REDESIGN OF WINDOWS AND DOORS
OF A CONVERTIBLE CAR

Bachelor Degree Project in Product Design Engineering
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López Fernández, Antonio José
López López, Aída

Supervisor: Dan Högberg
Assistant Supervisor: Lennart Ljungberg
Company supervisor: Francisco Javier Hurtado Salas
Examiner: Erik Brolin
Assurance of own work

This project report has on August 24th of 2015 been submitted by Antonio José López Fernández and Aída López López to University of Skövde as part in obtaining credits on basic level G2E within Product Design Engineering.

We hereby confirm that for all the material included in this report which is not our own, we have reported a source and that we have not – for obtaining credits – included any material that we have earlier obtained credits within our academic studies.

Antonio José López Fernández  Aída López López
Abstract

The objective to this bachelor degree project was to redesign a structure of the doors and add windows of a convertible car. This was carried out in collaboration with the company Hurtan Desarrollos S.L.

To establish the requirements for the design, initial studies were performed: a literature review, a benchmark of related products and a study of standard car door designs. After this the final requirements were defined and the concept generation design phase was begun. In this phase a number of design methods were applied. The design concepts were systematically evaluated in respect to if, and to what degree, the concepts met the defined demands and needs of the design. The final concepts were completed with the demands of the company to obtain the results.

In order to define, create and communicate ideas and solutions, the design was modelled in Solidworks software and exported to Creo Parametric 2.0 to create the final renders. Once the overall design was defined, materials and accessories were specified. The final result is presented in detail in photorealistic renderings and a physical design made by Hurtan Desarrollos S.L.
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1. INTRODUCTION

The first chapter of the report introduces the reader into the purpose of the project; the problems that were covered with the development of this product and where the project was performed.

1.1 Organizational environment

This thesis describes a project performed in Spain for the fulfilment of a Bachelor of Science degree in Product Design Engineering at University of Skövde, Sweden. The project is carried out in collaboration with the company Hurtan Desarrollos S.L. in Granada, Spain, during the spring 2015.

The firm Hurtan is an automotive manufacturer. The company’s cars are inspired by the models of the ‘40s and ‘50s. In 1991, the plans for the first car were designed. In 1996, the company finished the first Hurtan T2, a car with Renault’s motorizations and coachwork manufactured entirely by the Hurtan Company. Juan Hurtado, the company director, obtained the approvals and permits to begin to market the new prototype in 2004. In 2009, Hurtan Grand Albaycín (Figure 1.1) is introduced, the most advanced model (Hurtan, 2014).

Figure 1.1: The newest model, Hurtan Grand Albaycín
(http://www2.diariomotor.com)
Currently, Hurtan is working in new projects to expand the market. The company is developing new improvement systems that allow producing top quality automobiles. Furthermore, an “I+D+i” (investigation, development and innovation) department was recently added, to innovate the design process and the automobile models.

1.2. Problem description

The Hurtan cars were initially designed for temperatures and dry climates like in Spain where it usually is not necessary to keep the car closed. Therefore, the current model has a simple design where priority is given to the main aspect of the product, partly renouncing to functionality. As shown in Figures 1.3 and 1.4 in Section 1.3, the Hurtan Grand Albaycín has snap fasteners to attach the plastic windows to the car. Aesthetically the snap fasteners look good for the company style, but to put on the windows is not comfortable for the user.

Nowadays, Hurtan S.L. wants to expand its market abroad since new customers are interested in the company vehicles. These customers are from countries such as Russia, Dubai or Saudi Arabia. For this purpose, it is required that the most requested model of their automobiles is redesigned, the Hurtan Grand Albaycín. Hence it is necessary to isolate the car better against rain and similar weather conditions and to enable comfort when temperatures are high or low outside the car, which is typical for markets in cold and warm regions of the world.

Accordingly, the company has decided to make a total redesign on the automobile top. It includes the folding roof, the doors and the windows of the convertible car. The folding roof needed an entire redesign. This was carried out in a previous project. For the convertible top, a new structure was created to minimize the efforts that the current top requires to be used. Finally, the doors and the widows of the convertible car were designed in this project.

1.3. Current Design

The current design of the Hurtan Grand Albaycín has several problems to be solved in this project. These issues are explained in this section.

Presently, there it is the possibility to attach two rudimentary plastic covers (see Figure 1.2), with snap fasteners (see Figure 1.3) which is not a simple operation by the car user and it cannot be done while driving. Also the car lacks glass windows, so one of the main purposes is to create a window made of glass; the limits of the window are
represented by green and blue lines and the possibility to add a small triangular glass to completely close the door drawn in orange (see Figure 1.4). Consequently, two windows with manual crank are designed during this project and those are able to go up and down.

Figure 1.2: Plastic cover window
Figure 1.3: Snap fasteners
(http://www.exoticauto.ru/auto/x/hurtan/4734h)

Figure 1.4: Door window
For the second important part of the project, as the Figure 1.5 shows, the doors have to be made bigger to offer a better access into the car. The overall style of the car should be considered and the lines of the design established by the company must be respected, but making a more comfortable car ingress/egress. The current door has two hinges and a handle which do not provide easy handling of the door (see Figure 1.6).

![Figure 1.5: Door in Hurtan Grand Albycin](http://olgado.livejournal.com/12944.html?thread=177040)

![Figure 1.6: axis of rotation of the door](http://www.exoticauto.ru/auto/x/hurtan/4734h)
In addition, some kind of solution was needed in order to keep the door steadily open due to the different angle of the frontal edge of the door than on a normal car (see Figure 1.7).

![Figure 1.7: Changes in the car door](image)

1.4. Objectives

The two main aims of this project are to:

- Add a window and its mechanism on each door with the ability to go up and down.
- To modify size and elements of the doors for better access to the automobile.

1.5. Conditions and limitations

The restraints defined at project start were:

- The mechanism that provides the up/down movement would be a manual crank. The Hurtan company established as priority to keep the car style, hence a power window with a motor would not suit this aspiration.
- In the development of the window lifter and changes of the car doors, the materials are limited to those the company currently uses.
• The final design is limited in respect to how far in the design process the project reaches. This is since the company rather requires a general design on a conceptual design solution level, and do not expect detailed designs of each part. This is because the final idea from this project then is to be introduced in the company’s own design process.

• The task of making the door larger is restricted since the available space for expansion is only some centimetres. The door can grow to the edge of the windscreen.

• The project has to be done in the software SolidWorks since Hurtan company works with this software.

• The materials and productions processes were discussed with Hurtan S.L. The materials used in the production must be readily available, easily fabricated, and of the required properties. They must also resist the oxidation by rainwater, and the corrosion by dust and corrosive agents.

• The frontal edge of the door has a different angle than on a normal car, and it must be kept in order to keep the design style of the car.

1.6. Design strategy and methodology

This project basically follows a sequence of activities described by Cross (2008) in his book “Engineering Design Methods”; the first stage is the pre-study phase (exploration) where the customer needs are identified and the requirements and expectations are studied and summarized. Benchmarking and data gathering of cars, and especially convertible cars, were done, e.g. about manual windows used in cars and car door design. The input from the pre-study are summarised in a product design specification. In the concept generation phase, based on the product design specification, different solutions were generated in form of schemes, supported by sketching and CAD modelling and the utilisation of an assortment of applicable design methods.

The generated concepts are evaluated and selected to realise possibilities and restrictions with each concept. The promising design-schemes are then further detailed. Along the project, feedback from the company and potential customers are important input in order to identify the most promising final design concept. The final stage of the design process is the communication of the final design concept to the company.

For this project, a study of different design methodologies of a product is required to achieve a successful end solution.
How the specifications are formulated in early conceptual design was explained by Claus T. Hansen (2007) in the international conference on engineering design in Paris, in which he declared that specification statement can be developed as demand, criterion or wish. It is usually before the exploration of solutions. However, the author explained during the 19 empirical studies of documents that there are two different design strategies; solve a design problem or get a solution. Also, “the designer generate specifications during the design process” trying to describe “the good product or what the product has to do”, sometimes that produces different ways to interpret a specification statement, but this ambiguity can derive into several possibilities and solutions.

To accomplish any kind of design, from a cartel design or an urban furniture to a plane engine design, since an idea emerges, with or without a previous existing need, to produce the final prototypes, it is necessary to keep an ordained trajectory of activities that achieve to position the product or process into the market in the most efficient and economical way possible. To achieve this, the designer passes a series of steps that constitute and give shape to its methodology. For this purpose, the authors integrate in the book “Metodología del diseño industrial / Industrial Design Methodology” essential techniques and procedures of design methodology (Cabello et al., 2009).

1.7. Mission statement

At the beginning of this project, once the problems that needed to be solved were identified and the communication with the company was established, a table of initial demands and wishes for the design solution was created (See Table 1). These requirements are based on the comparison with the current door and window design. This step is important in a design process as it helps to limit the problem (Cross, 2008).

Table 1. Initial requirements specification.

<table>
<thead>
<tr>
<th>Demand (D) or wish (W)</th>
<th>Requirements</th>
<th>Measurements or means</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Doors that offer good visibility and comfort</td>
<td>Add a glass window to the doors.</td>
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<td>D</td>
<td>Windows that can be removed when desired</td>
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</tr>
<tr>
<td>D</td>
<td>Hermetic closure</td>
<td>Create a good closure between the door, the glass window, the canvas of the folding roof and the surrounding element</td>
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<td></td>
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</tr>
<tr>
<td><strong>D</strong></td>
<td>Easier and more comfortable car ingress/egress</td>
<td>Make the car doors larger at relevant places.</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>Use materials and production processes established at the company</td>
<td>Aim to use materials and production processes that the company usually uses.</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Keep the door opened when desired</td>
<td>Add a solution that facilitates that the door stays open when the user desires.</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Offer easy handling of the door</td>
<td>Consider different positions and designs of handles and hinges.</td>
</tr>
</tbody>
</table>
2. PRE-STUDY

The aim of this chapter is to describe acquired knowledge for being able to redesign the car in the best way. To achieve this, a literature review, and a benchmarking study of design solutions and components of car doors were performed. Finally a target specification is established based on the results from the pre-study.

2.1. Literature review

Information was found from different sources. The literature review is focused in a general view of car design and classic cars, the necessary software, the methodology to follow and the principal materials utilized in this project.

Journals, conferences, articles and product information is a good source of information about existing products (Ulrich & Eppinger, 2008), such sources was assessed in this literature review. All this information is also part of the external research and useful for generating early ideas and concepts.

2.1.1. Overview about cars

As this work is about a specific classic car, an overview of these types of vehicles was done to understand their history and evolution through the decades, besides a study of the currently market of classic cars.

The evolution of European, American and Japanese automotive design from 370 models from 1947 to 2004 is explained in “Car design” (Tumminelli, 2004). Each decade brought different lines to cars, bigger cars, smaller, more angular, more rounded, etc. Also the design changes by country; big cars in the USA, elegant and classic in Italy, functional in Germany, the British style and the revolutionary creation of French or Japanese design.

Maria Luisa Medrano (2008) writes in “Mercado de los coches clásicos y su revalorización” (“Classic car market and its revaluation” in English), that there is a large appreciation in classic or collectible cars, those over 25 years old (Medrano, 2008). This leads to a current market value much greater than the original price, plus the cost in insurance and repairs. The car model in this project is not a classic car, but it could be included in the same market segment due to its classic car appearance, although with much cheaper price and lower maintenance cost than original cars.
“What automobiles tell us” is an article by Rogelio Rodríguez Pellicer (2012). Cars parked on the street give us information about its users or the city where they are. Beginning with the class of vehicle, we know enough about the primary user, either an all-terrain, sports, minivan, or convertible car. The care given to the car tell us if the owner values his or her car or not, from internal and external dirty to vehicle dents or scratches on the sides, or a pristine and shiny car. Also the stickers on cars provide us much information, like sticker nightclubs or baby on board, which indicate young drivers or family cars. Cars can even say the economic situation of a neighbourhood.

These literature reviews were useful for learning and understanding the design of classic cars. This is important for this project because the entire Grand Albaycín Hurtan has a complex design process to achieve the car’s styling. It is also important to know in what kind of market are these cars to understand the needs of customers.

2.1.2. Mechanisms for windows and doors in vehicles

This section of the literature review covers the study of the typical parts that make up the door and window of a car and how it works.

Concerning car windows, the article “Car side window kinematics” describes the steps to follow in constructing a curved car window, where the designer has to think in aesthetics and functionality (Gfrerrer, Lang & Harrich, 2011). In older cars, windows were planar and they moved vertically in straight lines, which is a great advantage since it is easier to design and less costly, but may decrease appearance of the car. Window lifting mechanism has to be created to minimize deflections and move the window surface in a proper way along the seals (Gfrerrer, Lang & Harrich, 2011).

In a thesis from a master student at the University of Catalonia “Technical solutions in building interior door covers”, a study of existing car doors and their materials was performed (Roca, 2013). Functionality of every piece, mechanisms and different architectures of car doors are enumerated and described. Also, a selection of appropriate material for each piece is made thanks to a previous study of its properties. All this helps to create a good design for a standard door interior for any kind of car (Roca, 2013). All this descriptions is useful to acquire the knowledge about the structure and performance of door and window cars.
2.1.3. 3D Software

Hurtan Desarrollos S.L. started working in their cars with empirical methods (trial and error). But as its market was evolving, they needed computer methods; hence the company began using Solidworks.

Solidworks is one of the most commonly used software for creating and editing 3D objects and components nowadays. Sergio Gómez (2008) shows in “El gran libro de Solidworks” (the great book of Solidworks) evolution that this software has had in time and in what has become thanks to strong growth in the industrial market and 3D design.

2.2. Benchmark competitive products

Ulrich and Eppinger (2008: 107) say that, “benchmarking is the study of existing products with functionality similar to that of the product under development or to the sub-problems on which the team is focused”. For this, it is important to find existing designs which could solve the current problems, “looking at Strengths, Weaknesses, Opportunities, and Threats”, and if it is possible, apply these solutions in this project (Hawthorne, 2015).

The benchmarking was carried out in the pre-study with different sources of information. The study of design solutions and components of car doors were performed in Section 2.4. In addition, the cars in the Automobile Museum of Málaga were the inspiration for some ideas in the concept generation (Section 2.3).

2.3. Study of classic car door and window designs

To learn more about the cars and in particular the convertibles cars, a visit to the Automobile Museum of Málaga was performed (Figure 2.1). The visit was important for this project to know the history about cars and convertible cars designs.

At the beginning of the history of cars, automobiles were constructed without rigid top, only with a canvas or even without anything. But when the car had canvas, it was more like tarpaulin, not like the current convertible cars. The same problem occurred with windows. This fact was because the first cars had not enough force in the engine
to support so much weight. In 1910, the first car with rigid roof appeared (see Appendix 1, Figure 1). Here is the important part for this project where this visit helps to study convertible cars as the Hurtan Grand Albaycín. Different convertible cars that existed over the years were shown to follow. An explanation with more details can be seen in appendix 1.

![Figure 2.1: Automobile museum of Málaga.](http://www.museoautomovilmalaga.com/)

2.4. Study of standard car door

For this project, it is valuable to understand all parts of a typical car door; therefore a deep study of each part was done.

A door is defined as all elements of the mobile piece that is attached by hinges to the body and allows ingress/egress of people and/or objects in the vehicle. When the door is closed, this has to ensure complete water-air tightness and prevent excessive noise when the car is travelling at high speeds and the air interacts with doors (Parts Train, 2015).

The door is a fundamental part of any vehicle with respect to the exterior and interior design of it, because, it represents a significant percentage of both outer surface and interior of the vehicle. It is a piece that has to ensure the safety of occupants from a side impact. In addition a good design has to take into account the comfort of the users (Roca, 2013).

Due to its complexity, for the development, the door is usually divided into three distinct parts: outer cover, mechanisms and inside cover (door panel).
2.4.1. External cover

The external cover is the exterior of the door, as David Roca shows in *Exploded view external cover of car door* (Roca, 2013, p. 13) (see Figure 2.2), usually made entirely of steel and is composed of the outermost zone (sheet metal) and the inner zone (frame).

![Exploded view external cover of car door](Roca, 2013, p. 13)

- Internal frame: is the innermost part of the frame. Where some mobile elements are joined in the architecture of door DTM (Door Trim Module) (explained in Section 2.4.3.)

- Waist reinforcement: consists of two parts (exterior and interior) and serves to provide rigidity to the waist area. This rigidity is necessary, firstly, to ensure the safety of the occupant in case of a side impact and, secondly, to guarantee no deformation and the space necessary for the glass to be raised and lowered without any friction or interference with the bodywork.

- Frame-waist reinforcement: This is the piece that gives consistency to the area of the door frame. It is the area with less mass and therefore weaker.
- Rear mirror reinforcement: is the part responsible for giving consistency to the junction of the door mirror.

- Protection bar: This is the main piece that ensures no intrusion of any external element inside the passenger compartment in a lateral collision. It is a piece of steel welded to the inner frame.

- Hinges: These two parts have to support the full weight of the door when it is open, and allows the opening and closing movement.

- Guide: This is a piece that has two main functions: to guide the glass in its up and down movement, and to prevent excessive vibration of the glass in case of closing the door with the window completely lowered.

- External cover: is the outermost part of the door. Its main function is to cover the interior pieces with an attractive design to the user. Its design has to achieve good aerodynamic performance. Also it has to avoid noise when the vehicle is moving at high speed.

2.4.2. Mechanisms

This area of the door includes both mechanisms as well as sealing elements, covers, cables, etc., which are situated between the external cover or even outside of the sheet such as the mirror. Shown in Figure 2.3, the Exploded view window mechanisms of car door (Roca, 2013, p. 14).
- **Window**: It is the piece of glass covering the window area bounded by the rubber sweeps and window guide.

- **Window guide**: It guides the up / down movement of the glass. This provides an airtight seal in order to avoid entry of water in the carrier. It is a rubber element with aluminium grafts that confers rigidity to the piece.

- **Weatherstrip**: The part fixed to the outer sheath prevents as far as possible the entry of moisture and dust into the door (dry zone). In addition, it is to acoustically isolate the interior and restrict vibration of the glass.

- **Rubber sweeps**: assembled between the external cover and glass, whose main function is to prevent the ingress of water and dirt from the outside into the wet area of the door. It also restricts the vibration of the glass.

- **Foams**: are placed in areas where noise is generated due to wind flow when the car is moving. They are also used to cushion the collisions between parts caused by vibration.

- **Window regulator (mechanism)**: This is the set pieces that make possible the up / down movement of the glass pressing a button or using a manual crank. The mechanical part consists of four main parts (see Figure 2.4):
- Window regulator guides: are the rails that hold the glass to move it.
- Regulator carriage: they are clipped on the two lower holes of the glass and also attached to the Bowden cables.
- Bowden cables. Responsible for transmitting the force of the electric motor or manual crank to the regulator carriage. They are made of steel with a polymer coating (EHow En Español, 2015).
- Electric motor: powered by the car battery, provides the necessary strength to raise and lower the glass. A different option is a crank with which the movement is provided manually as the Figure 2.5 shown (Automotriz, 2015).

Figure 2.4: *Window regulator.*
(Roca, 2013, p. 16)

Figure 2.5: *Manual crank*
(http://www.debriefdaily.com/lifestyle/born-in-the-60s-will-understand/)
2.4.3. Architecture of the door

The architecture of the door is explained by David Roca (2013) as the way in which the three main parts interact (outer cover, mechanisms and inside cover). On the one hand there are different ways of setting the moving parts inside the door and on the other hand, it is possible to create watertight areas or watertight parts themselves. The four images below “Old architecture view”, “Exploded view of conventional architecture”, “Exploded view of AGT door architecture” and “Exploded view of DTM door architecture” show the different possibilities of architecture of a door (Roca, 2013, p. 22-26).

In the inside of the door are two areas: dry / watertight area and wet / unsealed area (Figure 2.6). All electrical devices and their cables must remain in the dry zone for proper operation.

![Diagram of door sections](image)

**Figure 2.6: Door section view.**
(Roca, 2013, p. 22)

**Old architecture**

The mechanisms of the wet zone are fixed to the door frame, and those of the dry zone to the door panel. Between them, a watertight sheet isolates both areas and only the necessary elements pass through this sheet, such as the crank shaft or the cable that open the door lock (Figure 2.7).
Conventional architecture

Elements that can stand in wet condition are introduced into the metal sheet through a gap and attached to the internal frame. Subsequently, this gap is sealed with a cover. In the panel (dry zone), the components do not have any cover to protect them from moisture (see Figure 2.8).
Figure 2.8: *Exploded view of conventional architecture.*
(Roca, 2013, p. 24)
AGT architecture

In an AGT architecture, the inner mechanisms are fixed to the watertight sheet (Figure 2.9). This sheet is attached to the exterior frame door to ensure isolation from outside. In addition, the external elements are also fixed on the sheet that will be in the wet zone. “AGT architecture” or “mechanisms subsets architecture” is a hybrid between old and conventional architectures.

Figure 2.9: Exploded view of AGT door architecture.
(Roca, 2013, p. 25)
DTM architecture (Door Trim Module)

In the DTM architecture there is no seal between the outer metal sheet and the inner cover of the door. The cover (panel door) itself has to seal the interior of the car from the wet zone. Each element that normally needs to be in the dry zone must have its own cover to isolate from moisture. Also, the internal cover needs watertight seals to avoid transferring moisture into the passenger compartment (see Figure 2.10).

Figure 2.10: Exploded view of DTM door architecture.
(Roca, 2013, p. 26)
2.5. Function Analysis

Two function trees were made to describe the current door in terms of function (see Figure 2.11.). The functions and sub-functions of the door were studied and ordered into sets of higher-level and lower-level functions. Also they were grouped into hierarchical levels (Cross, 2008).

![Function trees](image)

This step helps to understand the current solution in order to increase the chance to obtain a solution that still contain the good things of the present door and window while solving the current problems and adding future requirements. The function trees were created to better study each element function and divide it into sub-functions, showing hierarchical relationships and interconnections (Cross, 2008).

2.6. Target specification

Once the problem was identified and the initial specifications were defined (see Table 1), some conclusions were clarified regarding the mechanism solutions. Then, as Ulrich and Eppinger (2008) say, the specifications should be revised. Specifications which originally were only principal problems of the current door and window are now
refined and made more precise. The product concept should meet the company and users needs.

Taking into account the pre-study and remembering the initial requirements established, a final requirement specification table was made. This was carried out in collaboration with the company. The final requirements are listed by demand (D) or wish (W) (see Table 2)

Table 2. Target specification.

<table>
<thead>
<tr>
<th>Demand (D) or wish (W)</th>
<th>Requirements</th>
<th>Measurements or means</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Doors that offer good visibility and comfort</td>
<td>Add a window on the door.</td>
</tr>
<tr>
<td>D</td>
<td>Windows that can be removed when desired</td>
<td>Add a crank based mechanism to the door to manually move the window up and down.</td>
</tr>
<tr>
<td>D</td>
<td>Avoid glass window vibration</td>
<td>Prevent excessive vibration of the glass in case of closing the door with the window completely lowered.</td>
</tr>
<tr>
<td>D</td>
<td>Hermetic closure</td>
<td>Create a good closure between the door, the glass window, the canvas of the folding roof and the surrounding element of the car body.</td>
</tr>
<tr>
<td>D</td>
<td>Easier and more comfortable car ingress/egress</td>
<td>Make the car doors larger at relevant places.</td>
</tr>
<tr>
<td>D</td>
<td>Clean the water on the window surface</td>
<td>Possibility to add rubbers on the edge of the door that sweep the water and dust out of the door interior.</td>
</tr>
<tr>
<td>D</td>
<td>Keep the door opened when desired</td>
<td>A mechanism would be created to keep the door opened.</td>
</tr>
<tr>
<td>D</td>
<td>Use corrosion resistant elements</td>
<td>Create a dry area for mechanism or elements with its own cover to isolate from moisture.</td>
</tr>
<tr>
<td>D</td>
<td>Keep protection and safety</td>
<td>To not compromise or modify door safety with the window changes.</td>
</tr>
<tr>
<td>D</td>
<td>Offer easy handling of the door</td>
<td>Consider different positions and designs of handles and hinges.</td>
</tr>
<tr>
<td>W</td>
<td>Good aesthetics</td>
<td>Create a design that keeps the current car style.</td>
</tr>
<tr>
<td>W</td>
<td>Use materials and production processes established at the company</td>
<td>Aim to use materials and production processes that the company usually uses.</td>
</tr>
<tr>
<td>W</td>
<td>Use recyclable materials</td>
<td>Aim to use recyclable materials as much as possible.</td>
</tr>
<tr>
<td>W</td>
<td>Ease of assembly (during manufacture)</td>
<td>Aim to use a design with a good assembly in the manufacture process.</td>
</tr>
<tr>
<td>W</td>
<td>Easy up/down glass movement</td>
<td>Window regulator guides should facilitate the effort.</td>
</tr>
</tbody>
</table>
3. CONCEPT GENERATION

This chapter details the methods followed by a section describing how to obtain the generation of concepts. For the development of the ideas, many methods are used to find an appropriate design; therefore, it is divided into different stages. In the first steps, the procedure consisted in just originating ideas; when those ideas had been clarified, the concept selection phase started.

All the information gathered in the pre-study section was taken into account for the concept development. This will be shown in the following sections.

3.1. Early ideas

This first stage was where the early ideas were generated. Accordingly to Ulrich and Eppinger (2008), the methods used to create new concepts were those that stimulate new ideas and support relationships among them. Thus, methods such as Why? Why? Why?, Benchmarking and Search published literature helped to find good suggestions.


Refine the definition of the design problem using the Whys methodology, by asking the same question repeatedly, from most specific to most general cause of the problem. This help to consider alternative definitions of the design problem and see different solutions (Cross, 2008). This method was used to understand the product and its problems. Also, the Whys method is a good source of inspiration to open the mind for accepting different solutions.

3.2. Concept Classification Tree, decomposing by user needs

Due to the large number of elements to modify in this project, the way forward should be different from, for example, the design of a complete product with a known primary need. Therefore, the method of classification tree concept was chosen to be able to split the problem into several points and to have different approaches of each one.
The concept classification tree (Ulrich & Eppinger, 2008) was the method used in the concept generation. Besides this method, the approach showed in the course “Design and Artifacts” of the University of Pennsylvania conducted by Karl T. Ulrich, “Decomposing by Key/User Needs” was also introduced into this method (Ulrich, 2011). This was carried out because to use the user needs was the best starting point for dividing the overall problem.

Both views were mixed and conducted for this project. In these methods, the main purpose is to divide and compare the different options for the solution of the problem using the needs of the users and the company. As Ulrich and Eppinger (2008) say “rarely do teams generate only one classification tree and one concept combination table. More typically the team will create several alternative classification trees and several concept combination tables”.

1- Dividing the problem into different branches, the team is able to focus its attention on the most interesting branches of the tree for this thesis.
2- “Identify the independent approach to the problem” (Ulrich, 2008). To solve the entire problem, each branch of the tree is a different way of approaching. Some branches complement each other, and other branches may be independent to them.
3- Avoid improper emphasis. Branches that need a great effort are shortly studied, and others that are simpler, the group spend more effort to carry out them. For example, the window regulator requires intense study, but to extend the door does not need it because this is imposed by the company.
Two different concept classification trees were generated based on user needs decomposition (Ulrich & Eppinger, 2008), window and better ingress/egress or door (see Figure 3.1). Each one of them is divided at the same time into sub-problems which facilitate comparison.
3.2.1. Window

The first concept classification tree based on the car window was divided into three branches; window lifter, window and manual crank (see Figure 3.2). Although, the manual crank was established by the company, four ideas for the window lifter and three ideas for the glass were studied.

![Window concept classification tree](Figure 3.2: Window concept classification tree)
• **Window lifter**

The gear design is based on the design of classic cars, consisting of a crank that thanks to gears which convert the rotation into an up/down movement of the glass, supported by two lateral guides (Figure 3.3).

![Figure 3.3: Gear design](image)

The next design was called scissor gear. This idea is based on the same principle as above, but adding an extra bar that adds stability to the assembly during movement of the window. This design was widely used in classic cars (Figure 3.4).

![Figure 3.4: Scissors gear](image)

The following two mechanisms basically works equal, both of them containing Bowden cables (explanation in Section 2.4.2) for movement up and down of the glass window. In the first design the Bowden cable passes through a rail joined to the glass and it
moves the window up and down (Figure 3.5). The second design consists of two parallel rails, with Bowden cable inside, attached to the glass (Figure 3.6)
- Glass

The first kind of glass is a full window; aesthetically very simple and needs less elements (Figure 3.7). Other option is glass with a triangle window, typical in the current cars (Figure 3.8). The last option is a window with chrome frame; this glass has a style of some classic cars (Figure 3.9).

Figure 3.7: Full window

Figure 3.8: Glass + Triangle window

Figure 3.9: Chrome frame
3.2.2. Door

Accordingly to the second concept classification tree, the door generated three branches; larger door, door stays and hinges (Figure 3.10).

![Door concept classification tree](image)

- **Larger Door**

  The size of the door must be larger than currently, the door extends to the windscreen edge (see Figure 3.11). The final dimensions are imposed by the company, as it is explained in Section 1.3., conditions and limitations.
• **Door stay**

One of the door stays is that used in current cars. This design has been fully tested in cars nowadays, but its biggest defect is when the door is opened it is not very aesthetic (Figure 3.12).

Figure 3.11: *Door extended to the windscreen edge*

Figure 3.12: *Door stay used in current cars*
The second option of door stay is that the company currently uses in other car models. Aesthetically the door stay has a classic style and it does not need to create a space on the door and the body car for the installation (Figure 3.13).

![Figure 3.13: Company door stay](image)

- **Hinges**

  The hinges used in current cars. The positive point of this model of hinges is that every part keeps inside the door when it is closed (Figure 3.14) However, the main problem of this design is that need a space in the door to allow its installation, this would mean a major change in the design and manufacture door.
Secondly, the hinges that company uses are more aesthetic when the door is opened, because they do not need a space to installation. When the door is closed the hinges can be seen on the edge of the door (Figure 3.15).
3.3. External decision

Such as Ulrich and Eppinger (2011) said in their book, different methods are necessary to choose the correct design, in this occasion the external decision method was carried out with the company.

The different proposals were presented to the company. It was performed in several stages; firstly, the ideas from the concept classification tree were showed individually and the advantages and disadvantages were discussed. In this stage, Hurtan decided about some solutions, for example, in the “Window Lifter” branches, “Gear design” was rejected due to its simplicity. The company decided this design would have stability problems with the up / down movement. After that, the concept combination table was generated with the company preferences about the different combinations.

3.4. Concept Combination Table

The concept combination table, based on the following method of Concept combination tree, was the process used to create the ideas that become the final design. Here the results of the different branches of the trees are combined to obtain possible solutions.

3.4.1. Window combinations

Some of the possible combinations are showed in Figure 3.16. These combinations are between the window lifter and glass. At this point the gear design of the window lifter was rejected due to its simplicity. All of the combinations have not been done, but later in the concept selection it was carried out to know which the best combination for Hurtan Grand Albaycin is.
Three main combined design were the result of the Concept Combination Table; “Double Bowden cable and chrome frame” (Figure 3.17), “Single Bowden cable and triangle window” (Figure 3.18) and “Scissor gear and full window” (Figure 3.19)
• Double Bowden cable + chrome frame

![Double Bowden cable + chrome frame](image)

Figure 3.17: *Double Bowden cable + chrome frame*

• Scissor gear and Full window

![Scissor gear and Full window](image)

Figure 3.18: *Scissor gear + Full window*
• Single Bowden cable and triangle window

![Image: Single Bowden cable + triangle window]

Figure 3.19: Single Bowden cable + triangle window

3.4.2. Door combinations

The second concept combination table is based on the three branches of the “door tree”. This generates two different ways or ideas combining the solutions from each branch (Figure 3.20).

![Diagram: Door concept combination table]

Figure 3.20: Door concept combination table
Below, the Figures 3.21, 3.22 and 3.23 show the combinations with the hinges and door stays, and how they look aesthetically. Also, it is possible to see in both concepts the door extended to the windscreen.

The two different designs combine firstly the two company designs (see Figures 3.21 & 3.22), and secondly the hinges and door stays used in most of today vehicles (see Figure 3.23).

- **Company hinges and door stay**

![Figure 3.21: Hinges and door stay of company](image1)

![Figure 3.22: Door extended to the windscreen edge with company hinges](image2)
- Hinges and door stay used in current cars

Figure 3.23: Hinges and door stay used in current cars
4. CONCEPT SELECTION

To carry out the final selection, different methods were used which provided the way forward. As the previous concepts were not a completely perfect design, the work had to carry on with a final development to create a design that met the requirements.

4.1. Positive, Negative and Interesting. Concept comparison

When comparing the main concepts, their pros and cons were listed in a table (Tables 3 and 4). These tables classify the positive, interesting and negative (PNI) characteristics of each concepts (Hildebolt, 2010). The table was filled with the user need. The table was filled in a discussion during a study visit with Hurtan Desarrollos. The pros and cons of each design were decided and what would fit better in the design process of the company.

This was done to better realise possibilities and restrictions with each concept (Ulrich & Eppinger, 2008). This comparison was performed using the distinction obtained in the Concept classification tree, “Better access to the car or Door” and “Window”.

*Table 3. Car Window; Positive, interesting and negative for each concept.*

<table>
<thead>
<tr>
<th>Concept: Double Bowden cables and chrome frame (Figure 3.17)</th>
<th>Pros:</th>
<th>Cons:</th>
<th>Interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• The chrome frame helps to create a good closure between the window and the canvas of the folding top.</td>
<td>• The assembly is more complex because of the frame.</td>
<td>• The window frame shares the same aesthetic of some classic cars.</td>
</tr>
<tr>
<td></td>
<td>• Fluid movement when using.</td>
<td>• The chrome frame could be problematic in the up / down movement damaging the weather-strips between the window and the door edge.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increased stability of glass in the up / down movement thanks to the two guides.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 4. Car Door; Positive, interesting and negative for each concept.

<table>
<thead>
<tr>
<th>Concept: Company hinges and door stay (Figure 3.22)</th>
<th>Pros:</th>
<th>Cons:</th>
<th>Interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• When the door is opened, the hinges and the door stay are very aesthetic, because there is not a hole in the door and body of the car.</td>
<td>• Externally the hinges can see.</td>
<td>• When the door is opened or closed the aesthetic of the hinges and door stay is classic automobile style.</td>
</tr>
<tr>
<td></td>
<td>• High functionality to keep the door open.</td>
<td>• Having the hinges off, these create a hole through which moisture and dust could enter.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Good aesthetic as it is a piece chrome.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concept: Hinges and door stay used in current cars (Figure 3.23)</th>
<th>Pros:</th>
<th>Cons:</th>
<th>Interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Great functionality when holding the door open.</td>
<td>• Assembly more complex.</td>
<td>• Externally the door is very aesthetic, since the hinge is not visible.</td>
</tr>
<tr>
<td></td>
<td>• Ease of obtaining on the market.</td>
<td>• Need to create a hole in the door and body of the car for its installation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• When the door is open it is ugly aesthetically, because the hole in the door and body of the car.</td>
<td></td>
</tr>
</tbody>
</table>
The table provided a better overview of each concept and helped to choose the best design. The further development was performed following the ideas which were deduced from these strengths and weaknesses.

4.2. Evaluation of the most important concepts

The approach of the next stage consisted in the concept screening method. Ulrich and Eppinger (2008) describe this method as the process “to narrow the number of concepts quickly and to improve the concepts”.

To evaluate the concepts, the inputs (concepts and criteria) are entered on a matrix within which, the ideas created in the concept generation are rated against the reference concept (the current window and door utilized by the company) using the score of “better than reference” (+), “same as reference” (0), or “worse than reference” (-).

The selection criteria is based on the wishes of the final requirements established in the Table 2 (Section 2.6) and then evaluate according to what degree the concepts meet these wishes. The following points and the results were discussed together with the company and what concepts to go forward with were decided.

Table 4. Car Door. Concept screening.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>A</th>
<th>B</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company hinges and door stay (Figure 3.22)</td>
<td>0</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Ease of assembly (during manufacture)</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Ease of car ingress/egress</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Isolate against weather events</td>
<td>0</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Use materials established at the company</td>
<td>+</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Use recyclable materials</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Good aesthetic</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Sum +’s</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Sum 0’s</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Sum -’s</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Net Score</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Continue?</td>
<td>YES</td>
<td>NO</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5. Car Door. Concept screening.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Concepts</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scissor gear + full window (Figure 3.18)</td>
<td>Single Bowden cable with triangular glass (Figure 3.19)</td>
<td>Double Bowden cable + chrome frame (Figure 3.17)</td>
<td>(Reference) Current window</td>
<td></td>
</tr>
<tr>
<td>Ease of assembly (during manufacture)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Use recyclable materials</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Avoid window vibration</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Ease up/down movement</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Corrosion resistant elements</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Windows offer good visibility and comfort</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Good aesthetic</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sum +’s</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sum 0’s</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Sum -’s</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Net Score</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Continue?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The concepts were ranked subtracting the number of “worse than” ratings from the “better than” ratings. Once that was done, the concepts with more pluses and fewer minuses were ranked higher. As Ulrich and Eppinger (2008) say, some good concepts may be impaired by one bad feature. This happened on the “Double Bowden cable + chrome frame” where the design met most of the requirements, but the chrome frame is not fully supported by the company. Because the designs of the window partially meet the wishes of the requirements, they were discussed with the company and decide what features were part of the final design.

In a study visit to the company, in the design of the door, Hurtan decided that the idea that met the requirements of Hurtan and its customers was which has the components already used by the company. This is mostly due to its best aesthetics and its good ability to change the layout using the materials already available from the usual suppliers.
On the other hand, the concept screening method was not left entirely clear what design is above others. They showed some particular deficiencies of the concepts. These defects are shared by the opinion of the company, so the final decision was to choose some specific characteristics of each idea and create a final design combining them. This is explained in the following section.
5. Results

After having analysed all the concepts, the best features were chosen and improved to achieve the results. The company supervisor selected the definitive idea, therefore, the final concept was developed in Solidworks and Creo Parametric 2.0 to show the door and window in a real environment, since the model of the car body was provided in 3D CAD by the company.

5.1. Final design

The final design can be seen in the Figure 5.1. As it is possible to see in this picture, at the door, the position of the hinges and handles were changed. This causes that hinges are in an edge of the door that is not 90° with the ground, this was because the lines of the car must be kept.

Figure 5.1: Final door and window design on the Hurtan Grand Albaycin
In the Figures 5.2, 5.3 and 5.4 can be seen the window movement. This solution would be able to use a system with Bowden cables or the scissor window lifter, this is explained in more detail in Section 5.3, Materials. In addition, the folding roof frame has rubber profiles that prevent entry of water and dust into the car.

Figure 5.2: Window movement, 1

Figure 5.3: Window movement, 2
Finally, the chrome moulding was rejected and the window was designed with a clean edge (see Figure 5.5 & 5.6). The car would be protected against weather events thanks to the windows.
5.2. Prototype

During this project, Hurtan Development was developing a new prototype / functional model Hurtan Grand Albaycín. This development has the ideas studied in this project such as reposition the hinges and handle, maintain the angle of the door and install a door stay. Thanks to this, the viability of the new design could be affirmed. The prototype is done to improve the product and reduce future costs of manufacturing.

These requirements were part of a specific order from a customer. This was concerned that the door should stay opened when desired. In the Figure 5.7 the changes can be seen in the car studied in this project.

Figure 5.6: New windows and doors on the Hurtan Grand Albaycin without the folding roof.
Figure 5.7: New windows and doors on the Hurtan Grand Albaycin without folding roof.

Reposition the hinges to achieve a shift to the conventional direction in the cars doors. As shown in Figures 5.8 and 5.9, the door would open with a different angle than previous achieved.

Figure 5.8: Doors opened with a different angle.
Figure 5.9: *Doors opened with a different angle.*

The hinges and door stays utilized were which the company provides and used in other models of their cars (see Figure 5.10). These hinges would finally be visible on the outside of the door (see Figure 5.11). The door stays have a good exterior design with the style of classic car Grand Albaycín preserved.
The next step would be to create a larger door to introduce the window lifter and the window studied in this project.

Figure 5.11: Hurta Grand Albaycín.
5.2. Materials and unions

The materials utilised in this product were decided among the preferences specified by Hurtan Desarrollos S. L.

First of all, to decide the materials, the product had to be analysed during the whole process; what functions are performed, who is going to use it, how the mechanical parts work and interact, etc. The system has to be broken down into individual components and then analysed each one (Marchment, 2014).

The elements and materials that form the door are explained and showed below. The components that fits the design are provided from suppliers used before by Hurtan, besides new suppliers for new elements needed for this project.

5.2.1 Hinges, handles, door stay and crank

The company responsible of providing the hinges, door handles and stays is Cambridge motor sport. These parts are easy to assemble and meet the style model, thus maintaining the materials previously used by Hurtan.

**Exterior handle lock**

The handle lock selected is part of the components of Austin Rover Mini (1960) provided by the company Cambridge Motor Sport. The elements of the handle are chromed, they have a seal to keep out the moisture from the door and a key to keep the car locked (see Figure 5.12).

![Exterior handle lock](http://www.cambridgemotorsport.es/categoria.aspx?cat=351)

Figure 5.12: *Exterior handle lock.*
Hinges and Door stays

The hinges and door stays are that the company usually uses, also provided by Cambridge Motor Sport company (Figure 5.13).

![Hinges and door stay.](http://www.exoticauto.ru/auto/x/hurtan/4734h)

**Figure 5.13: Hinges and door stay.**

Manual Crank

The Cambridge Motor Sport company also sells manual cranks with the same classic style, thus they also provided the crank for this project (see Figure 5.14). This crank model is used in the classic car Morris Minor (1948).


**Figure 5.14: Manual crank.**

(see Figure 5.14). This crank model is used in the classic car Morris Minor (1948).
5.2.2. Window lifter

Finally, for this project, window door mechanisms (ready-made) were searched from suppliers since that was a cost effective solution.

**Scissor model**

Although it is an older design, this is still even used in modern cars like Mercedes or BMW (Figure 5.15).

![Figure 5.15: Scissor window lifter.](http://www.usa.vdo.com/generator/www/us/en/vdo/main/products_solutions/automotive/ replacement_parts/door_systems/power_windows_systems/power_windows_system_en.html)

Continental is one of the world’s leading automotive suppliers. This supplier provides different types of scissor window lifter, for a window lift manually, and another that has a motor to be used automatically by connecting it to the vehicle power (VDO, 2015). This has been made thinking on the likely future design of the door with power windows.

**Window lifter with Bowden cables**

This type of window regulator has also been studied because of its functionality (see Figure 5.16). Both solutions fit in this thesis, thus a supplier for this element was searched. Grupo Antolin is a Spanish manufacturer of vehicle interior component. This supplier offer “different window regulators of any morphology as another component
of the Door Function, meeting all requirements as to quality, cost, weight and simple assembly on the client’s own chain” (Grupo Antolin, 2015).

Figure 5.16: Window lifter with bowden cables. (http://www.grupoantolin.com/en/window-regulators)

These windows can be made of plastic, aluminium, steel or in case of doors without frame, magnesium.

5.2.3. Door Panels

The door is manufactured with laminated composite moulds. The outside and interior panel are made separately and they are later stuck together with an adhesive.

The composite is made of fiberglass, in which the glass fibers (strong but brittle) are embedded with a matrix of plastic material (ductile and flexible) that holds the fibres together and protects them. Composites offer a good combination of light weight and strength and the possibility of being moulded into complex shapes (The Royal Society of Chemistry, 2015).

In addition, the outer panel is covered on the inside by a bitumen layer to isolate the car inside from noises.
At the beginning of the design process, it was necessary knowing the problem of current design to understand the requirements that the company demanded.

The literature study was one of the main problems from the beginning of this thesis. To find related information was quite difficult since the product is part of an old style car, the market to which it belongs was very outdated.

The work in the Section study of a standard car door was very useful in this project for understanding the performance, materials and components of a car door. As well as the function analysis was very helpful to establish the initial project specifications.

The project had to be done in the software SolidWorks since Hurtan company works with this software. This is the reason why this program had to be learned by the group members. It took some time that would have been spent on the implementation of the report.

As the project progressed, the solution space seemed to be more limited. The position of the handle and hinges had been decided, besides the size that could reach the door. Perhaps the biggest contribution of the work was in choosing and proposing ideas within the window and its mechanisms.

Several methods were used for the development of the concept generation: benchmarking, why? why? why? and concept classification tree using decomposing by user needs. After these methods several concepts were selected among some ideas thanks to the Concept combination table. Perhaps, more ideas could have been generated applying different and more methods, but the lack of time due to first stages of the project caused a more direct search of concepts. On the Concept selection, the PNI (positive, negative and interesting) method was very useful for the evaluation of the possible solutions. Of equal importance, some ideas were dismissed thanks to the Concept screening, and the external decision carried out by the company.

Several options were offered to Hurtan, like the handles and hinges, but finally they decided to opt for the previous design already using. The second external decision was the key for choosing the final design which would be carried out along this project.
The final stage of the design process is the realization of the final design concept. This is not strictly in this thesis due to the final choices will be taken into the companies own design process before the manufacturing because of factors outside the control of this project.

To sum up, the evolution of the car door design has been conducted thanks to the application of the different methods, and the joined efforts from the company Hurtan Desarrollos S. L., the work group and the University of Skövde.
REFERENCES


APPENDIX 1: Visit to the Automobile Museum of Málaga

In the firstly cars, the top was like a tarpaulin which does not always cover the whole car, sometimes only the passengers and not the driver. Therefore, cars do not have any kind of lateral windows, and sometimes, they do not even have windscreen (see Figures 1, 2 & 3). As time progressed, the car designs were more complex. The tarpaulin covered whole car. This caused that the first cars with windows appear.

Figure 1: Delage France 1912
4cil. 12 HP

Figure 2: Charron France 1902.
4cil. 28 HP

Figure 3: MINERVA Belgium 1916 6cil. 26 HP
In 1929, the car “Ballot” was the first model equipped with the Baerth patent called “convertible body”. The windows can be stored inside the door with a hinge movement while the car becomes fully convertible (see Figure 4).

Figure 4: BALLOT France 1929 6cil. 11 HP

From that moment on, the car companies began to construct automobiles for costumers of the domestic market. Popular cars were produced with smaller dimensions (see Figures 5 & 6). However, these automobiles still lacks of windows and only luxury cars started having manual windows but exclusively for travellers, like the Minerva model created in Belgium (see Figure 7).

Figure 5: MORRIS MINOR England 1929
4 cil. 847 cc

Figure 6: AUSTIN SEVEN England 1930
4 cil. 13 HP 747 cc
The Packard was the White House car in EEUU. This very long automobile had four doors with a manual window each one. That makes a distinctive car where the windows are driven by a crank, and the front doors have a rectangular trapezoid glass that holds the window when it goes up (see Figure 8).

In addition, it is possible to see the first models with weather-strips placed on the exterior edge of the door but not in the interior (see Figure 9).

On the other hand, the 327 BMW was ahead of its time with designs very original. This car possesses a frame in the structure of the top for the windows, a rubber profile that

Figure 7: MINERVA Belgium 6 cil. 120 HP

Figure 8: PACKARD EEUU 1939 V12 7,2 lt.

Figure 9: PACKARD EEUU 1939 V12 7,2 lt.
helps to close the window with the folding top. Furthermore, as all the previous car models, the windows have a chrome frame in order to ensure maximum stability to the glass (see Figure 10).

Figure 10: 327 BMW Germany 1938 6 cil. 80 HP. Model 327/328

Another car in the museum with similar features to Grand Albaycín that attracted attention is the 1936 Auburn. This happened because the canvas and the windows is almost the same design in these two cars, since the window is a plastic cover that is attached to the chassis with snap fasteners (see Figure 11).
Figure 11: AUBURN EEUU 1936 8 cil. With compressor supercharged.

In the ‘50s and ‘60s, a new minimalist design appeared, window with no frame (see Figure 12). This could be possible thank to new lifting mechanism designs. Rubber profiles were also place in the edge inside the door in order to keep the car better closed against outside weather conditions, as the Citroën DS 1963 (see Figure 13).

Figure 12: JAGUAR England 1966 6 cil. 3,8 cc 265 cv-hp. Model E Type

Figure 13: CITROËN DS France 1963 4 cil. 102 HP