+.05 -.15	1 mm	0.5 mm	31 mm	0.019
4			8.2 mm	12.2mm	+.05 -.15	1 mm	0.5 mm	31 mm	0.017
6			8.2 mm	12.2mm	+.05 -.15	1 mm	0.5 mm	31 mm	0.086
7			8.2 mm	12 .2 mm	+.05 -.15	1 mm	0.5 mm	31mm	0.005
3	Passage	Rond	12.2 mm	---	+.3 -.2	3 mm	---	31 mm	0.028
5			12.2 mm	---	+.3 -.2	1 mm	---	31 mm	0.029
8			12.2 mm	---	+.3 -.2	1 mm	---	31 mm	0.003
10			12.2 mm	---	+.3 -.2	1 mm	---	31 mm	4.974 e-005
12		B	12.2 mm	16.2mm	+.3 -.2	1mm	0.5mm	38mm	4.974 e-005
9	Fixation Sertissage	B	5.2 mm	10.2 mm	+.1 -.15	1 mm	0.5 mm	26 mm	6.26 e-005
13		R	5.2 mm	---	+.1 -.15	1 mm	---	22 mm	5.714e-005
11	Fixation clippage	Carré	12.2mm	12.2mm	+.1 -.15	1 mm	0.5mm	38 mm	4.974 e-005
1	Pré-maintien	R	6.2mm	---	+.3 -.2	1 mm	---	22 mm	0.01

5.2.3 Manufacturing Method

For the general blank manufacturing all the cars are following the same procedure, which is cold stamping, but for the Peugeot 308 2017, some additional parts are assembled to the fender using hemming process.

hemming provides a better assembly design since manufacturers can add other joining methods, and it also provides a better performance for forces normal to the hem surface, it also makes the fabrication process faster.

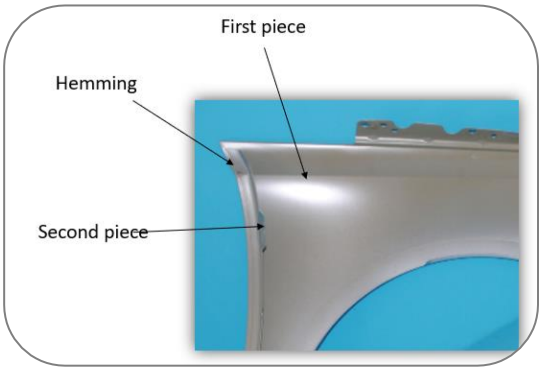
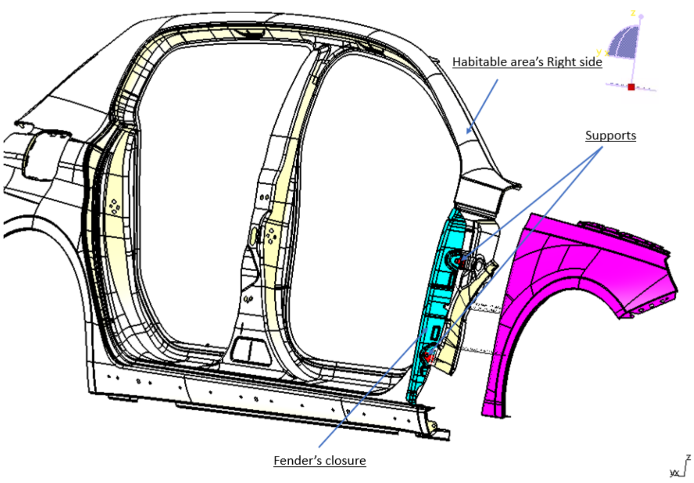
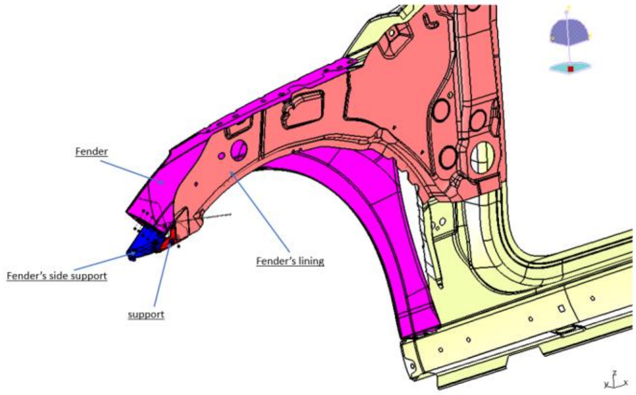
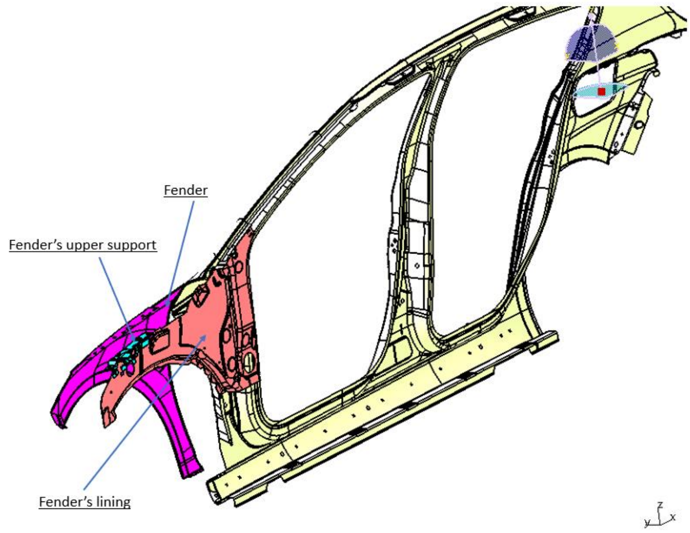
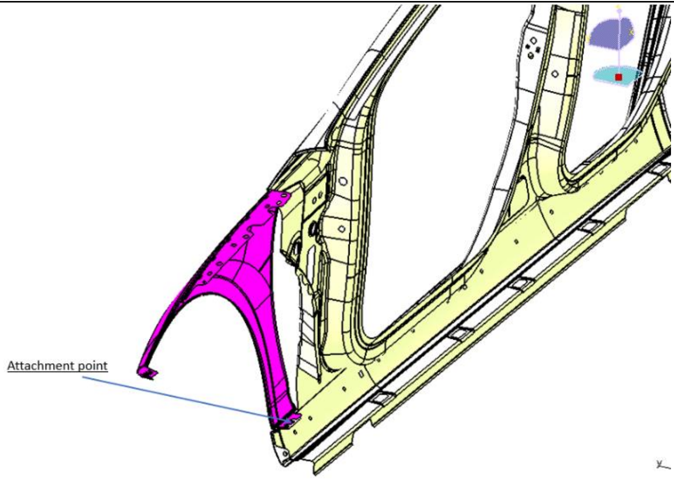
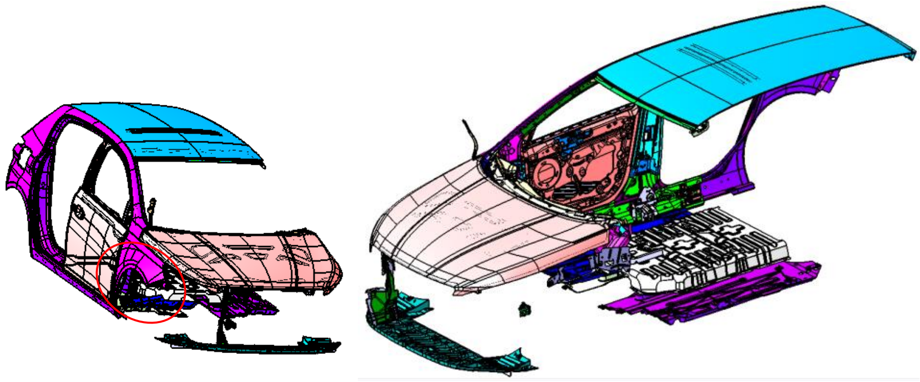


Figure 91: Technical zone of front fender.

5.2.4 Fender in Environment

The fender has 4 attachment points, each part is made of metal and multipurpose,

Designation	***Place in the environment***	***Description***
Fender Closure	 *Figure 92: Location of fender closure.*	the first part is the fender closure, which is a piece fixed to the fender by the hemming process, this part connects the fender to the passenger right side area.
Front Fastener (Fender side support)	 *Figure 93: Location of Front fastener.*	the second part is the fender's side support, it links the fender to the BIW

Fender upper support	 *Figure 94: Location of Front fastener.*	the third part is the upper support of the fender, it joins it to the lining of the fender using welding.
Habitable side	 *Figure 95: Habitable side.*	the last attachment point is on the side of the Body.
Environment of our fender	 *Figure 96: Environment of the fender.*	

Fastners

All fixtures are assembled to the fender using the same fasteners, i.e., a hexagonal screw with a washer:

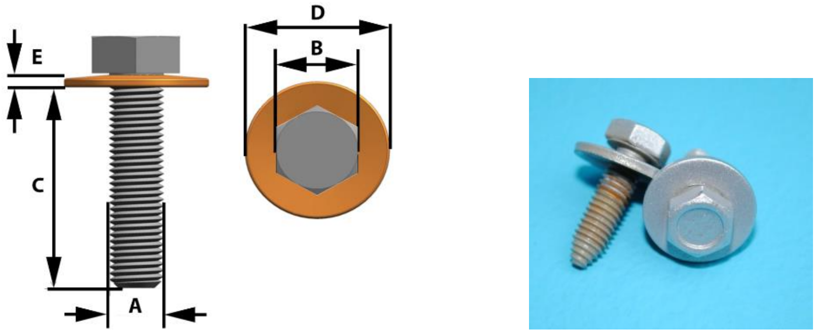


Figure 97: Fasteners used in fender.

A=6mm; B=10mm; C=18mm; D=18mm; E=2mm.

This part is a metal screw that weighs 0.0085 kg and has a hardness of 8.8.

Conclusion

This general study allowed us to understand the whole environment and the requirements of our fender, it also gave us through benchmarking an idea on the competition and an inspiration on what could be optimized.

5.3 Reverse Engineering

5.3.1 3D Scanning process

The digitization process we established consisted of a brainstormed process of all the necessary steps to attain the final goal we aimed for, namely the CAD model of the Fender.

we also made pictures of the parts we intended to modify (technical areas) in order to later compare them with the scanned STL.

Our fender is assembled by hemming with other parts (1), (2) as shown in figure below, these technical parts can't be dissembled from the fender:

Figure 98: assembled parts

1-Front Fastener

Figure 99: Location of front fastener in the fender (physical part).

2-Fender closure

Figure 100: Location of fender closure in the fender (physical part).

3-Technical zone attached with the fender

Figure 101: Technical zones of the fender (physical part).

5.3.1.1 Preparing the environment

Figure 102: Heling 3D laser Scanning spray

To begin the scanning process, we had to create a suitable environment with enough light and space to turn around the Fender.

we also were required to spray the fender with a 3D scanning spray, so that it can be detected by the scanner, its black color would render the scanning process impossible, as it attenuates the light from the laser.

Figure 103: Spraying the fender with healing spray.

After that we continued to place targets on the sprayed fender, the targets were meant to help the scanner detect the 3D model while also keeping the dimensional 3D movements in consideration, the targets were to be randomly placed to ensure that the scanner would not mistake one target pattern for another.

We also made sure that the technical parts had additional targets, as we wanted an accurate capture of the 3D model.

Figure 104: The sprayed fender with targets.

5.3.1.2 Starting the scanning process

We used a 3D hand scanner from Creaform which is an industrial scanner, it has a high resolution and a large scanning capacity, and it is easily used with the scanning programs that are assigned to it, VXmodel and VXelement.

Figure 105: Creaform HandySCAN 3D.

Calibrating

The first phase of our process once the environment has been set up is calibration, we started by acquiring the position of each target on the fender to establish a three-dimensional space, of course we had to ensure that we acquired each target, if a single target was missed, it would be difficult to scan the surface afterwards.

Starting to scan

Once the calibration was completed, we proceeded with the scanning by acquiring the geometric set in VXelement,

To scan the fender, we had to scan each surface by itself, and we decided to divide each surface into four parts, the global area, the first technical part, the second technical part and the third technical part, each part was given a duration of 20 min for scanning.

For the first scan we tried to have a maximum resolution of 0.2 mm then we decided to have another scan of 0.5 as resolution in case the first one was too large for the computer to handle.

Cleaning and refining

During this phase, we aimed to make the 3D model we had made as clean as possible by eliminating all the unnecessary scanned surfaces, such as the table on which we placed the fender, we realized that it was a good idea to add the 0.5 resolution scan, as the 0.2 scan took a lot of time to refine and clean, therefore we opted to focus our work on the 0.5 resolution scan.

Of course, this process took a lot of time considering the number of surfaces that were simply excess in the scan, and the degree of prudence in which the cutting process had to be done to preserve the necessary part of the fender.

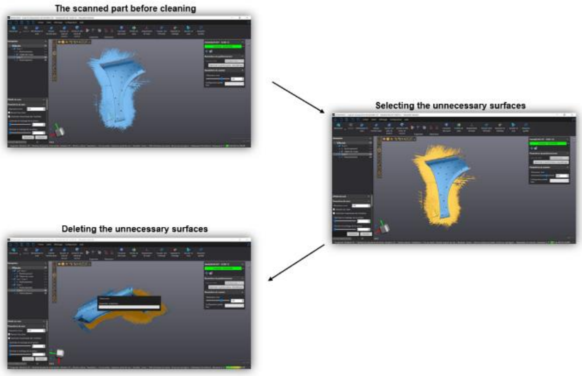


Figure 106: Cleaning the scan

Scans merging and the export of the points cloud

After completing the cleaning and refining phase, it was now time to merge the scanned parts together, we started by merging each technical part on each side with its global corresponding area.

Of course, this process was much easier as it was done almost automatically, since we neither added nor removed any targets during or after the scanning process, the merging was automatically done by matching the targets of each scan to the targets of the other, the only merging that was done manually was the merging of the opposite sides, we took about 40 common points between the two surfaces to get maximum accuracy of the merging

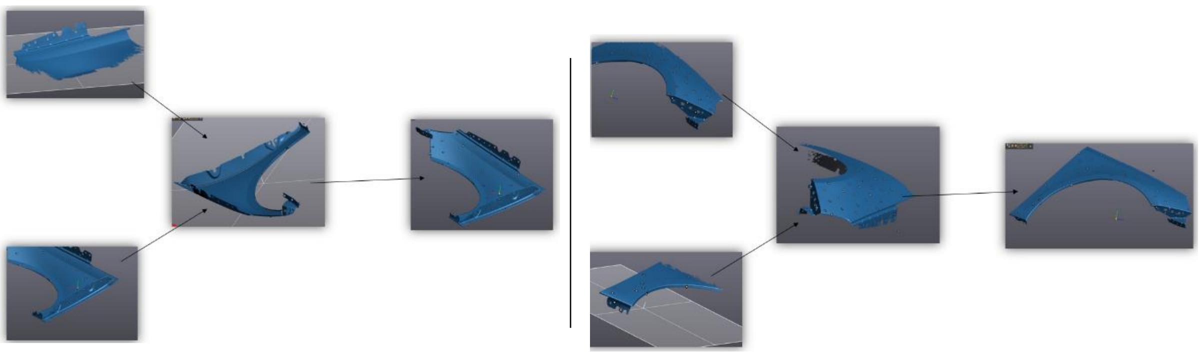


Figure 108: Scan Merging.

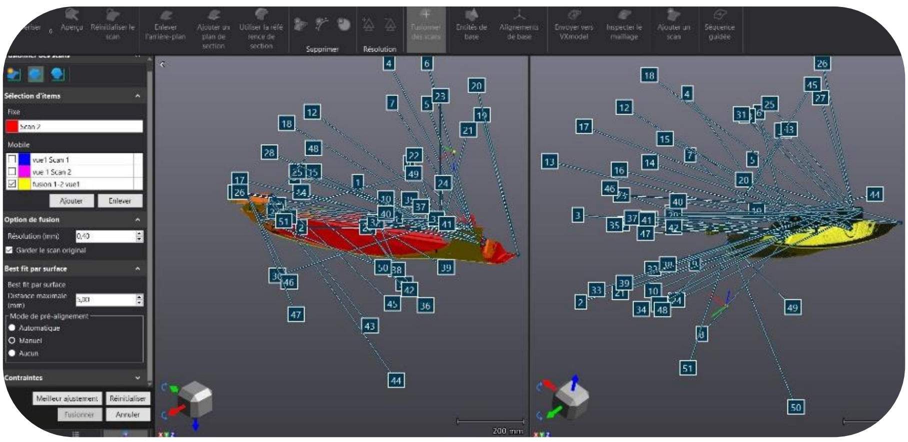


Figure 107: points taken to merge the sides

The reason we opted to scan both sides was to obtain an accurate visualization of the plies on the underside as well as the curves of the style on the other, also certain technical parts required two scans on each side as it was difficult to scan them while the fender was on the table.

5.3.2 RE in Geomagic Design X

5.3.2.1 **Mesh Cleaning & Refinement**

In Geomagic Design X we have tried to refinish the meshing we had exported from VXelement to the greatest extent possible, by filling in the gaps that were on the surface and connecting the surfaces that ought to be connected, and of course rendering the 3D scan as close as possible to the real fender.

i. Filling holes

This feature has been accomplished using the fill holes tool in Geomagic, in which we have to select each gap, of course this task cannot be done automatically since the program will fill the openings that are needed on the fender such as fixation points.

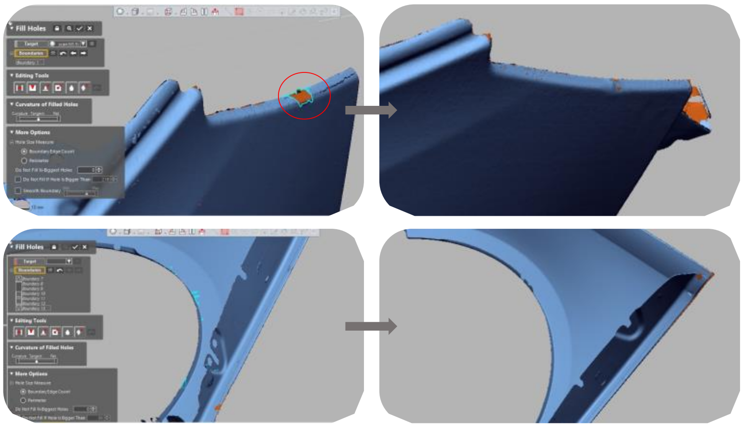


Figure 109: filling gaps and holes in Geomagic design X.

ii. Defeaturing

In this step, we aimed to refine the surface and remove every bad feature, such as a minor dents or very small holes, or trace of targets.

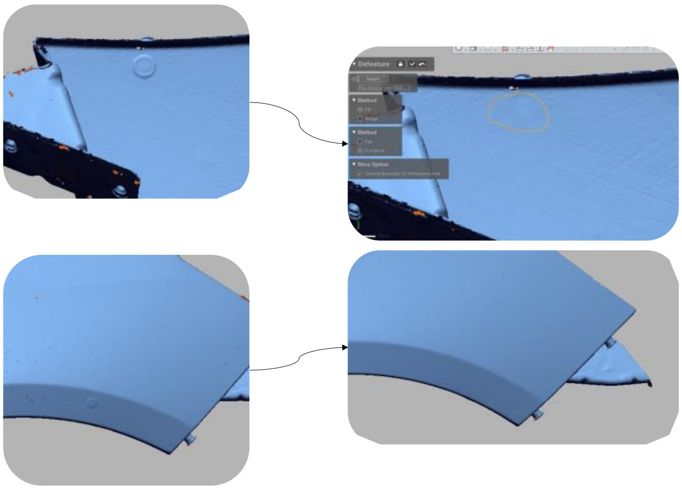


Figure 110: Process of defeaturing on the surface of the fender.

5.3.2.2 **Segmentation**

In RE, mesh segmentation makes the process of creating the surface model much easier, and that by adding each known feature or segment to the same selectable group. Figure 1 illustrate the first auto segmentation from Geomagic Design X.

Then manually we have tried to join the surfaces that belong to a single segment with each other, thus we made it easy to extract these segments later, of course, this meant joining every little part, no matter how small.

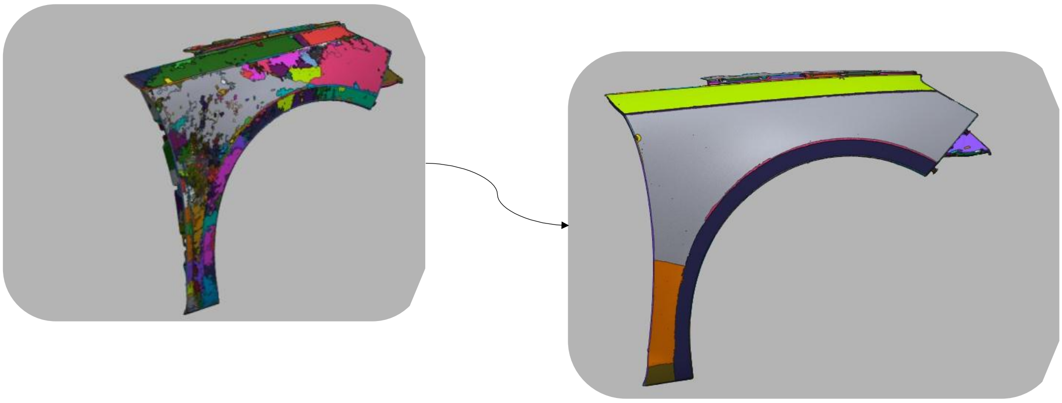


Figure 111: Auto-segmentation & manual segmentation in Geomagic design X.

Final results after creating all of the surface:

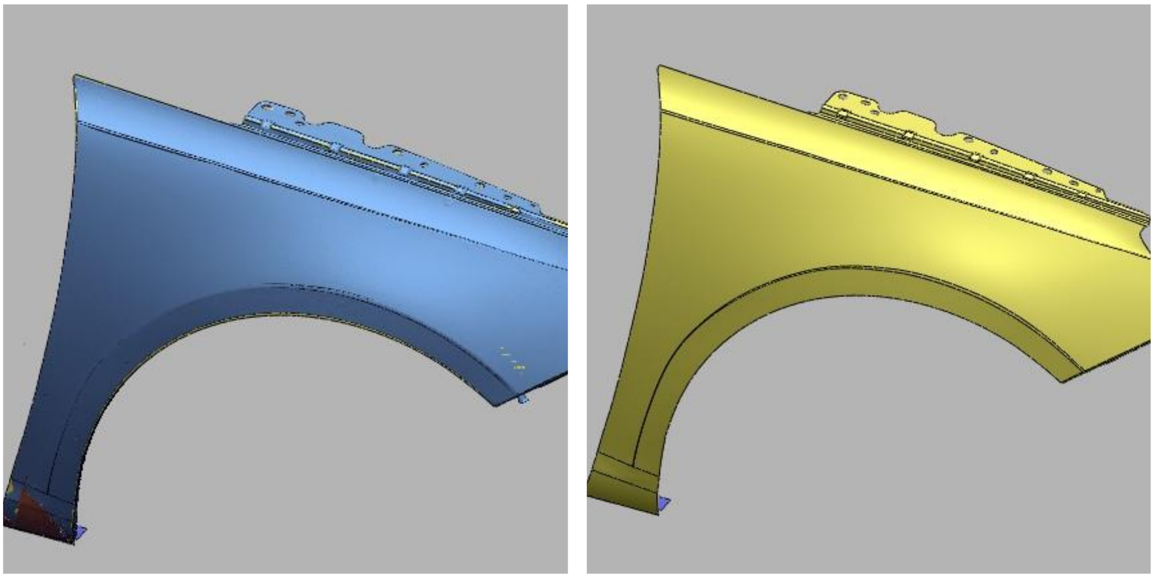


Figure 112: (a) 3D cloud points; (b) Surface model.

Figure 113: RE of all parts of the fender.

5.3.3 RE in Catia V5

Based on our research in chapter I, it's obvious that the CAD model will be divided to two big phases at the beginning of RE (creating the CAD from the scan), style area which needs to be at the minimum of deviation from the scan, and the technical areas.

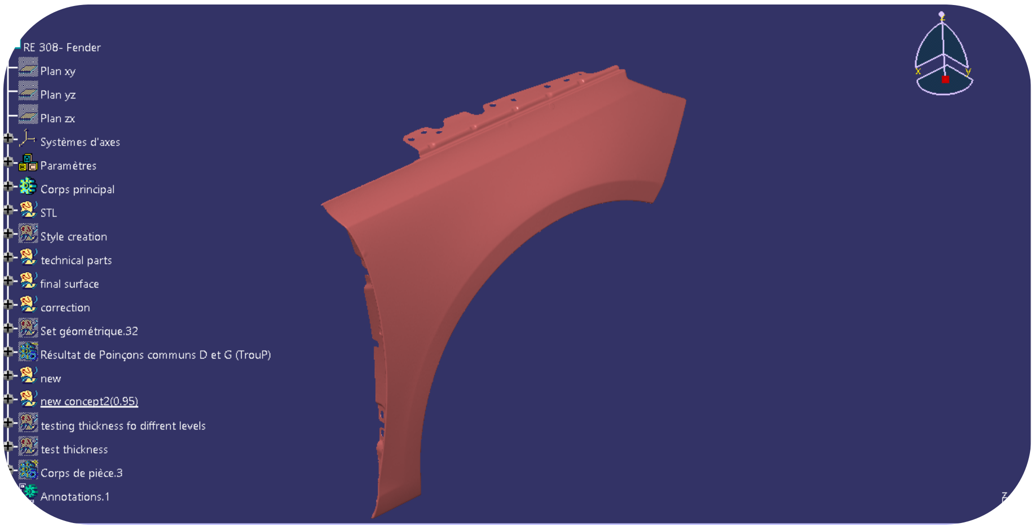


Figure 114: STL file of the fender in Catia V5.

<u>Phase I: recreating the Style of the fender</u>

Creating a surface CAD model in Catia V5 based on 3D cloud points, which means that we need to work mainly in tree workbenches:

- Digitized Shape Editor (DSE).
- Generative Shape Design (GSD).
- Quick Surface Reconstruction (QSR).

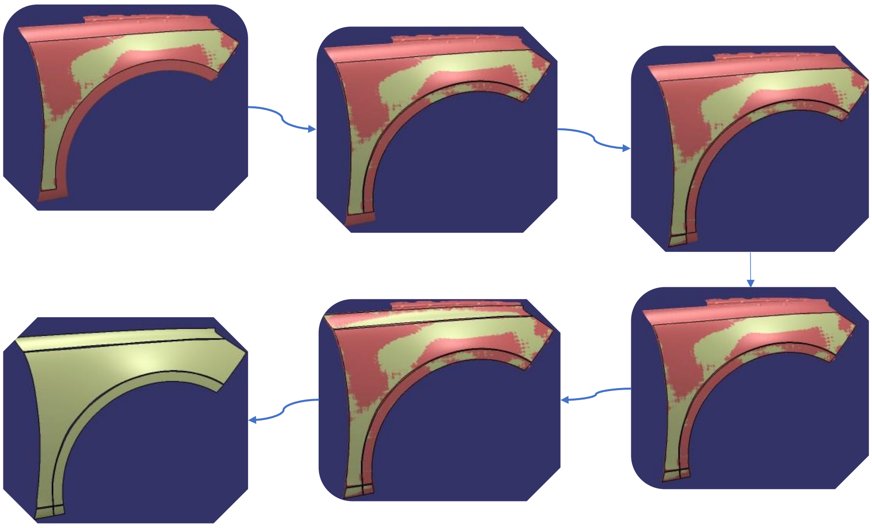


Figure 115: process of creating styling area of the fender.

After properly aligning our scanned data (STL file), we move to create the first surface of the of the style's fender. There are several ways of creating surface based on cloud points, one of them is creating a 3D curve on the data we have and then using QSR tools, we fit a surface using these curves.

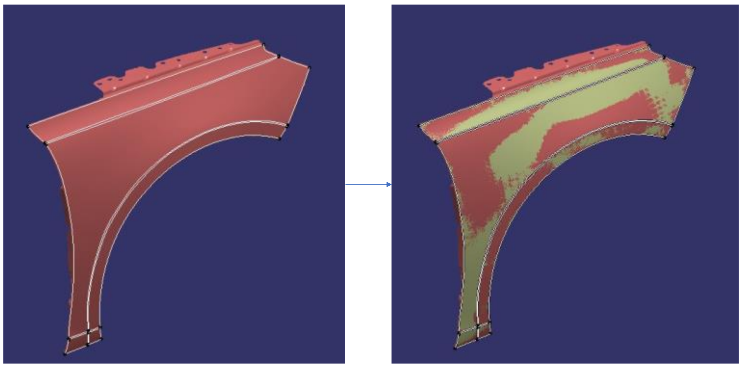


Figure 116: 3D curves on SLT to Surfaces

At this point all five surfaces of the style are disconnected from one another, using GSD tools we assembled all five surfaces at one as shown in figure below.

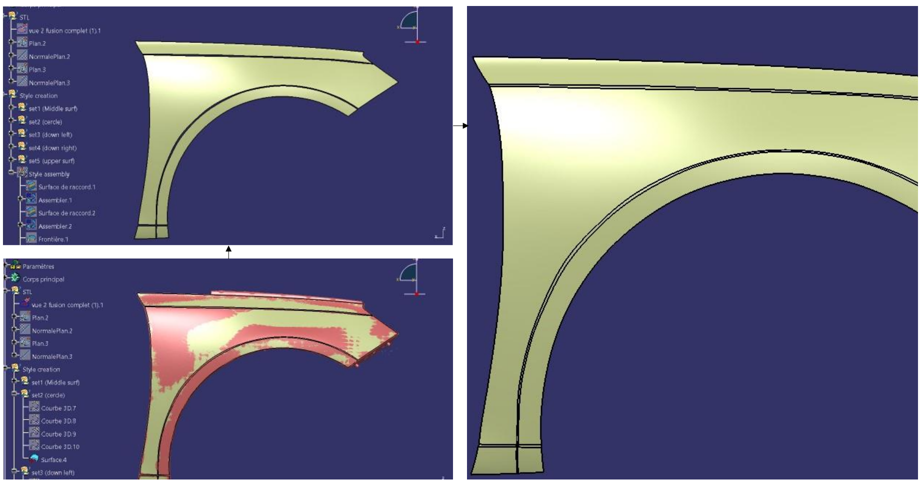


Figure 117: Results of style creation.

In order to validate if the created surfaces are in the tolerance zone of RE, there is some methodologies as mentioned previously on chapter 2.

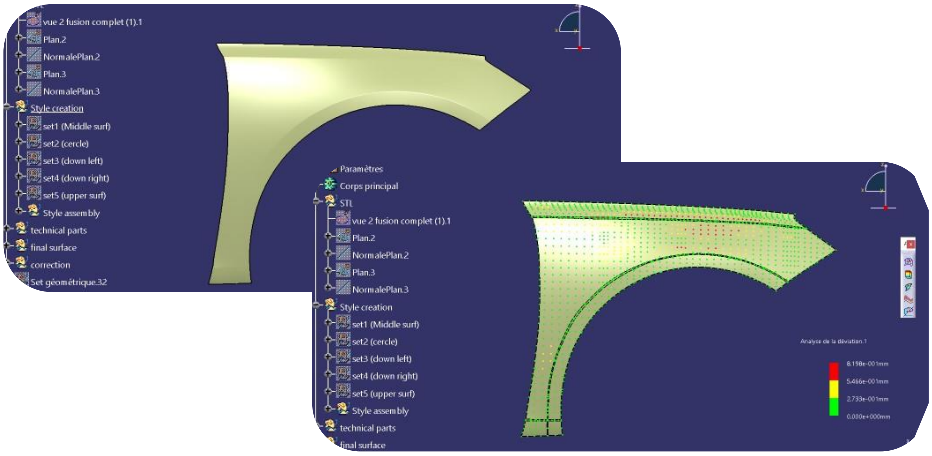


Figure 118: tangent continuity and deviation analysis of the fender's style.

Phase II: recreating the technical sides

1. The right side

The design of the technical parts was influenced by the style of the fender and the requirements of the environment.

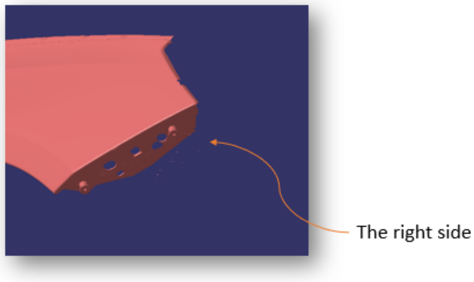


Figure 119: Right side in the scan.

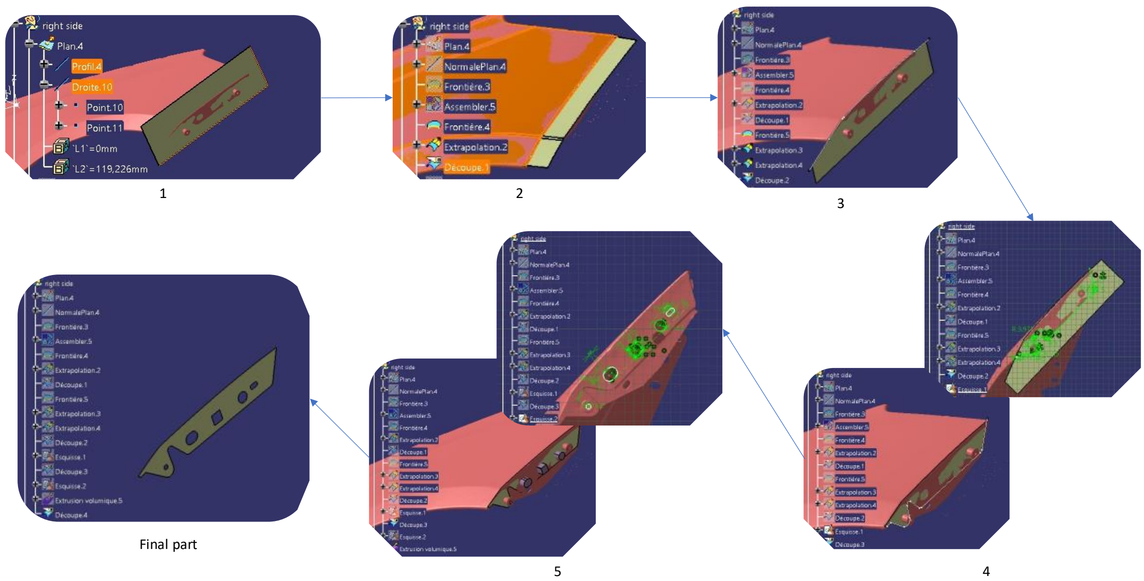


Figure 120: Process of creating right side of the fender based on scanned data.

First, we created a surface parallel to the surface of the technical part using lines extracted from two points in the STL.

Next, we created a small surface that joins the previous styling with the newly created surface, the use of the "interpolation" function is to keep the surfaces tangent.

After that, we trimmed the flat surface to be able to adapt to the style and a second trim to adapt to the shape of the environment (bindings).

Finally, we created the punching areas using the Stellantis requirements for this fender.

2. The First Hemmed edge

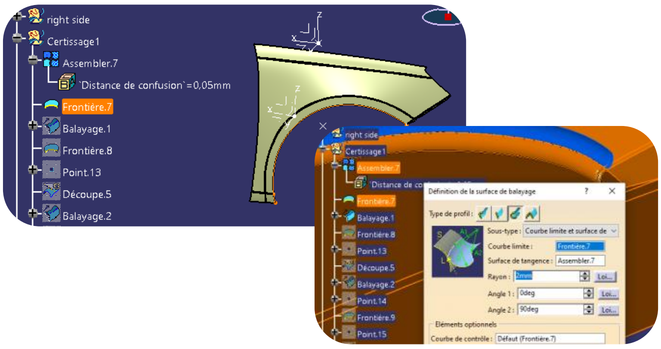


Figure 121: the first hemmed edge of the fender.

This first hemming is on the lower side of the fender, it incorporates two parts which are adjusted to adapt to the environment.

➢ The first part

This first part is at an angle of 90° to the styling surface.

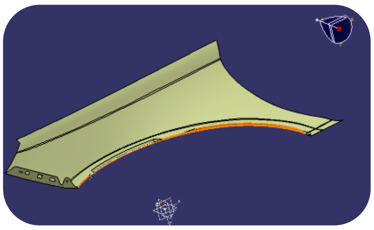


Figure 122: Hemmed edge by 90°.

This surface is created after the styling was created, this one had to be at a 90° angle relative to the styling surface, and we had to leave some small cuts so we could add surfaces that would eliminate sharp edges.

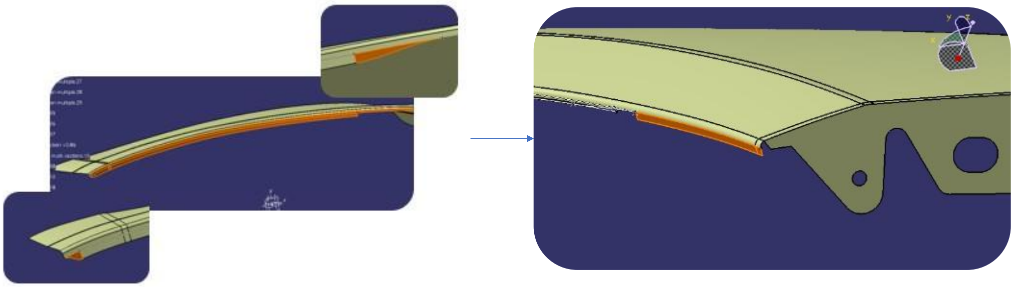


Figure 123: Creation of the first hemmed edge.

we created a similar surface on the other side; length 1mm.

➢ The second part

This second part is at a 60° angle to the styling surface

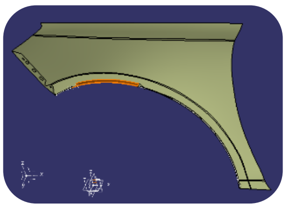


Figure 124: 60° hemmed edge

The creation of the first surface

Length 1mm.

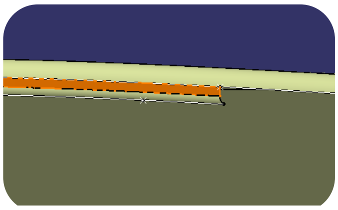


Figure 125: First swept surface.

The creation of the round surface at a 60° total.

Radius 1mm.

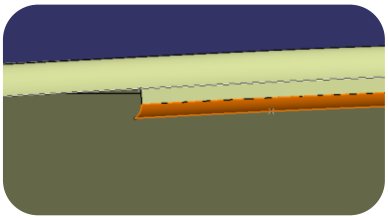


Figure 126: Creation of the next swept surface.

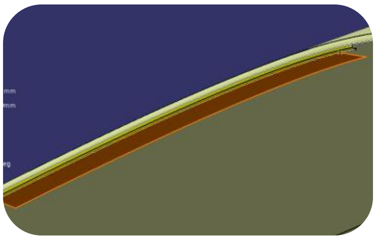


Figure 127: Final steps of the first hemmed edge.

The creation of the third surface using "interpolation".

Length 9mm

- joining parts

These surfaces are the link between the 60° angular surface and the 90° angular surface, these surfaces have proven to be difficult as they greatly influence whether the part can be stamped or not.

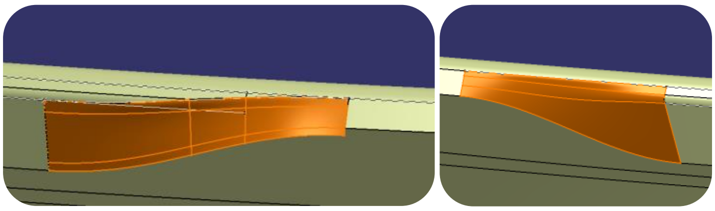


Figure 128: Joining the two surfaces.

3. The lower side

The lower side of the fender is constructed using several differently angled plane surfaces, its different design is due to its environment.

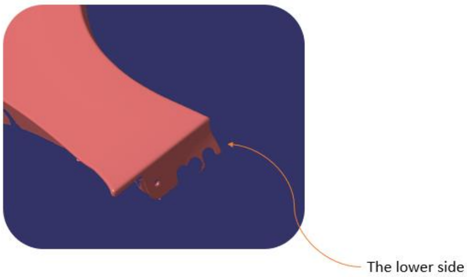


Figure 129: Lower side of the fender in the scan.

We first created a round surface tangent to the styling, then we created several planes with respect to the angles between them and the styling, then we trimmed the created surfaces to accommodate the shape of the environment.

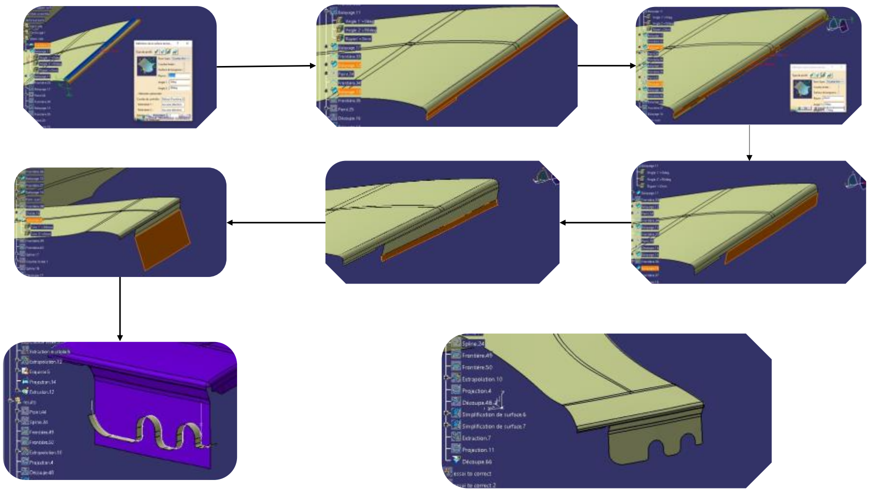


Figure 130: Process of creating the lower side.

Several fillings were made to eliminate the shape edges or empty spaces

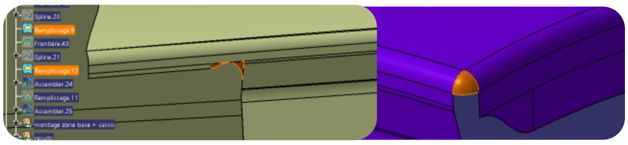


Figure 131: Eliminating "arret vive'

4. The second Hemmed edge

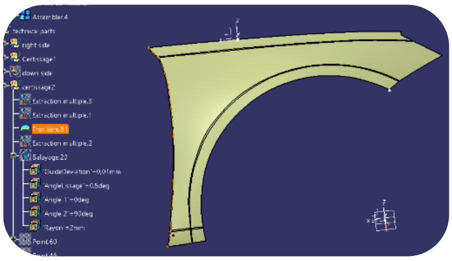


Figure 132: Second hemmed edge in the CAD.

The second hemming is located at the left side of the fender, it's a 90° hemming.

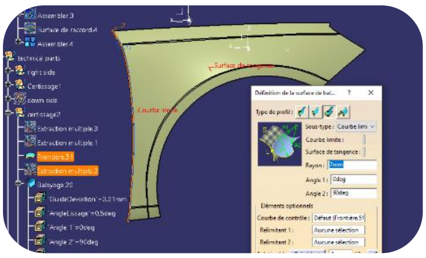


Figure 133: creating swept surface.

The first surface created is a round surface tangent to the styling surface.

R=1mm angle=45°

The second surface created is a round surface tangent to the first surface.

R=1mm angle=45°

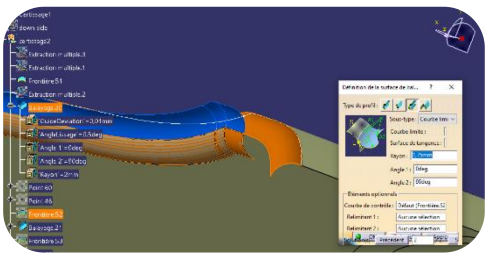


Figure 134: Creating tangent swept surface.

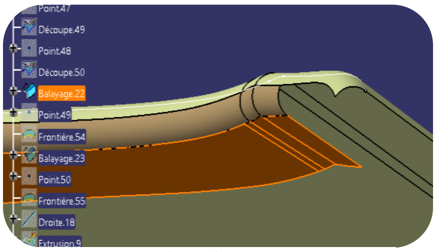


Figure 135: surface creation

The third part is a parallel surface to the styling,

Length =8mm.

The last part is perpendicular to the styling to have better assembly with the surrounding parts

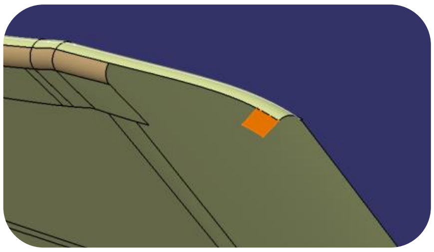


Figure 136: second surface creation

As before, several fillings were made to eliminate the sharp edges and to fill empty spaces

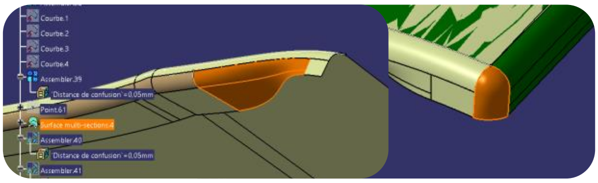


Figure 137: fillings

5. The upper side

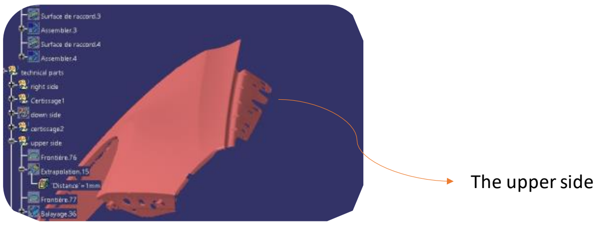


Figure 138: The upper side of the fender in the scan.

The upper part is composed of many difficult shapes.

These shapes were made while taking in consideration the Stellantis requirements.

- Creating the form:

we started by creating the shape that would fit the surrounding environment, followed by creating a tangent surface with a slight curve at the top, after which we made several cuts and a final cut to achieve the shape of the technical part.

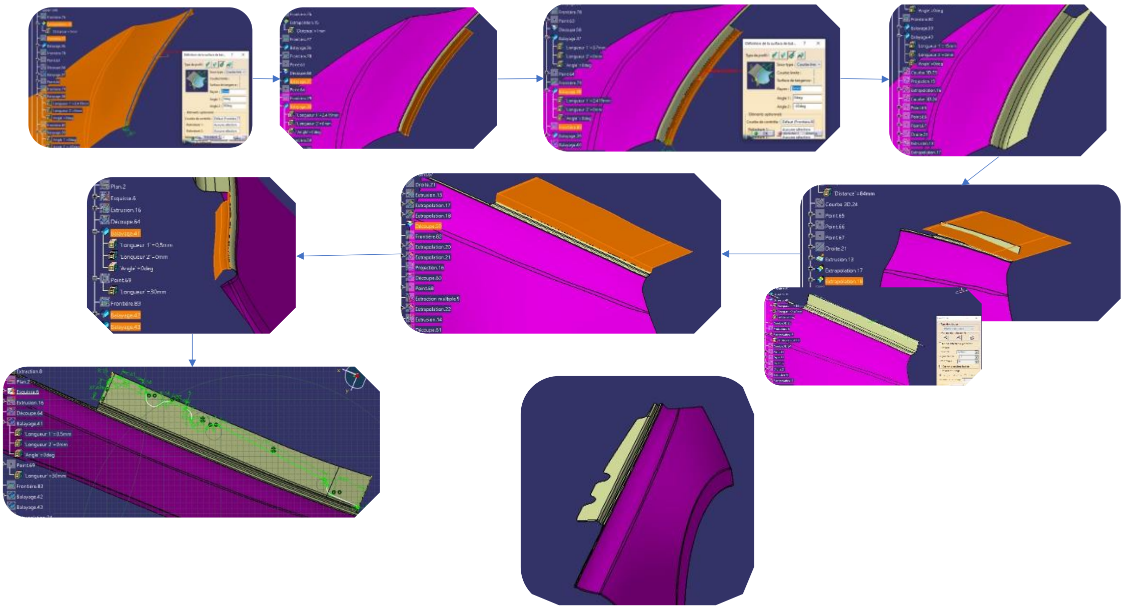


Figure 139: Process of creating upper side.

- Joining parts

As before, several fillings were made to eliminate the sharp edges and to fill empty spaces

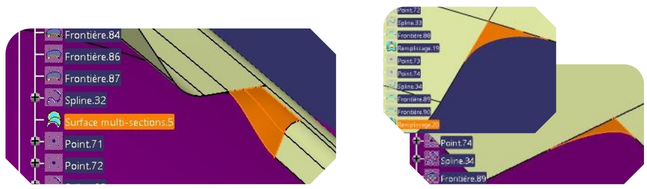


Figure 140: Eliminating part errors

- Punching areas

As we must respect the shape of the punching zones given by the client, we had to create them ourselves instead of basing it on the scanned part, these punching zones are composed of "boutonnière" slots and circles for the fasteners.

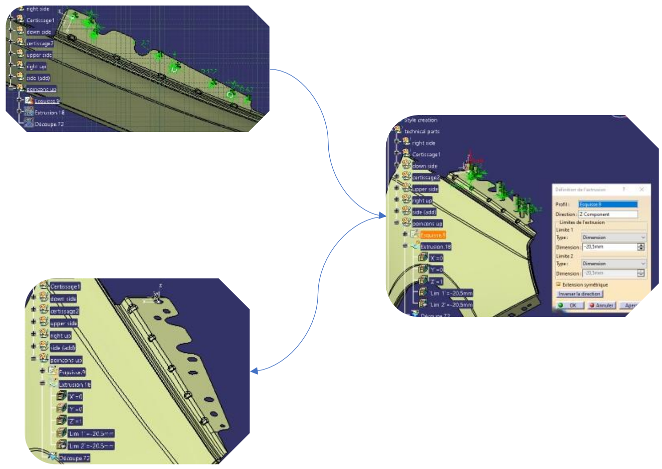


Figure 141: creating technical zones

Results:

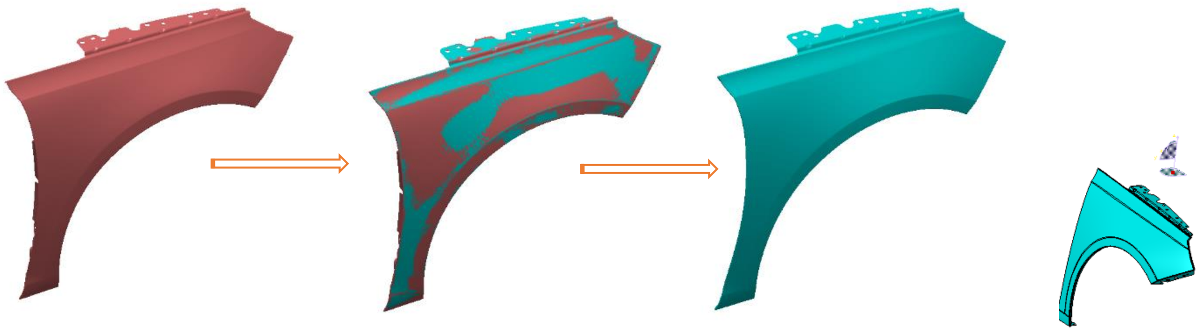


Figure 142: Scan to CAD using CATIA V5

5.3.4 Fender Inspection (CAI)

In this phase, using Polyworks Inspector we are going to investigate the quality of our Scan to CAD process, to see if the CAD data we proposed in in tolerance zone in reference to the cloud points.

5.3.4.1 Software: PolyWorks | Inspector:

PolyWorks Inspector is a universal 3D dimensional analysis and quality control software solution to control tool or part dimensions, diagnose and prevent manufacturing and assembly issues, guide assembly building through real-time measurements, and oversee the quality of assembled products by using portable metrology devices and CNC CMMs.

Figure 143: PolyWorks Inspector's logo.

PolyWorks is a universal software platform (USP), there is a wide variety of tools that can be operated using this software:

- ✓ Interface with all 3D measurement devices thanks to a universal digitizing hub.
- ✓ Bring all relevant data under one roof through a universal data hub.
- ✓ Perform all inspection tasks with or without CAD data using a universal 3D metrology workflow.
- ✓ Deploy universal inspection project playable on any 3D measurement device.

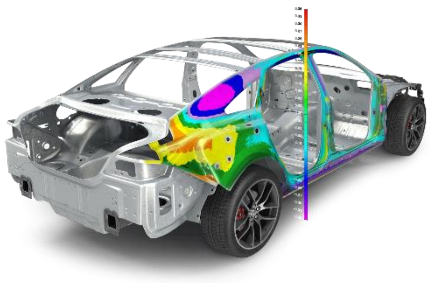


Figure 144: PolyWorks Inspector's logo

Importing the Reference object (CAD model):

The main idea in inspection is to see the exact deviation between the scanned data and the final CAD model, for that we first imported; as seen in figure; the CAD model into the inspection project, as reference object. Then we imported the STL file (cloud points) of the fender.

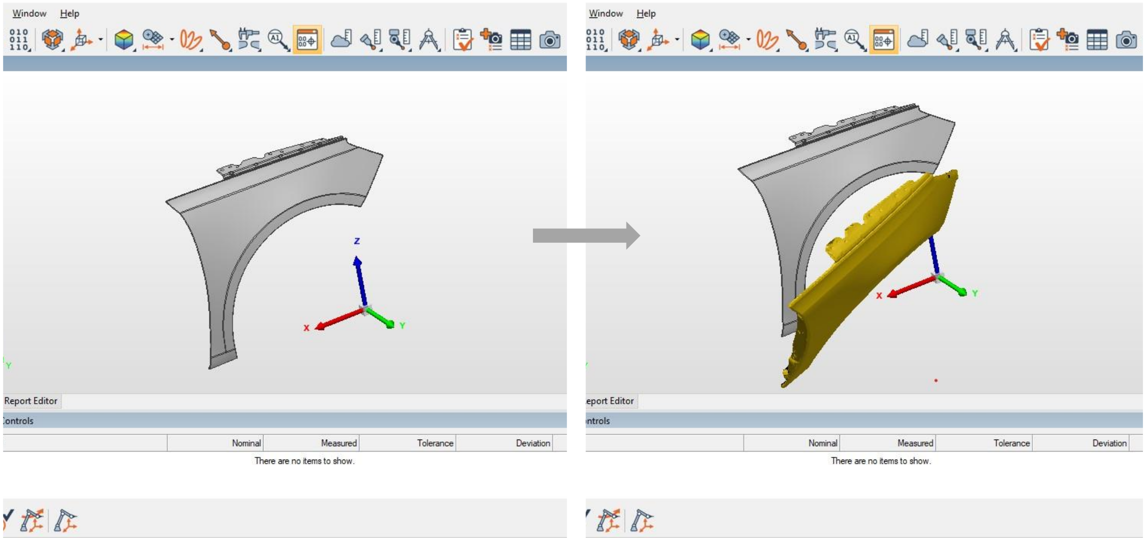


Figure 145: Importing STL and STEP file of the fender to the workbench.

Now the CAD model and the STL file can be seen in the tree view under reference & data branches.

Aligning Data objects (STL) to reference object (STEP)

An alignment is an object transformation operation that changes the position and orientation of a data object to bring it into the coordinate system of a reference object.

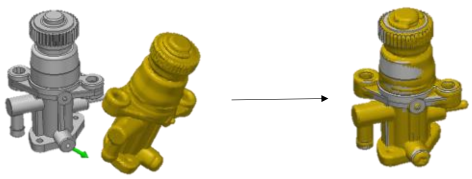


Figure 146: Aligning STL to STEP

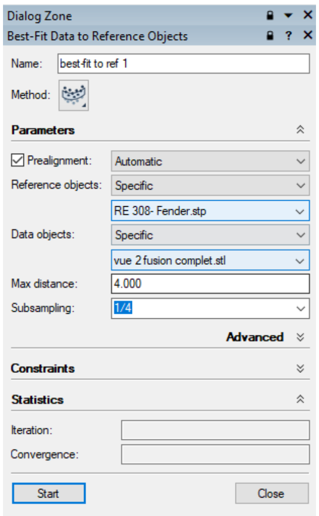


Figure 147: Best-Fit data to reference objects.

Aligning the scan to the CAD is a critical step in inspection, that's why it's very important to make sure the alignment is correct. Figure147 shows the parameter of how our alignment is conducted. While figure 148 shows the final results of this step.

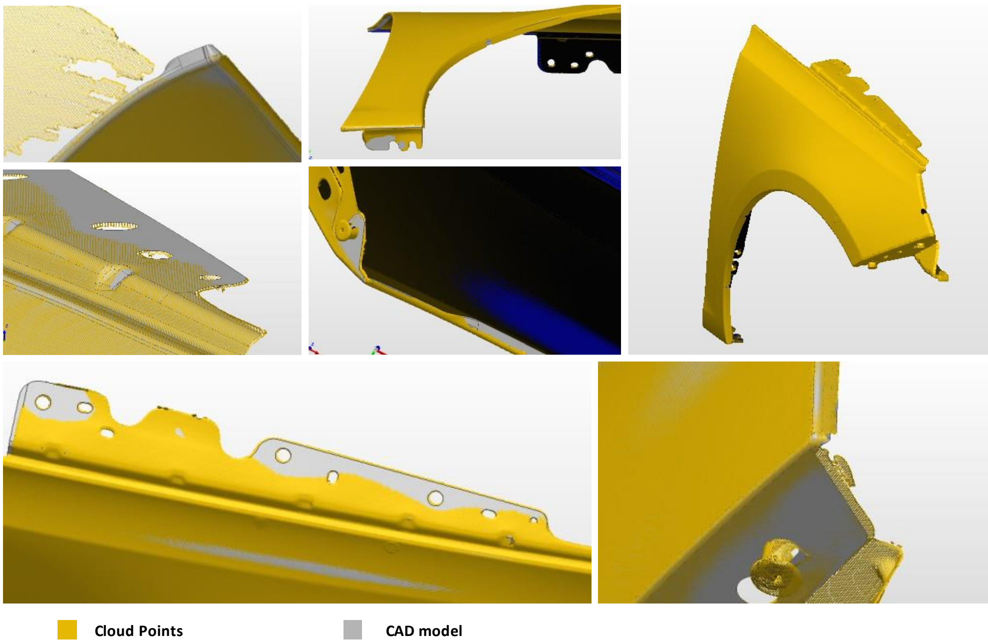


Figure 148: Results of alignment.

Deviation Analysis (Data color maps):

Deviation analysis or data color maps are measurement tools that measure the deviation of data objects from the surfaces or boundaries of reference objects. The analysis is mainly used in quality insurance to document reverse engineering deviations from the original 3D scan, like a pass/fail representation.

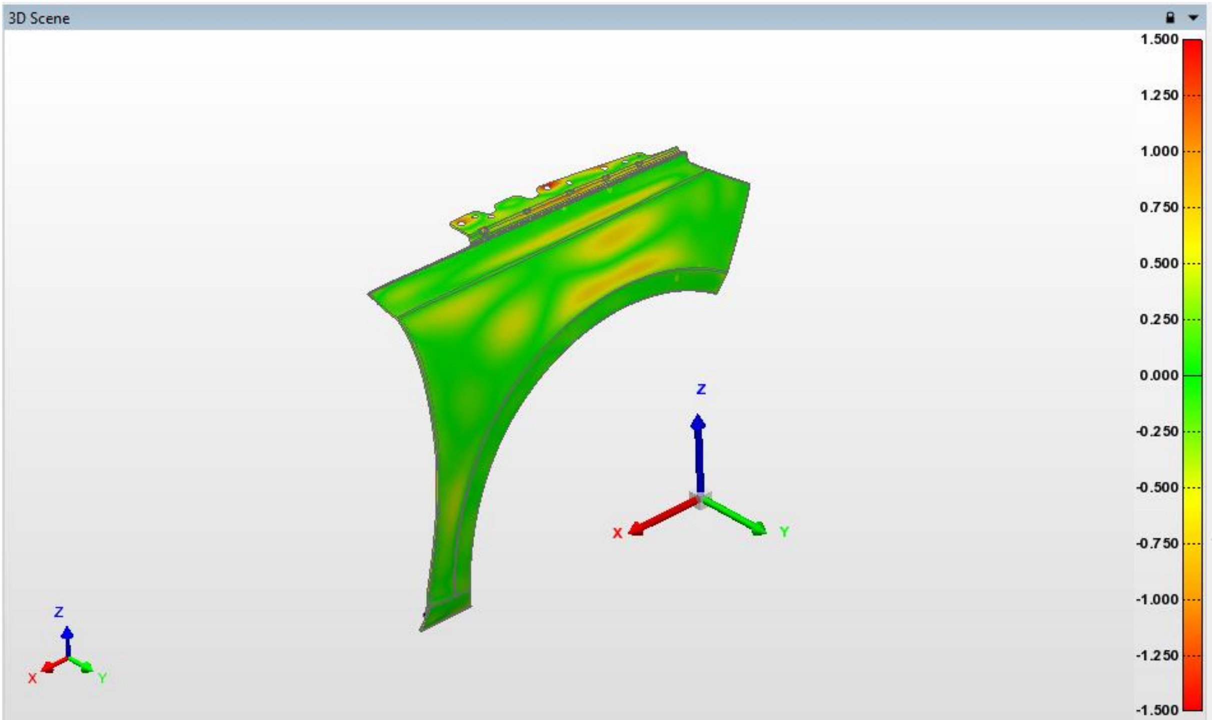


Figure 149: Deviation Analysis of the fender.

As seen in figure, the deviation between the scan and CAD model reaches its maximum of [1mm-1.5mm], just in the technical areas, which is great in our case because what we opted to have great results is the style of the fender and based on the deviation analysis the maximum deviation in the style area is 0.750 mm.

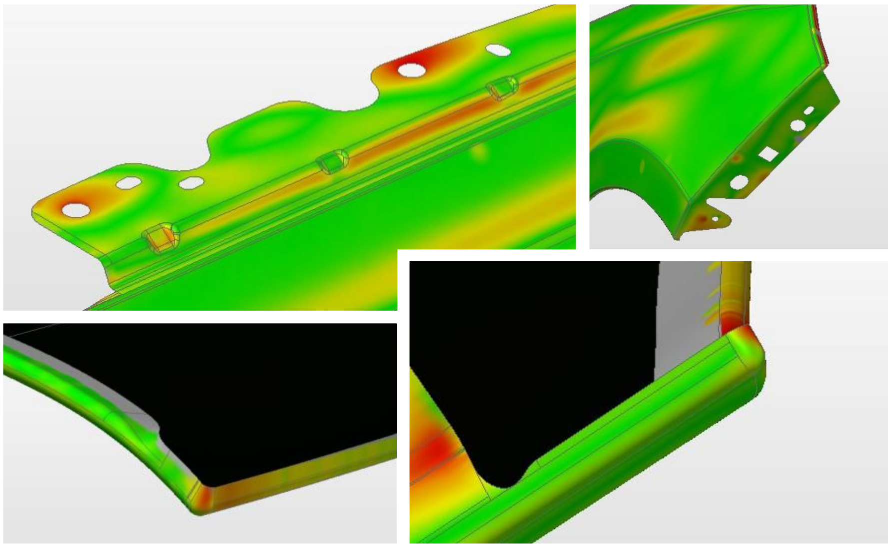


Figure 150: details of deviation analysis color map.

Checking Feature's tolerances

Based on TS table given in the previous phase (Table 7), each feature of the technical zone on the fender is assigned with a given tolerance(exp. Screw fastening AV1 : +0.3/-0.2), that's why this step is for

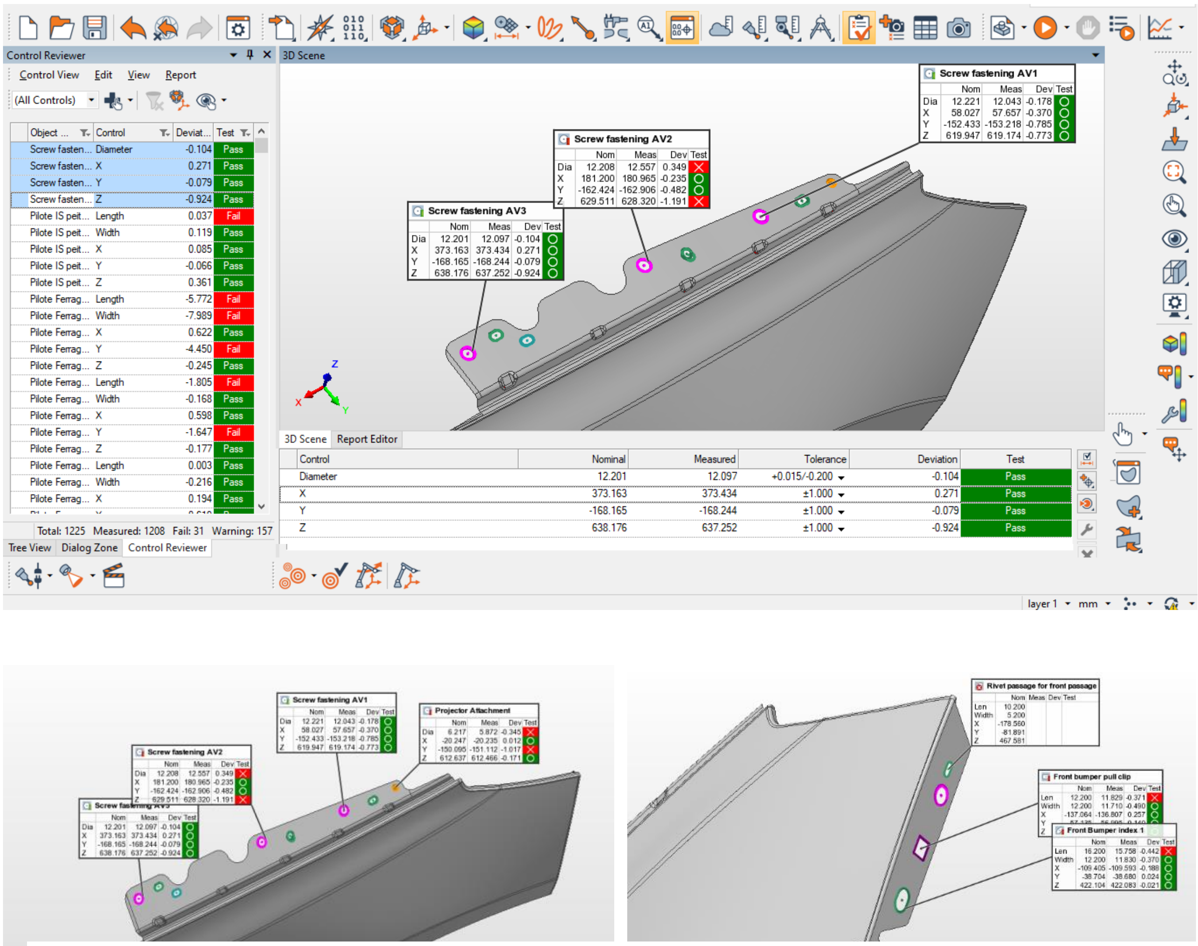


Figure 151: Feature tolerance measurement.

investigation the error between the feature in the scan and in the CAD (note that this step for us is optional since we know that the dimensions we based on are correct for the CAD model).

Comparison points

A comparison points contains an exact coordinate, usually located on a CAD model, on which the data deviation is to be measured. Comparison points can be positioned on a part surface or curve, or along cross-sections. There are five types of comparison points, each one tailored to calculate deviations in a specific context.

	Surface comparison points.
	Trimmed edge comparison points.
	Hemmed edge comparison points.
	Cross- section comparison points.

Since we want to obtain the deviation on a surface, we're going to use surface comparison points.

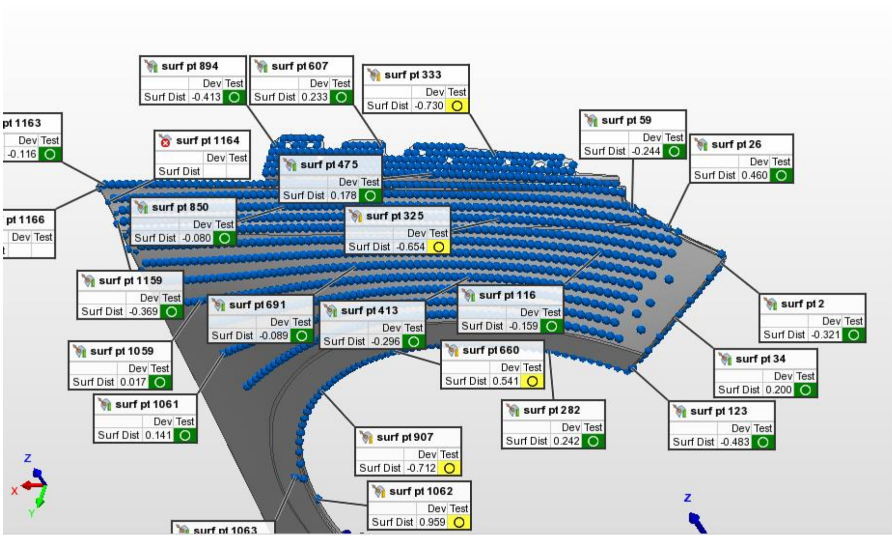


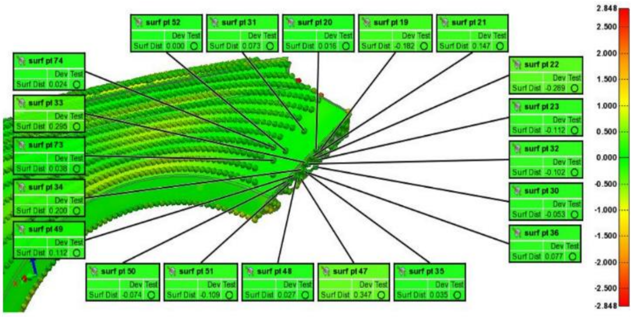
Figure 152: surface comparison points on the fender.

Results & discussion

The inspection phase generated a very long and detailed reports that would be difficult to present in full in this report, to simplify the results into diagrams where multiple details could be shown, we used MATLAB (part of the program we programmed can be found in the annex).

⇒ **Fender:**

1. Checking the surface of the style (Comparison points):



As shown in the figure 152, there are a number of points that exceeded the tolerance limits, others are in the acceptable zone, and almost 99% of points have passed which concludes that the style of the created CAD is as close as possible to the STL form, although some efforts will be needed to improve it even further.

Figure 153: Results of inspecting comparison points

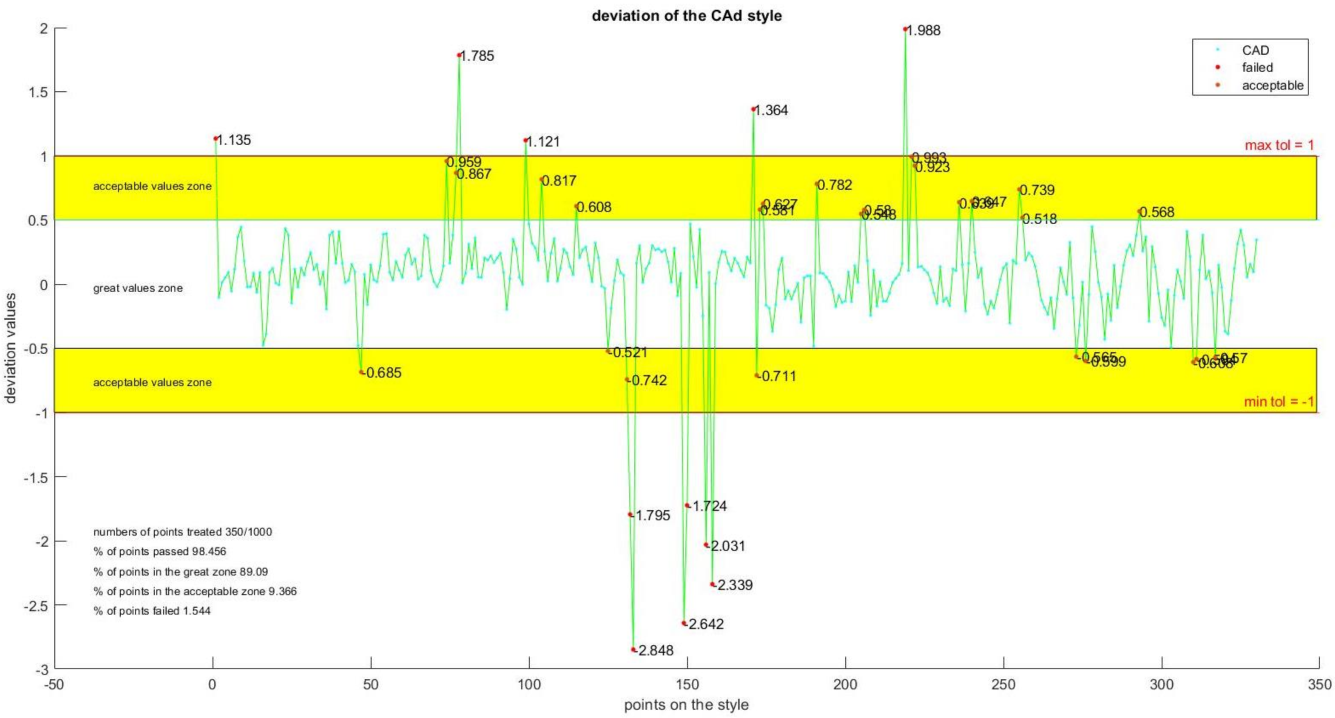


Figure 154: Visualization of the style inspection in MATLAB.

2. Technical zone (Upper side):

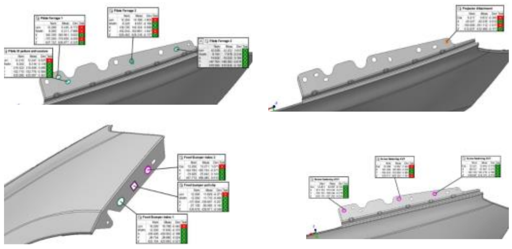


Figure 155: Fender's punching zones.

As shown in the first graph below, there is quite a big difference at some points in terms of the geometry of the punching zones, in particular points 10 and 11 h=which are the height and length of slot 2.

Since we made the technical parts ourselves without relying on the scan, we can deduce that this problem is a scanning problem, and that this particular large difference in this slot comes from the fact that the fender was a bit distorted in the technical part.

The second graph shows that the coordinates of the punching zones are almost exact, only 4 points out of 33 points failed with very small deviation

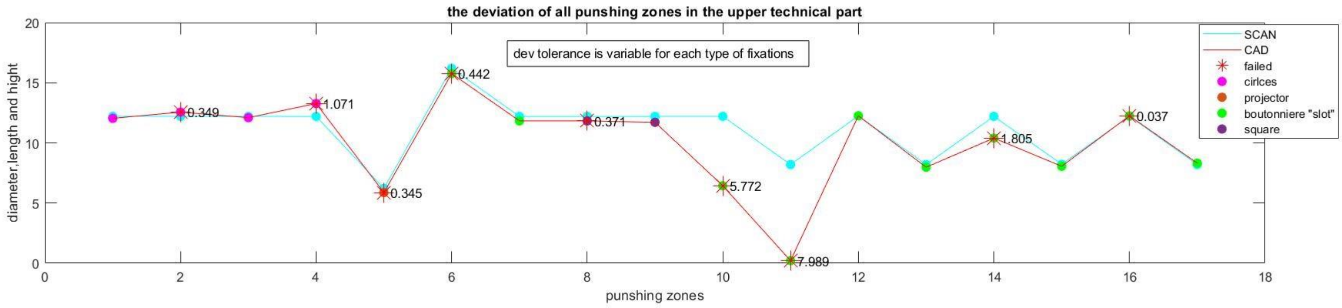


Figure 156: Deviation curve of punching zones in MATLAB.

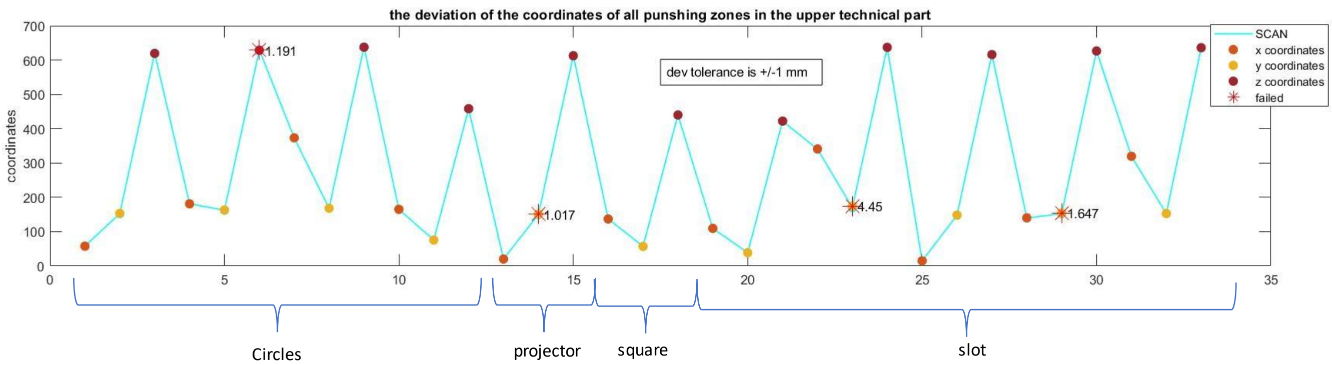


Figure 157: coordinates deviation curve of punching zones in MATLAB.

⇒ **Front Fastener:**

1. Surface (Comparison points)

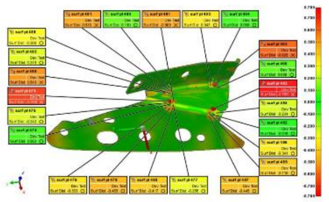


Figure 158: Surface deviation of front fastener.

As shown in the graph below, the CAD is close to the STL with exception of some points, but the advantage is that the largest deviation is only 0.3mm.

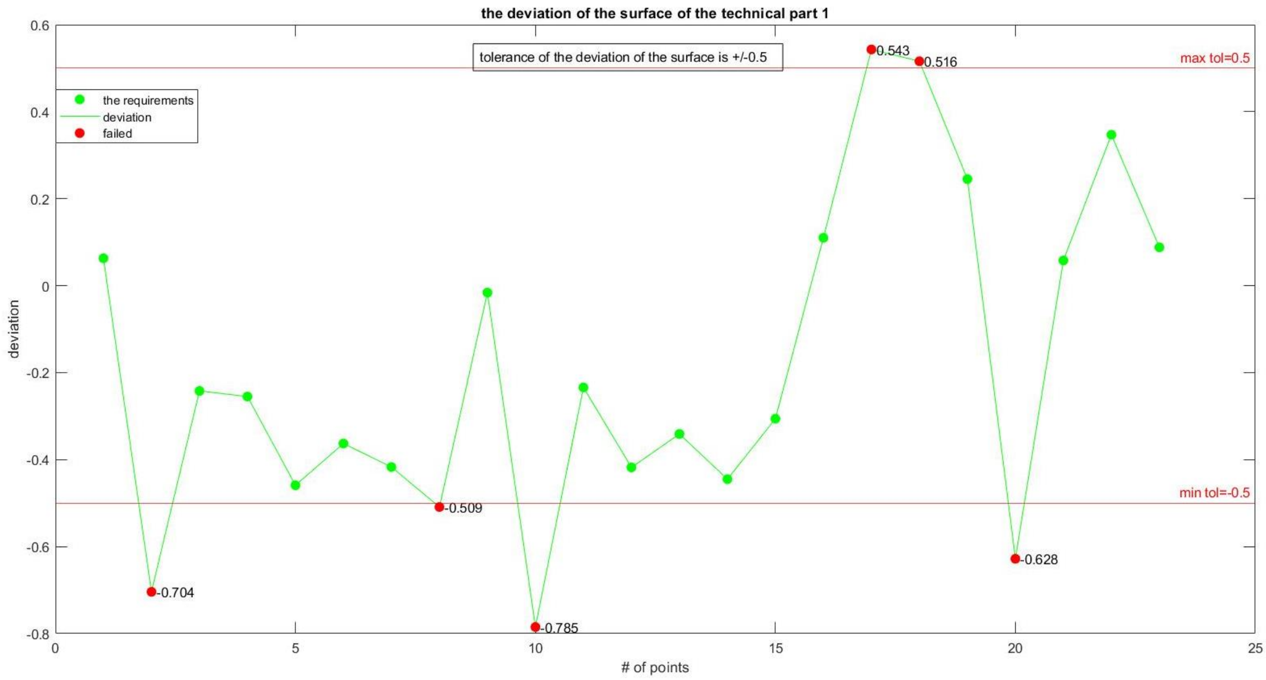


Figure 159: Deviation curve of front fastener's surface in MATLAB.

2. Punching zones:

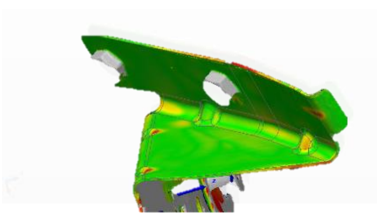


Figure 160: Deviation Analysis of front fastener.

the first two graphs shows that the first slot is a little distorted ith a maximum deviation of 2.159 mm, while on the other side, the coordinates are accurate for both slots

The two second graphs shows that contrary to the slots, the cirlces are very deviated with almost 4mm of deviation for the first cirlce, this problem is also a scanning problem and it is due to a welded bolt that couldn't be removed before scanning.

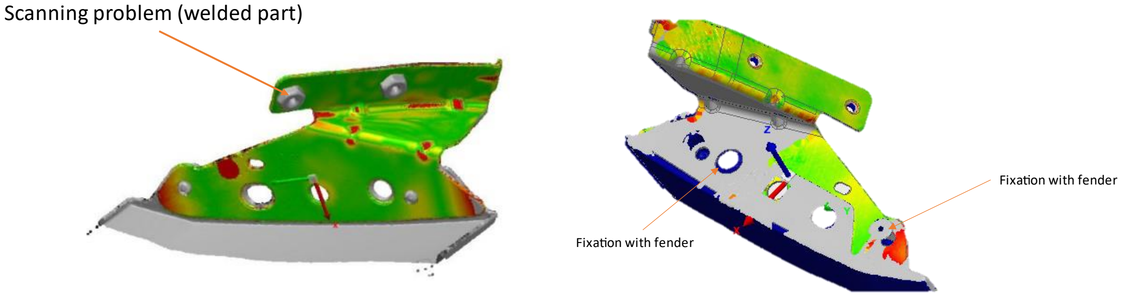


Figure 161: Source of errors in the inspection phase.

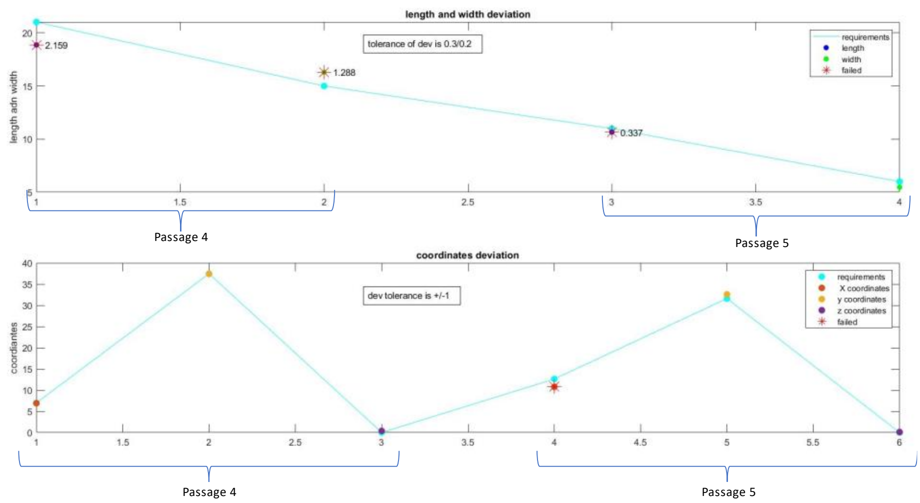


Figure 162: Results of inspection the punching zones.

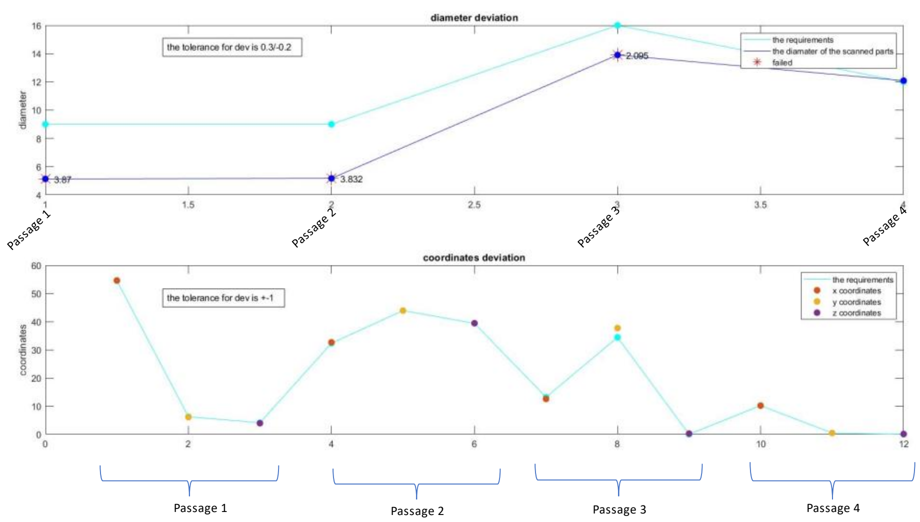


Figure 163: Results of inspection the punching zones.

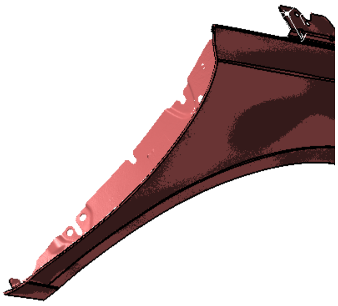


Figure 164: third part of the fender - closure.

The reason we did not inspect the last part of the fender is due to the fact that it is just an added part, fixed with a hem, and also because according to our benchmarking research, we found that while Peugeot chose to fix this part with a hem which made the production have extra steps, other companies chose to make it directly on the fender, which proved to be less expensive,

Therefore, we decided not to work on this part, as our goal being to optimize the fender.

At this point, it's very clear that the proposed CAD model is a very good replica of the original scanned part.

5.3.5 Assembly of the Fender

After validating each proposed CAD design in inspecting phase (part 1: Fender; part 2: Front fastener; part 3: Closure), we moved to assemble this tree part to visualize the global results and also to preform FEM analysis.

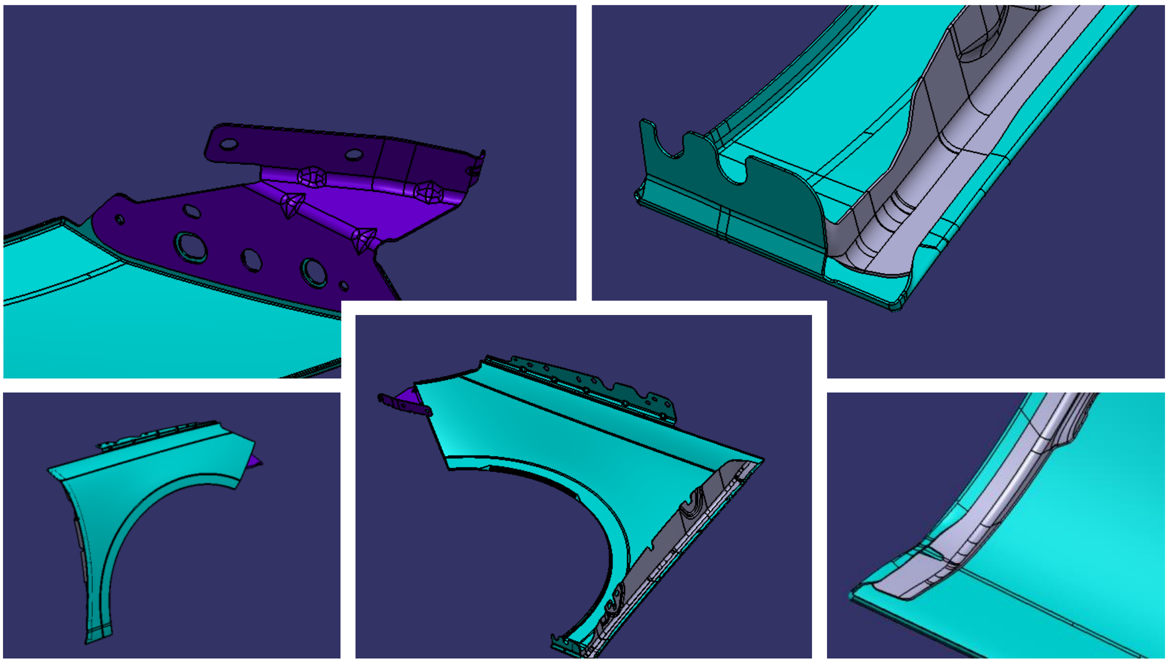


Figure 165: Fender Assembly.

5.4 Optimization

5.4.1 Material Side

In this step, our aim is to optimize or to verify if the material used for our Front fastener part (Figure 165) is the best one considering its material properties, price and manufacturing process.

With the help of Ashby data base (CES Edu pack) we choose to work with Performance Index methodology in order to select the best material suitable for our case study.

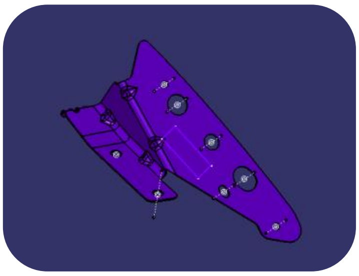


Figure 166: Front fastener.

<u>Designation of materials used by Stellantis for our part:</u>

Steel sheet metal ES 1.17 MM G10/10 X ; Grade ES ;Standard B53 3106 ; “Tôle Acier ES 1.17 MM G10/10 X ; Nuance ES; Norme Nuance B53 3106”

Table 9: Chemical Composition of the material used by the client.

Grade “Nuance”	**Coil** “Tole”	**Blank** “Feuillard”	**C max.**	**Mn max.**	**Si max.**	**P max.**	**S max.**	**Al min**
ES	XES ZES	FFES	0.08	0.40	0.12	0.025	0.025	0.020

Table 10: Mechanical Properties of the material used by the client.

Grade “Nuance”	**Thickness (t) mm** “Epaisseur”	**$R_{p0.2}$ (MPa) min max**	**R_m (MPa) min max**	**A (%) Min ISO 20x80**	**R_{18} min**	**N_{8-18} min**	**Grain size min**
ES	t≤1.47	160 200	280 340	37	1.8	0.19	6
	1.47<t<1.95	160			1.6		
	t≥1.95	210			1.5		

Material Selection - Performance Index

❖ *<u>Hypothesis I:</u> Lightweight and resistant part*

Table 11: Parameter table

Performance (Behavior)	Objective to optimize	**M**
	Fixed performance	**F**
Parameters (Structure)	Material Properties	**ρ, σ_y**
	Fixed structural parameters	**S**
	Free structural parameters	**t**
Constants		**α**

Equations:

$$\boldsymbol{\sigma = \frac{F}{S} = \alpha.\sigma_y \rightarrow F = S.\alpha.\sigma_y}$$

$$\mathbf{M = \rho.S.t}$$

$$\mathbf{F = S.\alpha.\sigma_y}$$

$$(2) \text{ ->} \qquad S = \frac{F}{\alpha.\sigma_y}$$

$$(1) \text{ ->} \qquad M = \rho.\frac{F}{\alpha.\sigma_y}.t$$

$$M = \left(\frac{F.t}{\alpha}\right).\left(\frac{\rho}{\sigma_y}\right) \rightarrow I = \frac{\rho}{\sigma_y} \quad \text{Performance index}$$

Selection line: Our goal is to minimize the mass while maintaining resistance

$$\ln(I) = cte \rightarrow \ln\left(\frac{\rho}{\sigma_y}\right) = cte \quad \rightarrow \text{Minimise the index I}$$

$$\ln(\sigma_y) = \ln(\rho) + cte \quad \rightarrow \quad \text{Reduce } \frac{\rho}{\sigma_y}$$

$$y = 1.x + cte \text{ (Slop = 1)} \rightarrow \text{Reduce } \rho \text{ \& Increase } \sigma_y$$

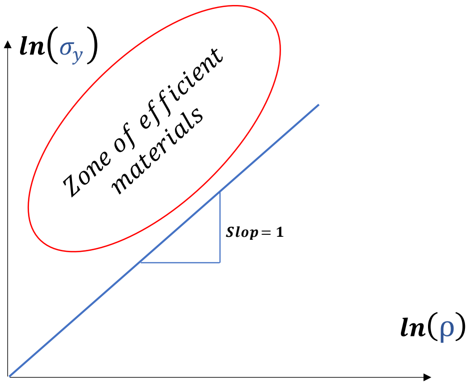


Figure 167:Visualization of zone of efficient materials (Hypothesis 1).

Results of this stage in CES

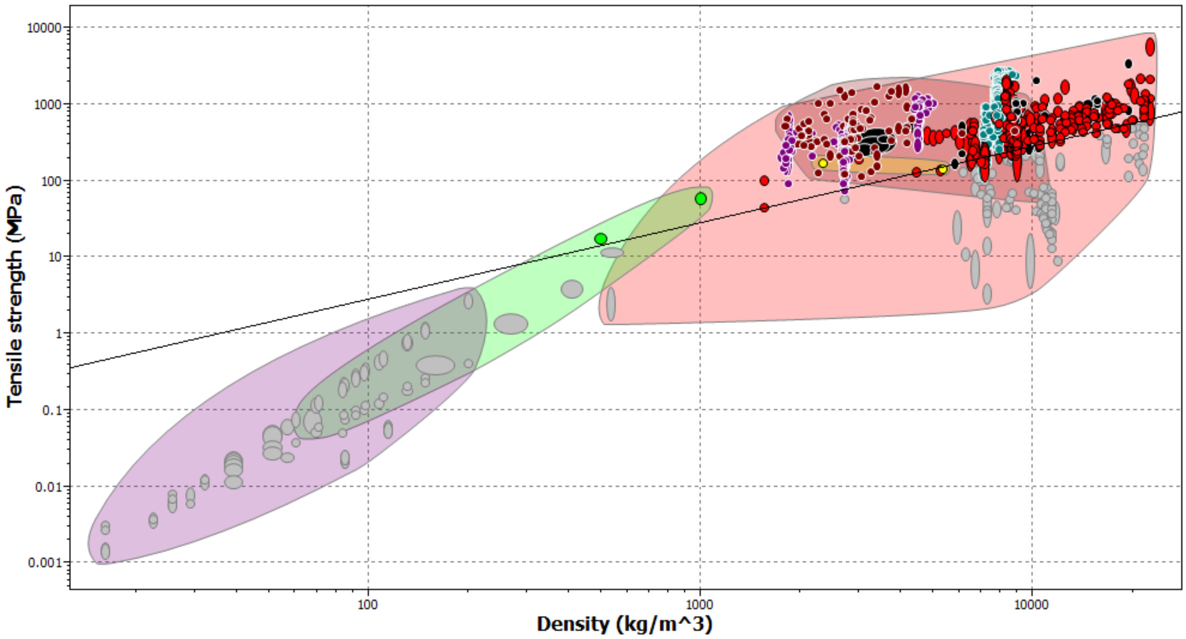


Figure 168: Results of the first hypothesis in CES.

❖ *<u>Hypothesis II:</u> resistant and inexpensive part*

Table 12: Parameter table

Performance (Behavior)	Objective to optimize	**Price**
	Fixed performance	**F**
Parameters (Structure)	Material Properties	**C_m, ρ, σ_y**
	Fixed structural parameters	**S**
	Free structural parameters	**e**
Constants		**α**

Equations:

$$\mathbf{Price} = \mathbf{C_m.M} = \mathbf{C_m.\rho.S.t}\ (1)$$

$$\mathbf{F} = \mathbf{S.\alpha.\sigma_y}\ (2)$$

$$(2) \Rightarrow S = \frac{F}{\alpha.\sigma_y}$$

$$(1) \Rightarrow \text{Price} = C_m.\rho.\frac{F}{\alpha.\sigma_y}.t$$

$$\mathbf{Price} = \left(\frac{\mathbf{F.t}}{\boldsymbol{\alpha}}\right).\left(\frac{\mathbf{C_m.\rho}}{\boldsymbol{\sigma_y}}\right) \Rightarrow \quad I = \frac{C_m.\rho}{\sigma_y} \quad \text{Performance index}$$

<u>Selection line:</u> Our goal is to minimize the mass and the price

$$\ln(I) = cte \rightarrow \ln\left(\frac{C_m.\rho}{\sigma_y}\right) = cte \rightarrow \text{Minimise the index I}$$

$$\ln(\sigma_y) = \ln(C_m.\rho) + cte \rightarrow \text{Reduce } \frac{C_m.\rho}{\sigma_y}$$

$$y = 1.x + cte\ (\text{Slop} = 1) \rightarrow \text{Reduce } C_m.\rho\ \&\ \text{Increase } \sigma_y$$

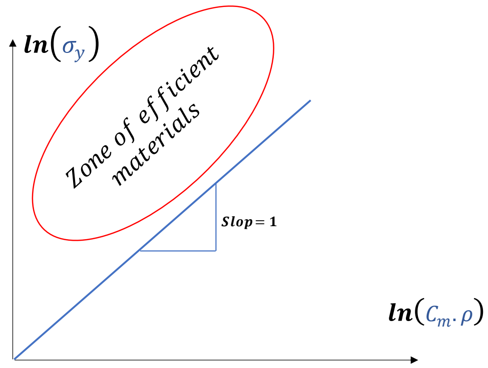


Figure 169: Visualization of zone of efficient materials (Hypothesis 2).

Results of this stage in CES

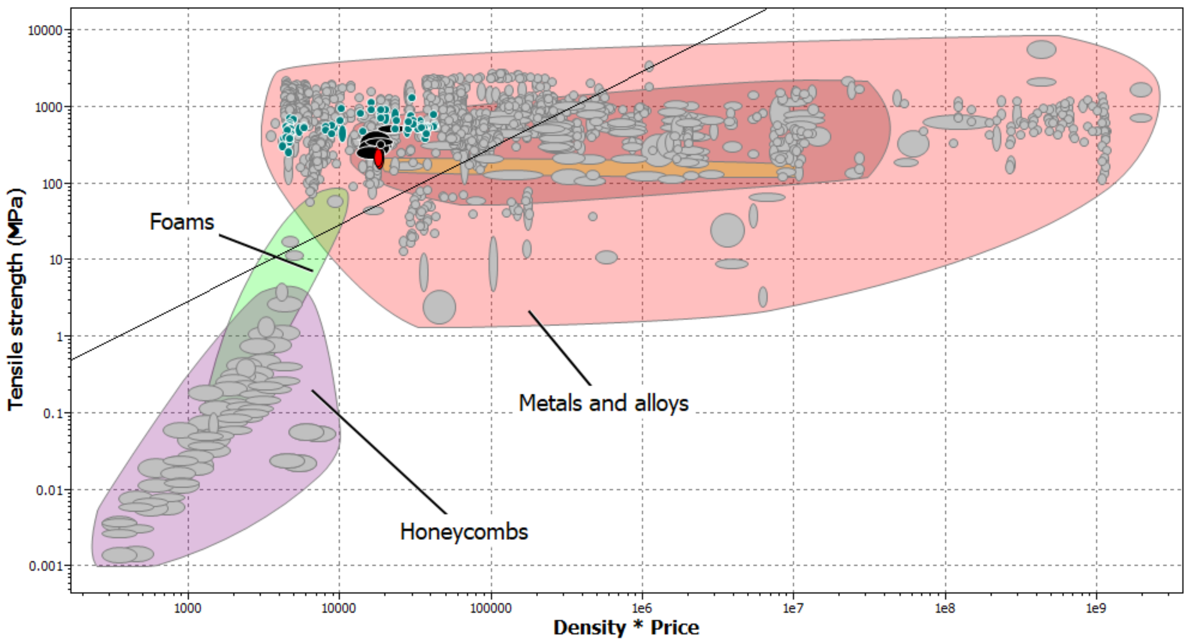


Figure 170: Results of the second hypothesis in CES.

To examine the final results, we are going to merge the two stages in one and add a minimum property of material based on the original one to ensure the final selected material is better than the first one in terms of price and resistance.

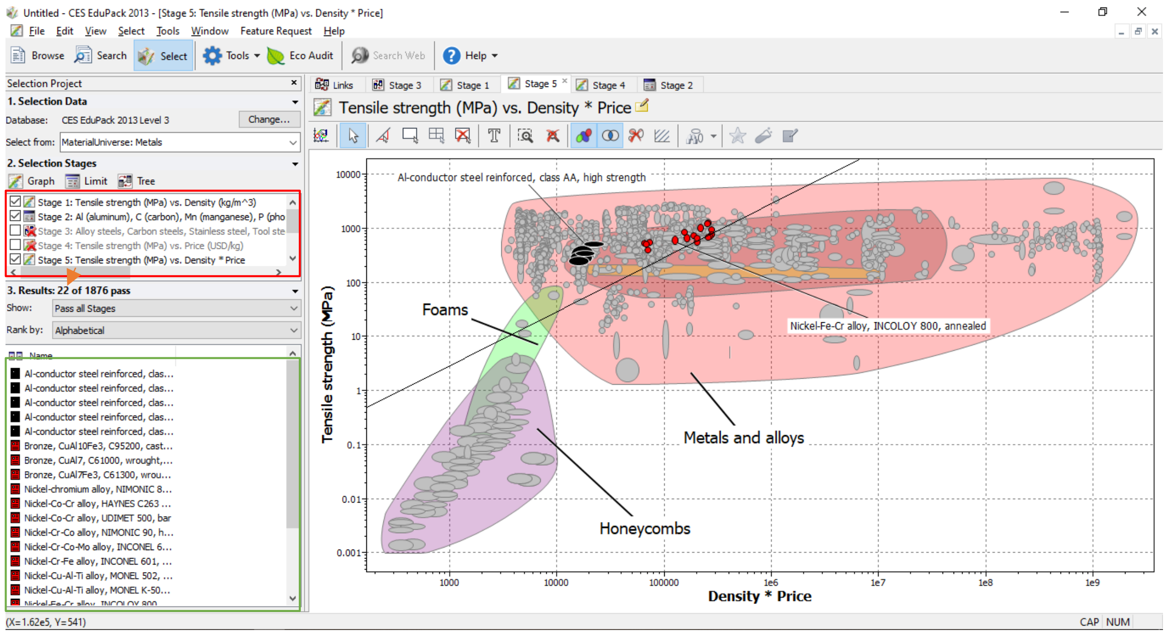
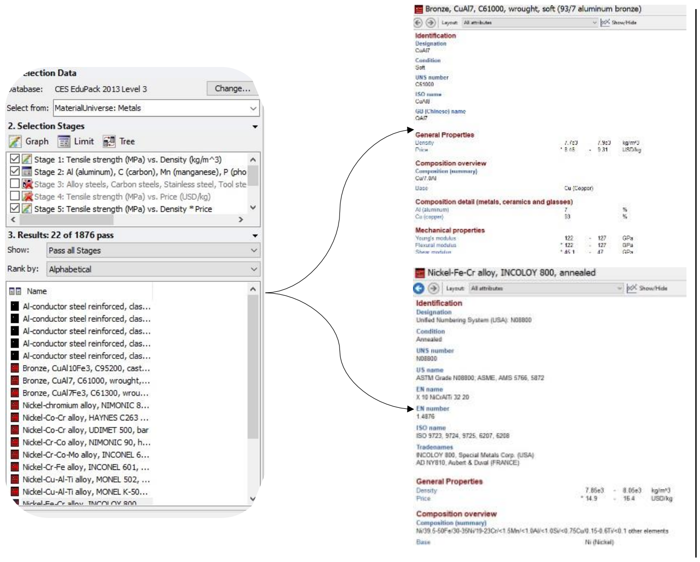


Figure 171: Intersection of the results.



in addition to the same family of grades used by Stellantis. We find that the database showed us more materials that respect all 3 stages, we find Aluminum bronze, CuAl7 C61000, wrought: Nickel-Fe-Cr alloy, and others.

Figure 172: Investigation the results.

After further examination of the results, it turns out that we need to add a new stage that limits the price at a given zone, after applying this stage we found that there is 5 materials that respect all of our stages.

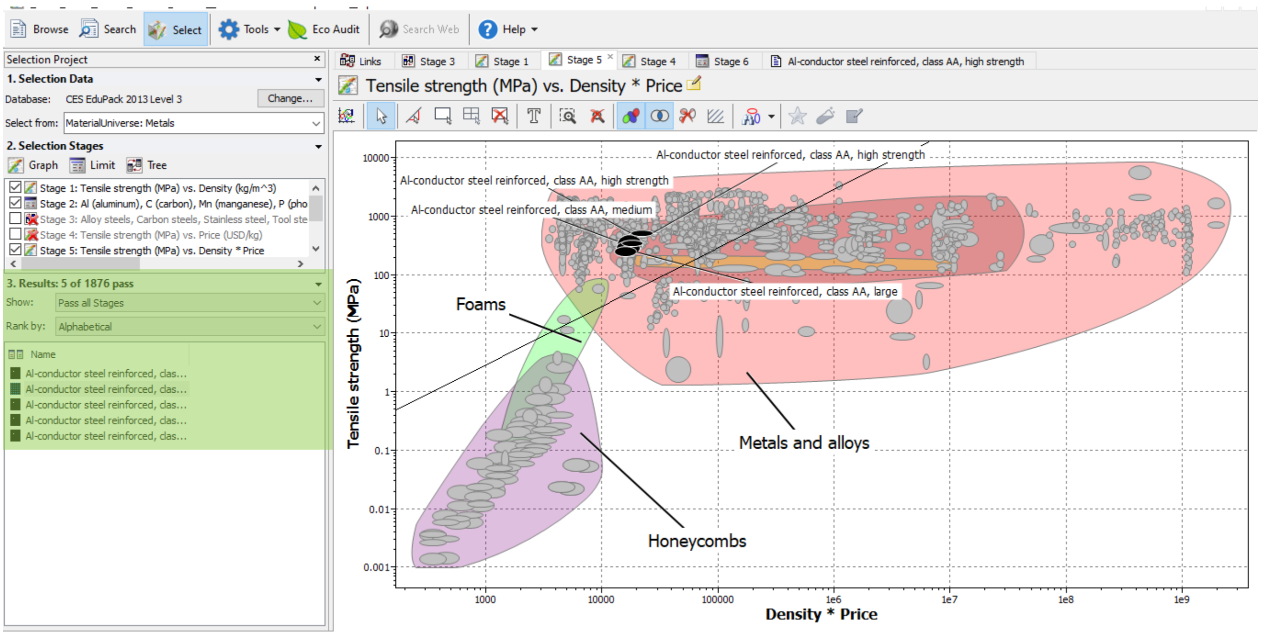


Figure 173: Limiting the results in a given price zone.

Table 13: Chosen material vs original material

	General Properties		*Mechanical Properties*				
	Density (kg/m^3)	Price (USD/kg)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (% strain)	Hardness-Vickers (HV)
Acier ES	7e3-7.01e3	----	----	160-200	280-340	37	121-23
Al-conductor steel, Hight strength	4.02e3-4.58e3	4.15-6.22	104-119	420-645	463-588	30-40	121-123
Al-conductor steel, medium	2.96e3-3.87e3	4.15-6.22	75.8-100	205-360	226-480	30-40	121-123

After searching for new material for our part in CES, it turns out that we could not make any conclusion since we do not know some properties of the grade of steel used by Stellantis. However, if we propose that the price of the grade used is close the price of sheet metal steel, its obvious that there is a big gap between the final proposed material and the first one.

5.4.2 Geometry Side

In this phase we tried to modify the part's geometry while respecting the constraint given by the environment, after proposing many concepts on paper we only moved on to design the best ones in CATIA.

Concept 1: modification of the rear technical part

Using the benchmarking results, we decided to adjust the rear technical part so that it can be a part of the fender, unlike the 2013 version which are assembled parts,

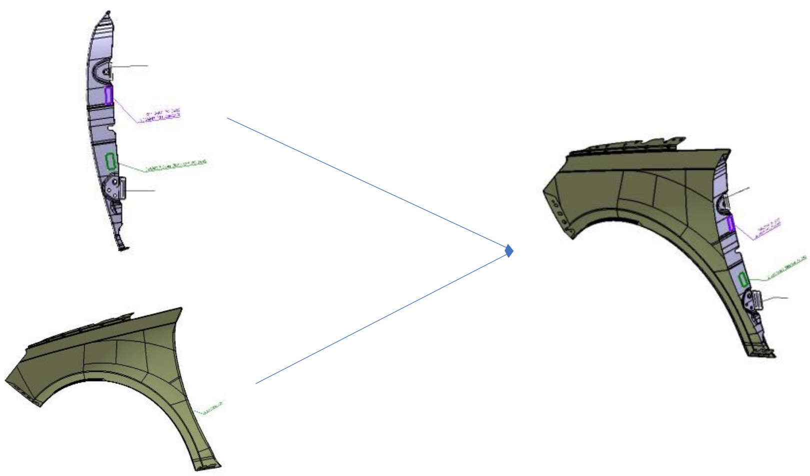


Figure 174:Assembly of the fender with its closure.

Our first idea was to keep the hemming as it adds some aesthetics to the fender, and to recreate the surfaces that connect the fender to the environment.

We started by exporting the surfaces we need to respect the most, the surfaces of the fixations, then we proceeded to create the technical part.

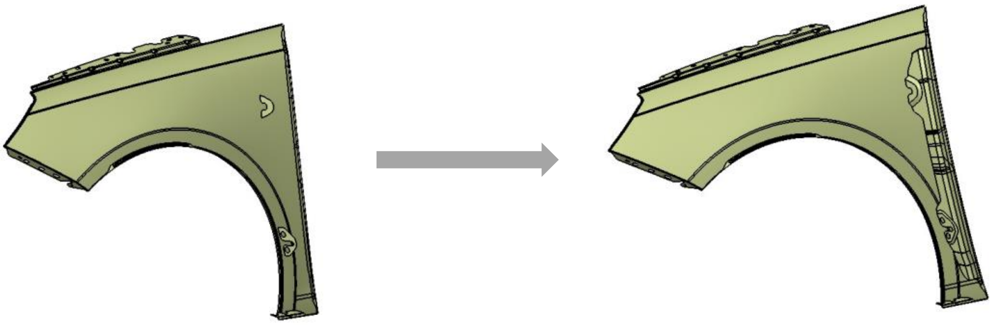


Figure 176: Design of the first solution in Catia V5.

The problem with this design is that it is expected to be fragile against frontal forces, so to strengthen it, we added some bulldozers.

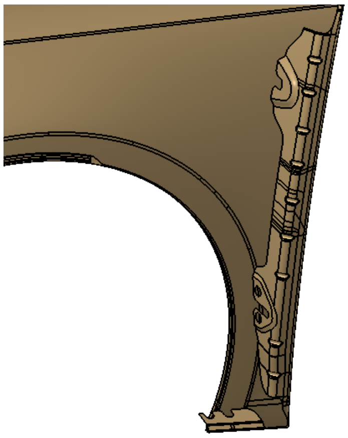


Figure 175: Reinforcements of the design.

Our final first concept:

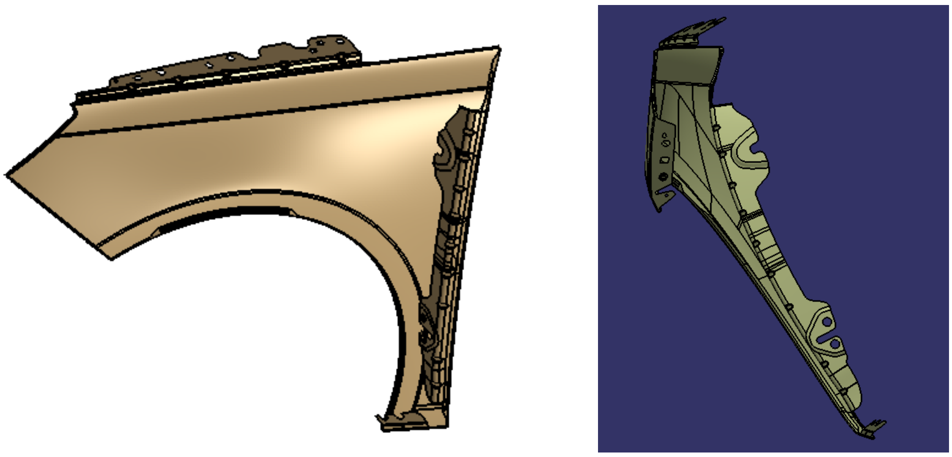


Figure 177: (a) Solide part of the first solution. (b) surface model of the concept.

<u>Concept 2</u>: modification of the rear technical part

we have figured out a way to further reduce the amount of material in the technical back end while trying to solve the problems of the first concept (to be explained in the next chapter in the concept selection).

In this second design, we modified the location of one of the bindings in the environment without changing its shape so that it could adopt the changes on the fender.

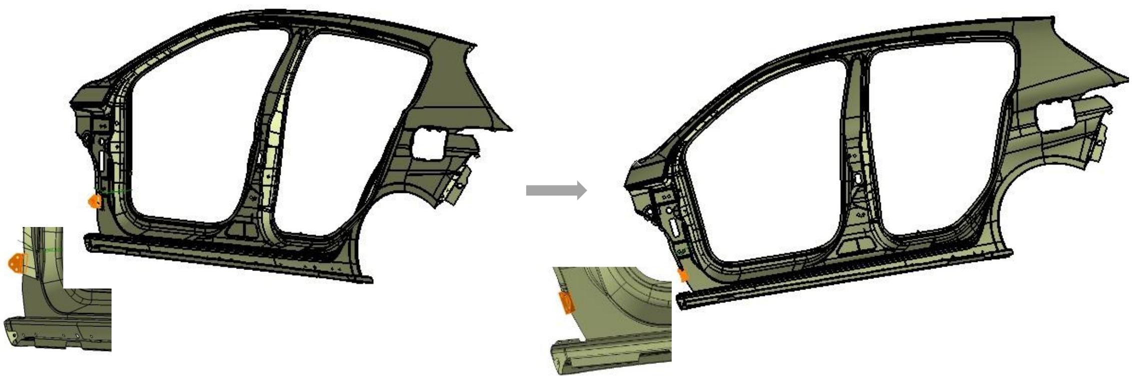


Figure 178: Modification in the environment.

We also have modified the angle of the hemming, and as before, added bulldozers to strengthen the part.

Our final second concept

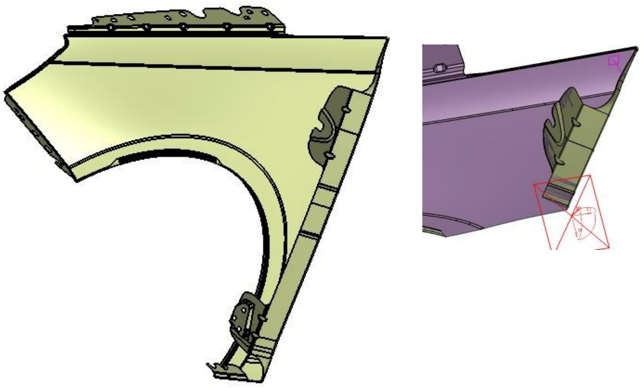


Figure 179: Solid and surface model of the second concept.

5.5 Concept Selection & Validation

⇒ **FEA in Ansys**

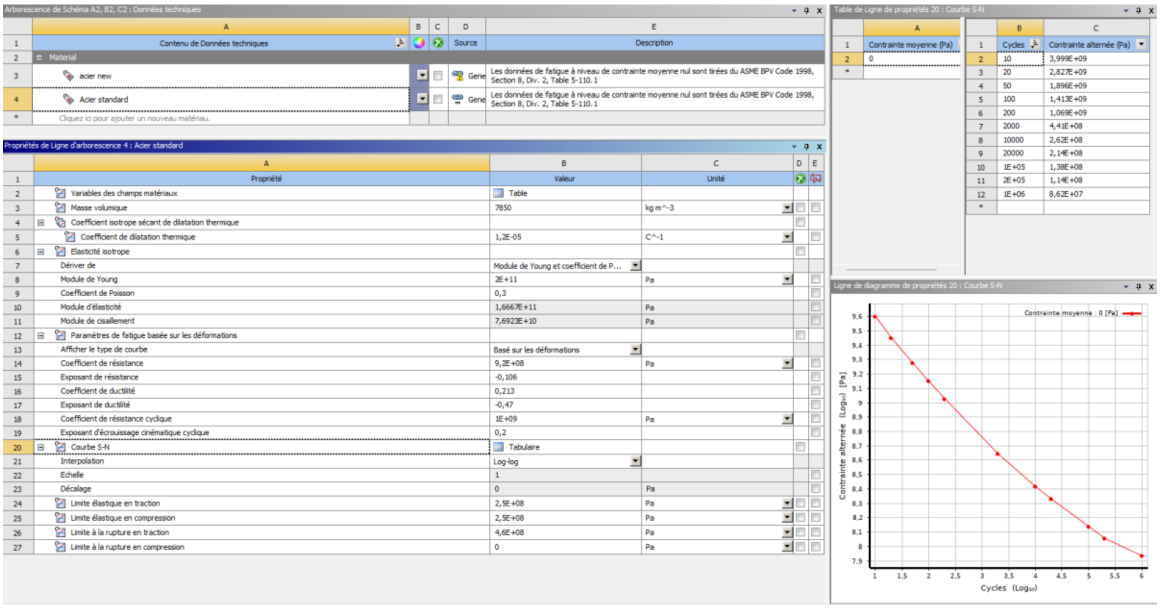
In this step, we decided to analyze the effect of a small pressure randomly placed on the 3 fender concepts (original, first redesign and second redesign) to visualize stress concentration and total displacement.

The results of this step could help us choose the right concept.

The analysis is done on Ansys.

- **Setting the environment:**

Material:



Arborescence de Schéma A2, B2, C2 : Données techniques

	A	B	C	D	E
1	Contenu de Données techniques			Source	Description
2	Material				
3	acier new			Gene	Les données de fatigue à niveau de contrainte moyenne nul sont tirées du ASME BPV Code 1998, Section 8, Div. 2, Table 5-110.1
4	Acier standard			Gene	Les données de fatigue à niveau de contrainte moyenne nul sont tirées du ASME BPV Code 1998, Section 8, Div. 2, Table 5-110.1
*	Cliquez ici pour ajouter un nouveau matériau.				

Propriétés de Ligne d'arborescence 4 : Acier standard

	A	B	C
1	Propriété	Valeur	Unité
2	Variables des champs matériaux	Table	
3	Masse volumique	7850	kg m^-3
4	Coefficient isotrope sécant de dilatation thermique		
5	Coefficient de dilatation thermique	1,2E-05	C^-1
6	Elasticité isotrope		
7	Dériver de	Module de Young et coefficient de P...	
8	Module de Young	2E+11	Pa
9	Coefficient de Poisson	0,3	
10	Module d'élasticité	1,6667E+11	Pa
11	Module de cisaillement	7,6923E+10	Pa
12	Paramètres de fatigue basée sur les déformations		
13	Afficher le type de courbe	Basé sur les déformations	
14	Coefficient de résistance	9,2E+08	Pa
15	Exposant de résistance	-0,106	
16	Coefficient de ductilité	0,213	
17	Exposant de ductilité	-0,47	
18	Coefficient de résistance cyclique	1E+09	Pa
19	Exposant d'écrouissage cinématique cyclique	0,2	
20	Courbe S-N	Tabulaire	
21	Interpolation	Log-log	
22	Echelle	1	
23	Décalage	0	Pa
24	Limite élastique en traction	2,5E+08	Pa
25	Limite élastique en compression	2,5E+08	Pa
26	Limite à la rupture en traction	4,6E+08	Pa
27	Limite à la rupture en compression	0	Pa

Table de Ligne de propriétés 20 : Courbe S-N

	A
1	Contrainte moyenne (Pa)
2	0

	B	C
1	Cycles	Contrainte alternée (Pa)
2	10	3,999E+09
3	20	2,827E+09
4	50	1,896E+09
5	100	1,413E+09
6	200	1,069E+09
7	2000	4,41E+08
8	10000	2,62E+08
9	20000	2,14E+08
10	1E+05	1,38E+08
11	2E+05	1,14E+08
12	1E+06	8,62E+07

Figure 180: Material properties used for FEA (Steel).

Importing all the parts to Ansys:

We imported the fender, the fixations, and their environment.

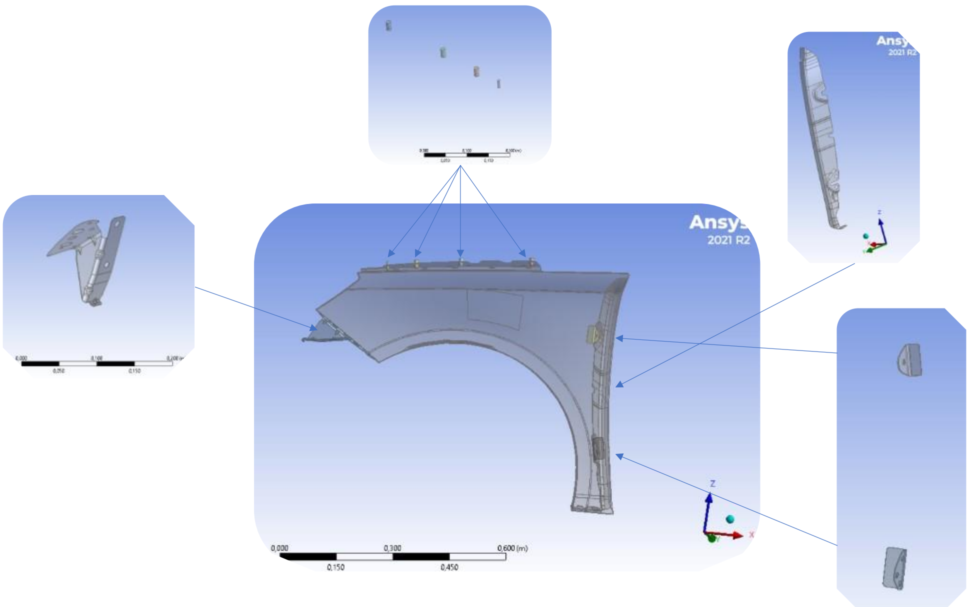


Figure 181: Fender in Ansys workbench.

Connections and meshing (B.C):

All the connections we made were deformable in order to better simulate the real experiment and because we didn't have access to import the environment to Ansys.

The only connection that in not deformable is the bottom attachment because it is welded directly to the interior body.

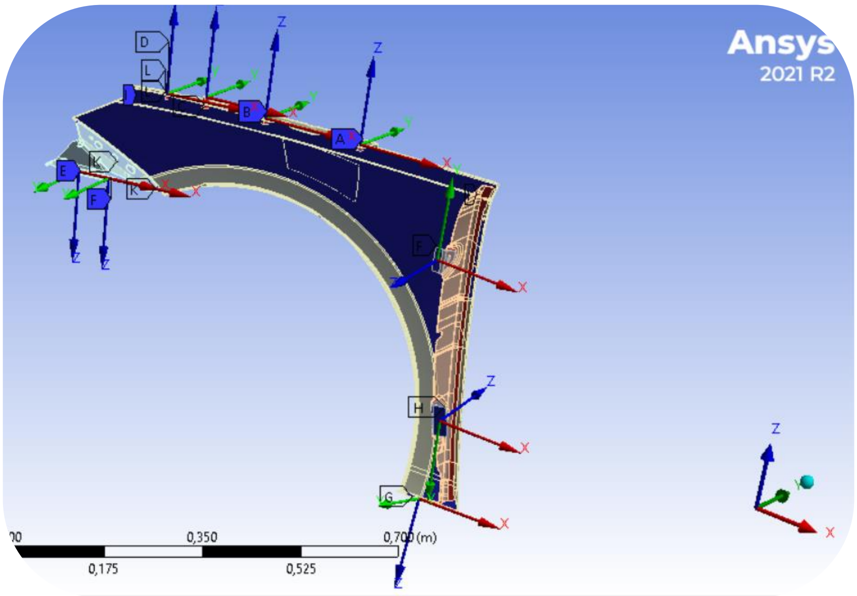


Figure 182: Fender boundary conditions.

For the meshing we chose an element size of 3 mm for general surfaces and 1 mm for fixations and connection zones.

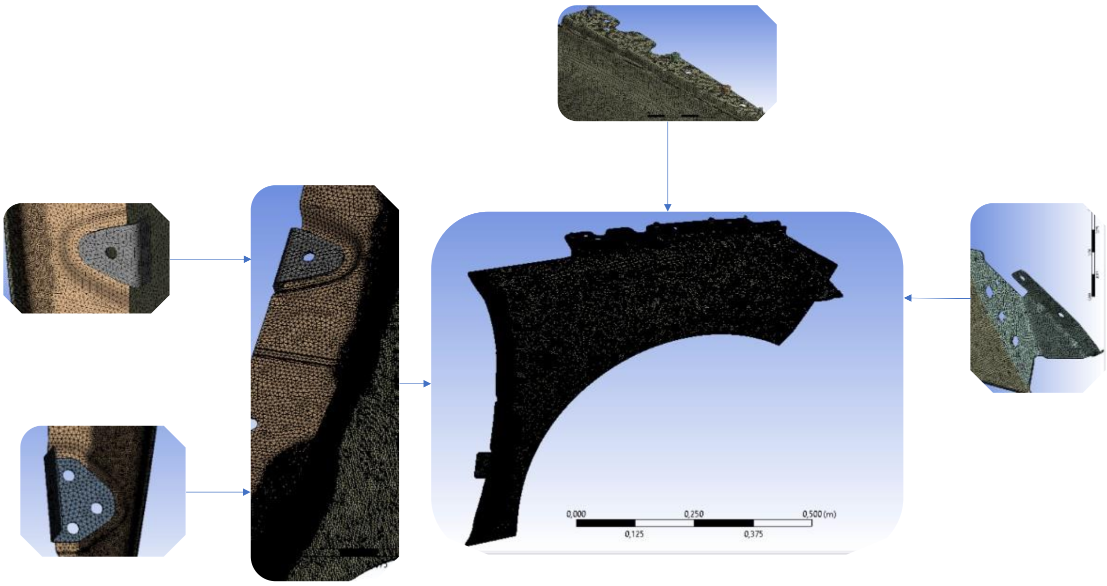


Figure 183: Fender meshing

Loading:

first, we had to calculate the amount of pressure needed.

We took a case of a same car (Peugeot 308 2013) with a velocity of 60 km/h crashing to a particular surface of 0.148 m^2

The resulting calculated pressure is estimated as:

$$P = 3{,}104\ MPa$$

results:

➢ *Original Design:*

We can see from the figure below that the max displacement is 35 mm with a stress concentration in the upper and lower parts.

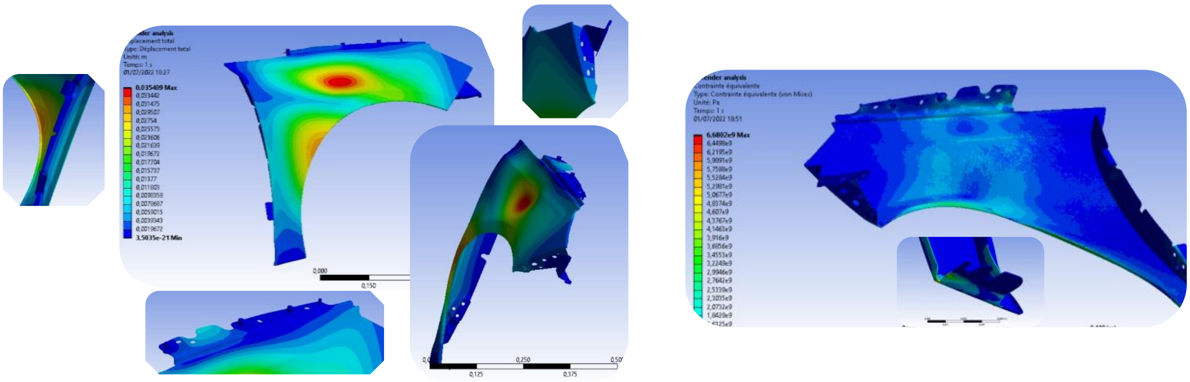


Figure 184: Stress concentration & displacement variation for the original design.

➢ *The First Concept:*

As seen in the figure below, the max displacement for this concept is 15 .5 mm lower as is the stress concentration in the back part.

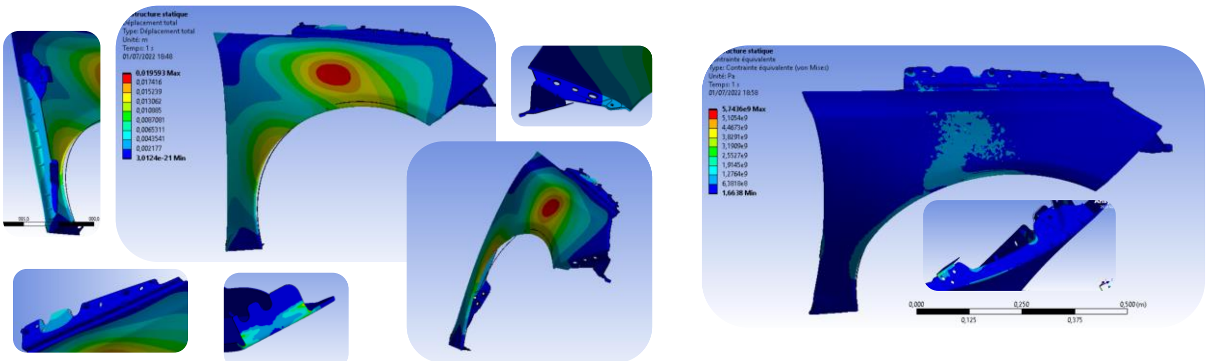


Figure 185: Stress concentration & displacement variation for the first concept.

➢ *The second concept:*

The max displacement for this concept is even lower than the one before by 1 mm, as is the stress concentration in the back part

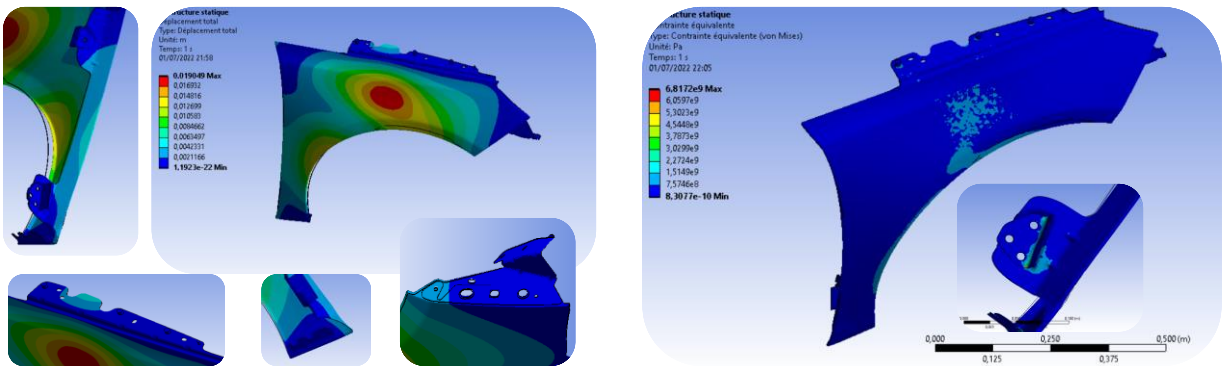


Figure 186: Stress concentration & displacement variation for the second concept.

We can notice a great improvement between the original concept and the first redesign concept, the displacement is 15 mm lower, with a concentration in the rear fixation which does not endanger the passengers.

The second concept, on the other hand, has an even smaller displacement with a smaller stress value,

This analysis showed that the third concept is better in terms of rigidity.

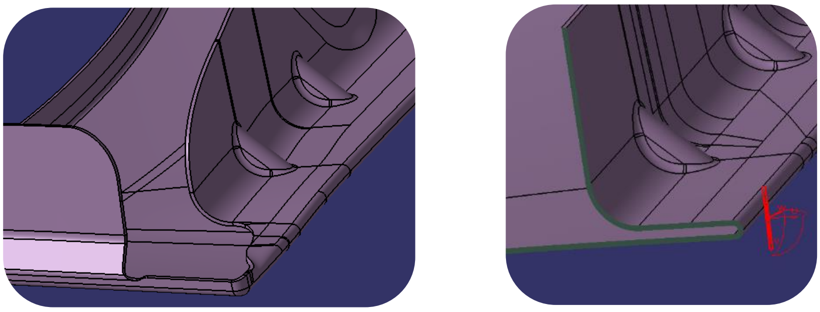
⇒ Manufacturing feasibility

First concept:

The first concept would ideally be produced using three manufacturing concepts, stamping for the general surfaces, punching for the attachment areas, and hemming for the edge surfaces.

The problem with this concept is the surface shown in the figures below, the L-shaped surface cannot be manufactured using hemming techniques, as the experts explained, the hemming machine would have no access to the second surface of the hemming process and the surface shape would be distorted.

and through the FEM analysis we saw that the stress in the back surface is concentrated mainly on the bulldozers under the fastening areas, so to have a more optimized design we had to reduce their number.

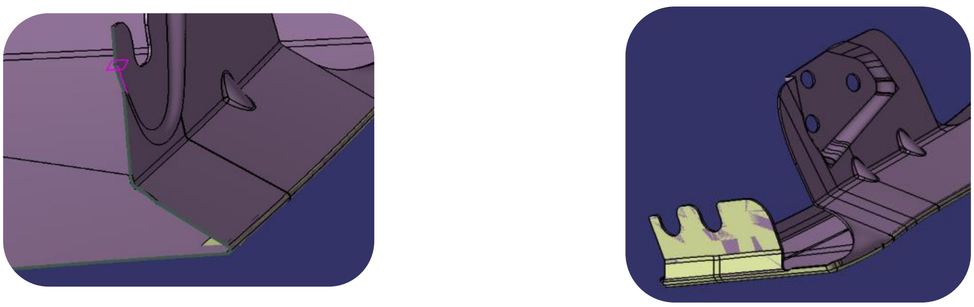


187: Technical surface of the first concept.

Second concept:

The second design was definitely more suited to the manufacturing process already in use, the raised hem surface shown in the figures below would allow the machine to access the second hem, and the reduced number of bulldozers is also an advantage.

The only problem with this surface is its environment, since we could not change the shape of the lower back attachment, we had to redesign its shape on the fender, if we could change the shape of the attachment the fender would have an easier design on the lower back.



188: Technical surface of the second concept

⇒ **Financial study**

The Fender is made of a variation of steel, which is the material imposed by the client. It is a good solution since the fender is one of the outer skins of the car and it need to be as stiff as possible while respecting the manufacturing feasibility. In addition, steel used for sheet metals is cheap and easy to weld, the only drawback is that it is vulnerable to corrosion but it get treated with an anti-corrosion layer in the BIW manufacturing process.

As shown in figure below, the total mass of the fender and its closure is approximately: M_{t1}= 2,312 kg

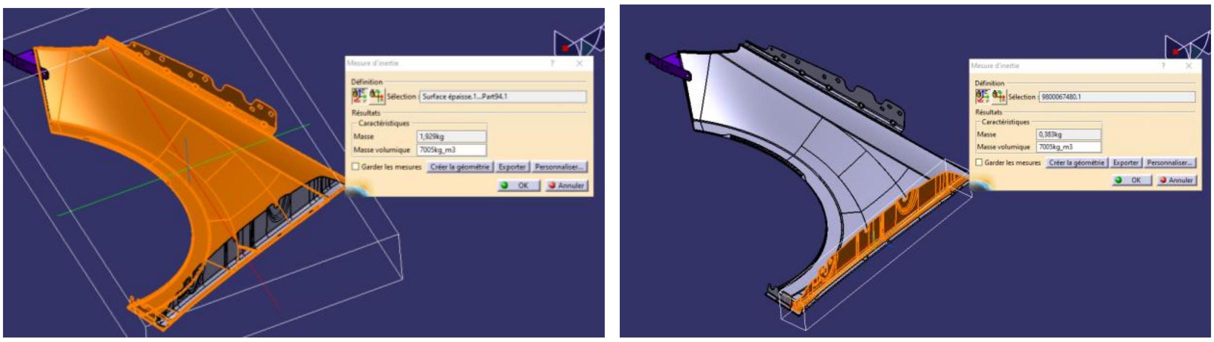


Figure 190: The mass of the original fender and its closure.

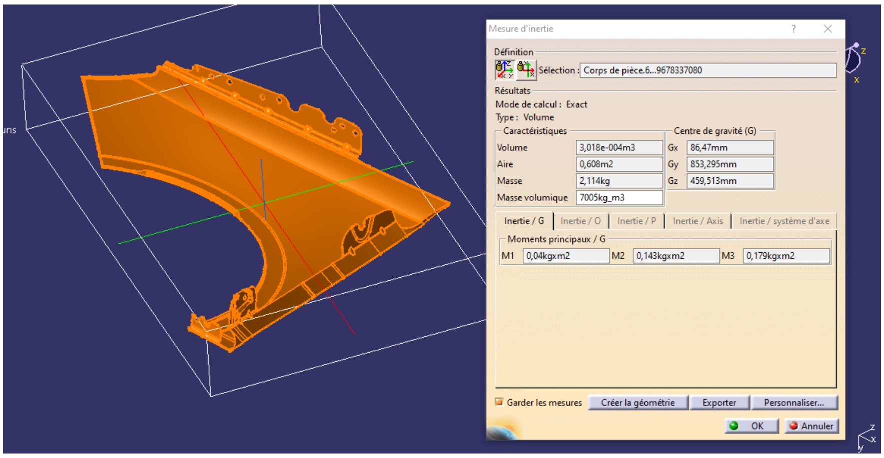


Figure 189: The mass of the proposed design.

The proposed solution, weigh approximately: M_2=2,114 kg

The mass of the Fender and its back fixature has decreased by 0.198 Kg, knowing that the price of steel is: 0.61 USD/kg, while the number of cars produced was nowhere to be found, about 194 650 vehicles were sold in 2013, the required materials would have costed **23 509,827 USD** less.

5.6 Results & Perspectives

As observed in the previous axe, the original design has many limitations, ranging from two separate parts joined by hemming to a weak structure, our improvement over the reconstruction of the first design showed great results in terms of structural rigidity with a small deformation of the surface that would be considered a safe crumbling area, but like the original design, it has a huge disadvantage which is the manufacturing problem, it cannot be manufactured using current manufacturing methods, which is a crucial criterion that would inevitably eliminate this concept.

The last concept is the ideal concept with less materials and an easier manufacturing process.

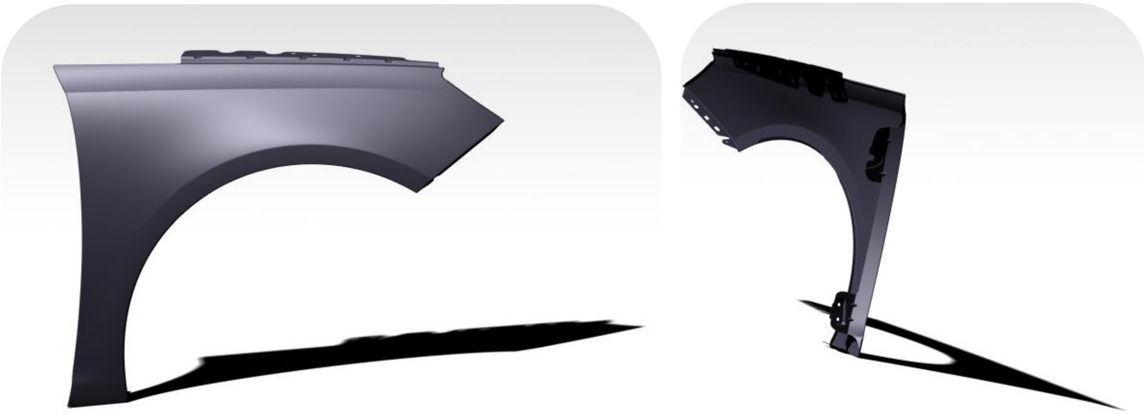


Figure 191: Peugeot 308 front fender (Rendering)

Conclusion

Throughout this chapter we have observed the effect of using a reverse engineering process while working on our main fender optimization project, by using 3D scanning technology we have shortened the redesign time considerably, rebuilding a non-existent CAD model would have been a difficult task, especially the style area which would have taken many takes between design and inspection.

We also found that although the scanning process could increase the error in surface deviation, especially because the part is old, inspection between STL and CAD showed excellent results, as did inspection between the original design and the reconstructed CAD.

The RE process showed a great effect on the final results, the use of a defined process gave meaning to the development, and the small goals in each phase were excellent for overall production morality.

General Conclusion

Our work at MG2 engineering has given us a great learning experience. Compared to previous internships, our 6-month internship at MG2 engineering allowed us to acquire a wide range of skills and to greatly improve our technical and soft skills, we learned both how to be a team member and how to carry and develop a project.

In this project, an in-depth study of the fender environment was carried out in order to have a better view of the constraints of our internship's topic,

Then, a planning phase was necessary to better fit our goals with our deadlines, while trying to create a process that meets our needs while respecting the original RE processes.

Following that the groundwork began, using both the benchmarking and the client's constraints as opportunities, we began to rebuild the CAD model using reverse engineering methodology with the help of 3D scanning technology which have been in compliance with clients' needs as proven by the inspection phase which have shown little to no deviation between the CAD model and the scanned data.

Next, further optimization was performed, in which we tried to create new models that would have an advantage over the original design, and then analyzed them using FEA and checking for price reduction and manufacturing feasibility.

Finally, we ended up selecting the best design that performed very well in all areas.

In this internship we have grown as engineers and gained a great sense of teamwork as it is a requirement in the project development sector, and in the work in general, we have also gained great understanding of the automotive industry, especially the design and manufacturing processes, and we have been privileged to work on a great subject in which we have a deep interest.

As demonstrated in this thesis, our work has been extensive, due to the large amount of information included in this project, we have chosen to remove some pages for better aesthetics. This includes some designs that failed in the RE phase, and some MATLAB programs used in the inspection phase.

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Appendices

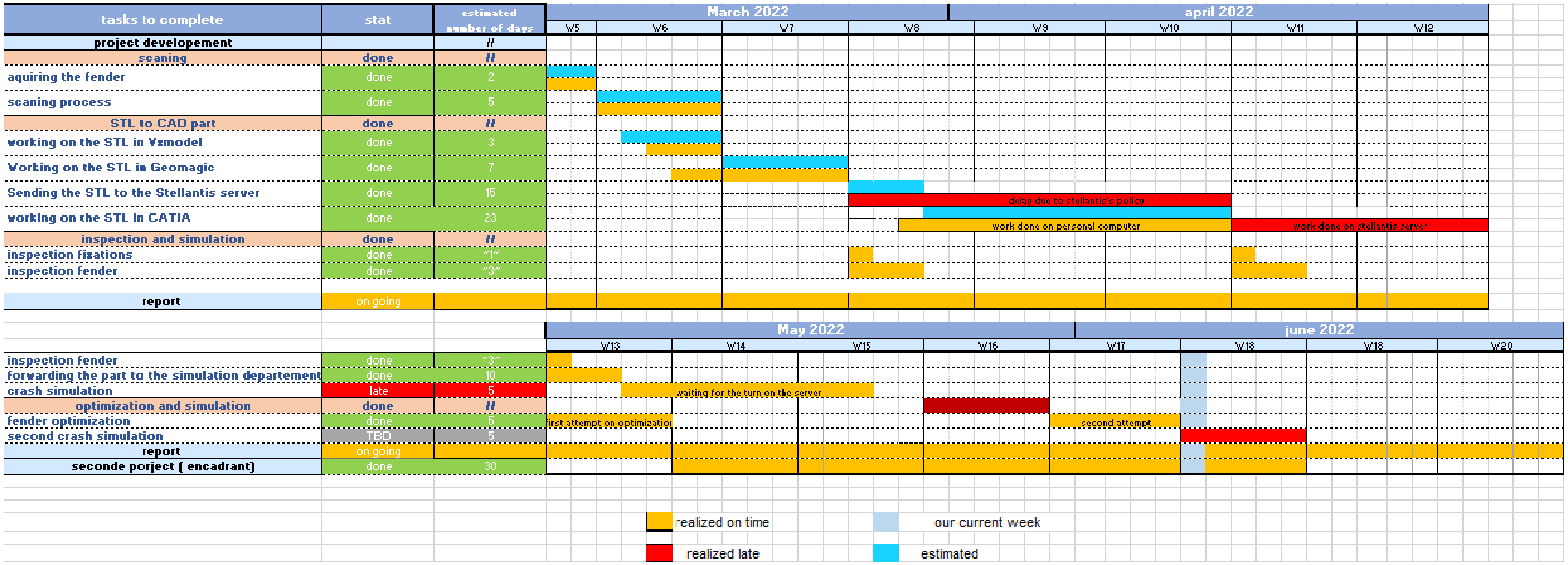


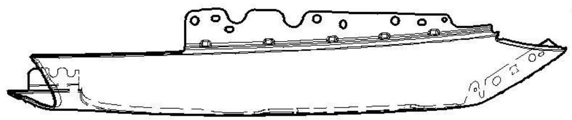
Figure 1: Project detailed post planning.

Table 14: Different segment of automobile.

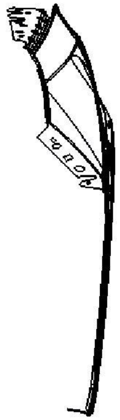
Euro Market Segment	**Market segment (British English)**	**Information**	**example**
A-segment **Length < 3700 mm Wheelbase < 2200 mm**	• Microcar/Bubble car	This model sets the boundary between cars and motorcycles, it is usually a car of 1 liter or less with usually two seats.	 *1:Renault twizy*
	• City car	City cars are generally a bit different from microcars, they are faster, have a larger interior and (in perception) a safer environment, which means they can be used in traffic at comparable speeds.	 *2: Citroen C1*
B-segment **3700 < Length < 4500** **2350 < Wheelbase < 2600**	• Supermini/Sub-compact	Supermini cars are a larger and more efficient version of the A-segment, they have 5 doors, can seat 4 people comfortably and feature a 1-to-1.5-liter engine, they are generally sold for urban markets	 *3: Ford Fiesta*  *4: Peugeot 208*
C-segment **4100 < Length < 4700** **2500 < Wheelbase < 2750**	• Compact car	this segment englobes the largest category of small cars, it is described as a 5-seater, 4-5 persons, 1-2 L engines. it includes a large category of cars.	 *5: Peugeot 308 2022*
D-segment **4530 < Length < 5200** **2650 < Wheelbase < 2920**	• Large family car • Compact executive car	Cars in the D-segment generally describe medium-sized family cars, which have (compared to the A-B-C segment) a large interior space and a good carrying capacity and 1.4-3 L engines.	 *6: Peugeot 508*  *7: Audi A4*

E-segment **4800 < Length < 5200** **2800 < Wheelbase < 3100**	• Executive cars	The E-segment includes executive cars which are luxurious, larger, and better equipped than the compact family cars in the D-segment. They are designed with a 2-liter or larger engine.	 *8: Ford Taurus*
F-segment **5000 < Length** **2900< Wheelbase**	• Luxury cars	This segment includes high-end luxury cars that outperform executive class cars, they are usually equipped with a powerful engine.	 *9: Rolls Royce phantom*
J-segment	• Mini 4x4 • Compact SUV	Small Sport Utility Vehicle This segment includes off-road sport utility vehicles, which are sporty, can go off the road and can clear terrains, they are usually equipped with high consumption powerful engines.	 *10: Peugeot 2008*  *11: Range Rover Velar*
	• LARGE 4X4		
S-segment	• Grand tourer • Convertible	This segment includes cars that appeal to customers who are interested in not only driving but also performance, they are usually equipped with a very powerful engine but are less comfortable than the other segments.	 *12: Aston Martin DB9 GT*
	• roadster • Supercars	for these cars, developers have practically abandoned comfort in favor of performance. they are equipped with high-end engines and high-end equipment. and they are also very expensive	 *13: Bugatti Veyron*

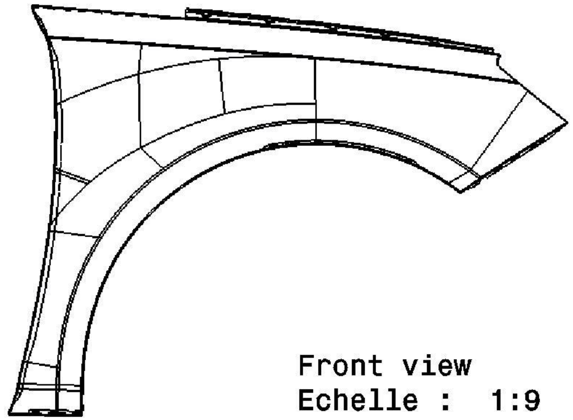
M-segment	• Mini MVP • Compact MVP • Large MVP	Minivan	MVP or multi-functional vehicles are the basis of this segment, as the name suggests, this type of car has many uses set by the designer, whether it is small trucks or vans....	 *14: Renault scenic*
	• Van	Cargo van		 *15: Renault Master*
	• Minibus	Passenger van		 *16: Mercedes Benz Viano*



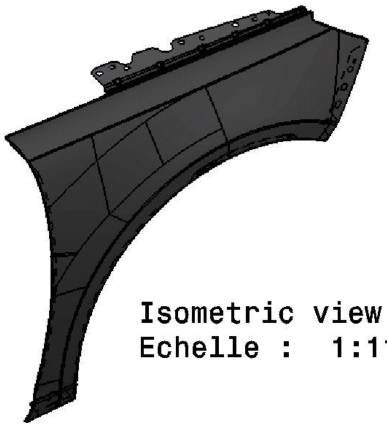
Top view
Echelle : 1:9



Left view
Echelle : 1:9



Front view
Echelle : 1:9



Isometric view
Echelle : 1:11

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CHECKED BY: XXX	DATE: xxx	SIZE: A4	DRAWING NUMBER: 1		REV: X
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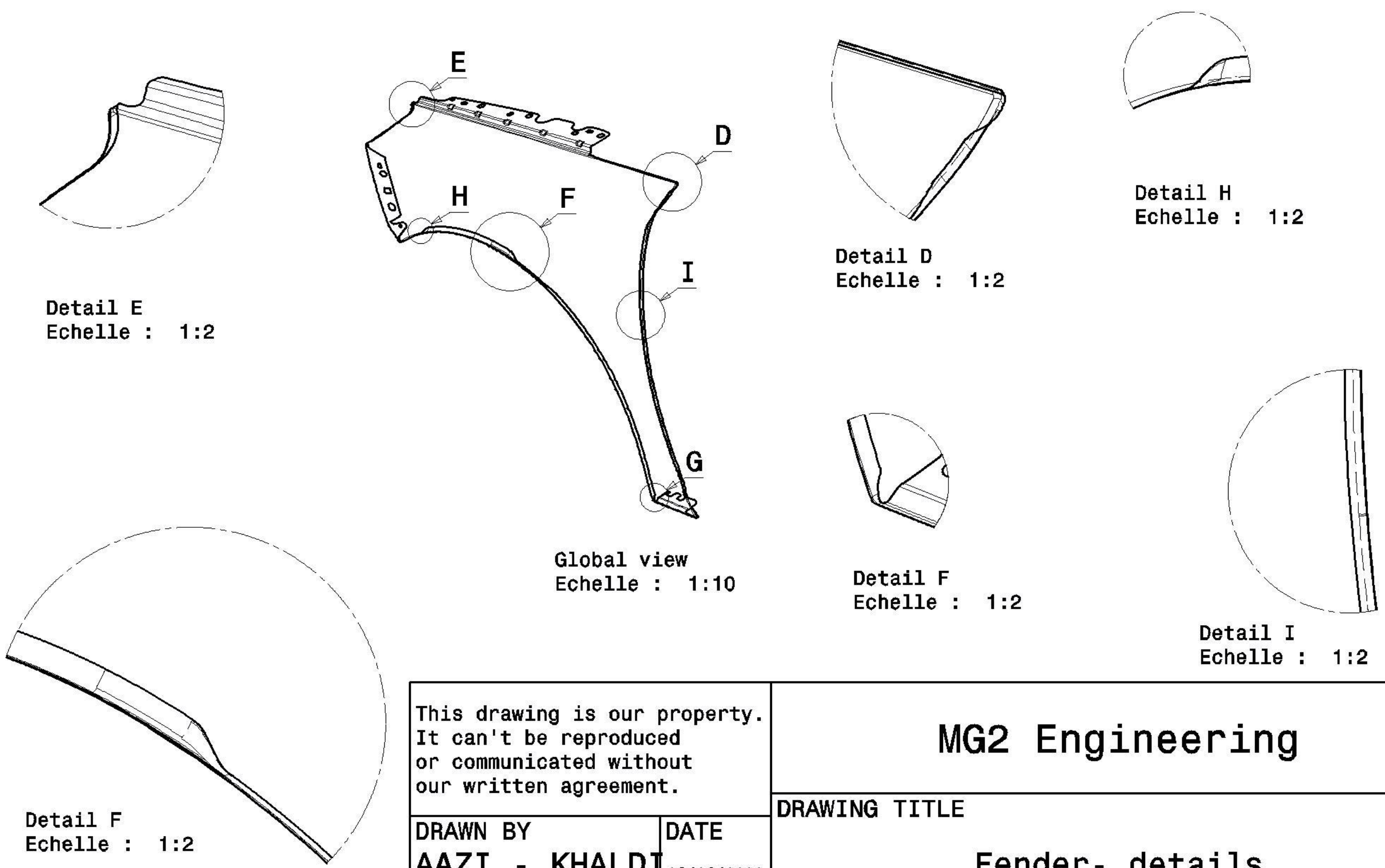

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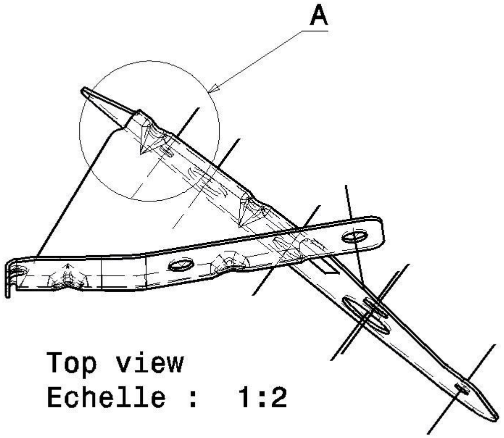

Top view
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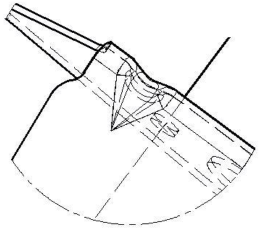

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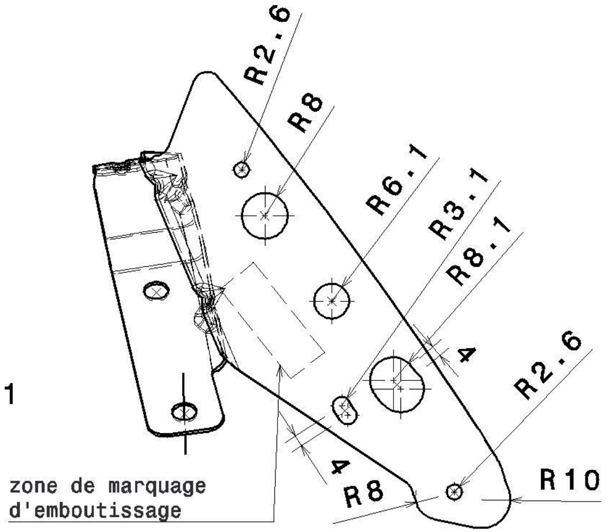

Front view
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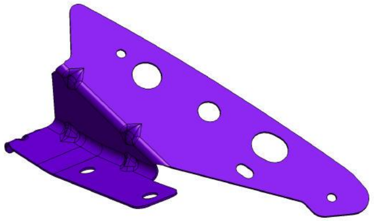

Realistic view
Echelle : 1:3

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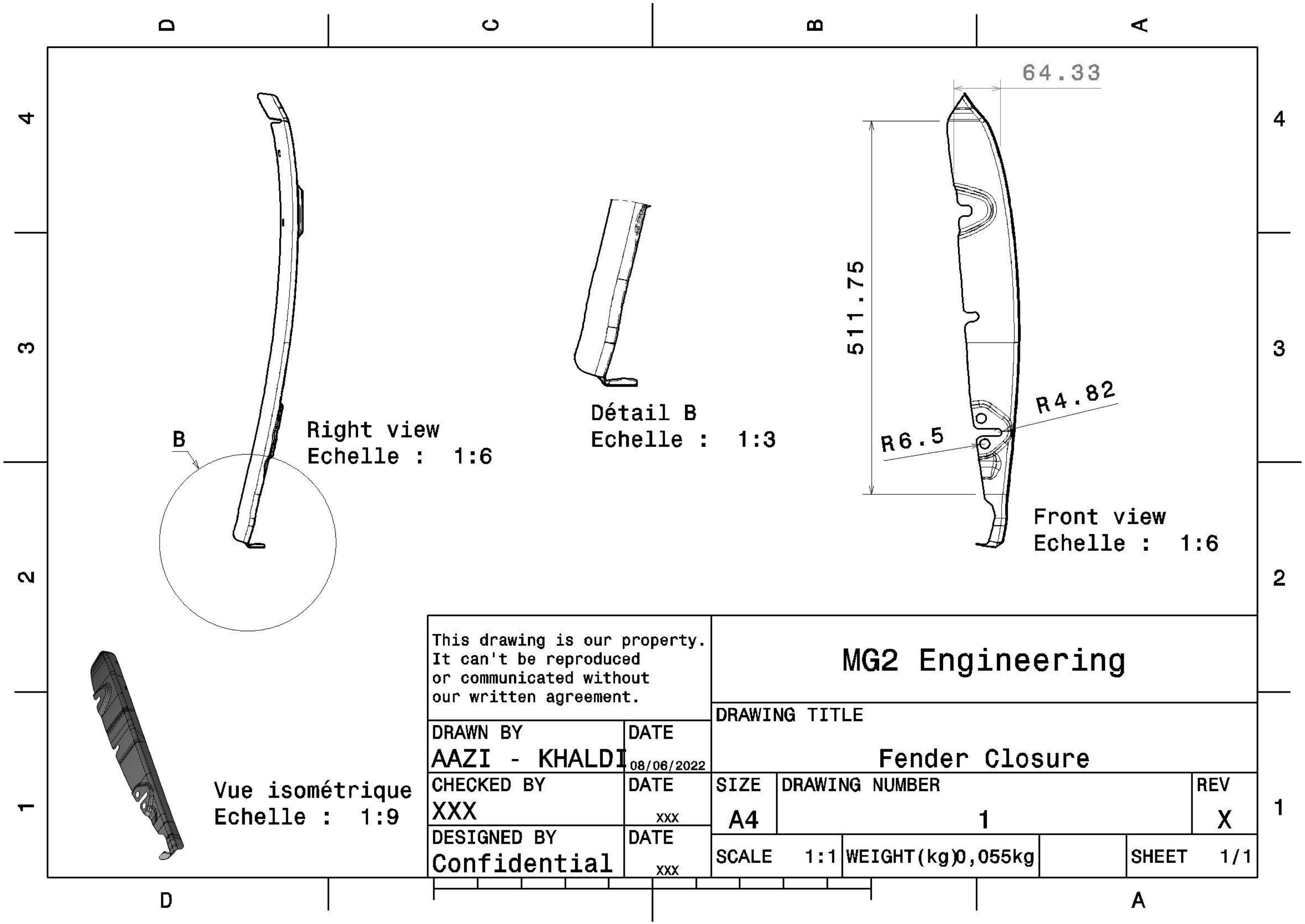

B
Right view
Echelle : 1:6
Détail B
Echelle : 1:3
64.33
511.75
R4.82
R6.5
Front view
Echelle : 1:6
Vue isométrique
Echelle : 1:9
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MG2 Engineering
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Fender Closure
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AAZI - KHALDI
DATE
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XXX
DATE
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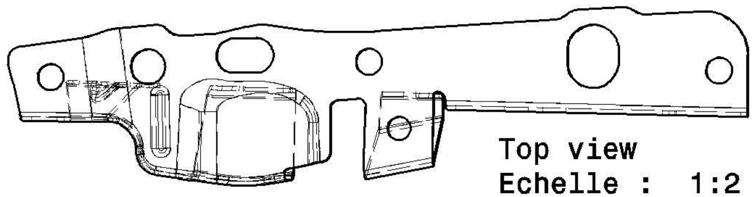
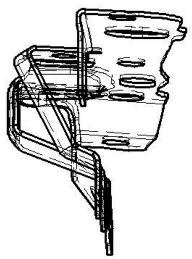


Top view
Echelle : 1:2



Right view
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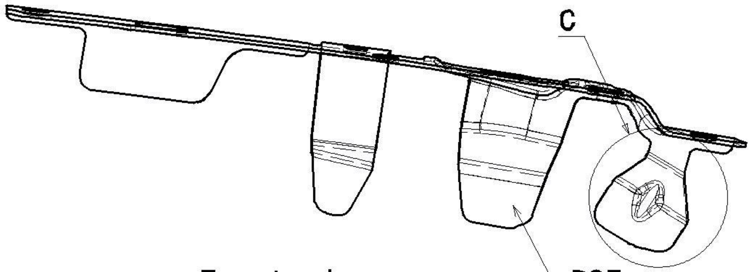
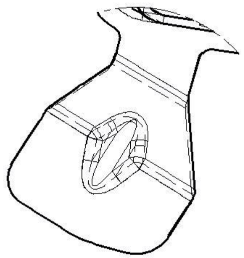
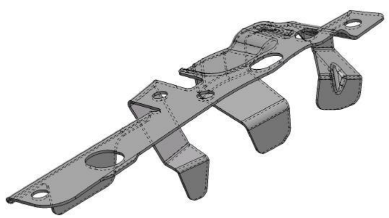


Front view
Echelle : 1:2



Detail C
Echelle : 1:1



Realistic view
Echelle : 1:3

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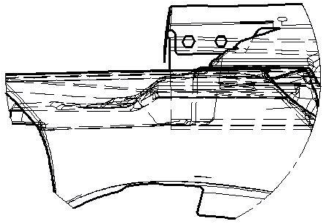

Détail J
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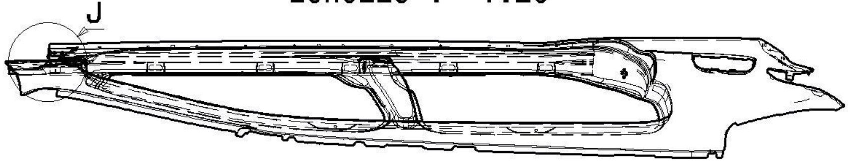
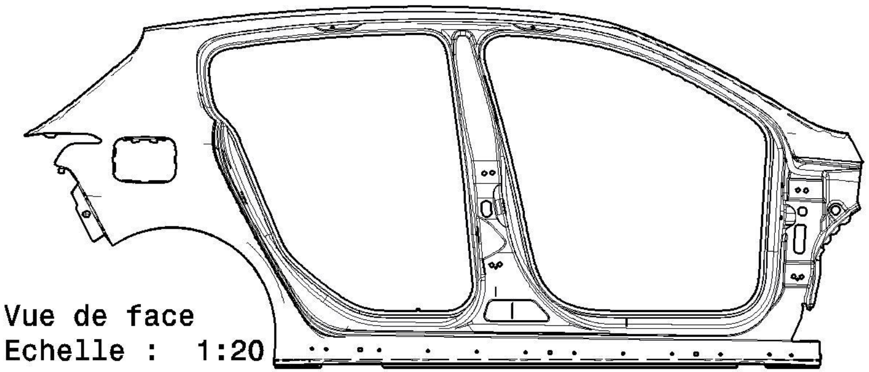


Vue de face
Echelle : 1:20



Vue de face
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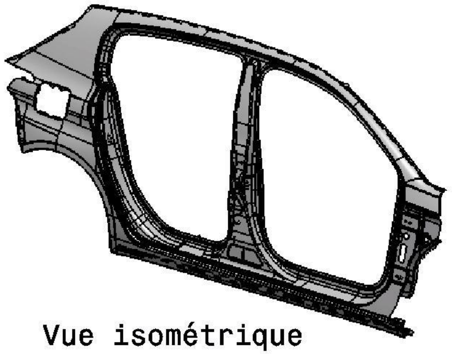

Vue isométrique
Echelle : 1:30

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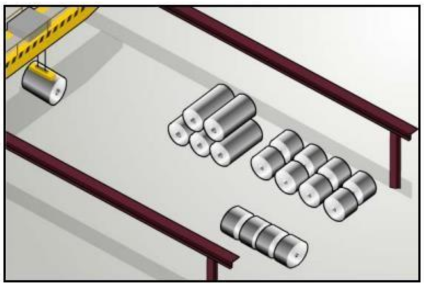
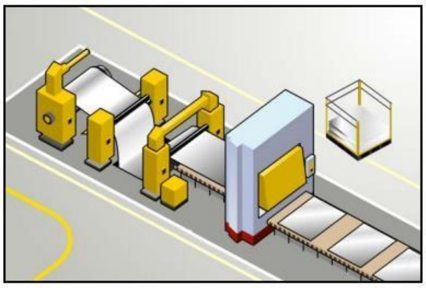
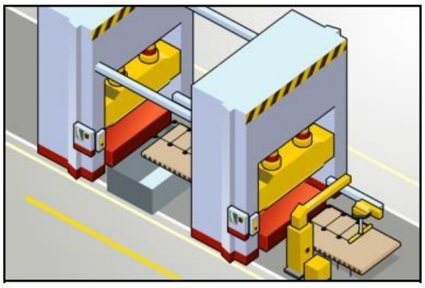
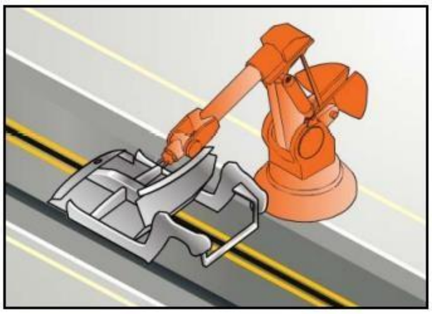
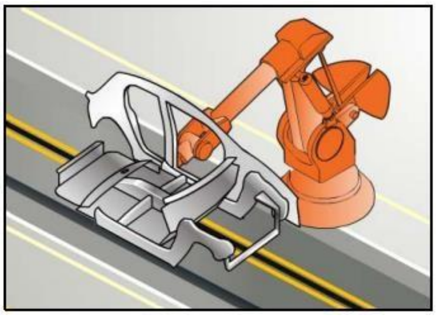
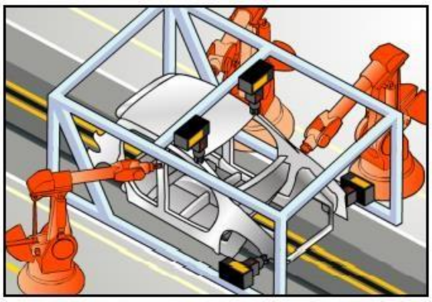
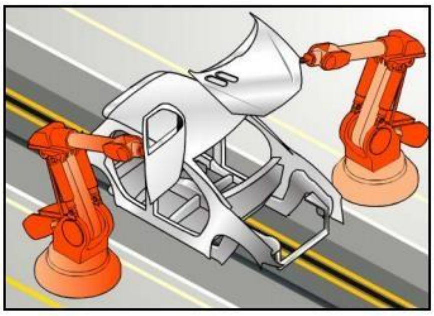
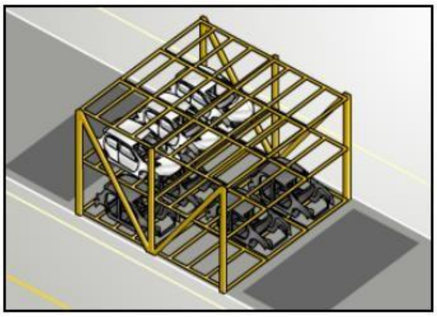
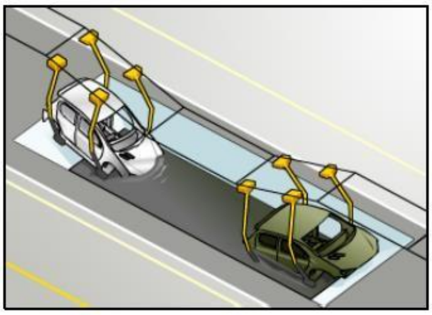
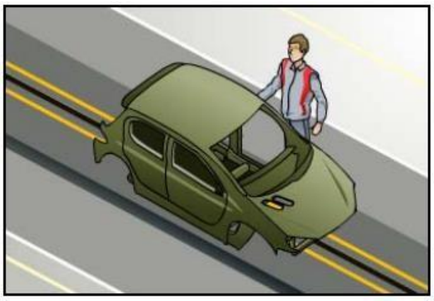
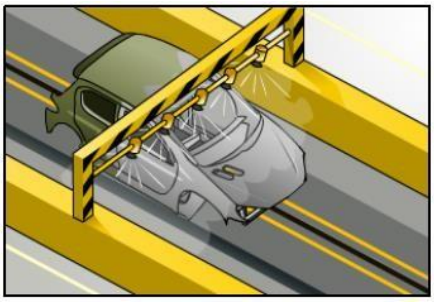
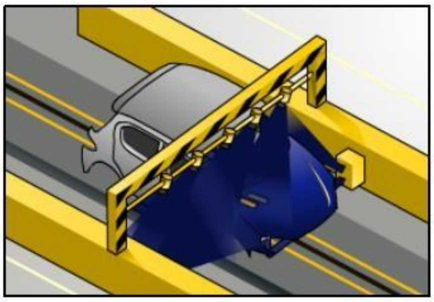
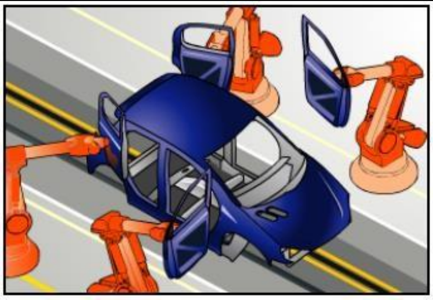
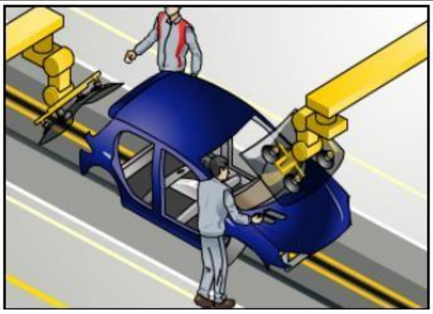
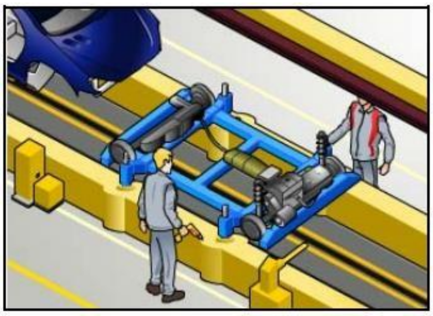
DRAWN BY AAZI - KHALDI	DATE 08/06/2022	DRAWING TITLE COTE HABITACLE			
CHECKED BY XXX	DATE xxx	SIZE A4	DRAWING NUMBER 1		REV X
DESIGNED BY Confidential	DATE xxx	SCALE 1:1	WEIGHT(kg) 21,781kg		SHEET 1/1

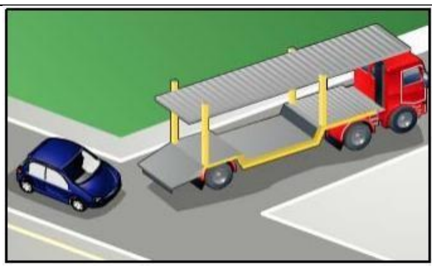
Table 15: Manufacturing process of cars.

Phase	Figure	DESIGNATION
Stamping		***Unrolling sheet metals:*** Galvanized sheet metal coils of various sizes and thicknesses are unloaded from the trucks and transported by overhead crane to the storage area.
		***Cutting the blanks:*** The metal coils are trimmed into blanks by shearing and then fed to the stamping line.
		***Stamping phase:*** Each blank is deposited at the beginning of the line before receiving the first deformation on a double-acting press, followed by reworking operations on single-acting presses.
Fitting		***Assembly of the frame:*** The handling units roll between the welding robots that assemble the front and rear floors of the unit to form the wheelbase and stiffen the substructure.
		***Assembly of the body's sides:*** The robots load the available body sides at the edge of the line and attach them to the base. At the same time, the additional sub-assemblies and the finishing are carried out by operators in additional areas.

		***Geometric Conformation:*** A geometric conformer holds the parts in position while the robots perform the first welding operations.
		***Body Assembly:*** After the welding is completed by attaching the roof, fenders and closures (doors, hood, fenders) are attached to the body frame. The body is then sent to the paint shop.
Painting		***Bodies Classification:*** Upon arrival, the BIW are sorted by color bursts (grouped by families of shades).
		***Body treatment:*** The BIW are then washed and degreased by immersion in various baths that uses an electrolytic process to cover each part of the sheet with phosphate of zinc layer. it provides a first protection and allow a better adhesion of the following layers. After this first treatment, the BIW are rinsed and dried in an oven at 160°C.
		***Laying the joints sealing:*** The treated bodies are passed between operators who put the sealing joints in place to prevent any water, odor or dust from entering the interior. These improved protections provide the customer with a 12-year anti-corrosion warranty. Some parts of the sheet metal will also be soundproofed.

		***Laying the anti-gravel layer:*** The anti-gravelling, applied by robots and operators, contributes to perfecting the sealing of the BIW and protects the base, which is particularly exposed to projections and corrosion. After a new treatment in the oven, the BIW are manually polished to eliminate any grain.
		***Laying the primer layer:*** An automatic painting system using electrostatic spray applies the primer layer to the body in special cabins. The primer layer can be chosen from three shades in terms of the final color of the vehicle, which significantly reduces the visual effects of graining. After heating in an oven at 140°C, the bodies are sent to the lacquering cabins.
		***Laying the lacquer:*** The same process of electrostatic spray is used for the application of the base and the lacquer. Operators provide the finishing touches. The painted body is then wiped with feathered wiper and put in an oven. The colored bases give to the body its final color and the lacquer, its final aspect.
		***Sanding, wiping and inspection:*** Throughout the line, the BIW undergoes several heating, and several wiping and inspections where possible traces, roughness, will be detected and corrected. At the end of the line, a final visual check ensures that the paint is perfectly homogeneous.
		***BIW Labeling:*** When the body enters the workshop, the painted bodies are labelled. A Vehicle Assignment Sheet (FAV) is issued for each body and follows it along the operations to indicate the parts to be mounted in the vehicle. Each additional module launched in parallel (engine, driver's

<table>
<tr><td rowspan="6">Assembling</td><td></td><td>station...), is also equipped with FAV.</td></tr>
<tr><td></td><td>Removing the closures:
The doors are disassembled (to facilitate the assembly of the vehicle's equipment) and sent to a parallel line to be prepared.</td></tr>
<tr><td></td><td>Putting the dashboard:
The dashboard, equipment for the interior trim are put inside the body.
To facilitate the installation, the handling and the installation are carried out by a robot.</td></tr>
<tr><td></td><td>Installation of the windshield:
In this step, the installation of the main windows (windshield and rear window) is carried. This operation is also robotized.</td></tr>
<tr><td></td><td>Capping:
The mechanical components (engine, gearbox, etc.) coming from specialized sites (forges, mechanical assembly, etc.) are prepared and joined to lower frame.</td></tr>
<tr><td></td><td>Assembling the body:
The body is then equipped with wheels, the front bumper, the rear bumper and the lights (previously delivered and prepared on a parallel line).</td></tr>
</table>

		***Adding the closures:*** The doors, once prepared (installation of windows, reinforcements, etc.), are joined to the bodywork to finish the assembly stage.
Inspecting		***Rolling test bench:*** Before being prepared for delivery, the cars are tested on test benches or even on tracks. Any defects are immediately corrected, and their origin identified for future purposes.
		***Expedition:*** Once checked, the vehicles are loaded onto trucks and delivered according to their destination.

"Part of MATLAB program"

```
dev=[];
length(dev)

m=-50:1:349;
length(m)
for j=1:400
    Tmax(j)=1;
    Tmin(j)=-1;
    Amax(j)=0.5;
    Amin(j)=-0.5;
end

length(Tmax)

yline(1,'color','r','label','max tol = 1');
hold on

a1=plot(m,Tmax,'color','r')
hold on

yline(-1,'color','r','label','min tol = -1');

a2=plot(m,Tmin,'color','r')
hold on

yline(0.5,'color','c');
hold on

a3=plot(m,Amax,'color','c')
hold on

yline(0.5,'color','c');
hold on

a4=plot(m,Amin,'color','c')
hold on

x=[m,fliplr(m)];
inBetween=[Tmax,fliplr(Amax)];
inBetween2=[Tmin,fliplr(Amin)];
fill(x,inBetween, 'y');
hold on
fill(x,inBetween2, 'y');
hold on

i=1:length(dev);
b1=plot(i,dev,'g');
hold on
b1=plot(i,dev,'.','color','c','MarkerSize',5);
hold on
n=1;
for j=1:length(dev)
    if abs(dev(j))>1
        f(n)=dev(j);
        p(n)=j;
        n=n+1;
    end
end
for j=1:length(f)
    txt=string(f(j));
    text(p(j)+0.03,f(j),txt);

b2=plot(p(j),f(j),'.','color','r','MarkerSize',10);
    hold on
end
n=1
```

```
for j=1:length(dev)
    if abs(dev(j))<1 && abs(dev(j))>0.5
        f2(n)=dev(j);
        p2(n)=j;
        n=n+1;
    end
end
for j=1:length(f2)
    txt=string(f2(j));
    text(p2(j)+0.03,f2(j),txt);

b3=plot(p2(j),f2(j),'.','color','#D95319','Ma
rkerSize',10);
    hold on
end
x=0;
y=0.75;
b4=plot(x,y,'.','color','y')

annotation('textbox',[0.15, 0.51, 0.1,
0.1],'string','great values
zone','FontSize',8,'EdgeColor','w')
annotation('textbox',[0.15, 0.39, 0.1,
0.1],'string','acceptable values
zone','FontSize',8,'EdgeColor','y');
annotation('textbox',[0.15, 0.64, 0.1,
0.1],'string','acceptable values
zone','FontSize',8,'EdgeColor','y');

legend([b1,b2,b3,b4],'CAD','failed','accep
table');
ylabel('deviation values');
xlabel('points on the style');
title('deviation of the CAd style');
length(f)
length(f2)
u=(length(f2)/length(dev))*100
v=(length(f)/length(dev))*100
w=((length(dev)-length(f)-
length(f2))/length(dev))*100
annotation('textbox',[0.15, 0.1, 0.1,
0.1],'string','% of points failed
1.544','FontSize',8,'EdgeColor','w')
annotation('textbox',[0.15, 0.125, 0.1,
0.1],'string','% of points in the acceptable
zone 9.366','FontSize',8,'EdgeColor','w')
annotation('textbox',[0.15, 0.15, 0.1,
0.1],'string','% of points in the great zone
89.09','FontSize',8,'EdgeColor','w')
annotation('textbox',[0.15, 0.2, 0.1,
0.1],'string','numbers of points treated
350/1000','FontSize',8,'EdgeColor','w')
annotation('textbox',[0.15, 0.175, 0.1,
0.1],'string','% of points passed
98.456','FontSize',8,'EdgeColor','w')
%%%%%%%%%%%%%

y=[9 9 16 12];
x=[5.13 5.168 13.905 12.086];
i=1:4;
tol=[0.2 0.3];
tol2=1;
y2=[54.519 6.224 4.085 32.309 43.911
39.371 13.160 34.409 0.001 10.177 0.441
0.002];
x2=[54.614 6.083 3.920 32.647 43.907
39.435 12.538 37.702 0.234 10.150 0.437
0.095];
n=5;
m=0;
```