Development of glass canopy for urban electric vehicle

Johan Reerslev

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2018

MASTER THESIS

Development of glass canopy for urban electric vehicle

Johan Reerslev

LUND UNIVERSITY

Development of glass canopy for urban electric vehicle

Published by

Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Product Development (MMKM05)
Division: Division of Product Development, Department of Design Sciences,
Faculty of Engineering LTH, Lund University

Supervisor: Per Kristav
Examiner: Olaf Diegel

Abstract

The aim of this thesis was to develop the Uniti One window design from a prototype stage to be ready for mass production. Uniti One is a lightweight, two-seated, electric vehicle of the L7e-category designed for urban transportation. In late 2017, three prototypes of this vehicle were built, and that construction was used as the start point of the development.

Vehicle regulations, material theory and manufacturing limitations were all investigated together with design intent data from Uniti's staff, to determine design limitations. Once all limitations were recognized, new glazing concepts could emerge. Since Uniti Sweden had put down years of research into the actual shape of the canopy, this was to be kept as close to the prototype shape as possible. The challenge was therefore to choose which regions of the glazing that should be manufactured in glass or plastic and how the split up should be defined.

The result was a new canopy designed with three glass and seven plastic windows which passed all L7e-regulations. For all windows, manufacturing techniques, alternative materials and coating suggestions are described. The construction of the glazing was made using surface modeling tools and the method is described in detail to allow Uniti to redo the work on future iterations. Further work needs to be done to optimize the construction of the Uniti One windows including supplier limitation control, aerodynamic and structural calculations and cost optimization.

Keywords: Electric car, Glazing, Surface modeling

Sammanfattning

Målet med denna masteruppsats var att utveckla designen av Uniti One's fönster, från prototypstadiet till att vara redo för massproduktion. Uniti One är en lätt, tvåsitsig, elbil i L7e-klassen som är designad för stadskörning. I slutet av 2017 byggdes tre prototypbilar av bilmodellen vars konstruktion stod som grunden till denna vidareutveckling.

Fordonsregler, materialteori och tillverkningsbegränsningar studerades tillsammans med designtankegångarna från Uniti's anställda, för att fastställa designbegränsningar. När alla begränsningar var kontrollerade kunde nya fönsterkoncept växa fram. Eftersom Uniti Sweden hade lagt ner år av forskning för att ta fram formen av bilen så skulle så lite ändringar som möjligt göras med prototypernas form. Därför blev utmaningen att bestämma vilka delar som skulle tillverkas i glas eller plast, och hur själva uppsplittringen skulle definieras.

Resultatet blev en ny topp av bilen, designad med 3 glasfönster och 7 plastfönster som är godkänd enligt alla L7e-regler. Tillverkningstekniker, alternativa material och förslag på skyddsbeläggningar finns beskrivet för varje fönster. Konstruktionen gjordes med hjälp av ytmodelleringstekniker och metoden är beskriven i detalj så att Uniti kan upprepa arbetet på framtida iterationer. Mer arbete behöver genomföras för att optimera konstruktionen av Uniti One's fönster. Däribland en kontroll av underleverantörernas begränsningar, aerodynamiska och strukturella beräkningar och en kostnadsoptimering.

Nyckelord: Elbil, bilfönster, ytmodellering

Acknowledgments

I would like to thank my supervisor at the University of Lund, Per Kristav, together with the rest of the staff at the faculty of Product development for making this thesis project proceed as easy as possible.

I would also like to thank the staff at Uniti Sweden for allowing me to do this thesis project. During my time in this start-up company I've been able to see how a modern tech company works and grows. I wish you guys the best of luck in the future and hope that my work can contribute in the story that is Uniti.

Finally, I would like to thank my friends and family for helping me through this master's degree with support and energy in times of need.

Lund, August 2018

Johan Reerslev

Table of contents

1 Background

This chapter introduces the thesis, the company and the problem.

1.1 Purpose

The purpose of this thesis is to give a product specified example of how the development process of glazing parts works for a start-up company. It will show how an early prototype design needs to change to cope with regulations, mass production limitations and demands.

1.2 Goal

The goal of this thesis is to validate the prototype glazing design of the Uniti One vehicle. This is done by controlling the individual window design regarding vehicle regulations, manufacturing limitations and the Uniti One product profile. An updated CAD-design and specifications for each window will be the result.

1.3 Uniti Sweden AB

Uniti Sweden is an electric vehicle start-up company located in Lund. The company was founded in 2016 by the current CEO, Lewis Horne, and the vision for the company is to renew urban mobility. Uniti's concept is a small, two-seated, electric vehicle of the L7e-category. There are other cars like this one on the market, but the idea is to build a car that is safer and intrigues higher quality. At the same time, Uniti is taking the opportunity to rethink and optimize the design of how drivers interact with the vehicle. A new steering concept where you turn, accelerate and brake with two joysticks have been displayed and they have built functioning prototypes of a large heads up display. The company also predicts connectivity to become more and more important in the automotive industry. They want to implement enough hardware to gather data, make software updates automatically and connect vehicles for safer road handling and possible autonomous features. The

Uniti team has been growing ever since the start in 2016. In just a little over two years the company has completed two crowd funding rounds and moved to larger offices 4 times.

The L7e-category is a vehicle class described as heavy quadricycles [1]. They have a maximum weight target of 450 kg, excluding the battery pack. This means that the Uniti vehicle components need to be lightweight. L-categorized vehicles has special rules which makes the homologation and certification less extensive compared to normal M1-vehicles.

1.4 Glazing design status

In the summer 2017 Uniti locked down the exterior design. This means that the exterior design was developed to a level where it was within a feasible range for both a prototype car but also for mass production. During the fall three prototype vehicles were built. The prototype vehicles windows were built with PMMA plastic and a technique called heat forming. The technique basically means that the plastic sheet is heated up and draped over a mold to get the correct shape. The part is then trimmed into correct size and polished up to a transparent finish. This technique is cheap, and the time required from final design to a prototype part is short which makes it standard for that type of show cars.

However, this method is not suitable for mass production. Uneven thicknesses, lots of manual work, many steps and tolerancing issues are just a few problems. Also, there are regulations which need to be followed to get the glazing approved for this type of vehicle.

The glazing, which can be seen in figure 1.1, consists of 9 parts in total. The overall idea is to have a uniform, sleek design with as few split lines as possible that covers the whole top of the vehicle. The prototype vehicle can be seen in figure 1.2.

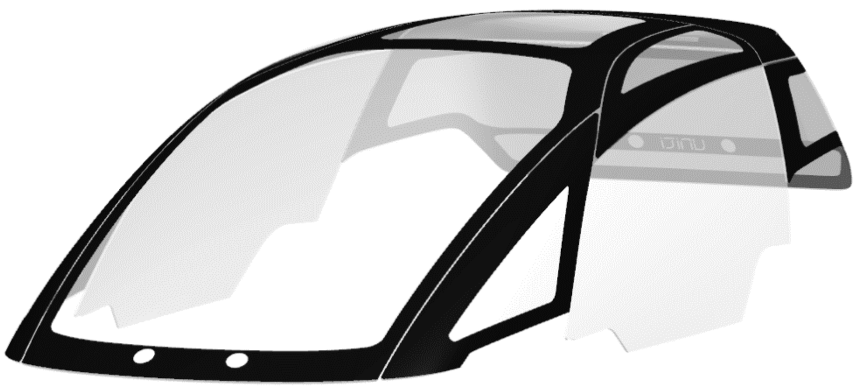

Figure 1.1 - Uniti One prototype glazing

Figure 1.2 – Uniti One prototype vehicle

1.5 Glazing terminology

During this thesis the names of each window will follow the terminology set for the prototype glazing, as can be seen in figure 1.3. The individual windows have been given different colors in this figure to show where the original boundaries lie.

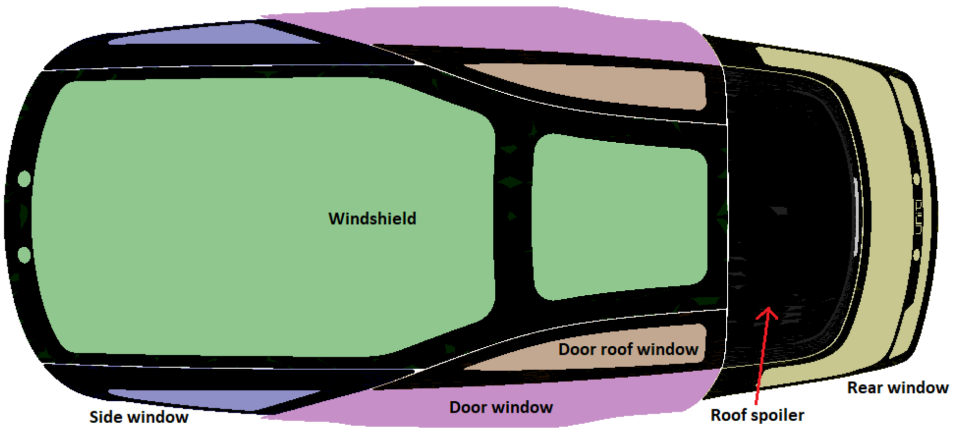

Figure 1.3 – Prototype glazing with colors and names

The windshield is the largest piece of the subassembly. It extends all the way from the front of the vehicle, along the roof to the roof spoiler. There are cutouts in the front obscuration for front view cameras.

The roof spoiler is the part of the glazing which has the most complex shape. There is a quite distinguished spoiler with a small radius at the rear top which makes this part harder to manufacture, even with heat forming. That's why this part was manufactured by milling and polishing for the prototypes. There are holes in the obscuration where you can see the break light of the vehicle through.

The rear window covers the back of the glazing. It has a deep curvature and you can see the taillight through the glass. Also, there are cutouts in the obscuration for rear view cameras and a Uniti-logo.

The door windows are completely transparent. The idea is that these windows should be possible to move up and down, but this feature was removed on the prototype cars to simplify them.

The door roof windows are a separate part of the door window system and have no other function than being transparent and attached to the door frame. The door has this structure to make it easier for people stepping in and out of the vehicle.

The side windows cover the front sides of the glazing. Originally these windows where part of the windshield, but that original windshield were cut into three parts to increase manufacturability.

1.6 Thesis coordinate system

When there is a picture of the canopy from the top or the side in this thesis, the forward direction of the car will be to the left, as seen in figure 1.4.

Figure 1.4 – Prototype glazing seen from the side, the forward direction of the car is to the left

1.7 Delimitations

This thesis is not meant to change Uniti's exterior design concept. It is destined to solve some of the design problems and to highlight what needs to be changed to reach a production ready glazing construction. This means that there were a couple of delimitations made to this thesis which can be found in table 1.1.

Table 1.1: Thesis delimitations

	Delimitation
1	No changes that interfere with the ergonomic model of the driver or passenger can be made.
2	No changes that drastically changes the design of exterior panels, frame members, door packaging or other subsystems of the car can be made.
3	No changes to the concept of covering the whole canopy with transparent materials can be made
4	As little changes as possible should be made to the shape of the canopy

2 Method

This chapter explains the method used in this thesis.

2.1 Workflow

The workflow for this thesis project was thought of already before the project started. The prototype glazing design which Uniti had developed had some neat design features and was considering some manufacturing limitations, but not all of them. The design needed to be controlled both regarding regulations and from a more theoretical standpoint. At the same time all design features needed to be preserved and controlled and interviews was conducted to gather that information from the Uniti staff. That’s why the first step was to look at the prototype design with a filter of these design limitations. A thorough benchmarking was then conducted to see how other companies solve some material and split up problems. After that, new concepts could emerge and be controlled before the final construction could be completed. The flowchart of this process can be seen in figure 2.1 below and the same structure will be followed in this report. The time plan together with the outcome is discussed in appendix A.

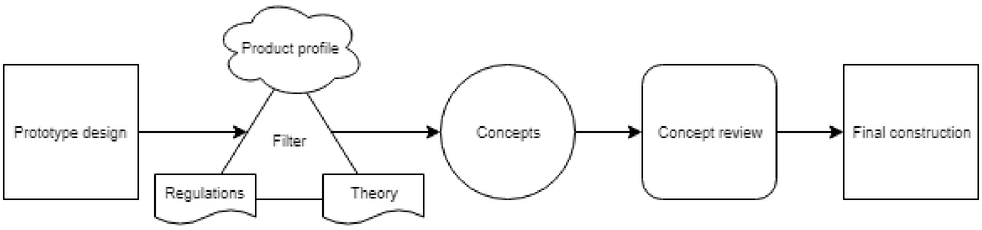

Figure 2.1: Method flow chart

3 Design limitations

This chapter explains the individual limitation segments for the design of Uniti's vehicle glazing.

3.1 Regulations

The first step towards a production ready design is to make sure all regulations are met. Reading vehicle regulations is tedious work where several documents, that reference to each other, need to be read. At all times the correct and latest version needs to be found and all rules need to be interpreted to actual design limitations. Given Uniti's decision to go for a L-categorized vehicle, more regulation documents apply which not only means more documents to read but it also introduces more regulations to interpret. The regulations that affect Uniti's glazing are found in table 3.1.

Table 3.1: Vehicle regulations that affect Unitis glazing

	Regulation
1	Regulation (EU) No 168/2013
2	Regulation (EU) No 3/2014
3	Regulation (EU) No 44/2014
4	UNECE No 26 – Rev 1
5	UNECE No 43 – Rev 4

The EU-regulations cover limitations for L-categorized vehicles within the EU. There are specific limitations to how glazing can look, which materials can be used and how to test them for safety reasons. In these documents there are several references to the UNECE-regulations, which are a vehicle regulation known and used all over the world. The UNECE regulations are also used in the EU but for larger vehicles, such as normal M1-vehicles. The EU-regulations are used to simplify the homologation for smaller L-categorized vehicles and are therefore to be applied firstly. All these regulations have been read and interpreted into design limitations which can be found in a summary in the next paragraph, or in detail in appendix B.

3.1.1 **Regulatory design limitations**

Apart from the more obvious regulations like that there should be no sharp edges that can be harmful for people in accidents or that the windows should stay in place and provide visibility and safety for the driver and passenger, all important regulations that affect the glazing of Uniti One are listed below in table 3.2.

Table 3.2: Regulation design limitations [2] [3] [4] [5] [6]

	Regulation	Direct	Indirect
1	Rigid plastic glazing is not allowed as windshields	X	
2	Toughened glass windshields are not allowed	X	
3	Flexible glazing, such as thin plastic windows, are allowed anywhere but the windshield	X	
4	The vehicle needs to have windshield wipers		X
5	There need to be a system to remove frost from the outside and fog from the inside of the windshield		X
6	There should be no noticeable distortion through the windshield	X	
7	The windshield needs to be fitted correctly in accordance with the R-point as described and showed in appendix B.5.4	X	
8	Light transmittance in windshields cannot be less than 70 percent	X	
9	Windows used for the forward, and rearward field of vision need to have light transmittance over 70 percent	X	

All the direct regulations set limitations to how the glazing can be manufactured and placed. Two of the regulations affect the design indirectly, regulation 4 and 5, and the explanation to this can be found later in this report where the limitation on glazing features is explained. Most of these regulations cover the windshield and the visibility of the driver which is most important out of a safety perspective. Regulation 1-3 in table 3.2 explains the most important design limitation of all, the windshield needs to be made from laminated glass.

3.2 Product profile

3.2.1 **Interviews**

To understand what Uniti's goal and vision for the glazing is, interviews was conducted. Since Uniti is a start-up with few employees, decisions and ideas of individual persons can get a large effect on the final design. Interviewing the correct people is thereby crucial to gather the correct data. Three people were chosen for these interviews and the names and company position can be found in table 3.3. These three people have all been involved in the decisions leading up to the Uniti One prototype design and everyone have an idea of how the final car should look, feel and work. Their input and values play an important role on how the final design should look and that can be valuable in a tradeoff situation.

Table 3.3: Interviewed staff at Uniti Sweden

	Name	Company position
1	Anton Franzen	CTO - Technically responsible for Uniti One
2	Marcelo Aguiar	Lead designer - Brains behind the looks of the car
3	Lewis Horne	CEO – Founder of the company and visionary of the car, its design and its functions

The interviews were conducted individually. This was done to make sure that all possible intel would be brought up and that none of the interviewed persons would take over the discussion and overrule all input at this first stage. The interviews were recorded (audio only) and then written down afterwards to make sure a good flow was kept through the interviews.

3.2.2 Interview questions

A total of eight questions were asked to the Uniti staff. Some of the questions were quite open to let the people speak freely about the key features that they thought were important to mention. These questions were about the design of the glazing and how the shape, look and feel was thought of. Other questions were more straight forward and the idea there was to pinpoint which features were important and decided upon. A few questions were based on the theory and general problems that were noted with the prototype design, to get an idea of how the staff was feeling about changes. All interview questions can be found in appendix C.

3.2.3 Interviews summary – Product profile design limitations

Through the interviews it became clear that the main design element of the Uniti One canopy is to have a seamless transparent top of the vehicle. This is done to maximize the visibility out of the car, but also to do something different and more appealing than a normal car with windows parted by frame members. Smooth transitions between the individual glass parts and continuous curvatures contributes to strengthen this design feature, which it is. Because of this it’s important to make sure split lines and transitions between the obscuration of each window merge in a nice way. The canopy should be designed as one unit.

Apart from the general shape and looks there should be some features integrated into the glazing which can be found in table 3.4.

Table 3.4: Design features of Uniti One's glazing

	Feature
1	The door windows need to be openable, all the way down into the door.
2	There is a plan to have a Head's Up Display showing information to the driver on the inside of the windshield. This is performed by shooting light rays from the dashboard onto the windshield.
3	The sunroof, or the glass square in the roof, should be able to tint by pressing a button or by some other mean. This is done to reduce the amount of sunlight and heat that comes into the car.
4	There needs to be a function to prevent the driver from getting sun in his/her eyes.
5	Both in the front and rear of the car there are sensors and cameras behind the glass which need to work with the transparent material chosen.
6	There needs to be some system to reduce frost and fog on the windshield, but this doesn't have to be integrated in the glass.

The staff at Uniti mentioned that in regards of design, it doesn't matter which material the glazing is manufactured of. What's important is that there is no visible difference between the individual glass and plastic windows, that it follows all regulations and that it's possible to use the material in mass production. Of course, the different features listed above need to work with the chosen material as well. If anything, a few windows in glass could be needed to make sure the perceived quality is not lowered.

There were also a few areas on the prototype design which needed to be changed. They are listed below in table 3.5.

Table 3.5: Possible design changes

	Prototype problem
1	The part called Door roof window is problematic and a bit complicated. To remove it would need to be investigated and the whole car width would possibly have to be changed. This is not considered in this thesis and the split line will have to stay.
2	The door windows need to be able to move up and down, which is not possible on the prototypes.
3	All windows need to be controlled for production.
4	The windshield could be split up into two pieces if that simplifies production and serviceability.
5	It might be possible to reduce the number of parts by merging some windows together, but that should only be done if it looks good with the overall split line and obscuration design.
6	Some obscuration lines on the prototype need more design time to look even better
7	The prototype didn't have windshield wipers, which need to be integrated

3.3 Material and manufacturing theory

Manufacturing complex shapes in transparent materials has its limitations. These material and manufacturing limitations need to be incorporated in the design to not jeopardize the safety or cause the glazing to cost a fortune to manufacture.

3.3.1 **Glass**

Automotive windows have been manufactured in glass since 1904 [7]. The transparent ceramic material has great properties for making large windows that can cope with all conditions that a car will have to endure. The surface is hard and withstands weather, scratches and chemicals without changing appearance. The problems with glass are the heavy weight, limitations of bending it and that it breaks completely when smashed.

3.3.1.1 Manufacturing techniques

Different manufacturing techniques for making automotive windows have one thing in common, they are all trying to bend a pre-cut glass sheet into a desired 3D-shape. This means that in all cases, the inside glass surface (concave) will be compressed, and the outside glass surface (convex) will be tensioned, as displayed in figure 3.1. When doing this incorrectly, or too much, there can be irregularities in the surfaces, causing distortion when looking through the glass. The goal for all manufacturers is to bend the glass sheets, into the desired shape, in as fast, precise and cheap way as possible, without causing these optical distortions.

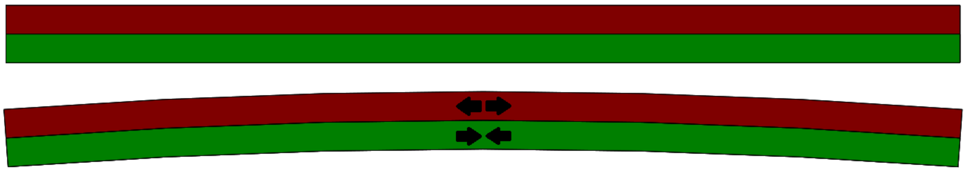

Figure 3.1 - Bending of glass

3.3.1.1.1 Sag bending

The first process of making glass is sag-, or, gravity bending. A flat glass is cut into the correct size and placed upon a mold. It is then transferred through an oven which heats up the glass until its own weight bends it down over the mold giving it the final shape. More advanced shapes need assistance to shape the glass and then a moving lever can be used to help push the glass into the correct shape. The other parameter manufacturers must work with is the amount of heat that is supplied to different areas of the glass. Design parameters that affect how good this manufacturing technique is for bending glass are the thickness of the glass, the depth of curvature, the change in curvature and the window size. [8]

3.3.1.1.2 Press bending

The second process of bending glass is press bending. The process is not that far off from gravity bending other than the fact that a two-sided tool is pushing the glass into its final shape from both sides, supporting the entire window instead of just the edges as in gravity bending. This method gives a better quality of the desired shape all over the window, it's faster than gravity bending but more expensive. [9]

3.3.1.1.3 Roll forming

The third process of bending glass is roll forming. This process shapes the glass by letting it move through a series of rolls after being heated up. The rolls gradually shape the window into its final shape. This method only works for window designs of lower complexity and the curvature can't be to extensive. The curvature needs to be constant along the axis of movement through the machine. It's possible to make a second curvature that is perpendicular against the first curvature axis. The process was developed to be a faster and thereby cheaper alternative to the other alternatives presented above. [10]

3.3.1.2 Types and characteristics

3.3.1.2.1 Laminated windows

A laminated window has several layers. It has an outer and inner layer of glass and a plastic layer in between holding them together. This plastic material is typically polyvinyl butyral (PVB) and is designed to hold the glass in place if the window would crack. This makes these windows a lot safer for drivers, passengers and pedestrians and is standard for windshield applications. Sound isolation and UV-resistance are two other functions being improved by this window structure. [11]

The outer and inner glass is shaped together, according to the methods described above (gravity or press bending). This is done to make sure that the two glass parts have the exact same shape before laminating them together. Because of this method, the two glass parts are laying on top of each other while being bent, forcing the surfaces in contact to slide on each other. This can cause problems in the optical quality of the surface and end up giving the driver optical distortions when looking through the window. After the bending of the two glass parts is completed, the PVB sheet is put in-between the sheets and the whole laminate is heated up in an autoclave to finish the part, making sure no air stays in the laminate. [11]

A standard configuration for an automotive windshield is two glass sheets of annealed soda-lime glass and then the PVB layer in between. The glass sheets are typically 2.1 mm thick each and the PVB layer 0.76 mm, but this can off course vary depending on the specifications and the manufacturer of the window. There are manufacturers making stronger glass sheets where one of the two layers in the laminated window can be as thin as 0.7 mm, reducing the overall weight of the part. These windows with unsymmetrical thickness also show better performance regarding impact resistance, both in testing and in a hail or stone shot scenario. [12]

3.3.1.2.2 Single layer windows

A non-laminated window is usually a toughened window. After bending the glass, it is heated up to at least 720 degrees Celsius and then rapidly cooled down. The laminated version doesn't have to be toughened because the PVB interlayer holds the cracked window parts in place, making it safe in a crash scenario. A single layer window on the other hand needs to be toughened because this processed glass shatters into very small pieces instead of large shards, making it a lot safer in such a situation. The toughening process also makes the glass stronger, preventing the glass to crack as easily. [11]

3.3.1.3 Glass window manufacturing limitations

Glass can be shaped into complex forms. The problem is to do it and to keep a high optical quality at the same time. Manufacturers are very secretive about where their limitations lie and how their processes work exactly, but there are some guidelines to follow. Both regarding maximum bending capabilities and how large windows that fits in the bending furnaces. These can be found in table 3.6.

Table 3.6: Glass manufacturing limitations [11] [13]

	Type of limitation	**Limitation**	**Unit**
1	Maximum window size – Sag bending	3048x1880	Mm
2	Maximum window size – Press bending	2082x1168	Mm
3	Maximum depth of bend – Sag bending	558	Mm
4	Maximum depth of bend – Press bending	170	Mm
5	Maximum depth of bend – Roll forming	15	Mm
6	Minimum radius of curvature – Press bending	890	Mm
7	Minimum radius of curvature – Roll forming	890	Mm

3.3.2 **Plastic**

Plastic is a great material for making automotive windows. It can be formed in complex shapes, it's lightweight and strong in crash scenarios. The problems with plastics are that it has been problematic to produce larger parts, the plastic ages which changes the appearance over time and it scratches easier than glass.

3.3.2.1 Manufacturing techniques and characteristics

3.3.2.1.1 Injection molding

Injection molding is a standard manufacturing technique when it comes to plastic parts. It's used for a wide range of products and plastic materials and it's especially useful when producing larger volumes. Automotive windows have been manufactured with this technique since the late 90's with polycarbonate materials as the main choice. This material has also been standard for exterior light covers since the early 90's. A common practice is to use a two-component molding technique where the transparent plastic is molded first and then the black print is molded on the inside of the window. The industry is continuously pushing the limits of how large windows that can be produced since this is a very delicate manufacturing form. There can be no distortions allowed in the plastic and because the material is transparent, every little defect is visual. In 2006, the values stated in table 3.7 was possible. [14]

Table 3.7: Plastic manufacturing design limitations

	Type of limitation	Limitation	Unit
1	Window size	1.5 - 2	m^2
2	Flow rate to thickness ratio	300:1	-

Manufacturers know that the plastic material used is more expensive than glass. Raw plastic suppliers have been forced to develop better and more optically clear compounds to enhance the possibilities and quality of plastic glazing. In 2014 Zbinden writes that a polycarbonate part can cost up to 3 times as much as the equivalent in glass [11]. They see that the biggest advantage to make plastic glass parts cost effective is to integrate other details into the parts. Door handles, spoilers or fasteners for lights is just a few examples of what can be done. With injection molding, there are huge possibilities to do this. [14]

3.3.3 **Sealants**

Rubber seals are used to safely shut out water and dirt from the car and the gap in between windows. They also help to reduce aerodynamic noise by evening out the overall surface [15]. Since these rubber seals are very versatile in shape and material properties it can be considered that there will be an alternative suitable for Uniti’s glazing gap. The gap width itself is also easy to change depending on the chosen sealant.

To seal off the inside of the door from water and dirt, there is normally a rubber seal that touches the door window. To have an even, continuous pressure on this rubber seal, throughout the movement of the window, the door window should be barrel shaped. This means that it has a continuous radius in one direction, and a continuous radius in a direction perpendicular from the first one. If the window then moves up and down along one of these two radiuses, the window surface will follow a continuous path, putting no special demands on sealants, rails and lifting devices.

The other problem with the door seal is to properly shut out water and dirt all along the movement of the window on the sides and on the top of the glass. This can either be done by having rubber tracks on the top and sides in which the door glass can safely slide, or by having a very stiff window being pushed at a sealant, or by a combination of the two alternatives. A stiff window would require a heavier construction, less durability for the system and possibly a less robust solution. With guide sealants added to the design, it would be easier to seal off the cabin from water and dirt. All design limitations dependent on sealants is summarized in table 3.8.

Table 3.8: Sealant design limitations

	Type of limitation	Limitation
1	Shape of door window	Barrel shaped
2	Door sealant grove at sides and top of door window to slide in	Needed, to reduce complexity and increase durability of the system

3.3.4 Coatings

Coatings are a part of the automotive window specification. These compounds are either sprayed on after the windows have been shaped or in between layers in a laminated window. There are compounds to reduce UV-light from entering the cabin which wears colors from interior parts, compounds to reduce IR-light which makes the temperature in the cabin more stable, compounds to reduce sound and compounds to increase scratch resistance. [16]

UV-repealing coatings is the most common to add. This compound helps reflect the UV-rays that usually makes plastics and other materials degrade over time. For plastic windows, this is essential. A plastic part which doesn't have this coating will change color and look completely different after a few years in the sun. [16]

With larger surfaces of glass on today's vehicle designs, more sunlight can enter the cabin, increasing the heat and putting more demand on the cabin temperature managing system. The same goes for colder conditions where heat can exit the cabin through the glass panes. Glass lets light through at steeper angles which means that a sunroof will let more light through in the middle of the day when the sun is at its highest position. Adding a tint to make the glass darker stops a lot of the warming IR-rays from entering, but a coating which reflects these rays also helps. [16]

Glass is very hard and does not scratch easily. This is the main reason why it has been used for so long in this industry other than transparent plastic alternatives. It is therefore crucial to add a scratch resistant coating to plastic windows. There are strict tests for controlling this scratch resistant coatings described in the vehicle regulations and they vary depending on where the glass will be implemented on the car. This mandatory coating also makes plastic glass more expensive compared to glass, given the fact that it means many more processing steps. [16]

3.3.5 Optical distortion

Distortion or double image problems can be seen through transparent materials due to physics of light rays. The path of parallel rays reflects differently in an uneven glass pane and causes the human eye to find an object distorted. This can be so delicate that the driver feels dizzy or tired after driving for a while, even though he/she can't see an obvious distortion when looking through the window [11]. A double image is when an object or a light source appears to be in two places, slightly offset from each other.

There are different ways of increasing this problem of distortion through a window. Firstly, a light ray who hits a transparent sheet in perpendicularity will go straight through. If the sheet is tilted, the light ray will be slightly offset. There will also be a reflection of light, which means the amount of visible light rays through the sheet will be reduced. When this angle is increased, the light ray will be more offset, and more light will be reflected, making the distortion worse. For a driver, this angle is called rake angle or angle of inclination and is affected by the tilt of the windshield through the vision zone [11]. A rake angle of a normal car is usually around 60 to 67 degrees from the vertical. These angles are therefore regulatory approved even though there are some problems with reaching the target for how much light transmittance can be transmitted through the window [17].

The second physics phenomena increasing distortion is if the sheet is not flat. Automotive windows are often curved in two directions. The more curvature difference there is, the more distortion will occur. This is also increased together with the previous stated fact about the angle of inclination [11].

The last part of the physical distortion is the thickness of the glass. Thicker glass means more distortion for the light rays [11].

Apart from the physical distortion there can be problems in the process of manufacturing and bending windows, both for glass and plastic. When bending glass, the surface of the glass touches the mold and can get stuck, forcing the structure of the glass sheet to slide. This makes the glass wavy. For a plastic part there can be problems when injecting the plastic compound which makes marks that is visible in the finished part. Less complex parts will therefore have less problems with manufacturing affected distortions. All design limitations dependent from optical distortions can be found in table 3.9.

Table 3.9: Optical distortion limitations

	Type of limitation	Limitation
1	Shape of windshield	Less complex shape means less optical distortions
2	Windshield Rake angle	< 67 degrees from the vertical

3.3.6 **Features**

The different features explained earlier have all been controlled to see if there are any special demands to make them work with Uniti's design. The different features are all individually explained in the following paragraphs. In table 3.10, a summary of all design limitations can be found. Some features don't have a finite limitation level, but they are explained on how they might be easier to include.

3.3.6.1 Moving door window

To allow the door window to move up and down it needs to be enough room inside the door packaging. There will also need to be some kind of guidance so that the window can slide in a controlled movement up and down, and to let it find the same start and end position every time.

3.3.6.2 Windshield wipers

Windshield wipers can look very different from car to car. The biggest limitation regarding wiper performance is the complexity of the outside of the windshield. A less complex surface is easier to wipe, giving the wiper blade less rate of change throughout the movement. This can off course vary depending on direction. Also, there needs to be a place to fit the wiper blades and the motor in a nice way.

3.3.6.3 Head's up display

A head's up display is a feature where the driver gets information displayed on the inside of the windshield, letting him or her never to take their eyes of the road. A display shoots rays of light through several mirrors and on to the windshield, letting the rays bounce into the vision of the driver. For this static system to work, a close to perfect resemblance to the designed system needs to be assembled, and tight tolerances on all components are necessary. This means that a windshield with a HUD system in place needs to be manufactured with press bending. Also, to decrease the overall complexity of the system, a less curved windshield might help to lower the cost of such a system.

3.3.6.4 Defogging and deicing the windshield

Defogging and deicing are often solved in cars by shooting hot air onto the inside of the windshield. There are ways to integrate wires inside the glass to heat the window, but this is not necessary to solve the problem.

3.3.6.5 Tinting

Tinting on a window is done to reduce the amount of light that enters the cabin. The darker color helps the window absorb heat, making the thermal conditions easier to control. It can be done by adding a color to the window or by having switchable optical layers in between the laminated glass sheets which can be turned on and off by a switch. The switchable alternative will have to be in between the protective layers of a laminated window [16].

3.3.6.6 Sensors and cameras

There are different kinds of sensors used for assisted or autonomous driving functions. Lidar, radar and cameras are all used for different tasks and they both cost and work differently. Both lidar and radar uses light rays, in the non-visible light ray spectrum, to locate objects around the car. This will be problematic if placed behind windows coated with protective layers which are designed to reflect light rays which is not part of the visible light ray spectrum (UV/IR-rays). Cameras on the other hand uses visible light as input for the autonomous functions and work just fine behind transparent windows designed for the human eye to see out through.

Table 3.10: Feature design limitations

	Type of limitation	**Limitation**
1	Maximum door window size	Needs to fit inside the door packaging
2	Complexity of windshield shape	Less complex shape means less complex wiper design
3	Complexity of windshield shape	Less complex shape means less complex HUD-system
4	Tolerance on windshield shape	Press bending is necessary for HUD to work
5	Type of sunroof	Laminated adds possibility for a switchable tint function
6	Placement of sensors	Lidar and Radar - not behind coated windows

4 Concepts

This chapter provides new concepts for the Uniti One canopy.

New concepts for the canopy were generated in two steps. First, a benchmarking was made to see how other companies solve certain glazing problems. After that, new canopy concepts could emerge by combining glass and plastic windows in different ways. There are already a lot of design-elements in action when looking at Unitis profile for the glazing. The challenge is to make those elements happen. The important question to answer is which materials are to be chosen where and how the split ups are made between the individual windows.

4.1 Benchmarking

A good way of understanding how windows can be split up on cars is to look on how other vehicle manufacturers have solved some problems. This external way of searching for concept ideas is a step described in Ulrich and Eppinger's book about product development [18]. Hereunder follows a selection of interesting attributes and solutions.

4.1.1 **Windshield and sunroof**

Tesla model X has a large panoramic windshield which continues over the driver's head as can be seen in figure 4.1. There have been complaints made for this large windshield both regarding the cost for replacing it and the amount of heat that is transferred into the compartment [19] [20]. Tesla even had to send out sun visors to customers to allow less sunlight to enter the compartment through the roof, even though there is a darker tint made in the roof to help with this problem.

Bugatti Veyron 16.4 Grand Sport has the option to add a transparent roof, made of polycarbonate. This decision is made to cut off unnecessary weight at the top of the vehicle to lower the center of gravity. At the same time, this material passes the Bugattis quality tests and copes with sun temperatures at the top of the vehicle [21]. The roof can be seen in figure 4.2.

Figure 4.1 - Tesla model X windshield [19]

Figure 4.2 - Bugatti Veyron 16.4 Grand Sport [21]

4.1.2 Door window

Making a door window look good at the same time as it can roll up and down is harder than it sounds. The shape of the door together with the curvature of the window creates some limitations to how large the window can be while still being able to fit inside the door completely. Here are a few examples on how vehicle manufacturers solve this.

Renualt Zoey has a small separate door side lite at the very front of the door glass, as can be seen in figure 4.3. There are probably several reasons for this small window to be there to simplify the movement of the window down into the door. The front edge has a straight line to follow which could help to align the window in its guiding rails. The window is also smaller, allowing more space inside the door for frame, rails and motors.

BMW M5 is another alternative of this solution. Here the split has been made on the rear door side lite, as can be seen in figure 4.4. It can clearly be seen that if this split hadn’t been made, the rear door window would never be able to fit inside the rear door with the rear split line of the rear door in mind.

On both two cars, the split line for the door windows are parallel or slightly tilted towards each other. This is made to let the window move down without getting stuck along the way.

Figure 4.3 - Renault Zoey [22]

Figure 4.4 – BMW M5 [23]

4.1.3 Plastic windows

There is a greater opportunity for designer freedom when building plastic windows. Vehicle manufacturers have started to get creative with this fact and there are a few interesting features on the market.

Seat Leon has a plastic quarter lite at the rear edge of the door, as can be seen in figure 4.5. There is a recess in the window where the door handle can be reached. This cavity would be impossible to make with glass and becomes a design feature.

Figure 4.5 – Seat Leon quarter lite [24]

Honda civic has a model with a rear backlite merged with the spoiler as can be seen in figure 4.6. The break-light can also be seen through the spoiler. This way of integrating multiple functions into one part is really the alternative to increase the value of a plastic window part.

Figure 4.6 – Honda civic merged backlite and spoiler [25]

Fiat 500L has a model where the front side windows are made of plastic. The car is designed in a way so there are minimal splits between the windows wrapped around the A-pillar. As can be seen in figure 4.7, the car gets a more continuous reflection around the A-pillar compared to a conventional car with visual steel pillars.

Figure 4.7 – Fiat 500L [26]

4.2 Concept generation

After considering the limitations written down in chapter 3, new concepts could emerge. Here it was interesting to see how Unitis design could emerge as resembling to the prototype as possible, with a low price and with a low weight. The price is always interesting to lower as much as possible when it comes to production of parts. The weight on the other hand is extra interesting because of the weight limitation in the L7e-vehicle category, forcing lighter alternatives to be more interesting. The different concepts can be found in table 4.1.

Table 4.1: New canopy concepts

	Concept
1	A canopy made of as much glass windows as possible
2	A canopy made of as much plastic windows as possible
3	A canopy made of different combinations of the two materials - Many combinations

Since the third option was still quite open, it was decided to start by looking at induvial windows and areas to decide if they were more suitable to be made in glass or plastic or if they could be split up in other ways. This would reduce the total amount of concepts before moving on to a decision-making process.

4.2.1 Long windshield vs sunroof

This idea was thought of at an early stage in this thesis and already included in the product profile interviews conducted with the employees at Uniti. The windshield, which extends all the way back to the roof spoiler, is long, complex, requires good tolerances for a HUD to work and will be an expensive piece to manufacture. This will mean that it is expensive to replace in a crash or stone shot situation, leaving Uniti with unhappy customers. The regulations also state that Uniti one will need to have a glass windshield, but not a glass sunroof. To replace the longer alternative with a two-part solution opens the possibility to make the sunroof in plastic instead, reducing the weight of this part by approximately 1.6 kgs. The split would happen where the frame roof beam crosses the car, as can be seen in figure 4.8.

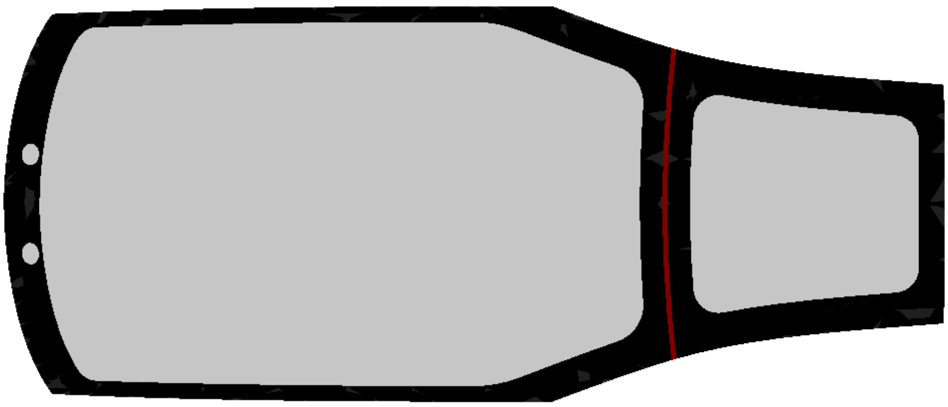

Figure 4.8 – Windshield split line concept

Other things that speak for this alternative is the fact that Uniti wants to have a tint-alternative in the roof. Making this integrated into the same part as the windshield would increase the complexity and possibly make that large part even more expensive. With a split solution the smaller sunroof can be completely covered by a tint-screen which is turned on when needed, and this could even be added as an ad on function.

Another factor which is in favor of splitting this window into two is that the overall depth of the long windshield version is too deep for press bending. As can be seen in figure 4.9, the depth would decrease from 181.37 mm to 93.65 mm if the part would be split as seen in figure 4.8.

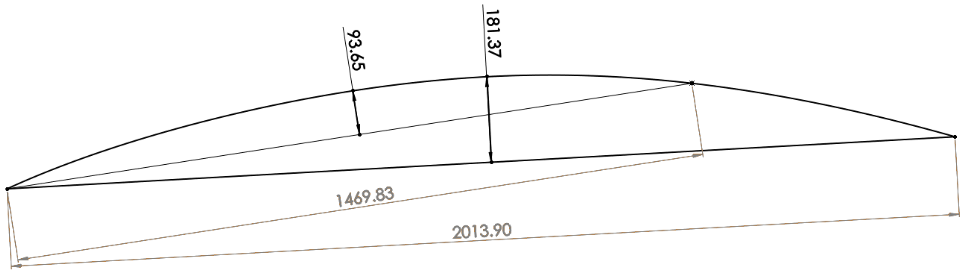

Figure 4.9 – Windshield depth for the long (old) version and the short (new) version

4.2.2 Glass vs plastic door windows

As stated in chapter 3, the door windows should be barrel shaped to work as good as possible with the sealants in the door. This makes them manufacturable in glass, if the shape is not to complex. The door windows are also moving up and down, meaning more wear on the surface which could be damaging for a less durable plastic window. The cheaper glass alternative is more suitable if the final shape fits the design and if that shape can be manufactured.

4.2.3 Front end split up limitation

Since the windshield needs to be made in glass, and the door roof split line can't be changed due to the limitations of this thesis, most of the windows in the front can't be split up differently. As seen in figure 4.10, the split lines concept around the green windshield, the pink door windows and the orange door roof windows are already set and can't change too much. This means that the blue side windows are trapped in between and can't be integrated or changed more than in the shape of itself.

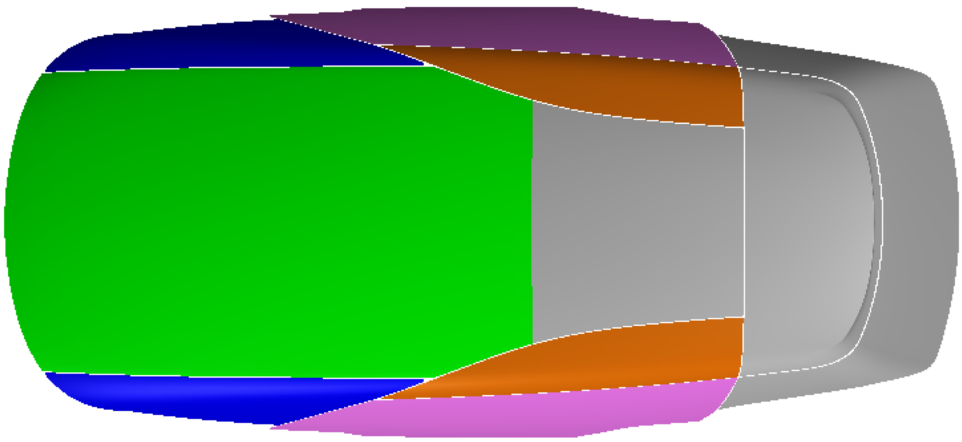

Figure 4.10 – Front end split up of prototype canopy, with a shorter windshield

4.2.4 Rear end split up opportunities

In the rear part of the car, there are more opportunities to split up the windows differently. The rear window, roof spoiler and possibly the sunroof doesn't have to be made of glass. The roof spoiler can't be made in glass and the other two windows would only be cheaper and possibly more durable in glass compared to plastic. The rear window would also have to be controlled and checked for manufacturing feasibility before a glass design could be realistic.

This opens the possibility to reduce the amount of parts by integrating two, or maybe even all three, of these parts into one instead. Figure 4.11 shows the current position of the different parts and table 4.2 shows the combination of surface area which are all within the limitations of plastic injection molding. The sunroof is red, the roof spoiler is yellow, and the rear window is purple in the figure. There can't be a combination between the sunroof and the rear window without including the roof spoiler.

Table 4.2: Combinations of surface area for the rear window, roof spoiler and sunroof

Part combination	Total surface area	Unit
Sunroof + Roof spoiler	0.57	m^2
Roof spoiler + Rear window	0.71	m^2
Sunroof + Roof spoiler + Rear window	1	m^2

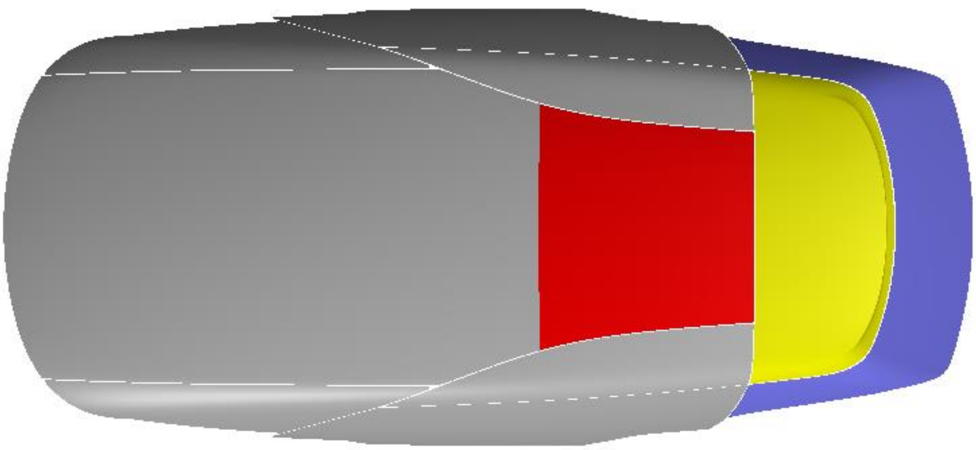

Figure 4.11 – Rear end split up of prototype canopy, with a sunroof

4.3 Concept-ranking

Four different concepts were evaluated which are all named in table 4.3. The all glass concept consisted of as many glass windows as possible. The all plastic concept consisted of as many plastic windows as possible. Concept number 3 consisted of a glass windshield, glass door windows and the rest of the windows in plastic. And at last, concept number 4 had the same glass parts as number 3, but in the rear of the canopy the plastic parts were joined together to create a concept with as few parts as possible.

The characteristics that were evaluated was number of parts, weight, design freedom, cost, manufacturability and durability. All these categories show where the concepts have their strengths and their weaknesses and will result in a stable concept for Uniti. The evaluation of each concept can be found in appendix D and the ranking score can be found in table 4.3. Each characteristic-category was given a (++) for the best concept and a (--) for the worst concept and then either (+) or (-) for the concepts in between. This was considered a reasonable level of ranking because it was often clear which category was the best or the worst at something, and then the other concepts could be placed in between the other ones accordingly.

Table 4.3: Concept ranking

Concept	Parts	Weight	Cost	Design	Manufacturability	Durability
1 – All glass	10	33.7 kg	+ +	- -	- -	+ +
2 – All plastic	10	24.8 kg	- -	+ +	++	- -
3 – Glass windshield and door windows	10	28.1 kg	-	+	+	+
4 – Lowest amount of parts	8	28.1 kg	-	+	-	-

The concept with the best score was concept 3, with a mix of both glass and plastic windows. The decision to go for glass door windows to make sure the wear of moving the window up and down made a good impact on the score. The mix of glass and plastic windows also seems like a good alternative to construct the shape that Uniti wants.

5 Construction of new glazing

In this chapter, the construction of the new glazing concept is explained in detail.

After deciding on a material and split up concept, the final analysis and construction of the glazing could be completed. Each individual window was controlled and designed with the limitations in mind and to fit the Uniti prototype design shape as close as possible.

5.1 CAD-software and method

The software used to construct this new canopy was Solidworks 2017. First, the old glazing geometry together with other relevant car geometry was imported as reference. New surfaces were created with the design limitations in mind as will be explained in detail in the following paragraphs. Surface-modelling is a powerful tool to create complex shapes before creating the final solid models resembling the part. Since windows have a constant thickness all over the part, this is a great way of working.

The glass window surfaces were modeled first. This was done because those surfaces were modeled with arcs of constant curvature while the plastic window surfaces were modeled with splines. The glass surfaces set the base shape and the plastic surfaces handles the shape in between.

After split lines had been added to create individual window surfaces, a thicken command could easily model the final part.

5.2 Windshield

The windshield of Uniti One will be made of laminated glass and the manufacturing method should be press bending.

5.2.1 Shape analysis

The original windshield shape is made of a freeform surface constructed with splines. This means that the shape of the surface changes all along the windshield, making it harder to manufacture without causing distortions. The radius along the length of the car was close to constant at a value of 2935 mm along the centerline of the windshield as can be seen in figure 5.1.

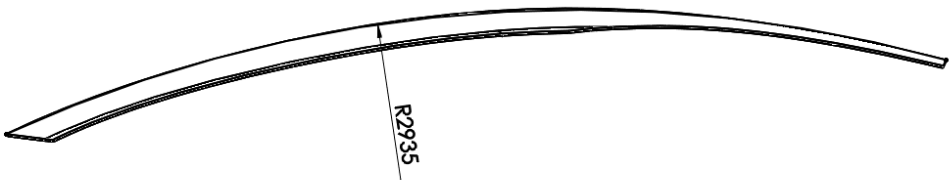

Figure 5.1 - Windshield longitudinal curvature

When looking at the radiuses along the width of the windshield, these are constantly changing as can be seen in figure 5.2. The average radius value was 1651.545 mm in the front part of the windshield (not including the sunroof).

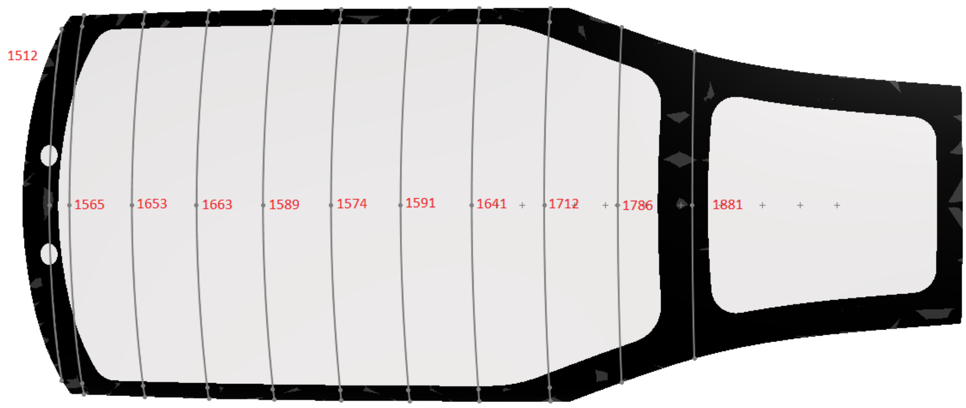

Figure 5.2 – Windshield width curvature

When looking at the curvature difference it becomes obvious that this surface has a changing structure for different parts of the glass. As can be seen in figure 5.3, the radius changes from the black areas (around 2000 mm) to the green areas (around 250 mm).

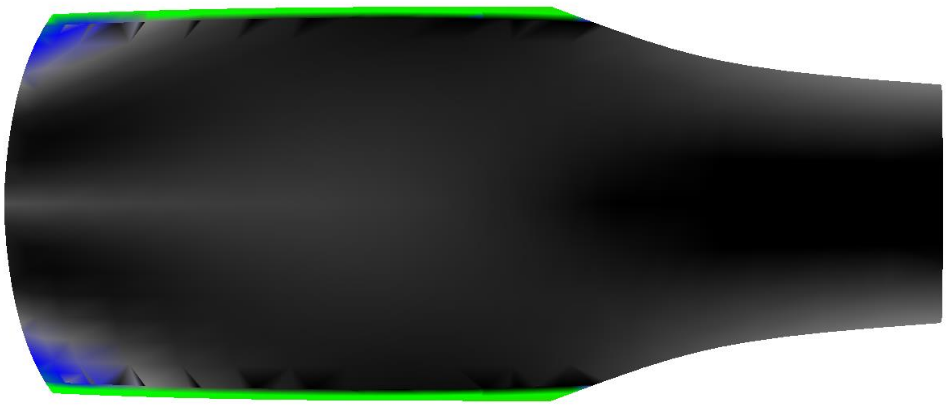

Figure 5.3 - Windshield curvature

A constant surface curvature radius of 2935 mm (length) and 1650 mm (width) was tested as the new windshield shape. This will eliminate as many curvature differences as possible.

5.2.2 **Split lines**

The split lines from the prototype design should be kept as close as possible in the new design as well. The only difference is the new split line between the windshield and the sunroof. This should be placed right in the center where the roof beam crosses. The location can be seen in figure 5.4.

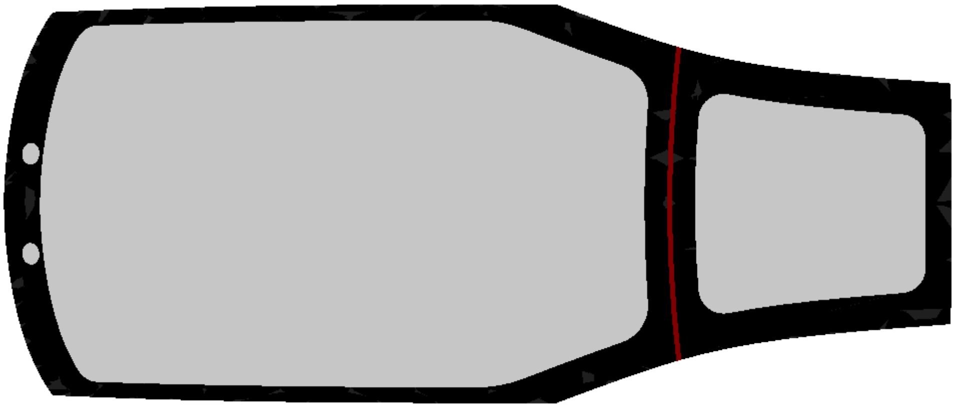

Figure 5.4 - Windshield and sunroof split line

5.2.3 **Rake angle**

The rake angle of the windshield affects how much optical distortion and light transmittance is seen through the window. Two ways of improving this angle was considered as can be seen in figure 5.5 and figure 5.6 below. If only the bottom edge was moved inwards, the rake angle didn't change more than 0.86 degrees. 100 mm was considered enough space to fit windshield wipers and motors. To reach a rake angle of 60 degrees, the top point of the windshield had to move 200 mm as well. This would result in a fundamental shape change to the canopy and was not included in the final construction due to time limitations and uncertainty of distortion improvement.

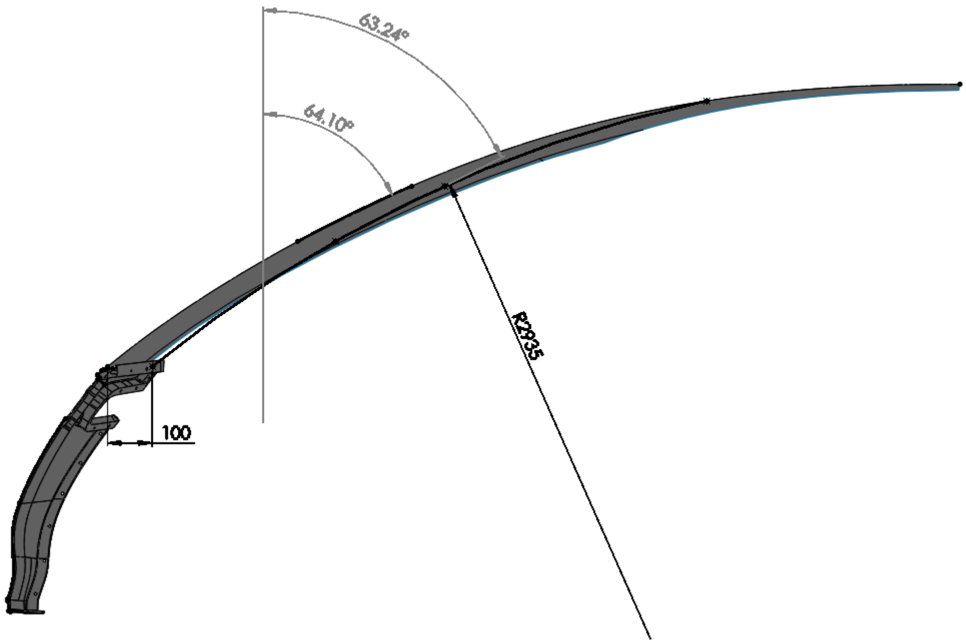

Figure 5.5 - Rake angle change, concept 1

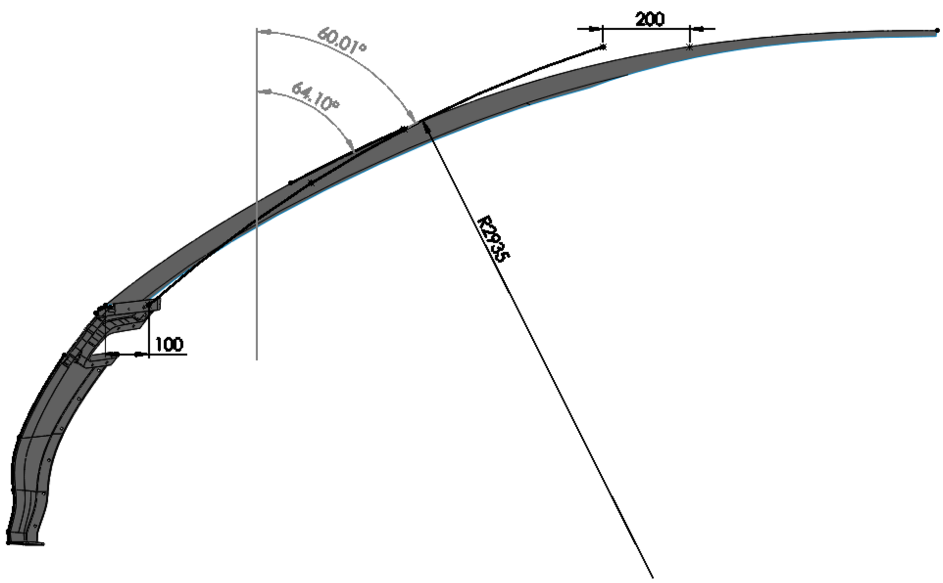

Figure 5.6 - Rake angle change, concept 2

5.2.4 **Driver sun protection**

As shown in the benchmarking, a shade band at the top of the windshield doesn't shut out enough sunlight in hot conditions. Such a solution would also mean a permanent color change in the windshield, reducing the overall canopy design looks. An alternative would be to integrate a switchable tint in the design, but that increases the complexity and cost. Some kind of mechanical solution which is fastened in the frame member above the driver's head would be an easier solution and preferable. Either way, this does not affect the shape of the windshield and can be decided later on in discussions with suppliers.

5.3 Door window

The door windows of the Uniti One will be made from either a laminated or a single sheet glass. The window should have a barrel shape and needs to fit inside the door packaging to allow a complete movement up and down. The window also needs to have a rubber sealant guide to make sure it slides into place when moving up and down and to make sure water and air stays out while driving.

5.3.1 **Door packaging analysis**

The first step is to check how the window needs to be cut to fit inside the door. This is done first because it limits how large the window is and, in that sense, also limits in what region the shape is limited. In figure 5.7, the door and door window are seen from the side. There are several things that are of interest here. The three blue lines are all equally long and parallel and simulates the movement of the tallest part of the glass to be hidden completely inside the door, as required. This is done at an angle, which doesn't allow the glass to touch any other parts of the glass or door. There is a safety margin of 50 mm all around the inside of the door to make sure frame members and rails can fit. A reasonable angle seems to be 17 degrees from the vertical which fulfills all requirements. This angle does now set the limitation for the vertical movement of the glass, which also means that one of the constructing radiuses of the glass curvature needs to be established along this plane.

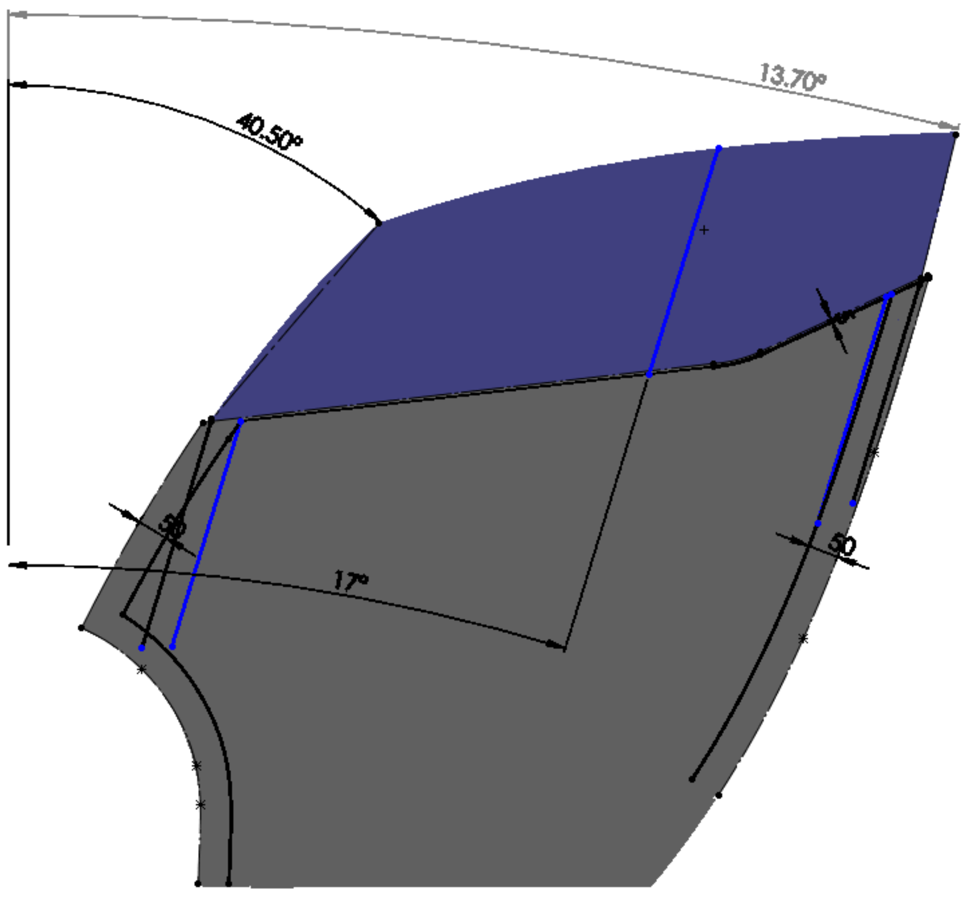

Figure 5.7 – Door packaging limitations, side view

The second thing to look at is the depth and curvature limitation inside the door packaging. The door window needs to have a similar curvature as the door, or it won't fit when moved down. In figure 5.8, the vertical curvature is controlled. An offset from the inside of the door panel surface has been set to 10 mm to make sure the glass doesn't touch it. The window needs to roll down close to 450 mm to be completely hidden inside the door. A vertical radius of 2800 mm set's the limit to the maximum curvature before the door window touches the inside of the door, or the vertical draft of the window is changed.

The horizontal curvature was also controlled and the most important limitation there is the curve representing the window sealant in the bottom part of the window. This curve had a radius around 6130 mm and is crucial to hold as close to this value as possible so that the shape of the door is affected as little as possible. There were curvatures inside the door which were smaller (around 5500mm), but this can be solved by placing and curving the window in a way so that the window doesn't touch the walls anyway. Also, the curvature at the top of the glass was less then at the door opening (around 5000 mm) meaning the shape will have to change quite a lot in some part of the window.

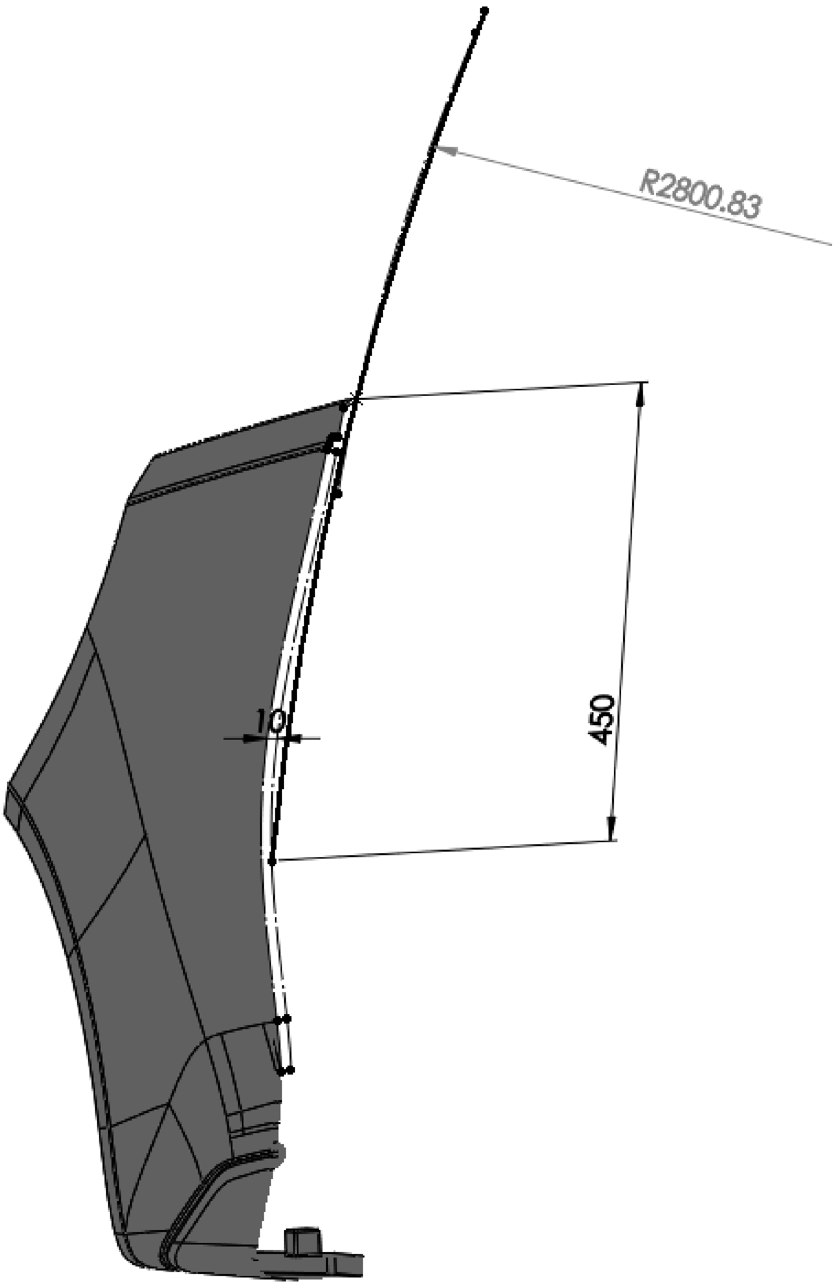

Figure 5.8 – Door packaging limitations, vertical curvature inside door

5.3.2 **Shape analysis**

The door window is also constructed as a freeform surface like the windshield, giving it little continuity in curvature all over the surface. In figure 5.9 the curvature differences are displayed. The green areas have a curvature around 250 mm and the black/grey areas somewhere between 2000/1000 mm. The old shape doesn't need to be analyzed more than that because the new surface to be modeled is already so dependent on the door limitations that it will get a shape that fits those limitations.

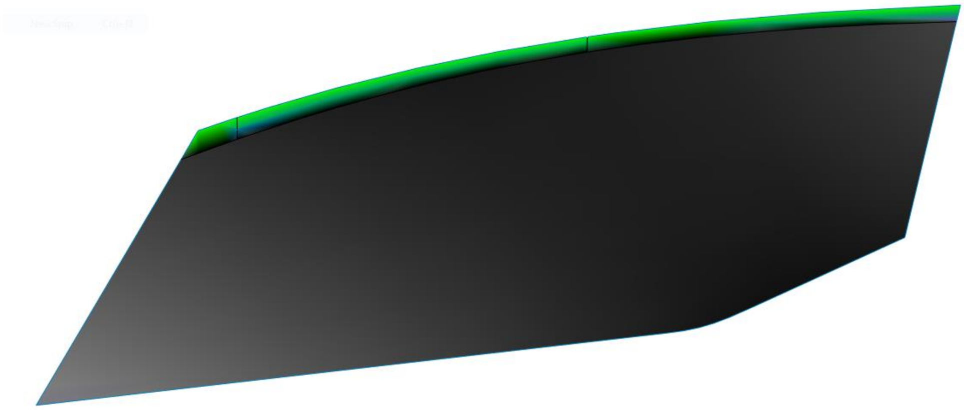

Figure 5.9 – Door window curvature

5.3.3 **Split lines & sealants**

The split line between the door and the door window cannot follow each other as shown in picture 5.7 above. But if there is a rubber seal added as a channel for the glass to slide in, it could follow the door split line. This would offset the window split line inwards, making the window smaller, and at the same time allow for a controlled window movement. This idea is shown in figure 5.10. The glass itself is then offset inwards slightly to allow the sealant to be flush with the other windows, keeping the shape continuity as much as possible.

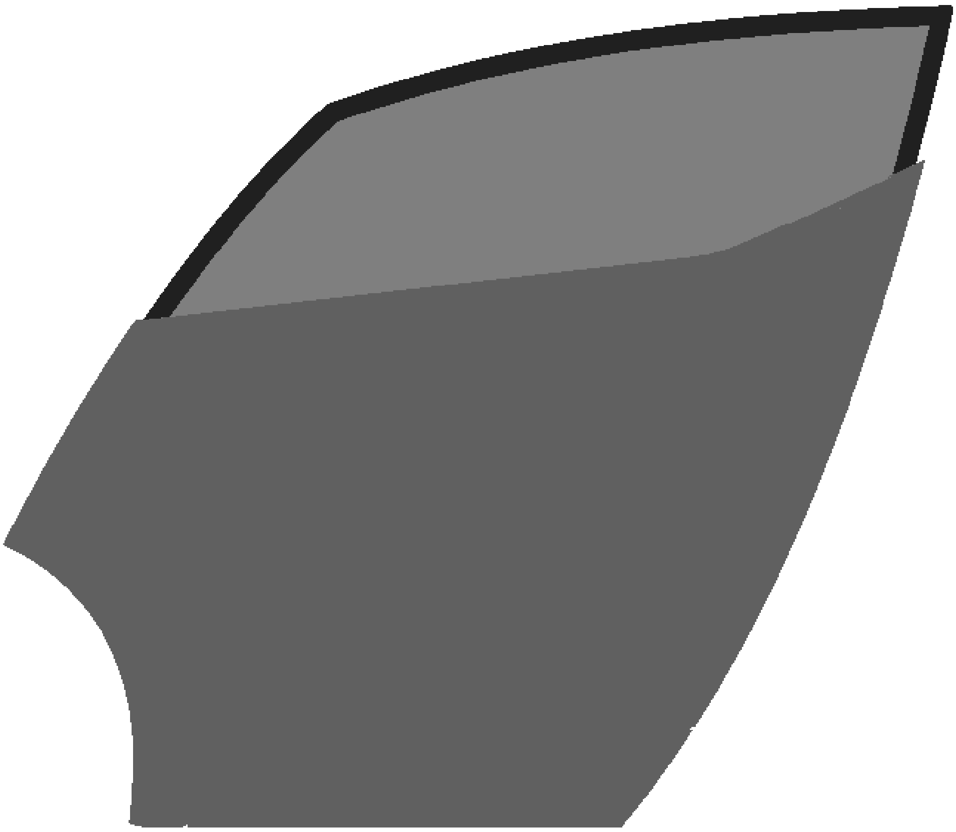

Figure 5.10 – Door sealant split line concept

5.4 Plastic windows

The rest of the canopy will consist of 7 plastic windows. All of these will be injection molded in a transparent polycarbonate plastic and covered with a suitable coating to reduce wear as much as possible.

5.4.1 **Shape analysis**

The shape should be as close to the prototype design as possible. At the same time, curvature consistency needs to be accomplished between the plastic windows and the already designed glass windows. Plastic windows have a design freedom which makes this possible. Since the glass windows have been designed to resemble their predecessors, there will be as little design change as possible if the plastic windows can be constructed without curvature problems. The goal is to reach the same curvature consistency as the old design. In figure 5.11 and 5.12 the curvature and reflections of the old design is displayed.

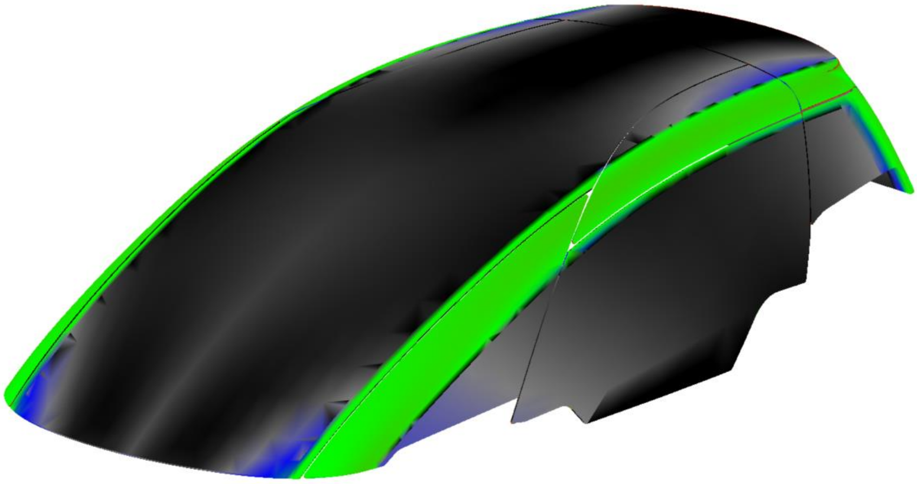

Figure 5.11 – Curvature of old canopy

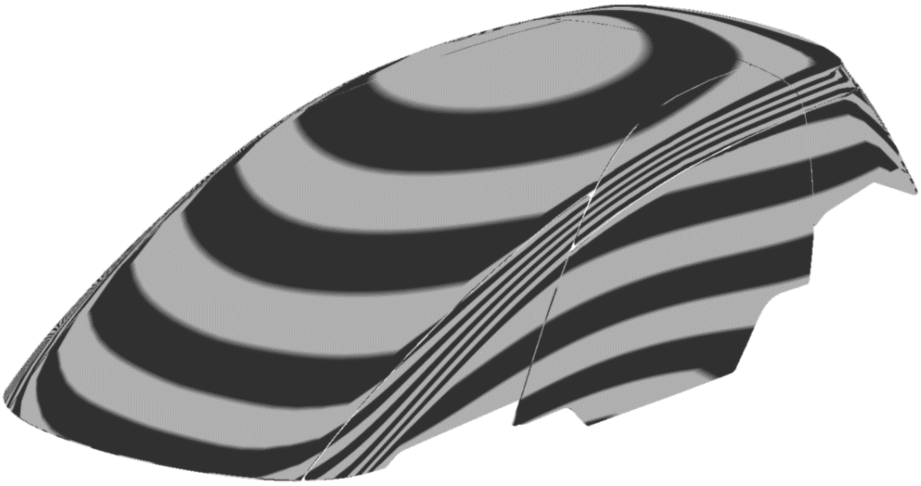

Figure 5.12 – Reflections of old canopy

5.4.2 **Split lines**

The split lines should be kept as close to the prototype design as possible, but they need to be adapted to fit the new shape of the glass windows. At the bottom edge of the canopy, the split lines should stay as close to the original form as possible to not affect the shape of the exterior panels.

The rear split line of the door roof window needs to change to allow for a conventional hinge to work for the door opening. In figure 5.13, two alternative placements have been displayed for the door hinge rotation center. The door roof window will hit the other windows if the rear split line is not tilted slightly.

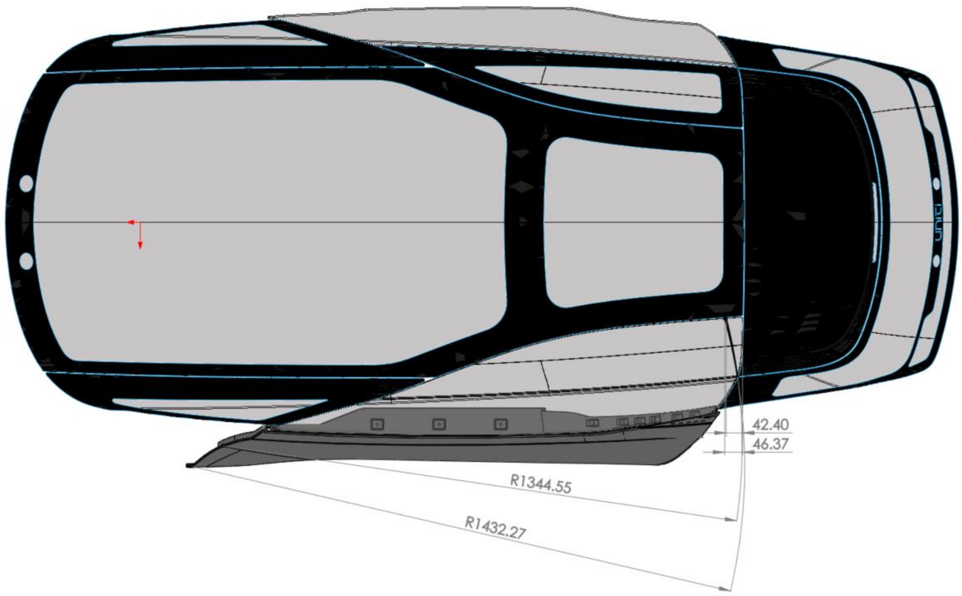

Figure 5.13 – Door rotation limitation on door roof split line

5.4.3 **Integration of other plastic parts**

One advantage of designing plastic parts is the opportunity to include several parts into one more complex part. This was considered for the Uniti One canopy and one part that could be integrated was the camera cover sitting on the outside of the side windows. This camera cover, which can be seen in figure 5.14, is part of the exterior design and is allowing the rearward facing side cameras to get a better field of view by protruding a bit from the canopy surface. This part could be integrated into the side window to be manufactured as one unit, which could decrease the cost of the system. This would also increase the feeling of a complete covering canopy with as few split lines as possible.

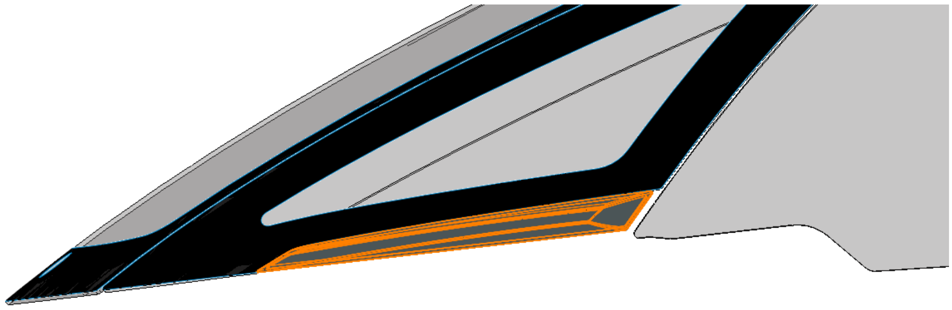

Figure 5.14 – Camera cover seen from the side of the car

5.5 Obscuration lines

The obscuration lines are covering the attachment points of the glass to the frame. The frame shape is therefore affecting this design a lot and the obscuration lines should stay as close to the prototype layout as possible to not change the frame design. There is also a design intent, that most of these lines should merge in between the windows, to increase the feeling of a complete covering canopy. This lead to problems in one area.

On the prototype design, the obscuration of the side window and the door roof window were able to follow the curvature of the door window split line and the windshield as can be seen in figure 5.15. But when the canopy shape changed in the new construction, this alternative became unsuitable. Since there was a door sealant added to the door window split line, the obscuration line had to be lowered on the side window. This made far too much of the window black as can be seen in figure 5.16. The same happened at the door roof split line which in the prototype design was tilted to match the curvature of the inside of the windshield. This concept did not work for the new canopy shape and the result covered far too much of the window. A trade of design was chosen where the obscuration lines were instead matched between these two windows as can be seen in figure 5.17.

There are round cutouts in the lower part of the windshield obscuration and in the rear window obscuration for cameras. In the rear window, there is also a cutout for the taillight and a Uniti-logo. In the roof spoiler, there is a cut out for the break light. All the obscuration features in the rear of the car can be seen in figure 5.18. All these positions and sizes was kept as they were designed for the prototype.

Figure 5.15 – Obscuration lines of the prototype car

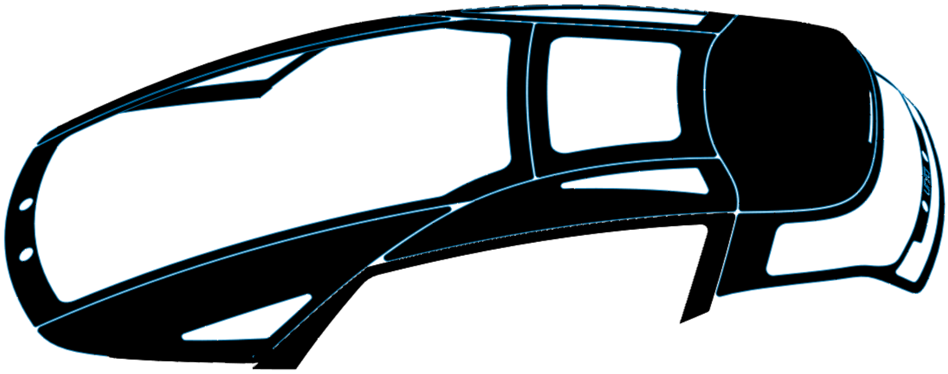

Figure 5.16 – Obscuration lines of the new canopy, version 1

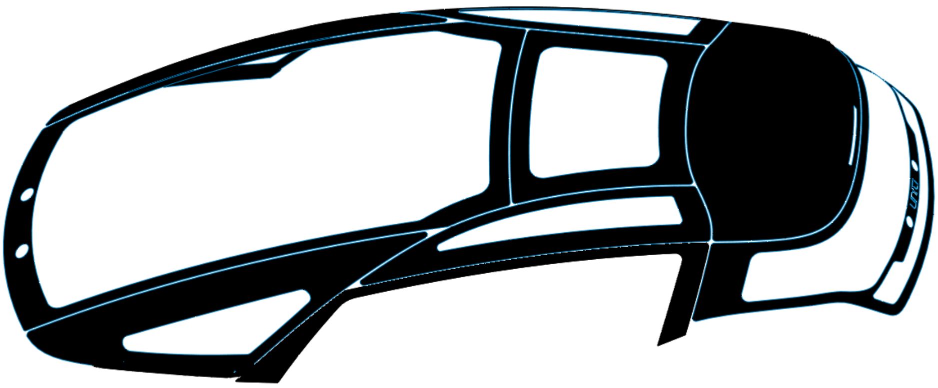

Figure 5.17 – Obscuration lines of the new canopy, version 2

Figure 5.18 – Obscuration lines of the new canopy, seen from the rear

6 Results – new design

In this chapter, the new design of the glazing is displayed and explained in detail

The result of this thesis is an updated canopy design for the Uniti One vehicle, consisting of 3 glass windows and 7 plastic windows, as can be seen in figures 6.1, 6.2, 6.3, 6.4(a)(b). The specifications for each window can be found in table 6.1. There are two windows who have multiple alternatives regarding manufacturing methods and the sunroof also have both glass and plastic as the possible material. This is to show that with the new construction, all these materials and manufacturing methods are possible alternatives. Uniti can then decide whether a cheaper but heavier solution (glass-sunroof) is more suitable or a cheaper but less accurate solution (sag bending of door glass) is good enough. The door window can also be manufactured both in a single sheet or in a laminated version, where the second alternative would increase the safety of the car but at a higher cost and weight.

Figure 6.1 – New canopy of Uniti One, generic view

Figure 6.2 – Side view

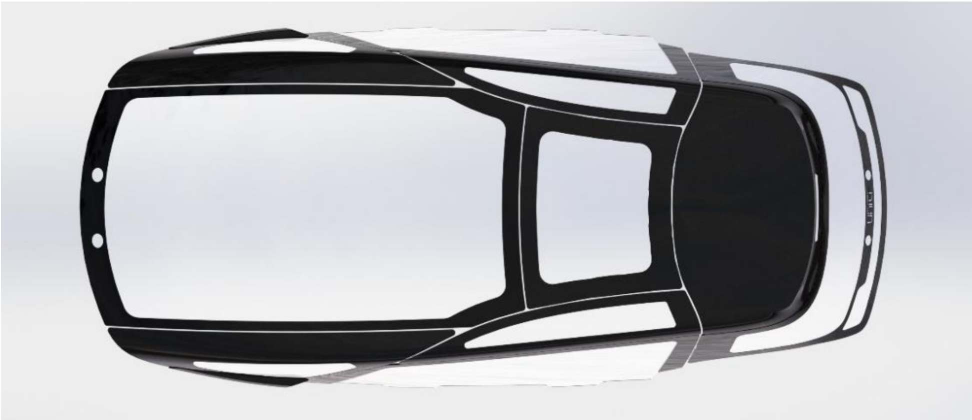

Figure 6.3 – Top view

Figure 6.4(a) – Front view, (b) – Rear view

Table 6.1: Window specifications

	Window	Material type	Manufacturing method
1	Windshield	Laminated glass	Press bending
2	Sunroof	Laminated glass/plastic	Sag bending/Injection molding
3	Roof spoiler	Plastic	Injection molding
4	Rear window	Plastic	Injection molding
5	Door window (L)	Laminated/single sheet glass	Press/sag bending
6	Door window (R)	Laminated/single sheet glass	Press/sag bending
7	Side window (L)	Plastic	Injection molding
8	Side window (R)	Plastic	Injection molding
9	Door roof window (L)	Plastic	Injection molding
10	Door roof window (R)	Plastic	Injection molding

Apart from the 3D-shape, split line concept, material decisions and manufacturing method recommendations, coatings should be added to the result as well. All windows should have UV-protective layers to prevent the glazing and parts of the interior from degeneration and the plastic windows should have scratch resistant layers. It could also be wise to add a heat reflective coating to the windshield to reduce as much heat as possible to enter the cabin this way.

6.1 Shape analysis

The final shape of the canopy was not far from the shape of the prototype canopy. In fact, the total surface area only changed from 3.56 m^2 to 3.54 m^2. The curvature can be seen in figure 6.4 and the reflections can be seen in figure 6.5. The biggest difference is the curvature on the glass windows. The color doesn't change, meaning that there is a continuous curvature difference all over the surfaces, compared to the same analysis which was conducted in figure 5.11 where the curvature differed from different parts of the same glass window surfaces.

It should be noted that the final shape of the plastic windows could have been better modeled. There are inconsistencies both in the curvatures and reflections which could have been avoided with a more skilled surface modeler and possibly a more advanced surface program.

The second problem affecting the plastic window inconsistencies is that these windows have been forced into place between the glass windows, the predefined exterior panels and the original glazing shape. If the whole exterior would have been remodeled, these inconsistencies could have been minimized.

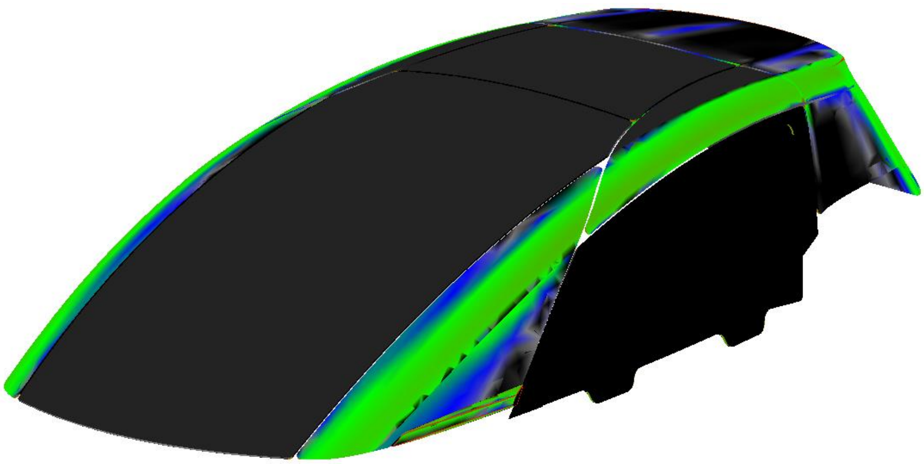

Figure 6.4 – Curvature of final canopy design

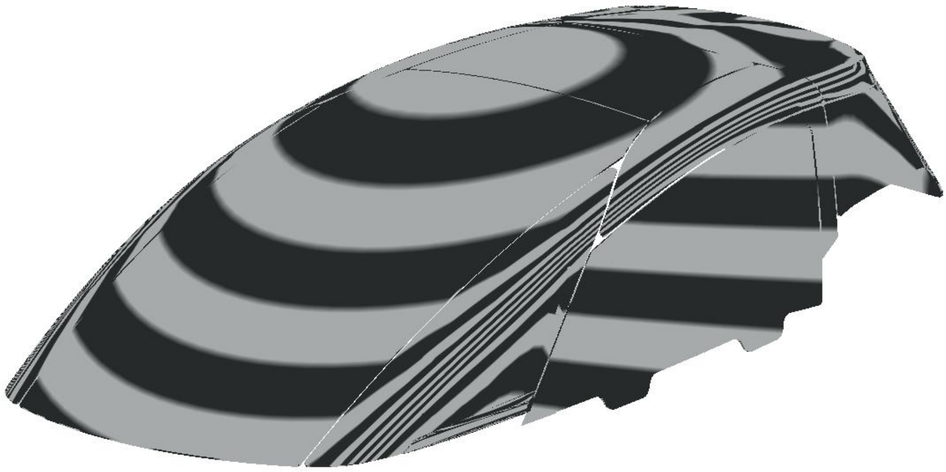

Figure 6.5 – Reflections on final canopy design

6.2 Method analysis

The method used to re-design these car windows can be written down in a few simple steps. These are found in table 6.2.

Table 6.2: Method of designing complex glazing parts for vehicles

	Design step
1	Import start shape from designers
2	Determine which regulations that applies for the vehicle regarding glazing design
3	Decide where glass shall be used as the material on the canopy, with regulation and design limitations in mind
4	Construct the glass surfaces, with manufacturing and design limitations in mind
5	Construct the plastic window surfaces in between the glass surfaces, making sure the surface continuity is at a sufficient level
6	Split up the canopy surface into individual windows, with manufacturing and design limitations in mind
7	Make solid models
8	Design obscuration lines with design limitations in mind

This method can be used by Uniti to safely construct exterior designs of complex transparent geometry. This will make sure less iterations will be needed to reach a manufacturable exterior design. These simple rules also allow Uniti to design other types of vehicles if the regulatory limitations are updated accordingly.

7 Discussion

In this chapter, a discussion is written for this thesis.

7.1 Purpose and delimitations

The delimitations were set together with the Uniti team. The surface design of the car is something that Uniti wants to lock down on a more stable level. If the shape and concept of the whole canopy were decided to be iterated upon, this would have been a completely different project. Then there could have been completely new concepts built which could have been lowering the complexity and optimizing the cost and weight of the glazing. This was not the purpose of the thesis.

7.2 Vehicle category and regulations

Uniti One is a L7e-vehicle. This has made some simplifications possible for the homologation and design of the glazing, but not that many. For most parts of the regulations, the same rules apply for M1-vehicles. If Uniti would not be able to pass the vehicle regulations for L7e and decided to go for M1, the glazing would already be ready for it. That would mean that a design with a heavier weight, but lower cost could be interesting. On the other hand, some regulations might even be less limiting for M1-vehicles. Those regulations have been updated more recently and since the development of plastic parts and coatings is getting better and better, more windows are now allowed to be made in plastic, including the windshield.

7.3 Trade offs

The cost for this glazing will be a lot higher than for a standard car. Not only will the plastic parts be more expensive than a glass alternative, but the windshield will also be expensive due to its complexity and size. Uniti has made the decision to make the glazing into a design element which should allow for a higher cost in the budget. The weight-limit on this vehicle is also easier to reach if the windows are made from the lighter plastic alternative. There is a tradeoff made here which is more complex than just designing something complex and beautiful and allow the price to increase. By choosing the more expensive material, it's also easier to pass the weight limitation and the desired complex shape can be met. But there is one other problem with plastic. The durability could be questioned, both regarding scratch resistance and UV-wear. Both these problems are absent with glass and speaks in the hard materials advantage.

So how do all these different factors rank in importance? Well the product profile has an important role in this matter. An M1-vehicle with slightly less demands on the desired shape could have ended up with more windows made of glass, which would have been cheaper, more durable, but heavier.

7.4 Supplier limitations

The information regarding what suppliers can and cannot manufacture is very delicate. They don't want their competitors to know what their limitations are or how they solved complex manufacturing problems. It was decided at an early stage of this thesis to not involve suppliers for gathering information at all, to make sure no confidentially agreements were trespassed.

That means there is a part missing from this manufacturability control. Individual suppliers have their own limitations on how large and complex windows that they can manufacture. Uniti will have to think about which suppliers are located close to their assembly site which limits their alternatives. That might set even tougher limitations on the design than considered in this thesis. Off course this is something that can be solved, but for a small car manufacturer, building up their supply chain will be something that takes time and costs money. Being flexible and having multiple alternatives might be what is needed when building those first set of cars. Then it's unwise to push the design towards the limitations of what can be manufactured at all.

Also, building these cars is highly volume dependent. With these expensive manufacturing techniques chosen, Uniti will have to build a high number of cars to keep parts costs down. Building molds both for press bending glass windows and injection molded plastic windows costs a lot of money. This will be a problem for Uniti's liquid funds as more money will be bound up in the assets which is the molds for this glazing design. If something wouldn't work or needed to be changed, there would be huge costs.

7.5 Software and construction method

Solidworks is a very capable tool for making complex parts. However, Uniti will have to use their own software to create the parts in the end. Today they use Siemens NX 11 which is a very good software for creating surface models and parts of this kind, maybe even better than Solidworks. The method of creating the glass surfaces first and then the intermediate plastic surfaces should be very capable as well. The alternative would be to create the surfaces together and then alternate were the final split line lies, making sure the glass surfaces is built from static arcs.

7.6 Design maturity and results

The product profile used in this thesis is something that Uniti have been working on for over two years. Although it was not written down in stated specifications, a lot of the shape elements have been given some serious thoughts. The problem is that all subsystems need to be checked in the same matter as the glazing has in this thesis. Is the ergonomic model accurate enough? Will the frame be stiff enough? Can the exterior panels be split up as they are designed? Is the door split line vertical enough for a hinge to function properly? Will a HUD work with this windshield shape and angle together with the shape of the dashboard? All subsystems which is affected by the glazing need to be designed in correlation with the glazing design. That’s why the result of this thesis only shows that the method of designing the glazing like this works, not that this construction is the final one. The construction in this thesis can be the final one but should absolutely be checked together with all other subsystems first. A design of such a complex system as a car is cannot be performed by individual developers, everything must fit together in the end.

8 Reflections and future work

In this chapter, some reflections on this thesis is written together with a list of future work to be done to reach a finished canopy design.

8.1 Reflections

The design level maturity after this thesis project is higher than in the start, but probably not high enough to move straight to production. To take the last step, Uniti needs to discuss the limiting parameters together with the suppliers of their choice. The manufacturing limitations might be less or more restrictive than set in this thesis which could affect the final shape of the canopy.

At the same time, all other subsystems need to be controlled together with the glazing. In this thesis, most decisions have been based on the prototype design of other subsystems which might have to change in the same matter as the glazing has. That’s why the process is the most important result that Uniti can use in the next iterations of the exterior design for this car or other cars in the future.

One thing is clear though, the canopy design as it is designed in this thesis can be manufactured and would be regulatory approved. It’s just not clear if it is optimized enough to fit Uniti’s demands and cost-model.

8.2 Future work

A large part of this thesis has focused on the shape, material and split up concept of the canopy. To finish of the specification, a thickness would have to be added to each window. This was considered a secondary specification because it doesn’t change the modeling and split up of the windows. None of the windows are unconventionally large which means there is no special demand on the thicknesses. In the canopy-concept weight calculations, normal car window thicknesses were used as a reference for the concept differences. It was also considered reasonable that a frame-design would not have to be dependent on a very stiff window in any region, and thus not being limiting in that sense. Now when a shape and split up concept is ready a thorough calculation can be performed to optimize the thicknesses of each window to reduce the weight and cost of the glazing as much as possible.

A second thing which was not controlled is aerodynamic limitations. This could maybe affect the shape of the roof spoiler and the other plastic windows. In general, the concept of having a complete covering canopy would be good aerodynamically. But a more thorough investigation would have to be performed to sort out if there are specific regions which are affected more.

The future work will off course focus mostly on optimizing this design to be as lightweight and cost effective as possible. Once more data can be gathered from possible suppliers, Uniti will be able to take smart decisions regarding this.

9 References

[1] The United Nations Economic Comission for Europe (UNECE), *Consolidated Resolution on the Construction of Vehicles (R.E.3),* Geneva, Switzerland: The United Nations Economic Comission for Europe (UNECE), 2017.

[2] European Parliament, Counsil of the European Union, *Regulation (EU) No 168/2013 of the European and of the Counsil of 15 January 2013*, Geneva, Switzerland: European Parliament, Counsil of the European Union, 2013.

[3] European Parliament, Counsil of the European Union, *Comission Delegated Regulation (EU) No 3/2014 of 24 October 2013*, Geneva, Switzerland: European Parliament, Counsil of the European Union, 2014.

[4] European Parliament, Counsil of the European Union, *Commission Delegated Regulation (EU) No 44/2014*, Geneva, Switzerland: European Parliament, Counsil of the European Union, 2014.

[5] The United Nations Economic Comission for Europe (UNECE), *Regulation No 26. Uniform provisions concerning the approval of vehicles with regard to their external projections,* Geneva, Switzerland: The United Nations Economic Comission for Europe (UNECE), 2013.

[6] The United Nations Economic Comission for Europe (UNECE), *UNECE No 43. Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles,* Geneva, Switzerland: The United Nations Economic Comission for Europe (UNECE), 2017.

[7] L. Hedgbeth, "Second Chance Garage," Reed Web Design, 2018. [Online]. Available: http://www.secondchancegarage.com/public/windshield-history.cfm. [Accessed 24 May 2018].

[8] D. H. M. George A. Koss, "METHOD AND APPARATUS FOR BENDING". United states of America Patent 5,129,934, 14 July 1992.

[9] T. A. N. V. N. P. S. D. Jeffrey R. Faugher, "Method and apparatus for controlling the temperature of glass sheets in press bending". United states of America Patent 5,279,635, 18 January 1994.

[10] T. L. W. Randall S. Johnson, "Method and apparatus for shaping glass sheets by roll forming". United states of America Patent 4,139,359, 13 February 1979.

[11] L. R. Zbinden, Glass engineering: Design solutions for Automotive Applications, Warrendale, Pennsylvania: SAE International, 2014.

[12] T. C. M. M. S. S. a. W. K. F. Thomas Leonhard, "Novel Lightweight Laminate Concept with Ultrathin Chemically Strengthened Glass for Automotive Windshields," *SAE Int J. Passeng. Cars - Mech. Syst,* vol. 8, no. 1, pp. 95-103, 2015.

[13] Glasstech, Inc, "Glasstech," 14 November 2011. [Online]. Available: http://www.glasstech.com/32Automotive.aspx. [Accessed 1 June 2018].

[14] M. Knights, "Auto Glazing: Window of Opportunity For Molders," *Plastics Technology,* pp. 52-57, 71-73, 1 April 2006.

[15] F. Alam, "The effects of car A-pillar and windshield geometry on local flow and noise," RMIT University, Melbourne, 2000.

[16] G. B. A. D. J. G. G. G. B. K. B. S. K. Bewilogua, "Surface technology for automotive engineering," *CIRP Annals - Manufacturing Technology,* pp. 608-627, 2009.

[17] G. W. &. I. Pearce, "The influence of automobile windscreen rake on effective light transmittance," *Ophthalmic and physiological optics,* vol. 1, no. 30, pp. 785-789, 2010.

[18] K. T. U. a. S. D. Eppinger, Product Design and Development - Fifth edition, New York: McGraw-Hill, 2012.

[19] F. Lambert, "Electrek," Wrights Media, 3 June 2016. [Online]. Available: https://insideevs.com/due-complaints-tesla-will-send-model-x-owners-front-windshield-sunscreen-free-charge/. [Accessed 29 May 2018].

[20] S. Loveday, "Inside EVs," Motorsport Network, 12 June 2016. [Online]. Available: https://insideevs.com/due-complaints-tesla-will-send-model-x-owners-front-windshield-sunscreen-free-charge/. [Accessed 29 May 2018].

[21] Covestro AG, "Covestro," [Online]. Available: https://www.plastics.covestro.com/en/Applications/Inspiration-Gallery/Panoramic-roof-of-a-car.aspx. [Accessed 18 July 2018].

[22] L. Todorova, "Automobiles review," BGO Media, 1 November 2012. [Online]. Available: https://www.automobilesreview.com/auto-news/emissions-free-renault-zoe/55892/. [Accessed 29 May 2018].

[23] B. Group, "EuroCar News," Magazine net, 15 June 2011. [Online]. Available: http://www.eurocarnews.com/0/0/1393/0/introducing-the-all-new-5th-generation-2012-bmw-m5.html. [Accessed 29 May 2018].

[24] AutoCar, "AutoCar," Haymarket Media Group, 2015. [Online]. Available: https://www.autocar.co.uk/car-review/seat/leon-2005-2012/design. [Accessed 29 May 2018].

[25] M. 1, "Motor 1," 1 August 2005. [Online]. Available: https://www.motor1.com/photos/438502/new-honda-civic-for-europe/. [Accessed 29 May 2018].

[26] J. Beckwith, "Auto Car," Haymarket media group, 23 May 2017. [Online]. Available: https://www.autocar.co.uk/car-news/new-cars/fiat-500l-facelift-revealed. [Accessed 29 May 2018].

Appendix A - Time plan

In this appendix the time plan of this project is shown.

A.1 Project time plan and outcome

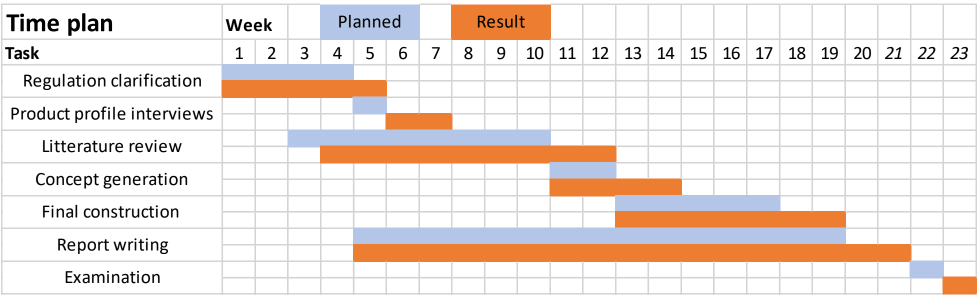

Figure A.1: Project time plan and outcome

As seen in figure A.1, the time plan set in the beginning of the project was followed, but slightly off set. The amount of time to do the different steps was estimated to a level which resembled the result. The reason why some steps are delayed, or overlapping, is because some decisions had to be verified and iterated before the work could continue with confidence. All design limitations had to be checked before the final concept could be approved for final construction. The product profile interviews had one-week delay because one interview got delayed due to travels of one Uniti staff member.
Also, the final construction had to be iterated several times due to problems with surface modeling.
The decision to write the report alongside the work load of the project was done to make sure no information was forgotten.

Appendix B – Vehicle regulations

In this appendix all vehicle regulations which affects Uniti's vehicle glazing have been noted and interpreted.

The following paragraphs explains the different documents that affects Uniti One's vehicle type, what segments of those documents that affect the glazing and what the final interpretation of those segments imply. Citations from the different documents are written in square brackets with the interpretation underneath.

B.1 Regulation (EU) No 168/2013

Regulation No 168/2013 is the overall vehicle regulation for L-categorized vehicles used in the European union [2]. This document is written to clarify which regulations applies for L-categorized vehicles and if there are changes made specific for this region. This summarizing document doesn't have any actual vehicle regulations written down that's specific for the design and manufacturing of vehicle components, but it states where these regulations are written in other documents as well as if there are special regulations or not.

B.1.1 Annex II [2, pp. 102-105]

There is a table in Annex II that states that if a L7e-categorized vehicle wants to be mounted with safety glazing, there are rules to be followed for it.

B.2 Regulation (EU) No 3/2014

Regulation No 3/2014 is a supplement to the previous regulation No 168/2013 [3]. This document provides more clear regulations regarding the functional safety of L-categorized vehicles.

B.2.1 Annex VII, Requirements regarding glazing [3, pp. 34-38]

The following points describe the main rules that affects Uniti's glazing.

- Only safety glazing is allowed
- The different types and specifications of safety glazing is specified in UNECE No 43
- The windows should stay in place and always afford visibility and safety to the driver/passenger during normal operating
- Category L-vehicles should follow rules for M1-vehicles set up in UNECE No 43 annex 21
    - Flexible glazing with marking IX is allowed anywhere but the windshield
    - Rigid plastic glazing is not allowed as windshields
- The vehicle needs to have windshield wipers
- These wipers need to cover at least 90 percent of vision zone A described in annex 21 in UNECE No 43 regulations
- There needs to be a system to remove frost from the outside of the windshield and mist from the inside of the windshield

This clearly means that there are more rules to be found in the document specified as UNECE No 43 and that L-vehicles should follow the rules stated for M1-vehicles in this document, apart for some minor changes. This thesis does not care for the design of windshield wipers, defrosting and demisting solutions apart for the points that also affects the glazing design. The fact that the vehicle needs to have solutions for these problems might do that.

B.3 Regulation (EU) No 44/2014

Regulation No 44/2014 is a supplement to the previous regulation No 168/2013 [4]. This document provides more clear regulations regarding the construction of L-categorized vehicles.

B.3.1 Annex VIII, Requirements regarding external projections [4, pp. 50-51]

- Category L7e-vehicles shall follow rules for M1-vehicles set in UNECE No 26
- The vehicle is not allowed to have pointy, hard, protruding edges that can harm people in the event of an accident

This means there are more rules to be found in UNECE No 26 and that L7e-vehicles shall follow rules set for M1-vehicles.

B.4 UNECE No 26 – Rev 1

UNECE No 26 is a regulation that gives clarifications regarding vehicle projections to reduce risk of bodily harm for persons in collisions [5]. It's mainly for M1-vehicles but as stated in Regulation (EU) No 44/2014 before, the same rules apply to L7e-vehicles.

B.4.1 Particular specifications [5, p. 12]

- In the case of moving windows that move out of the external surface of the glazing
    - No exposed edge may face forward
    - No part of window may project outside of extreme edge of vehicle

These rules might affect the design or limit how the door windows can move up and down.

B.5 UNECE No 43 – Rev 4

UNECE No 43 is a regulation that gives clarifications regarding the installation of safety glazing on vehicles [6]. As stated earlier in Regulation (EU) No 3/2014 the rules that is stated for M1-vehicles also applies to L7e-vehicles.

B.5.1 General requirements [6, p. 13]

- Glazing materials should be resistant to normal traffic, atmospheric, temperature, chemical and abrasion conditions
- If the glass is shattered, danger of bodily injury should be reduced as much as possible
- There should be no noticeable distortion through the windshield
- If the windshield shatters, the driver should be able to see enough to stop the vehicle safely

These points are very straight forward. They describe how in general the individual glass parts should be thought of. The limitations and expectations are different depending on where on the vehicle a window is placed. The more specific rules come later in the document.

B.5.2 Types of safety glazing [6, p. 5]

Hereunder are the different types of safety glazing described. They have a definition but some of them have special requirements which depends on where they are placed on the vehicle or which vehicle type they are situated on.

A toughened glass window is a one-layer glass that's been treated in some way to increase its mechanical strength.

A laminated glass window is a glazing part consisting of two or more layers of glass with a layer of plastic holding them together.

A rigid plastic window is a plastic window which is stiff enough to not deflect to much in the flexibility test. The flexibility test is performed by cutting out a 300 mm long and 25 mm wide sample piece of the material and clamp it in a way so 275 mm is hanging free in the air. If the free end deflects more than 50 mm vertically, the material is not rigid [6, p. 104].

A flexible plastic window is a plastic window which does not pass the flexibility test.

B.5.3 Tests [6, pp. 14-18,48-112]

In this segment test-methods are described for safety glazing that can be mounted on vehicles. Most of the tests are defined as pure material tests and only describes if a material is good enough to qualify to the different safety glazing material categories. Two tests are performed on actual windshields in the actual setup used on the vehicle, the optical distortion test and the secondary image test. Some tests need to be performed if a window type is placed at certain positions on the car.

The optical distortion test is performed by shooting a raster image through the windshield in the correct vision zone. If the image deflects to much from the theoretical position, the glass is declared bad. Optical distortion appears or becomes more apparent by increasing the angle of incidence, increasing the thickness of the window and/or having a more curved window.

The secondary image test is performed very similarly to the optical distortion test. By looking at an illuminated ring through the windshield, a specific amount of double imagery can be seen, and it needs to stay below a certain value.

The headform test is a test where windows, which can be reached by a person's head in an event of collision, is controlled to crack correctly. This test is also performed on an actual windshield if the windshield is made from laminated glass.

Test of resistance to abrasion is a test where the glazing's scratch resistance is tested. This is a test that is more delicate when it comes to plastic windows. Depending on where on the car a window is placed, everything from one to three different tests need to be performed. There are four different tests described. The abrasive wheel test means that said wheel spins over the plastic plate for a specific time, scratching the surface. Material suppliers are allowed to test with the sand drop method instead of the abrasive wheel test. The sand drop method means that three kilograms of sand is dropped from a height of 1650 mm through a specific tube while the plastic sample is spinning on a turntable at a 45-degree angle underneath.
In the car wash test the window is simulated to run through a car wash of rotating plastic striped cylinders rotating on the surface, much like a real car wash. In the Wiper test, simulated windshield wipers perform 20.000 cycles over the surface of the material sample. The surface is covered in water filled with so called ISO test dust which helps symbol real life scenarios.

There are other tests for resistance to radiation, fire-resistance, light transmittance, mechanical performance, resistance of chemicals, resistance to humidity, resistance to simulated weather and so on but these tests are more adapted for the material performance, not the actual design of the window.

B.5.4 Annex 21 – Determining test areas on windshields [6, pp. 181-188]

This annex explains in detail how to determine the vision zones described in some regulations. The vision zones are based on the ergonomic position of the driver and all measurements relate to the R-point which is the hip point of the driver. In figure B.1 the vision zones named A and B are shown for the Uniti One prototype design. The red zone is called A and the green zone is called B.

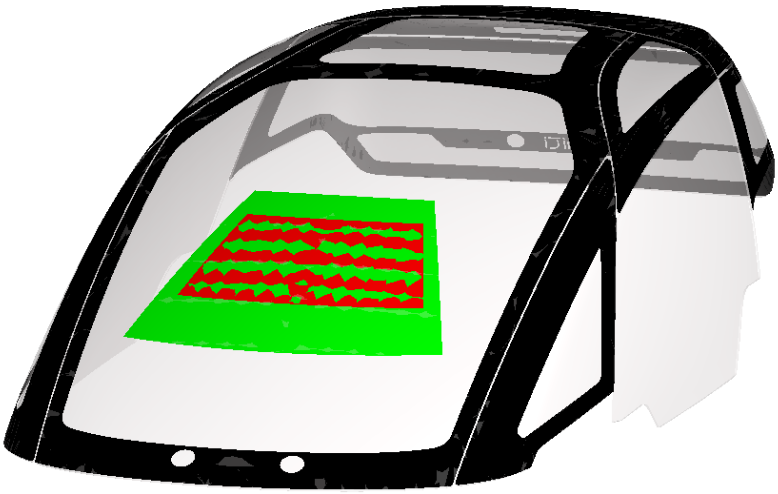

Figure B.1 - Vision zones of prototype glazing design

Both these zones are located at the very center of the windshield. There is a lot of room from the edge of the zones to the obscuration, meaning there is a good field of view.

B.5.5 Annex 24 – Installation of safety glazing on vehicles [6, pp. 198-200]

This annex explains in detail how safety glazing should be installed on vehicles. There is a lot of regulations that affect the design of the glazing and underneath follows a list of them.

B.5.5.1 Windshields

- Light transmittance in windshields cannot be less than 70 percent
- Windshields need to be type approved for L7-cars, which means M1-vehicles as stated before, except the fact that rigid plastic windows are not allowed. Also toughened windshields are not allowed
- They need to be correctly fitted in accordance to the R-point as defined in the previous annex, stating the vision zones

B.5.5.2 Safety glazing within the driver's forward field of vision, other than windshields

The forward field of vision is defined as [6, p. 8]:

> All glazing which is situated in front of a plane passing through the driver's R point and perpendicular to the longitudinal median plane of the vehicle through which the driver can view the road when driving or maneuvering the vehicle.

In this zone, these rules apply.

- Light transmittance needs to be over 70 percent
- If a plastic window is used, the material needs to pass the abrasion wheel tests described earlier in this report. The light scatter can't exceed 2 percent after 1000 cycles on the outside of the glass or 4 percent after 100 cycles on the inside.

B.5.5.3 Safety glazing within the driver's rear field of vision

The rear field of vision is defined as [6, p. 8]:

> All glazing which is situated behind a plane passing through the driver's R point and perpendicular to the longitudinal median plane of the vehicle through which the driver can view the road when driving or maneuvering the vehicle.

In this zone, these rules apply:

- Light transmittance needs to be over 70 percent, if not two exterior rear-view mirrors are mounted
- If a plastic window is used, the material needs to pass the abrasion wheel tests described earlier in this report. The light scatter can't exceed 2 percent after 1000 cycles on the outside of the glass or 4 percent after 100 cycles on the inside. If two rear view mirrors are mounted to the car, the light scatter needs to stay below 10 percent after 500 cycles on the outside of the glass.

B.5.5.4 Sunroofs

- If a plastic window is used, there is no requirements regarding abrasion resistance.

B.5.5.5 Safety glazing in other locations

- If a plastic window is used, the material needs to pass the abrasion wheel tests described earlier in this report. The light scatter can't exceed 2 percent after 1000 cycles on the outside of the glass or 4 percent after 100 cycles on the inside.

Appendix C – Interview questions

In this appendix all questions that were used during the Uniti product profile interviews are written

1. Describe the main design elements of the Uniti One glazing. Please be elaborate and pinpoint important areas (Shape, feel, looks etc).
2. Are there any “features” designed apart from the physical shape? (Tinting, in-glass heating, de-fogging, HUD, moving windows etc).
3. Plastic vs Glass as window material, do you have an opinion?
4. After seeing the prototype vehicles in physical form, is there anything you would like to change regarding the glazing?
5. Could you consider making the windshield into two parts instead of one? (This could help simplify the production, reduce weight and increase serviceability).
6. How important is it that the door windows can be opened? How much need to be opened?
7. If it were possible to make the side windows in the front as a part of the windshield, would that be favorable to the current design?
8. Do you have any other input that you have thought about regarding the glazing?

Appendix D – Concepts

Here the different canopy concepts are explained and analyzed

D.1 Concept 1 – All glass

This concept is made up of 10 individual windows. 9 made of glass and 1 out of plastic (roof spoiler). The overall weight of this concept will be roughly 33.7 kilos.

D.1.1 Design trade off

There are a few areas that will be affected if they shall be manufactured in glass. In figure D.1, these areas have been marked red. All these areas have too much curvature to be manufactured out of glass. The design will have to be flattened out, and this might not even be possible without making more splits. Also, the windshield and door windows need to be controlled for manufacturing.

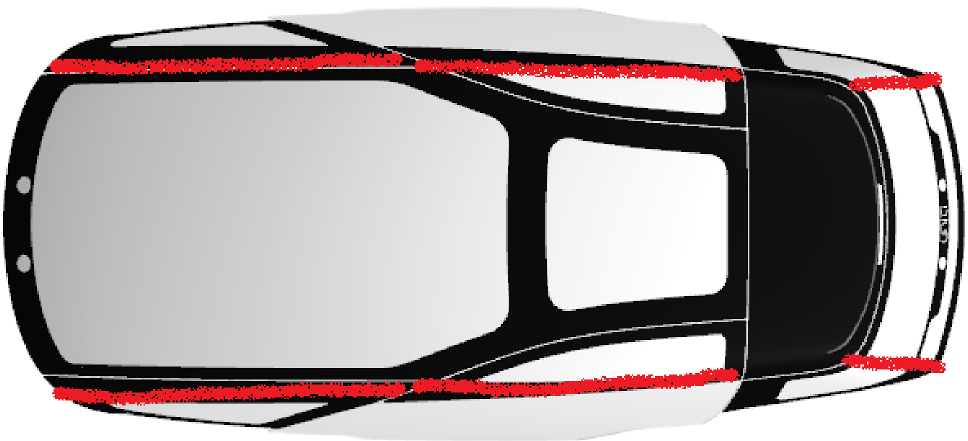

Figure D.1 – Zones which need to change shape

D.1.2 Cost

Glass is cheaper than plastic windows, which makes this the cheapest concept. All though, this is not a cheap window concept for a car. Normal cars have very flat windows which demands easy tooling and less complex manufacturing methods such as gravity bending or roll forming, which are cheaper than press bending.

D.1.3 Manufacturability

Even if the shape would be changed to allow manufacturing in glass, the double curved side windows in the front and the door roof windows will be a challenge to manufacture. The rear window is the biggest problem though. Such a deep part demands very special tooling and have limited companies which can make the part, making the supply chain constrained.

D.1.4 Durability

Glass parts have a higher durability than plastic and this is therefore the most durable concept.

D.2 Concept 2 – All plastic

This concept is made up of 10 individual windows. 9 made of plastic and 1 out of glass (windshield). The overall weight of this concept will be roughly 24.8 kilos.

D.2.1 Design trade off

This concept would have the most design freedom. Plastic windows are injection molded which means they can be shaped in very complex ways. Only the windshield would have to be controlled for production in glass but apart from that, all individual windows would be able to fit the designer's needs and are adaptable to change for whatever reason.

D.2.2 Cost

The cost for this concept would be expensive. All parts require expensive molds and coatings. As written in chapter 3, a plastic part cost about three times as much as the glass equivalent.

D.2.3 Manufacturability

The manufacturability of this concept is good. All parts are small in themselves and they are within the limitations of production.

D.2.4 Durability

The durability of this concept is questionable. Coatings for plastic parts are good but they are not as good as glass parts in scratch and wear resistance. Especially the moving door windows will be affected by this problem.

D.3 Concept 3 – Glass windshield and door windows

This concept is made up of 10 individual windows. 7 made of plastic and 3 out of glass (windshield and the two door windows). The overall weight of this concept will be roughly 28.1 kilos.

D.3.1 Design trade off

This concept follows the shape to the extent which is reasonable. The windshield needs to be made in glass for legal reasons and the door windows need to be barrel shape for sealant reasons, which then also makes them possible to be made in glass as well. Yes, there might be a design trade off on the sides of the car, but this might be worth it in the end if this increases the durability and reduces the cost slightly of the concept. The problems with the design constraints for the glass windows can be solved or at least evened out by the more adapting plastic parts in between.

D.3.2 Cost

There are still a lot of plastic parts in this concept which makes the cost high, but it is slightly cheaper than concept 2 since the door windows are made in glass instead.

D.3.3 Manufacturability

All windows in this concept should have no problem with manufacturing. The problem could be to get an easy enough shape on the door windows to use a cheap manufacturing method there.

D.3.4 Durability

This concept has good durability. All windows which are continuously having contact and wear (windshield/wipers, door windows/moving) are in glass and all static windows are in plastic. Still, the durability is probably not as good as the all glass concept.

D.4 Concept 4 – Lowest amount of parts

This concept is made up of 8 individual windows. 5 made of plastic and 3 out of glass (windshield and the two door windows). The real interesting thing is that all the windows in the rear (rear window, roof spoiler and sunroof) have been combined into one large window. The overall weight of this concept will be roughly 28.1 kilos.

D.4.1 Design trade off

This concept has the same design trade off as concept 3. The door windows and the windshield set some limitations to the shape, but the plastic windows in between are evening the shape out. The large rear window is also reducing the number of splits which makes the design look sleeker than all other concepts. The interesting thing would be to see how that affects the design though, since the split lines have been given some serious thoughts and taking them away might actually danger the design.

D.4.2 Cost

The cost of this concept is a bit tricky to give an exact opinion on. On one hand, the amount of parts has been reduced, reducing the number of tools and making the assembly easier. But the question is if that enormous injection molding tool is cheaper than the three substitutes.

D.4.3 Manufacturability

This concept is trickier to manufacture than concept 3. Even though the combined surface area for those rear parts are within the limitations of injection molding, the problem occurs with the coating. Coating of plastic parts works better on small areas and as soon as the parts get bigger, the part is harder to coat evenly.

D.4.4 Durability

In correlation with the manufacturing problems this massive rear part might have problems with durability. Also, a larger rear window part will have more problems with heat deflections compared to a split-up part.

D.5 Concept weight calculations

Table D.1: Concept weight calculations

Part	Nbr	Area (m^2)	Thickness, glass (mm)	Thickness, plastic (mm)	Mass, glass (kg)	Mass, plastic (kg)	Thickness, PVB (mm)	Mass, PVB (kg)		Density (g/cm^3)
Winshield (long)	1	1.45	4.2	-	15.225	-	0.76	1.19016	Glass	2.5
Windshield (short)	1	1.15	4.2	-	12.075	-	0.76	0.94392	PC	1.2
Sunroof	1	0.29	4.2	4.2	3.045	1.4616	0.76	0.238032	PVB	1.08
Door window	2	0.41	3.5	4	3.5875	1.968	-	-		
Side window	2	0.16	3.5	4	1.4	0.768	-	-		
Rear window	1	0.43	3.5	4	3.7625	2.064	-	-		
Door roof window	2	0.13	3.5	4	1.1375	0.624	-	-		
Roof spoiler	1	0.28	-	4	-	1.344	-	-		
	Mass, kg									
All glass	33.6585									
All plastic	24.8466									
Glass windshield and door windows	28.0856									
Lowest amount of parts	28.0856									