

MASTER IN PRODUCT AND INDUSTRIAL DESIGN

Carro Adaptativo (Adaptive Car)

Matheus Borges Dias

M

2019



MESTRADO EM DESIGN INDUSTRIAL E DE PRODUTO
UNIVERSIDADE DO PORTO

O JÚRI

PRESIDENTE

Doutor Rui Mendonça

PROFESSOR AUXILIAR DA FACULDADE DE BELAS ARTES DA UNIVERSIDADE DO PORTO

ORIENTADOR

Doutor António Torres Marques

PROFESSOR CATEDRÁTICO DA FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

ARGUENTE

Doutor Luís Norberto Miranda Torres

PROFESSOR ADJUNTO DO INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
POLITÉCNICO DO PORTO.

I 3

28 JUNHO 2019

MESTRE Matheus Dias
MDIP/66



University of Porto

Adaptive Cars

Matheus Borges Dias

Master Thesis in Product and Industrial Design

Supervisor at FEUP: Prof. António Torres Marques
Co Supervisor at FEUP: Prof. Fernando Jorge Lino Alves
2019

For all those technically or emotionally involved with this thesis

Abstract

Thanks to the advances in battery technologies, electric cars are now a reality. This project intends to present a car that is better adapted for the personal transportation in the big cities.

The project will develop a whole process of designing a vehicle, starting with the background analysis passing through the characterization of problems faced by the current vehicles and selecting a methodology for approaching the solution.

After these initial steps, a survey and consequent analysis will be made. This survey is important in order to better understand the possible future costumers of this product. Done the user analysis, some criteria will be put in evidence as the features and characteristics that are mandatory for the success of the project.

With these criteria in mind, the basic shape of the car will be designed. With the shape of the vehicle, the forces involved in the movement of the vehicle will be calculated and, with that, the quantity of batteries needed for the vehicle. After that, the adaptive solutions will be presented. At the end, a feasibility analysis of the project will be done.

It is possible to conclude with this project that it is very feasible to produce a small car that fulfils most of the people needs for the personal transportation at low cost.

Key words: Car, adaptive, electric, project, industrial design.

Resumo

Graças aos avanços nas tecnologias de baterias, os carros elétricos são agora uma realidade. Este projeto pretende apresentar um carro melhor adaptado para o transporte pessoal nas grandes cidades.

O relatório descreve todo o processo de projeto de um veículo, iniciando com a análise dos veículos e soluções do passado, seguindo para a caracterização dos problemas enfrentados pelos veículos atuais e selecionando a metodologia para abordagem da solução.

Após essas etapas iniciais, será feito um questionário e sua consequente análise. Este questionário é importante para entender melhor os possíveis clientes deste produto. Após a análise do usuário, serão colocados em evidência critérios e características que serão obrigatórias para que os objetivos do projeto sejam atingidos.

Com esses critérios em mente, será projetada a forma básica do carro. Com a forma do veículo, serão calculadas as forças envolvidas no movimento do veículo, com isso, a quantidade de baterias necessárias para o veículo. Depois disso, serão apresentadas as soluções adaptativas. No final, será feita a análise de viabilidade do projeto.

É possível concluir com este projeto que é viável produzir um carro pequeno que satisfaça a maior parte das necessidades das pessoas para o transporte pessoal com um baixo custo.

Palavras chave: Carro, adaptativo, elétrico, projeto e design industrial.

Acknowledgments

Thanks to the Supervisor and Co-Supervisor professors, without them this project would not be possible.

A special thanks to my family that supported me during my masters, even they were 7500 km away from me, they were always present.

Table of Contents

List of Tables	xi
List of Figures	xii
List of Graphs	xiv
List of Abbreviations	xv
List of Symbols and Units	xvi
1 Introduction.....	1
1.1 Project background	1
1.2 Problem description	2
1.3 Research questions	2
1.4 Report outline	2
2 Literature Review	3
State of the art	3
2.1 Parking problems:	3
2.2 Japanese Kei cars.....	4
2.3 European Microcars	5
2.4 Flying cars.....	6
2.5 Comfort solutions	8
2.6 Pollution solutions	8
3 Problem Characterization.....	10
3.1 Pollution	10
3.2 Battery Electric Vehicles (BEVs) scenario.....	11
3.3 Parking	12
3.4 Range.....	14
3.5 Safety	15
4 Methodology.....	17
4.1 Comparative analysis of existing approaches and reasons for the choice adopted	18
4.2 Method used in the project.....	18
4.3 Application of the methodology	19
5 Project Analysis.....	20
5.1 Survey.....	20
5.2 Analysis of gathered data.....	20
5.3 Solution aims.....	21
5.3.1 Price.....	21
5.3.2 Simple	22
5.3.3 Electric	22
5.3.4 Small.....	24
5.3.5 Lightweight.....	24
5.3.6 Two-seat car	25
5.3.1 Adaptive.....	25
6 Solutions.....	27
6.1 Drag analysis	34
6.2 Rolling resistance force	35
6.3 Rolling coefficients for cars	36

6.4	Calculation of batteries.....	37
6.4.1	Drag resistance.....	37
6.4.2	Rolling resistance	38
6.4.3	Potential energy.....	38
6.4.4	Accessories energy	39
6.4.5	Total energy use:	39
6.5	Cost analysis of first solution.....	41
6.6	Second solution.....	47
6.7	Third solution.....	48
6.7.1	Calculation of batteries for the third solution	49
6.8	Adaptive features	50
6.8.1	Size adaptive car	50
6.8.1	Driver adaptive car.....	52
6.8.1	Range adaptive car.....	52
6.8.2	Battery charger	54
6.9	Cost analysis of third solution.....	59
6.10	Feasibility analysis	62
7	Conclusion and Future Research.....	63
7.1	Future work:	63
	Bibliography.....	64
	APPENDIX A: Survey.....	69
	APPENDIX B: Technical Drawings and Table lists	76
	APPENDIX C: Drag Analysis	78

List of Tables

Table 1 - Japanese development in the Kei cars legislation through the years (AIRIA s.d.).....	4
Table 2 - Regulation of the Microcars in Europe (REGULATION (EU) No 168/2013)	5
Table 3 - USA Parking Search Cost (INRIX Research 2017).....	13
Table 4 - U.K. Parking Search Cost (INRIX Research 2017)	13
Table 5 - Germany Parking Search Cost (INRIX Research 2017)	14
Table 6 - Annual kilometers driven per driver gender per age group (FHWA 2018)	15
Table 7 - Summary of purchase influence by factor (APPENDIX A: Survey)	21
Table 8 – Car occupancy by country by trip type (INRIX Research 2017)	25
Table 9 – Specifications of selected vehicles.....	29
Table 10 - Drag analysis result from SolidWorks	34
Table 11 - Rolling Resistance Coefficient of different tires and pavements (Engineering ToolBox 2015).....	35
Table 12 – Rolling coefficient and rolling resistance for the selected situations	36
Table 13 – Drag Resistance in kWh for the selected distances and speeds.....	37
Table 14 – Roll resistance in kWh for the selected distances and speeds	38
Table 15 – Potential Energy in kWh.....	38
Table 16 – Accessory Use in kWh	39
Table 17 – Total energy use in kWh for selected speeds and distances.....	39
Table 18 - Percentage of use per factor per trip	40
Table 19 – Weight of battery packs for selected speeds and distances in kg.....	40
Table 20 – Range in km of a 600 kg car at selected speeds and battery packs capacities	40
Table 21 - Estimative of Suspension parts for the first solution	43
Table 22 - Estimative of interior parts for the first solution.....	44
Table 23 - Estimative of plastic parts for the first solution	45
Table 24 - Estimative of LED parts for the first solution	46
Table 25 - Estimative of total cost of the car for the first solution	46
Table 26 – Energy used for the third solution	49
Table 27 – Range in km of the third solution at selected speeds and battery packs capacities	49
Table 28 - Range for each battery configuration	53
Table 29 - Estimative of Suspension parts for the third solution.....	60
Table 30 - Estimative of plastic parts for the third solution.....	61
Table 31 - Estimative of total cost of the car for the third solution.....	61
Table 32 - Estimative of Adaptive Solutions.....	61

List of Figures

Figure 1 - Global sales of cars (JATO 2019)	1
Figure 2 - Global sales of electric cars (JATO 2019)	1
Figure 3 – Brooks Walker parking solution (1950s Car Had An Extra Wheel To Help With Parking 2017)	3
Figure 4 –US3061028A patent (Walker, Motor vehicle lifting and traversing device 1962)	3
Figure 5 –US4516653A patent (Walker, Vehicle mounted parking device for use on FWD vehicles 1985).....	4
Figure 6 - Nissan DAYZ ROOX Key car (Nissan 2018).....	5
Figure 7 - Airbus transportation concept of the future (Italdesign and Airbus 2017)	6
Figure 8 - Integration of Airbus concept with the public transport (Italdesign and Airbus 2017).....	7
Figure 9 - EHANG 184 long range test 8,8 km result (EHang 2018)	7
Figure 10 - EHANG 184 two people-lifting test (EHang 2018)	8
Figure 11 - EURO NCAP for Microcars (Euro NCAP n.d.)	16
Figure 12 - User-centered Design method (Product Tribe 2018)	17
Figure 13 - Flow chart of design process.....	18
Figure 14 - Comparison of a frame and a unibody car (Infoupdate s.d.)	22
Figure 15 - Ackerman steering geometry (Wikipedia s.d.)	24
Figure 16 – Concept of extendable car (Antonelli 2012)	25
Figure 17 - Maximum dimensions for L6eBP or L7eCP models.....	26
Figure 18 - Moodboard	27
Figure 19 - Aixam Minauto Access (Aixam 2019).....	28
Figure 20 - Aixam Crossover Premium (Aixam 2019)	28
Figure 21 - JS50 Progress Club (LigierGroup 2019)	28
Figure 22 - JS50L DCI Sport Ultimate (LigierGroup 2019).....	28
Figure 23 - DUE5 Progress Initial (LigierGroup 2019).....	28
Figure 24 - MGO5 DCI HIGHLAND X (LigierGroup 2019).....	28
Figure 25 – Microlino (Micro Mobility 2019)	29
Figure 26 - Sketches of a three wheeled car.....	30
Figure 27 - First Designed Tubular Frame.....	30
Figure 28 - Second Design of Tubular Frame with passengers	30
Figure 29 - First design of car fairing	31
Figure 30 - Improvement of the fairing	31
Figure 31 - View from the back-right of the vehicle.....	32
Figure 32 - View from the left side of the vehicle	32
Figure 33 - View from the front-left of the vehicle	33
Figure 34 - View from the back of the vehicle.....	33
Figure 35 – Simplified analysis of car weight	33
Figure 36 - Upper view of wind displacement analysis at 45km/h (12,5 m/s).....	34
Figure 37 - Side view of wind displacement analysis at 45km/h (12,5 m/s)	34
Figure 38 - Body frame made of 1020 steel	41
Figure 39 - Cast iron disk brake	41
Figure 40 - Cast iron upper arm	42
Figure 41 - Cast iron lower arm	42
Figure 42 - Cast iron steering knuckle	42
Figure 43 - Cast iron hub.....	43
Figure 44 - Magnesium alloy rim.....	43
Figure 45 - Headlight case made of Acrylonitrile Butadiene Styrene (ABS)	44

Figure 46 - Fairing made of ABS.....	44
Figure 47 – Panel made of ABS	45
Figure 48 - Headlight Lens made of Polycarbonate (PC).....	45
Figure 49 - Selected shape of body	47
Figure 50 – Drag Force at 45km/h (12,5 m/s)	47
Figure 51 - Drag Force at 45 km/h (12,5 m/s)	48
Figure 52 - Drag Force at 90 km/h (25 m/s)	48
Figure 53 - Scheme of a gate mechanism (Garen 2019)	50
Figure 54 - Shortened Frame	51
Figure 55 - Extended Frame	51
Figure 56 - Detail of the worm gear assembly of the extension system.....	51
Figure 57 - Extendable Chassis ad Frame adapted to the Second Solution.....	51
Figure 58 - ID card reader.....	52
Figure 59 - Left battery drawer.....	53
Figure 60 - Adaptive Battery.....	53
Figure 61 - Charger pad in the lower and higher position	54
Figure 62 – Charge pad below the vehicle before and after the car turn off.....	54
Figure 63 - Charge pad charging.....	54
Figure 64 - WiTricity wireless charger at the 2015 CES expo in Las Vegas (Nikkei 2018).....	55
Figure 65 - Driver view for the Third Solution	55
Figure 66 - Rear passenger view for the Third Solution	56
Figure 67 - Front-right view of the Third Solution	56
Figure 68 - Side-left-bottom view of the Third Solution.....	56
Figure 69 - Side-left-upper view of the Third Solution.....	57
Figure 70 - Front view of the Third Solution	57
Figure 71 - Front view of the Third Solution	57
Figure 72 - Detail of side mirror and panel of Third Solution.....	58
Figure 73 - Front-right view of the Third Solution	58
Figure 74 - Right side view of the Third Solution	58
Figure 75 - Rear-right view of the Third Solution.....	59
Figure 76 - Body frame made of 1020 Steel.....	59
Figure 77 - Suspension arm made of 1020 steel tube.....	59
Figure 78 - Cast iron steering knuckle	60
Figure 79 - Cast iron rear axis.....	60

List of Graphs

<i>Graph 1 - Sales of Microcars in UK (Statista 2019)</i>	<i>6</i>
<i>Graph 2 - Lithium-ion battery price outlook (BloombergNEF 2019)</i>	<i>9</i>
<i>Graph 3 – CEDS in comparison to Lamarque et al. (2010) (Geoscientific Model Development 2018)</i>	<i>10</i>
<i>Graph 4 - Sales in Electric and Hybrid vehicles per region per year (IEA 2019)</i>	<i>11</i>
<i>Graph 5 - Projected world fleet of BEV and PHEV vehicles (IEA 2019).....</i>	<i>11</i>
<i>Graph 6 - Change in distance travelled by car for selected countries (Odyssee-Mure 2016)</i>	<i>14</i>
<i>Graph 7 - Emissions of CO₂ ICEV vs BEV, 2015 vs 2025 (Arthur D Little 2016)</i>	<i>23</i>
<i>Graph 8 - GWP Emissions from a 2025 ICEV vs BEV during Vehicle Life (Arthur D Little 2016).....</i>	<i>23</i>
<i>Graph 9 - Share of energy from renewable sources by EU member (Eurostat 2019).....</i>	<i>23</i>
<i>Graph 10 - Retail Price Equivalent multiplier (FEV 2013)</i>	<i>62</i>

List of Abbreviations

3D	Three Dimensions
AAV	Autonomous Aerial Vehicle
ABS	Acrylonitrile Butadiene Styrene
BEVs	Battery-powered Electric Vehicles
CAD	Computer-Aided Design
CD	Contextual Design
CO	Carbon monoxide
CO ₂	Carbon dioxide
EOL	End of Life
EU	European Union
EUR	Euro
EV	Electric Vehicle
FEUP	Faculty of Engineering of University of Porto
FHWA	The Federal Highway Administration
FWD	Front-Wheel Drive
GHG	Green House Gases
GWP	Global Warming Potential
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
LCV	Light Commercial Vehicle
NCAP	New Car Assessment Programme
NMVOC	Non-Methane Volatile Organic Compounds
NO _x	Nitrogen Oxide
PC	Polycarbonate
PD	Participatory Design
PHEV	Plug-in Hybrid Electric Vehicle
PLDV	Passenger Light Duty Vehicle
RPE	Retail Price Equivalent multiplier
U.S.	United States
UCD	User-Centered Design
UK	United Kingdom
USA	United States of America
WWII	World War II

List of Symbols and Units

%	Percentage
\$	US Dollar
€	Euro
bar	Bar = 0,1 Mega Pascal
EUR/kg	Euro per kilogram
kg	Kilogram
km	Kilometres
km/h	Kilometres per hour
kW	Kilowatt
m	Meters
m/s	Meters per second
m/s ²	Meters per second squared
mm	Millimetres
N	Newton

1 Introduction

1.1 Project background

Since the Model T, one of the first vehicles accessible to the masses, with more than 15 million unities sold between 1909 and 1925 (Hounshell 1985), many innovations were developed in the automotive area. Today, the autonomous cars are erupting and the countries are adapting the advance of these technologies with new legislations (The state of autonomous legislation in Europe 2019).

With the autonomous vehicles, the electric car industry is also developing. Global sales of cars decreased in 0,5 % from 2017 to 2018 Figure 1, going in the opposite direction of electric vehicles sales. The sales in battery-powered electric vehicles, BEVs, increased 73,4 % from 2017 to 2018, Figure 2 (JATO 2019).

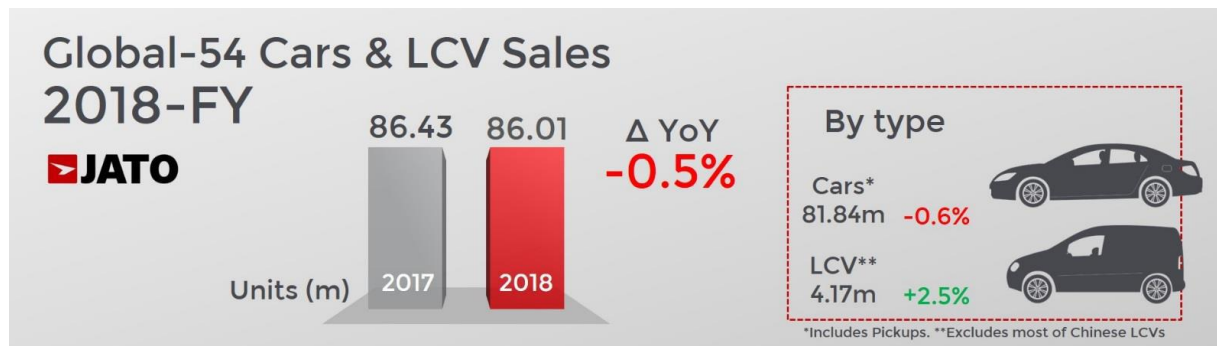


Figure 1 - Global sales of cars (JATO 2019)



Figure 2 - Global sales of electric cars (JATO 2019)

Nowadays, it is extremely common to see an electric vehicle in the streets and most of the people think that this is a new technology. Nevertheless, the Handbook of Automobiles from 1919 (National Chamber of Commerce Inc. 1919) shows, between the several combustion engines, four models of electric vehicles, proving that, in 1919, there were already electric vehicles commercialized.

The decline of the electric vehicles began when the road trips became more popular due to government investments in better roads and the trips started to be within long ranges, impossible for the battery technologies at that time.

Thanks to the advance of the battery technologies, nowadays, it is possible to have an electric car with range up to 600 km (Tesla 2019), and warranty of 8 years like the Tesla model S 100D, long-range edition. These advances happened thanks to the investment in chemistry

technologies that created new and better performance batteries. The batteries used in the cars, nowadays, are completely different chemically compared to the batteries 90 years ago.

1.2 Problem description

With the advance of the transportation and the production technologies, more and more people were able to afford a car. Some countries, like San Marino, have more than one car per person in average (The World Bank 2019). With more cars on the streets also raised the pollution levels. This project intends to design an efficient and adaptive car that fulfil better the consumer needs and can reduce the pollution and other problems that current vehicles faces.

1.3 Research questions

Who are the costumers of an adaptive car?

Which are the next steps of the automotive industry?

What the currently produced cars have in common with the cars of the future?

What is an adaptive car?

Which are the examples of adaptive cars?

How to create an adaptive car?

What features can be added in an adaptive car?

1.4 Report outline

This report would be presenting the final project of Master's in Industrial and Product Design. After this introduction, it will go on with a literature review of adaptive solutions over the years and other solutions proposed to enhance the transportation experience.

In the third chapter, the problems faced by the current car market and costumers will be discussed. The pollution and parking problems generated by the cars that are currently in the market will be analysed as well as the safety of the Microcars, which were supposedly a better solution of cars adapted to the big cities.

The fourth chapter will present the methodology used to approach the solution for the project. In addition, two variants of the User Centered Design will be presented: Participatory Design and Contextual Design.

In the fifth chapter, an analysis of the project will be made, evaluating the gathered data from the survey and previous research to create some criteria for the project of the car.

At the sixth chapter, the solution will be presented and three different final projects will be delivered, adapting to different costumers and aiming in different businesses models.

Finally, the seventh chapter will conclude the report presenting the problems faced during the project, suggesting solutions for the future and analysing the whole report.

2 Literature Review

State of the art

In order to design an adaptive car one of the first steps is to do a research and to look at the past, present and future to see the solutions that were designed, developed and built to solve or mitigate the problems of the modern and postmodern society in the car sector.

Some of these solutions were developed in the beginning of the century; others were release few years ago and are still in concept, development or test phases.

2.1 Parking problems:

In 1932, Brooks Walker patented the fifth wheel car, with the patent number: US2139341A (Walker, Vehicle lifting and traversing device 1938). This car had a fifth wheel in the back of the car that could be used to enter and leave from tight parking spots. Figure 3 shows the prototype created by Walker to show the effectiveness of the solution.



Figure 3 – Brooks Walker parking solution (1950s Car Had An Extra Wheel To Help With Parking 2017)

Later on, Brooks Walker developed another project registering a second patent: US3061028A (Walker, Motor vehicle lifting and traversing device 1962), part of the patent is presented in Figure 4. This patent consisted in a lifting mechanism to park a car sideways.

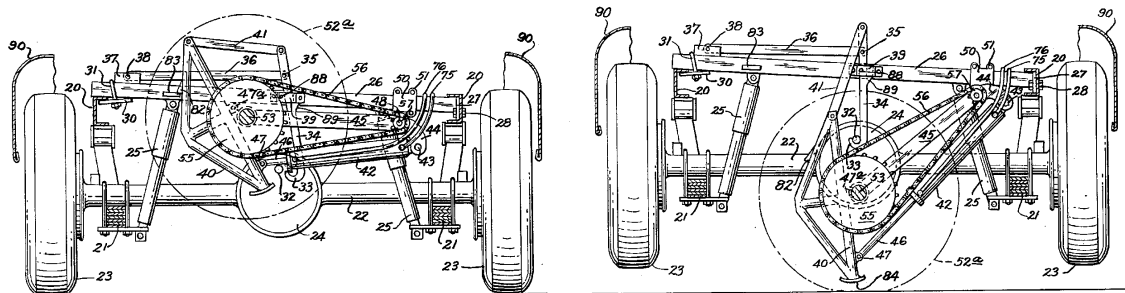


Figure 4 –US3061028A patent (Walker, Motor vehicle lifting and traversing device 1962)

In the eighties, Brooks Walker developed another concept of parking solution, which he patented with the code US4516653A (Walker, Vehicle mounted parking device for use on front wheel drive vehicles 1985). This project, similar to the first one, added a fifth small wheel for parking diagonally, that can be seen in Figure 5.

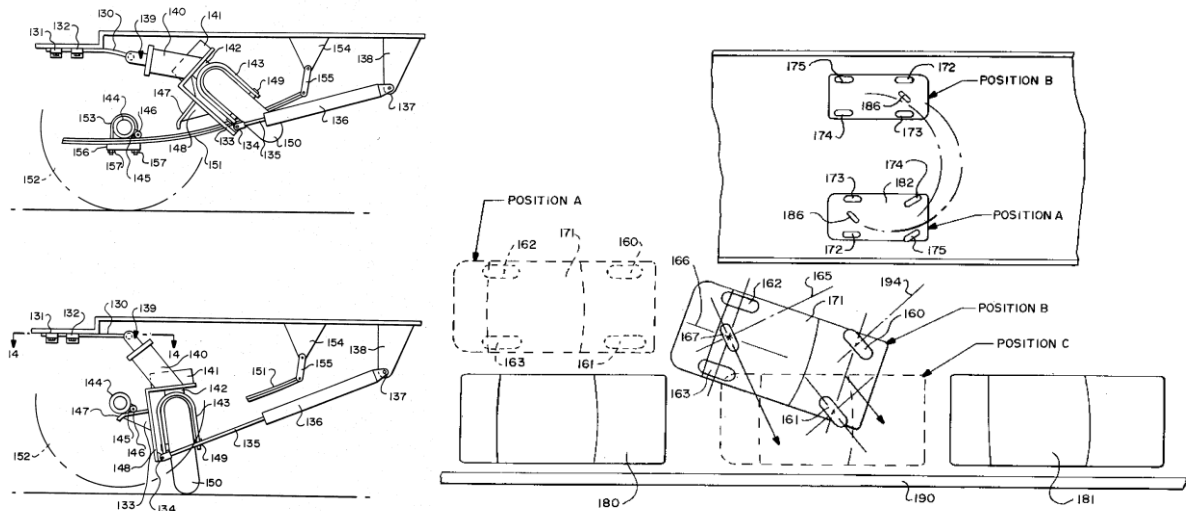


Figure 5 –US4516653A patent (Walker, Vehicle mounted parking device for use on FWD vehicles 1985)

2.2 Japanese Kei cars

After the Second World War, WWII, the Japanese government made a regulation that created a new class of cars, the Kei Cars, minicars of the Japanese market. The first regulation of a Kei car was applied on July 8, 1949: the car needed to follow several limitations to receive tax and insurance benefits. The Japanese government created this category to promote the cars sales due to the WWII. In fact, many Japanese had money to buy motorcycles, but this value was not enough to buy a car. Hence, the Kei car category, which would receive benefits, facilitating the production and sale of this type of vehicle. In Table 1, are presented the changes in the Kei car regulation since was created in 1949. In Figure 6, it is presented the Nissan DAYZ ROOX, with its boxy format for a bigger intern space due to the size restrictions.

Table 1 - Japanese development in the Kei cars legislation through the years (AIRIA s.d.)

Date	Max. Length (m)	Max. Width (m)	Max. Height (m)	Max. Displacement (cc)		Max.
				four-stroke	two-stroke	Power (kW)
8 July 1949	2,8	1,0	2,0	150	100	N/A
26 July 1950	3,0	1,3		300	200	
16 August 1951				360	240	
4 April 1955				360		
1 January 1976	3,2	1,4		550		47
1 March 1990	3,3					
1 October 1998	3,4	1,48		660		



Figure 6 - Nissan DAYZ ROOX Key car (Nissan 2018)

2.3 European Microcars

As in Japan, the Microcars industry started in Europe in the beginning of 1940. In the book *British Microcars 1947-2002* (Cameron 2018), the history of the Microcars in the UK is presented, with special attention to Reliant and Bond brands, one of the first companies and one of the companies that lasted longer. Bond was bought by Reliant in 1969 after being liquidated, and lasted until 2002.

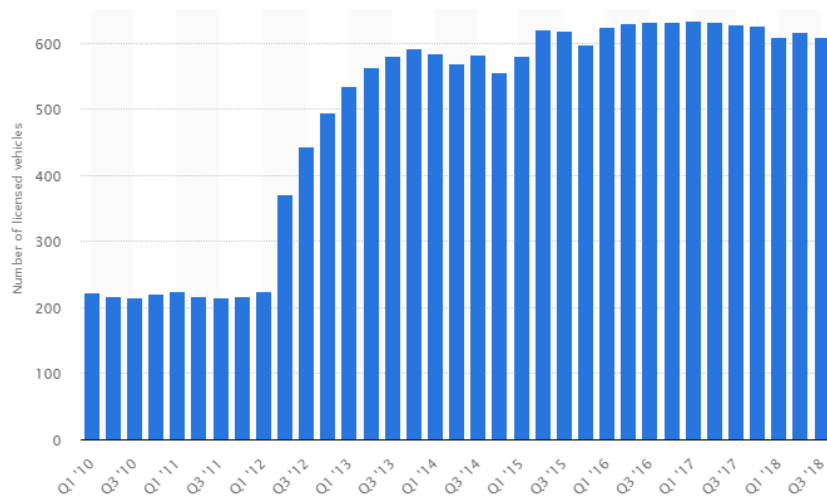
One of the first and most important pushes that the Microcars industries received in the UK, was with the United Kingdom Road Traffic Act, 1930, because defined “Motor cycles: mechanically propelled vehicles (...) with less than four wheels and the unladen weight does not exceed eight hundredweight” (Road Traffic Act 1930). Therefore, a three wheeled car could be considered a motorcycle and receive the lower taxes of the category.

Currently in Europe, there is a class of cars known as Microcar (Regulation (EU) no 168/2013 of the European parliament and of the council of 15 January 2013). This class of cars has two categories L6eBP and L7eCP and the specifications of the categories can be seen in Table 2.

Table 2 - Regulation of the Microcars in Europe (REGULATION (EU) No 168/2013)

Category	L6eBP	L7eCP
Max Dimensions (m)	Length =3 Width =1,5 Height =2,5	Length =3,7 Width =1,5 Height =2,5
Maximum speed (km/h)	45	90
Maximum power (kW)	6	15
Unladen weight (kg)	425 (with fuel)	450 (with fuel)

Due to crowded cities, population getting older and the easiness in purchasing, driving and parking these vehicles, the number of licensed vehicles grew almost 200% from 2012 to 2018 in the UK, reaching a stable number nowadays as can be seen in Graph 1.



Graph 1 - Sales of Microcars in UK (Statista 2019)

However, one of the problems with the Microcar is the safety. None of the evaluated vehicles by Euro NCAP got a score better than 2 out of 5, showing that these cars are extremely dangerous for the occupants, even though the speed is limited in these vehicles (Lavrador 2016).

2.4 Flying cars

Due to the engineering and technological limitations, the dreamed flying cars are not available yet, but great advances have been achieved lately. With better capacity batteries, stronger and light composites and technologies such as used in drones, the future of flying cars may be possible.

Some companies already presented their concepts of a flying car of the future. The Airbus concept is a modular vehicle that can be attached to wheels or to a quad-copter, as can be seen in Figure 7.



Figure 7 - Airbus transportation concept of the future (Italdesign and Airbus 2017)

But, the Airbus concept go a little bit further and integrates the concept of self-driving flying car with the public transport, making the dislocations more accessible. This integration is presented in Figure 8.



Figure 8 - Integration of Airbus concept with the public transport (Italdesign and Airbus 2017)

Besides the innovative design, the Airbus flying car is still far from the production phase. There are too many limitations for creating a flying car in 2019, but this did not stop some companies to pursue this dream.

One company that is developing a product to facilitate the transportation is EHANG, with the concept 184. Differently to the Airbus model, this concept is not modular; being an AAV (Autonomous Aerial Vehicle), the EHANG 184 is a concept of a drone company EHANG (EHang 2018).

The EHANG 184 is already in the test phase. The actual prototype, presented in Figure 9 and Figure 10, could reach 300 m of altitude and 8,8 km of range in the tests, reaching a speed of 130 km/h, also in the test the prototype could lift two people with a summed weight of 210 kg.



Figure 9 - EHANG 184 long range test 8,8 km result (EHang 2018)



Figure 10 - EHang 184 two people-lifting test (EHang 2018)

2.5 Comfort solutions

With the Citroen DS was introduced the hydro-pneumatic suspension. At that time, the conventional cars had the hydraulics only in the break and power steering. The Citroen DS introduced the use of hydraulics in the suspension, clutch and transmission.

However, the most noticeable innovation of the Citroen DS was the hydro-pneumatic suspension, also called active suspension. This suspension was pioneered one year before designed to be used in top of the range, Traction Avant 15CV-H, but only in the rear wheels.

Hydro-pneumatic suspension is a type of motor vehicle suspension system, designed by Paul Magès, invented by Citroën. The first four-wheel implementation was in the Citroen DS in 1955, a milestone in the automotive industry.

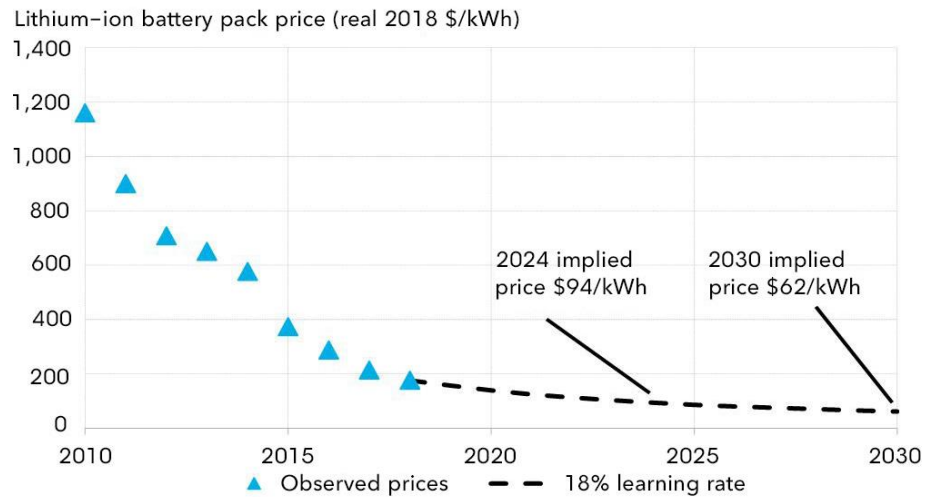
Nevertheless, due to the complexity of the suspension and the cost attached to it, this technology is not available in most of the cars yet.

2.6 Pollution solutions

It is impossible to talk about innovation in the car industry and not talk about Tesla, Inc. The company, founded in 2003, is one of the most known companies in electric cars in the moment. According to JATO, Tesla was the company with more sales in the world, with 230 thousands of vehicles sold, out of these, 138 thousands are units of the model 3, the most sold fully electric vehicle of 2018 (JATO 2019).

One of the motives for the success of Tesla is the partnership with Panasonic in the creation of the GigaFactory, where the batteries and other components could be developed and fabricated. This strategy reduced the price of one of the main components in the Electric vehicles, the batteries.

Depending on the quantity of the batteries used by an Electric Vehicle (EV), the cost associated to it can be up to 50% of the cost of the vehicle, but this cost has been shrinking in the last years. In 2015 the cost of the batteries in an EV represented 57% of the car cost, in 2019 this value is around 33% and is expected that this value will be 20% in 2025 (Bullard 2019). So, each year its being cheaper to produce an EV, in Graph 2 the trend of battery prices can be seen.



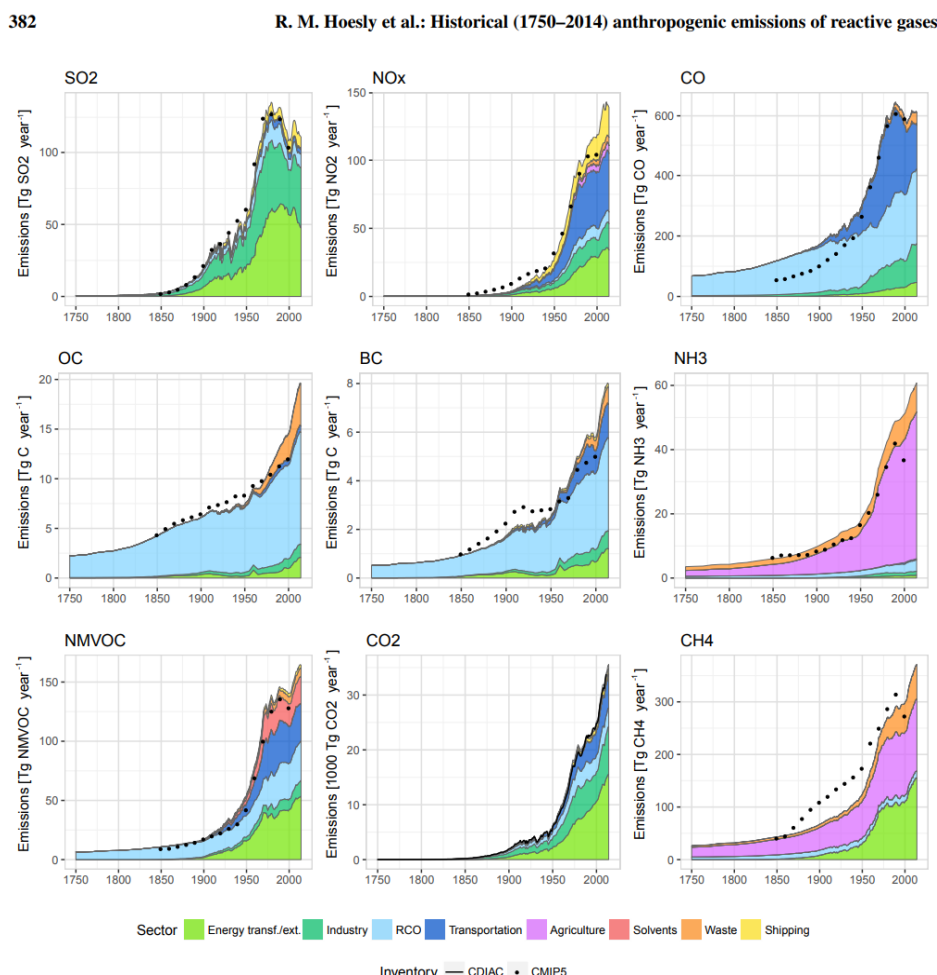
Graph 2 - Lithium-ion battery price outlook (BloombergNEF 2019)

3 Problem Characterization

The present project aims to develop an adaptive vehicle concept. This could be a solution for the problems faced by the actual vehicles, such as pollution, parking, range, safety and comfort; adapting to the post-modern lifestyle.

3.1 Pollution

Seeing the blue sky is every day more difficult, and most of the reason for that is the pollution produced in the several sectors. Some big cities already started to ban the polluting cars from the city centre in order to have these blue skies back (Business Insider 2019). As can be seen in Graph 3, the transportation sector represents an important slice of the carbon monoxide (CO), nitrogen oxide (NO_x), non-methane volatile organic compounds (NMVOC) and carbon dioxide (CO₂) emissions.

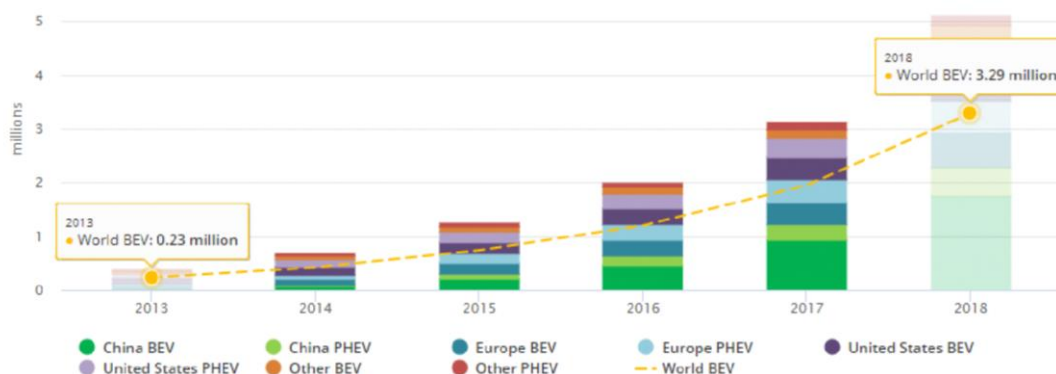


Graph 3 – CEDS in comparison to Lamarque et al. (2010) (Geoscientific Model Development 2018)

The BreathLife2030 is a campaign that “...combines public health and climate change expertise with guidance on implementing solutions to air pollution in support of global development goals”. It says that air pollution is a leading cause of many common killers such as 7 % of lung cancer deaths, 18 % of COPD (pulmonary disease) deaths, 20 % of stroke deaths and 34 % of heart disease deaths (BreatheLife 2016).

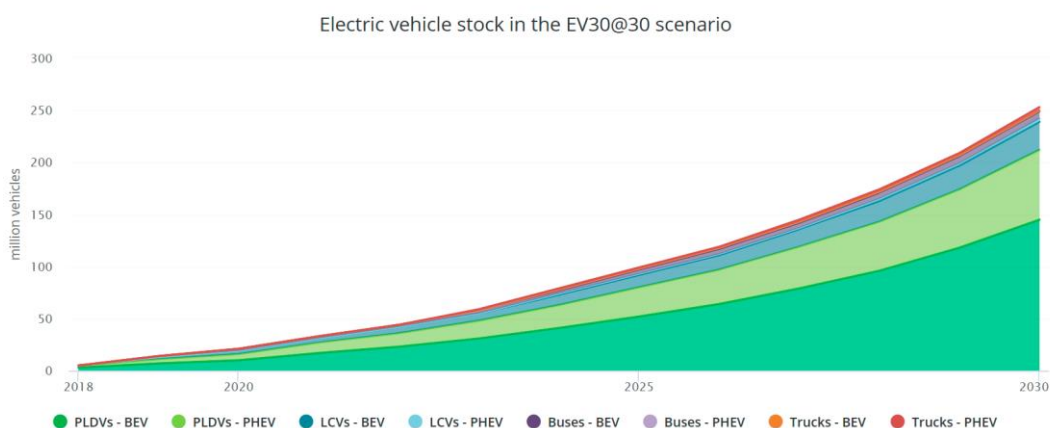
3.2 Battery Electric Vehicles (BEVs) scenario

The sales of Battery Electric Vehicles (BEVs) have been growing annually, the Global EV Outlook 2019 (IEA 2019) shows that the sales of BEV went from 0,23 million in 2013 to 3,29 million in 2018 a growth of 1430 % in just five years as presented in Graph 4.



Graph 4 - Sales in Electric and Hybrid vehicles per region per year (IEA 2019)

The report also makes an expectation for the EV market. According to the report the “EV sales reach 44 million vehicles per year by 2030” (IEA 2019). The report also present a graph with the fleet of BEVs and Plug-in hybrid electric vehicle (PHEV) separated by different categories of vehicles as can be seen in Graph 5.



Graph 5 - Projected world fleet of BEV and PHEV vehicles (IEA 2019)

It can be concluded from the report that the BEV market is growing in a fast rate, being a great opportunity for new entrants. Also, due to the competition and more investments in technology, the price of the components, as the battery price presented in Graph 2, tend to drop.

However, one of the disadvantages of the electric car is the toxicity of the lithium batteries and the amount of Greenhouse Gas (GHG) emissions during the production phase. In the article *Life cycle greenhouse gas emissions of Electric Vehicles in China: Combining the vehicle cycle and fuel cycle* (Qinyu Qiao 2019), they compared the amount of GHG emissions in each phase of the cars life. And, although the BEV produces more GHG in the manufacturing, at the end of the life cycle the BEV still produces 41t of equivalent in CO₂, 18% less GHG than an Internal Combustion Engine Vehicle (ICEV). This value is expected to reduce to 34,1t of equivalent CO₂ in 2020, due to the investments in greener energy sources, like photovoltaic panels and wind farmers. The authors suggest investments in

recycling the batteries for reducing the GHG in the production phase. Other article *U.S. end-of-life electric vehicle batteries: Dynamic inventory modelling and spatial analysis for regional solutions* (Ning Ai 2019) analyses the end of life (EOL) of the batteries in California. It suggests both the recycling of the batteries as well as the reuse of these batteries: “50% of retired EV batteries before 2025, cumulatively 280.000 battery units, could sufficiently support all existing wind and solar utilities in the state”.

3.3 Parking

According to the report (INRIX Research 2017), an average American wastes 17 hours per year looking for a parking spot, a German 41 hours and a British driver 44 hours. And, as time is money, a lot of money is also wasted in fuel, carbon footprint and not working hours. The study estimated that Nationally, drivers in the USA waste \$72 billion (€64,6 billion) per year in time, fuel and emissions searching for parking, in the UK this number is £23,3 billion (€26,2 billion) annually, and Germany €40,4 billion. The values were converted to euro in the rate of one British pound to 1,1258 euro, and one US dollar to 0,8891 euro, the values can be seen in Table 3 to

Table 5.

Table 3 - USA Parking Search Cost (INRIX Research 2017)

INRIX parking rank	City	Annual Search Time (Hours per Driver)	Cost per driver per year (€)	Total per City per Year (billions of €)
1	New York City	107	1994	3,8
2	Los Angeles	85	1587	3,3
3	San Francisco	83	1543	0,6
4	Washington D.C.	65	1215	0,3
5	Seattle	58	1071	0,4
6	Chicago	56	1044	1,2
7	Boston	53	988	0,2
8	Atlanta	50	927	0,2
9	Dallas	48	885	0,6
10	Detroit	35	650	0,2
USA		17	307	64,6

Table 4 - U.K. Parking Search Cost (INRIX Research 2017)

INRIX parking rank	City	Annual Search Time (Hours per Driver)	Cost per driver per year (€)	Total per City per Year (billions of €)
1	London	67	1243	4,8
2	Belfast	56	1045	0,2
3	Leeds	47	869	0,3
4	Bristol	46	865	0,2
5	Birmingham	46	852	0,4
6	Cardiff	44	830	0,1
7	Manchester	41	775	0,2
8	Glasgow	40	743	0,3
9	Edinburgh	38	704	0,2
10	Southampton	35	662	0,1
UK		44	825	26,2

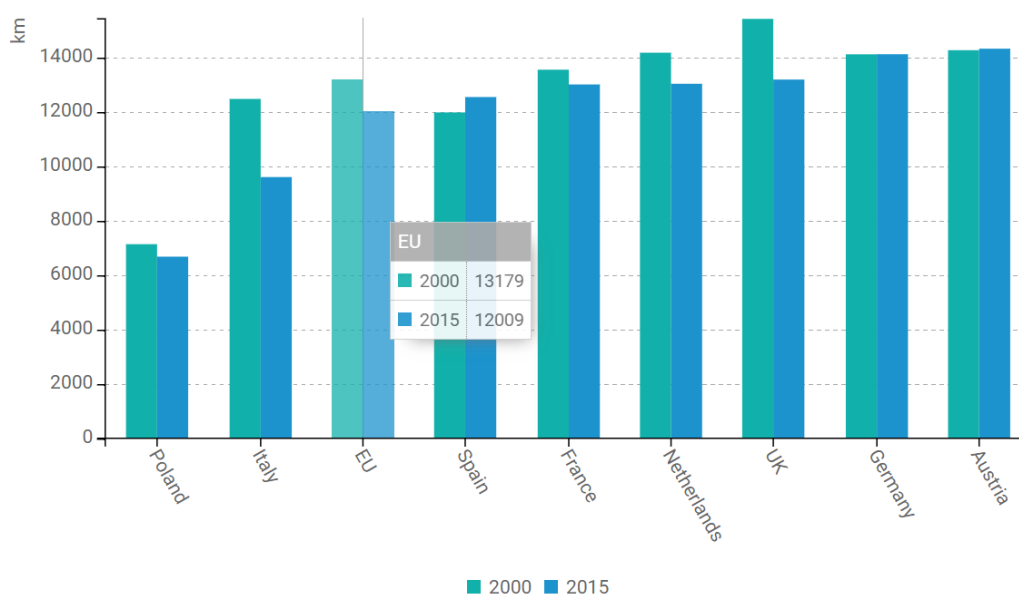
Table 5 - Germany Parking Search Cost (INRIX Research 2017)

INRIX parking rank	City	Annual Search Time (Hours per Driver)	Cost per driver per year (€)	Total per City per Year (billions of €)
1	Frankfurt	65	1410	0,7
2	Essen	64	1390	0,5
3	Berlin	62	1358	1,8
4	Dusseldorf	61	1337	0,6
5	Cologne	60	1302	0,9
6	Dortmund	57	1239	0,5
7	Hamburg	52	1139	1,5
8	Stuttgart	52	1136	0,4
9	Munich	50	1092	1,1
10	Bremen	49	1065	0,4
GERMANY		41	896	40,4

These numbers could be drastically reduced if the cars were smaller, so in the same area more parking spots were available. In the Parking Know How Bay Size report (British Parking Association 2016), the suggested size of a parking spot is 4,8 m x 2,4 m being an area of 11,52 m². If this parking is reduced to 4 m x 2 m, sufficient size to fit a L7eCP micro car model or the biggest Kei car, the parking spot would be 30,5 % smaller in area, this could represent 30,5 % more parking spots for the same parking slot area. In addition, with the smaller distance between the wheels, this car could be easily maneuvered and with a smaller width, the corridors of the parking slot could be narrow, improving the use of the area.

3.4 Range

The annually amount of km driving a car varies according to the country and the culture. This value reduced in the last decade from 13179 km in the year 2000 to 12009 km in 2015 per year in Europe (Odyssey-Mure 2016), as presented in Graph 6.

**Graph 6 - Change in distance travelled by car for selected countries (Odyssey-Mure 2016)**

In the United States, due to geographic and cultural differences, the American drove in 2018 an average of 21561,6 km per year, almost 80 % more than the European average, as presented in Table 6 (United States Department of Transportation - Federal Highway Administration 2018).

Table 6 - Annual kilometers driven per driver gender per age group (FHWA 2018)

Age	Male (km)	Female (km)	Total (km)
16-19	13206	11061	12270
20-34	28929	19319	24298
35-54	30349	18449	24608
55-64	25523	12521	19267
65+	16583	7701	12305
Average	26635	16322	21687

With the possibility of an adaptive range vehicle, the vehicles could be best harnessed, because, as will be seen in the chapter 6, the battery represents a significant factor of the cars weight, and consequently the car range, since with a heavier vehicle more energy is used to move the car.

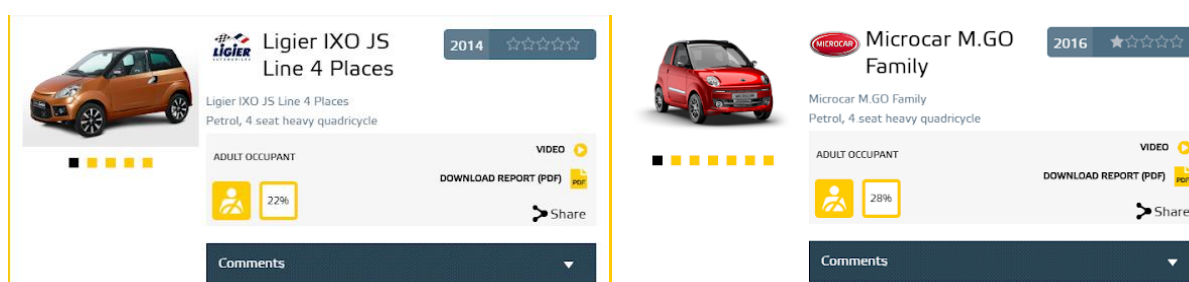
The possibility of an adaptive car range, with an adaptive battery and consequently vehicle weight, could improve a lot the car efficiency and reduce the price, since not everybody needs a car with 600 km of range.

3.5 Safety

As was cited in chapter 2.3, European Microcars, one of the biggest problems in the Microcars is the safety. Most of them do not have the same safety standards as the average vehicle (Pavlovic e Fragassa 2015).

Figure 11 shows all the Microcars tested by the EURO NCAP, and none of those had a better score than 2 stars, in comparison the BEV Nissan LEAF got a score of 5 stars, with 93 % of safety for the adult occupant.

This low score of the micro cars can be explained by two major factors: the lower standards needed to produce a micro car and the second and main factor is the smaller distance from the outer side of the vehicle to the passenger. In the report Japanese Proposal and Research Plan (JASIC 2011), they either suggest a reduction of the speed, from 32 to 26 km/h, in the pole collision test for the Kei cars or exempted from the scope of this regulation.



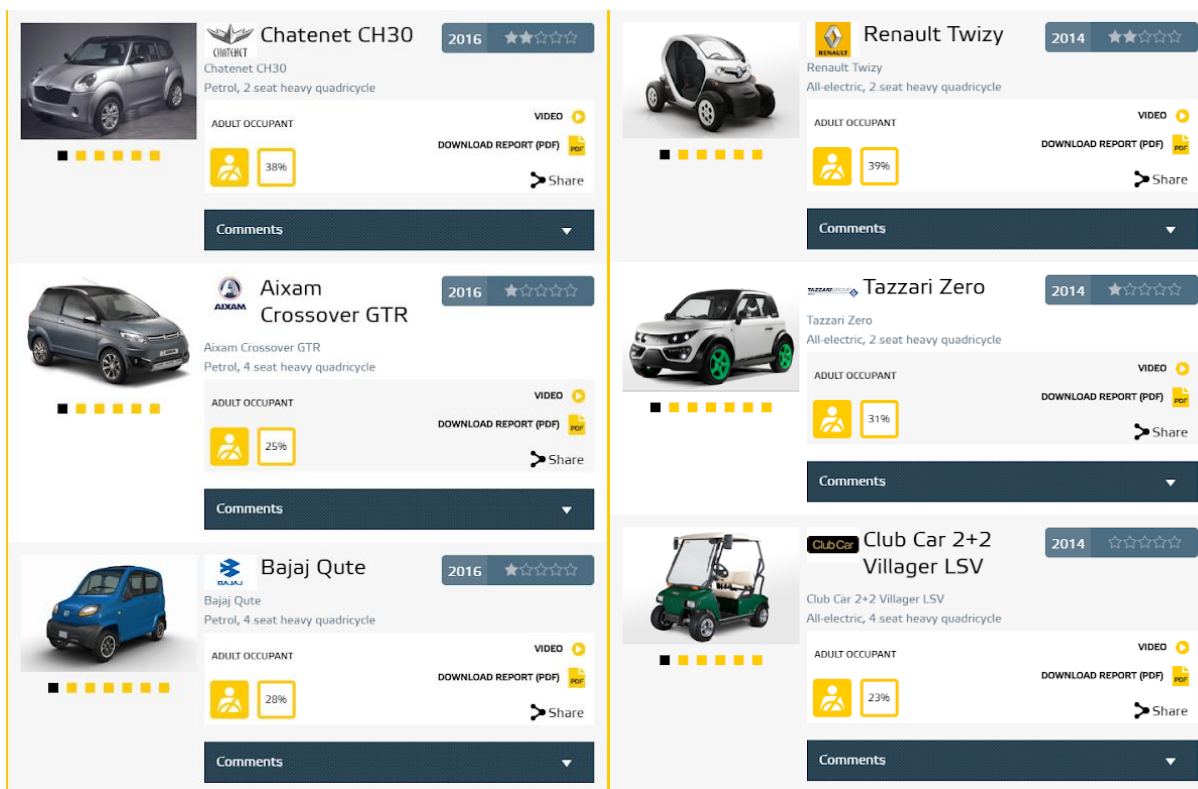


Figure 11 - EURO NCAP for Microcars (Euro NCAP n.d.)

4 Methodology

In this chapter, the User-Centered Design methodology will be presented as well as two ramifications of the UCD. The User-Centered Design is “an iterative design process in which designers focus on the users and their needs in each phase of the design process. UCD calls for involving users throughout the design process via a variety of research and design techniques so as to create highly usable and accessible products for them.” (Interaction Design Foundation 2018). In Figure 12, the UCD is summarized in a flow chart.

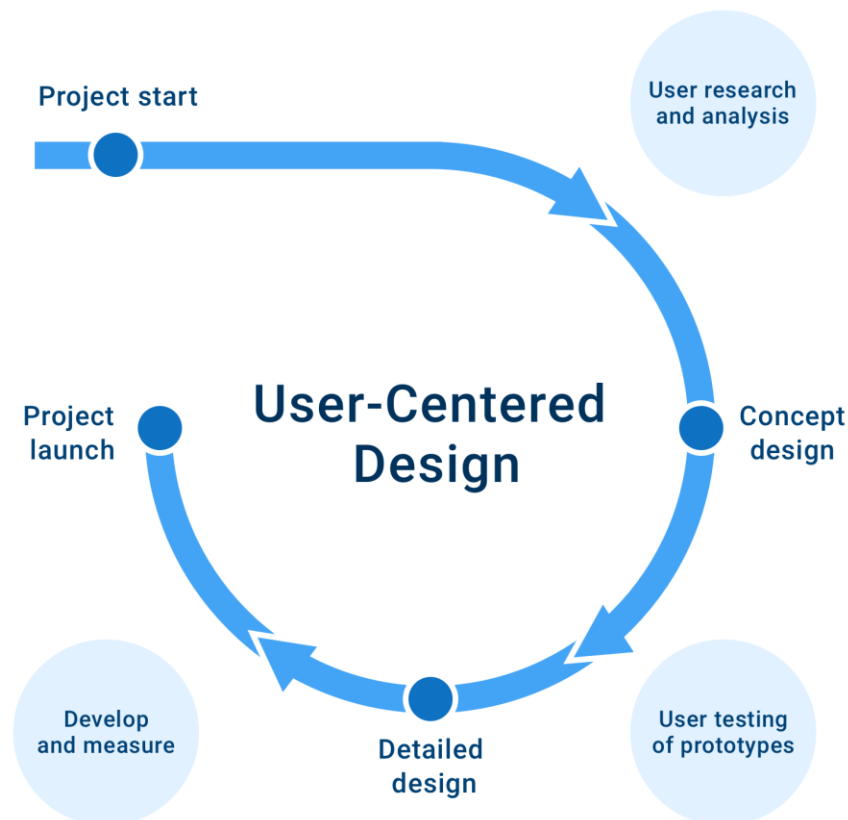


Figure 12 - User-centered Design method (Product Tribe 2018)

With the UCD method the questions presented in Chapter 1.3, Research questions, will be analysed in the user perspective and after that these questions will be answered. The questions presented in Chapter 1.3 can be seen below:

- What is an adaptive car?
- Who are the costumers of an adaptive car?
- Which are the next steps of the automotive industry?
- What is in common between the current cars and the cars of the future?
- Which are the examples of adaptive cars?
- How can you create an adaptive car?
- Which features can be added to an adaptive car?

For a better understanding of the design process of this adaptive car, a flow chart is presented, Figure 13. Due to the other prototypes, a loop is created after the first cost analysis to generate the second and third solutions. After presented all solutions is possible to make a feasibility analysis of the projects.

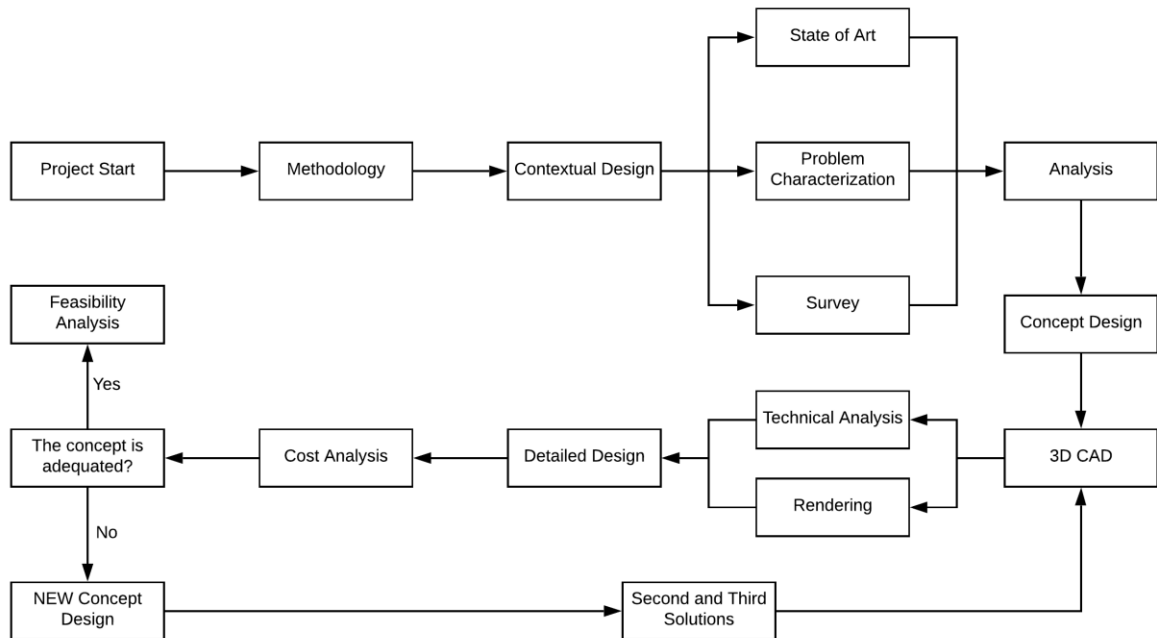


Figure 13 - Flow chart of design process

4.1 Comparative analysis of existing approaches and reasons for the choice adopted

The UCD divide in two main methods: Participatory Design (PD) (also known as co-operative design or co-design) and the Contextual Design (CD). The “Participatory Design is an approach where all stakeholders are involved in the design process.” (Participate in Design 2019) while the “Contextual Design is a customer-centred design process that uses extensive field data as the foundation for understanding users’ needs, tasks, intents, and processes in order to design products and systems that meet both users’ and business’ needs.” (InContext Enterprises Inc. 2018).

The Contextual Design is the chosen method due to the complexity and technological characteristics of the project.

4.2 Method used in the project

The present project will develop the design of an electric vehicle; the methodology used will be the Contextual Design. Firstly, some questions would be proposed and, after a survey, an analysis of the results will be made to understand better the average interviewed habits and how they make a decision to buy a car. This survey will help to guide and initiate the car design.

4.3 Application of the methodology

In order to use the CD method is important to understand the costumer, for developing a product that is targeted for them, so a **Survey** will be carry through students and ex-students of FEUP. To this understanding of the public, an **Analysis of gathered data** is essential, and will be carrying on after the Survey.

After analysing the collected data, a product **Proposal** will be presented that meets the needs of the customers taking into account the **Adaptive Features**.

With this proposal in mind, a **Solution** will be developed as well as a **Technical Analysis** of the product.

After presented the solution, an **Analysis of Solution** will be made to verify if the costumers' needs were attended.

5 Project Analysis

5.1 Survey

The survey, created in Google forms and spread to the students and ex-students of FEUP, and an e-mail was sent to 43216 people.

According to the book Statistics for Managers (Levine, Stephan and Szabat 2017), to calculate the sample size it is only needed the confidence interval, the proportion expected and the error.

$$n = Z^2 * p * (1-p)/e^2 \quad (1)$$

Where:

n = sample size

Z = confidence interval, in this case 90% or 1,645

p = proportion, in this case because we do not know what to expect the worst scenario is considered $p = 0,5$

e = error, in this case 5%

Calculating the sample size:

$$n = 1,645^2 * 0,5 * (1-0,5)/0,05^2$$

$$n = 270,6$$

$$n = 271$$

For this analysis with 90% of confidence and 5% of error, 271 answers are needed in the survey. To a better understanding of the possible costumer, a survey was conducted and can be verified in APPENDIX A: Survey. This survey had 271 participants from 3 continents being 69,4% from 20 to 34 years and 89,7% from Europe.

5.2 Analysis of gathered data

In the survey, a scale from 1 to 10 was used to verify the influence on the purchase or future purchase of a vehicle. This scale will be translated to be better analysed: from 1 to 4 will be interpreted as low influence, from 5 to 6 as medium influence and from 7 to 10 as high influence.

As the APPENDIX A: Survey shows, only 7,7 % of the interviewed do not want to have a driving licence, 89,7% of the interviewed uses a car at least 1 day per week and 41 % utilizes every day. From the people that do not have a car, 96,3 % says that if had a car they would utilizes less than 40 km per day. From the people that have a car 72 % utilizes less than 40 km per day. From the interviewed people only 13 utilizes a riding service, such as Uber or Taxi for more than 20 km representing 5,3 % of the interviewed. From the 271 people, 95,6 % says that the **PRICE** of the car have a **HIGH** influence when buying, 87,1 % **ECONOMY**, 86% **COMFORT**, 80,4 % **SAFETY**, 76,5 % **DESIGN** and 69,3 % **RANGE**. From the interviewed, 88,2 % of then says that would buy or already have an electric car, being the pollution and the price of the fuel the two major reasons for that.

Table 7 summarises the analysed data, with the average score per factor and the level of influence.

Table 7 - Summary of purchase influence by factor (APPENDIX A: Survey)

	Average Score (1 to 10)	HIGH Influence (%)	MEDIUM Influence (%)	LOW Influence (%)
DESIGN	7,3	76,4	15,1	8,5
PRICE	9,1	95,6	3,3	1,1
COMFORT	8,0	86,0	11,8	2,2
ECONOMY	8,2	87,1	9,6	3,3
SAFETY	8,0	80,4	13,7	5,9
RANGE	7,2	69,4	19,6	11,1

Analysing the data, most of the interviewed uses cars weekly and the main reason for the purchase is the price. So the car need to be **CHEAP**, the second biggest reason is the **ECONOMY** of the car, third **COMFORT**, fourth **SAFETY**, fifth **DESIGN** and last **RANGE**.

5.3 Solution aims

With the analysed data and taking into account the chapter 3, Problem Characterization, can be concluded that the car needs to be cheap, environment friendly, safe, easy to park, with a compatible range for the average usage, comfortable, small and that could be used for most of the population possible.

Thinking about that, this concept should have some limitations, some due to regulations and characterization of the vehicle and some due to the aim of the project.

- Price below 15000,00 €/€/\$
- Simple
- Electric
- Small
- Lightweight
- Adaptive

5.3.1 Price

As was verified in the Survey, the prices of the vehicle have the most important factor in the buying decision, 95,2 % consider that price have a high influence in the purchasing decision. Therefore, to be able to compete with the ICEV (Internal Combustion Engine Vehicle), the BEV (Battery-powered electric vehicle) needs to be as cheap as possible, considering the higher cost of production compared to an ICEV.

5.3.2 Simple

In order to fulfil all the criteria in the list, the car needs to be as simple as possible, and thinking in the production scale, as steady as possible in the different versions.

There are mainly two ways to build a car chassis, the body on a frame or the unibody as presented in Figure 14. Most of the modern cars nowadays use the unibody chassis, due to the lighter weight of it, the exception are some pickup trucks and bigger vehicles.

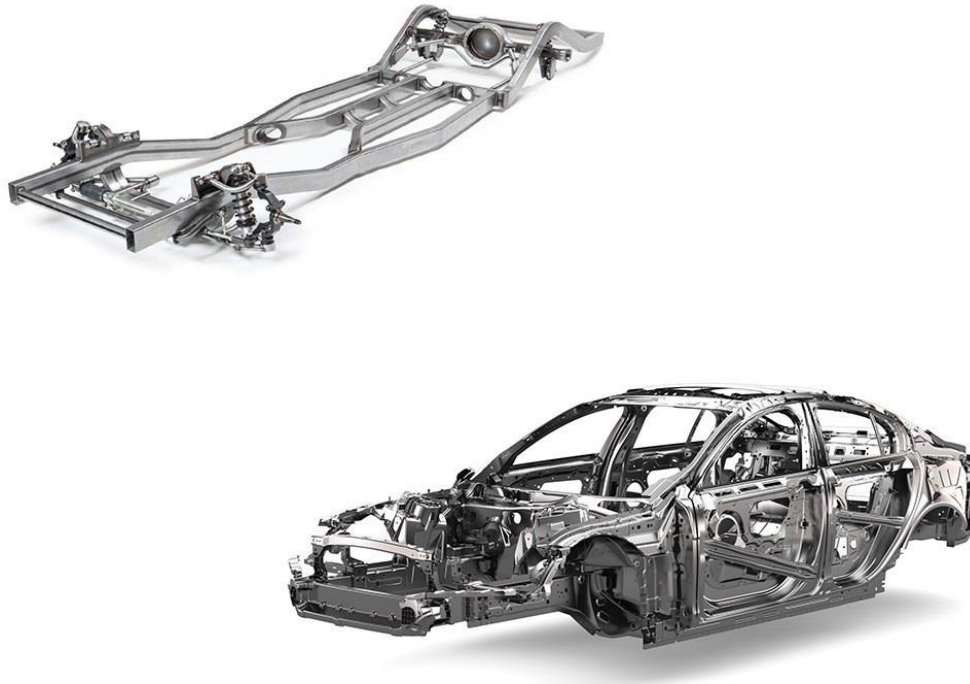


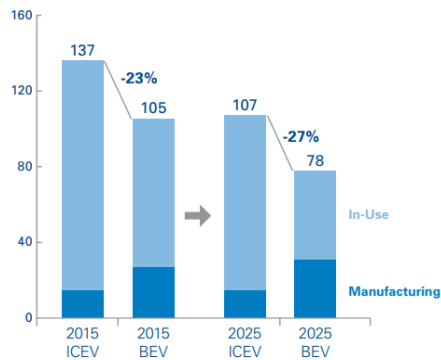
Figure 14 - Comparison of a frame and a unibody car (Infoupdate s.d.)

The unibody have the advantage of a lighter weight but is more complex to build, so in the initial phase of the construction the car will have a body on frame design.

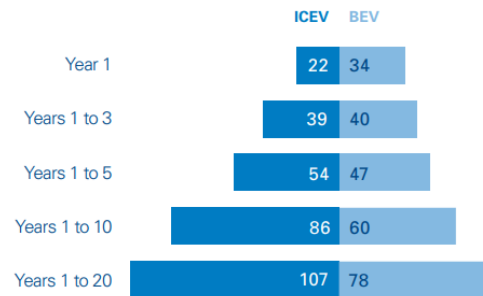
5.3.3 Electric

As seen in chapter 3.1, Pollution, the transportation sector has a great influence in the emissions of pollutant gases and, besides the BEV manufacturing and replacement of batteries produces more CO₂, the production of CO₂ over the lifetime of an electric car is lower than the ICEV. The report Battery Electric Vehicles vs. Internal Combustion Engine Vehicles (Arthur D Little 2016), shows that a BEV will produce 23% less CO₂ in a 20 years life time usage with a total of 241096 km travelled over that period of time. In 2025, it is expected this difference to be 27%. For a compact car the break-even point for the Emissions is around 3 years, after that the BEV is less pollutant.

In Graph 7, the Emissions of CO₂ from a Compact Passenger ICEV Compared to an Equivalent BEV, 2015 versus 2025 (Thousands of Pounds of CO₂ Emissions) can be verified. In Graph 8, it is seen the GWP (Global Warming Potential) Emissions from a 2025 Compact Passenger ICEV versus an Equivalent BEV at Different Stages of Vehicle Life (Thousands of Pounds of CO₂ Emissions).



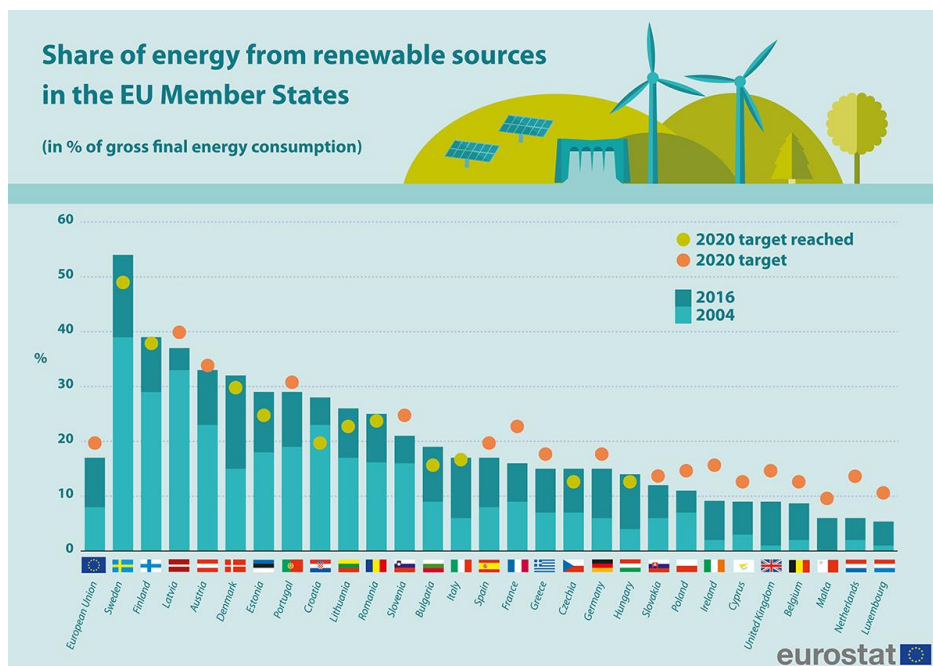
Graph 7 - Emissions of CO₂ ICEV vs BEV, 2015 vs 2025 (Arthur D Little 2016)



Graph 8 - GWP Emissions from a 2025 ICEV vs BEV during Vehicle Life (Arthur D Little 2016)

This analysis aligns with the survey, because only 11,8 % of the interviewed said that would not buy an electric car. From the 271 interviewed, 68,7 % said that pollution was a motive to buy an electric car, only 17,7 % said that the modernity was the reason, showing that the interviewed are aware of the dispersion of pollutant gases in the combustion engines.

This emission analysis was made for the United States production of energy model. That is based in the Fossil fuels, 63,5 % of the production of energy in the United States is based in fossil fuels (U.S. Energy Information Administration 2019), in Sweden, for example, the share of energy from renewable sources is over 50 % (Eurostat 2019) as presented in Graph 9.



Graph 9 - Share of energy from renewable sources by EU member (Eurostat 2019)

So, if the production of energy changed to a more renewable source, the electric car become even less pollutant then an ICEV.

5.3.4 Small

To be able to fit in small parking slots, be easily maneuvered and fit in the Microcar regulation, the car need to be small and lightweight. A small car is easier to be maneuvered, fits in tighter parking spots and with the smaller distance between the axis of the car, the turning radius of the car is smaller, making easier to be maneuvered.

Utilizing the Ackerman geometry, Figure 15, the turning radius can be simplified with the Ackerman Steer Angle (δa) - The angle whose tangent is the wheelbase divided by the radius of the turn (SAE 1952).

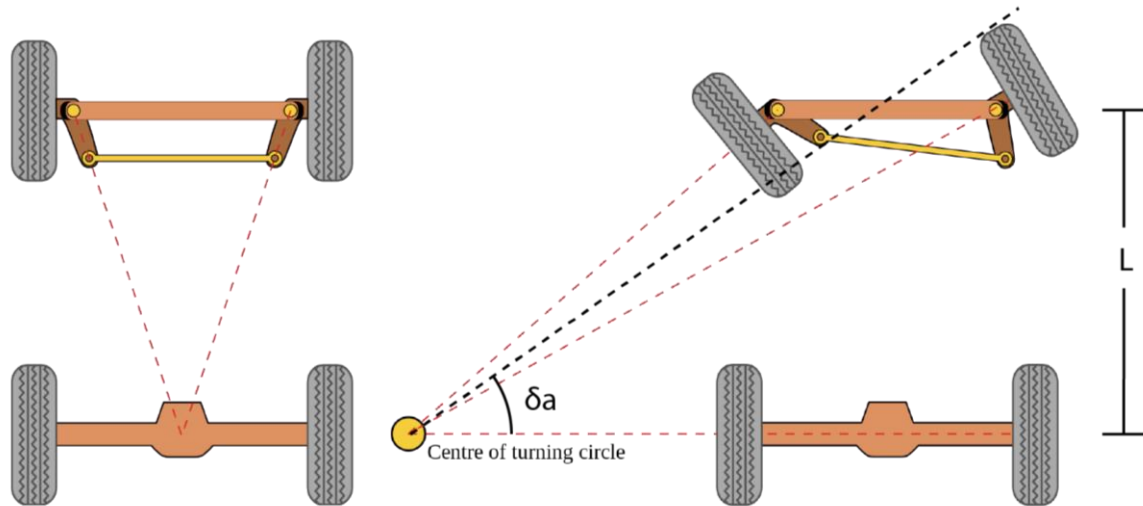


Figure 15 - Ackerman steering geometry (Wikipedia s.d.)

To calculate the turning radius of the vehicle are needed the distance between the front and rear wheels axis and the turning angle of the wheels.

$$\tan(\delta a) = L/R \quad (2)$$

$$R = L/\tan(\delta a)$$

Therefore, the turning radius only depends on the turning angle of the wheels and the distance between front and rear axis.

5.3.5 Lightweight

To be adequate to the Microcars European legislation and have a good performance due to a limited power, the car needs to be as light as possible. To be a Microcar, the car needs to be lighter than 425 Kg in the L6eBP category and 450 kg in the L7eCP excluded the batteries. (Regulation (EU) no 168/2013 of the European parliament and of the council of 15 January 2013).

The top speed, acceleration, range and power of the required motor depends directly with the weight of the car, the lighter the better.

5.3.6 Two-seat car

As can be seen in *The Impact of Parking Pain in the US, UK and Germany* report (INRIX Research 2017), the average car occupancy for all the analysed scenarios is less than two occupants, Table 8.

Table 8 – Car occupancy by country by trip type (INRIX Research 2017)

COUNTRY	CAR OCCUPANCY (driver + passengers)		
	COMMUTING	BUSINESS TRAVEL	OTHER TRIPS
U.S.	1,13	1,94	1,94
U.K.	1,2	1,8	1,8
Germany	1,2	1,8	1,8

5.3.1 Adaptive

To be able to serve most of the population the vehicle should be able to adapt to the consumer needs. These adaptations can be in size, performance, range, capacity of passengers and cosmetic adaptations.

Size adaptation

With an extendable frame and chassis, it is possible to adapt the size of the vehicle. This extension could use the same electric motor of the car in a threaded rod screw-nut assembly, being able to auto block the extension or could use a hydraulic pump and a piston. Figure 16 shows a concept of an extendable car.



Figure 16 – Concept of extendable car (Antonelli 2012)

With the size adaptation, it is possible to fit more than two seats, permitting a car with 3 or 4 seats, or a larger trunk.

Driver adaptation

Due to the regulation, the L6eBP have a limit of 6 kW and L7eCP a limit of 15 kW. If the vehicle is able to recognize the driver using an ID reader or fingerprint reader, these limits could adapt to the driver limitations. Hence, a person that is able to drive a normal car, the car would give the full potential of the motor, if the person has only the license to drive an L6eBP or L7eCP models, the car would only give the amount of power permitted in these categories, 6 and 15 kW respectively.

Also within the regulation, it is limited the size of the vehicle. So, identifying the Driver, the car could be bigger than $L=3\text{ m}$ $W=1,5\text{ m}$ $H=2,5\text{ m}$ and $L=3,7\text{ m}$ $W=1,5\text{ m}$ $H=2,5\text{ m}$ dimensions of the L6eBP or L7eCP models respectively as presented in Figure 17.

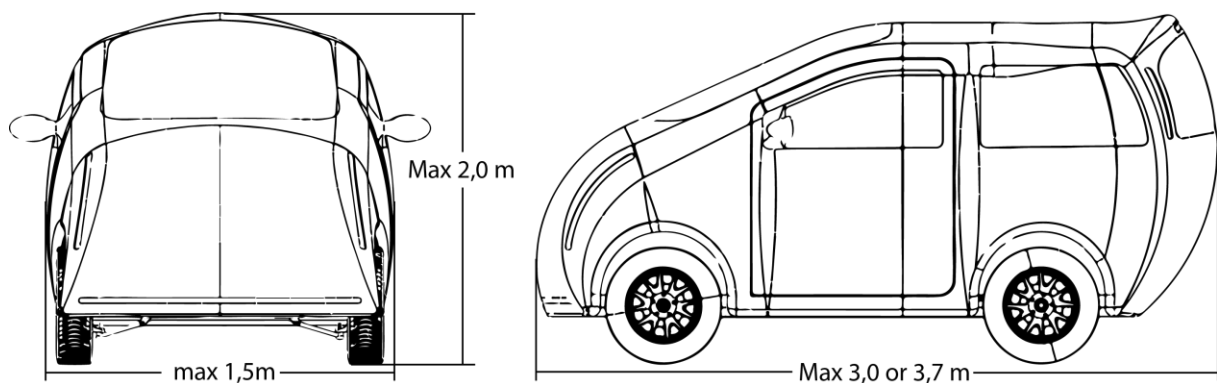


Figure 17 - Maximum dimensions for L6eBP or L7eCP models

Range adaptation

The adaptation of the range can be done in two ways: limiting the power of the motor or adding more batteries to the car. The limitation of the power/speed of the car has a big impact in the range, since the biggest force that the car need to surpass in order to keep going is the drag force; this force depends on the shape of the car and the square of the speed of the car.

6 Solutions

Considering the chapter 5, Project Analysis, a Moodboard was created. The Moodboard is an initial search for the form and colours of the project as presented in Figure 18.

Moodboard



Figure 18 - Moodboard

1 - The ladybug represents the organic and green aspect of the project (National Geographic 2019).

2 - The egg represents the beginning of the project, and represents the shell that will protect the users of the car (Gray Ridge 2018).

3 - The Nissan Twizy is an electric car considered a microcar (Nissan 2010).

4 - The smart fortwo is a very successful small car (2011 Smart ForTwo Passion Coupe 2011).

After the moodboard, an analysis of the Microcar Market was made.

Microcar market analysis

The Microcar market, as was presented in chapter 2.3, European Microcars, has currently solid sales. In Europe, there are three main brands of Microcars: Aixam, Microcar and Ligier, the last two ones joined, in 2008, to create the Ligier Group. The cheapest and most expensive options of cars from each brand will be presented for the current Microcar market.

The Aixam brand starts at €9657,00 for the cheapest version Minauto Access, Figure 19, up to €15050,00 for the most expensive Crossover Premium Figure 20, all the prices for the Portuguese Market accessed in 5th of June 2019. Both have the same 2-cylinder motor; they differentiate in the design, safety features and accessories. Both offer two years of warranty and are inserted in the L6eBP category.



Figure 19 - Aixam Minauto Access (Aixam 2019) **Figure 20 - Aixam Crossover Premium (Aixam 2019)**

The Ligier brand has a more premium approach with cars from €12299,00, for the model JS50 Progress Club, Figure 21, to €15598,00 for the model JS50L DCI Sport Ultimate, Figure 22. Both offers 3 years of warranty and are inserted in the L6eBP category.



Renseignements auprès de votre centre expert agréé. Option valeur 349 € TTC hors

Figure 21 - JS50 Progress Club (LigierGroup 2019)



microbox

Figure 22 - JS50L DCI Sport Ultimate (LigierGroup 2019)

The Microcar brand have the more popular approach with cheaper prices, the DUE5 Progress Initial starts at €7999,00, Figure 23, up to €13698,00 for the MGO5 DCI HIGHLAND X, Figure 24. Both offers 3 years of warranty and are inserted in the L6eBP category.



Renseignements auprès de votre centre expert agréé. Option valeur 349 € TTC hors

Figure 23 - DUE5 Progress Initial (LigierGroup 2019)



Renseignements auprès de votre centre expert agréé. Option valeur 349 € TTC hors

Figure 24 - MGO5 DCI HIGHLAND X (LigierGroup 2019)

The Table 9 shows the cars specifications and is possible to verify that these cars are very similar in the compared aspects.

Table 9 – Specifications of selected vehicles

Car Model	Motor	Number of seats	Lenght (mm)	Width (mm)	Weight (kg)	Range (km)	Economy (l/100km)
Aixam Minaouto ACESS	Diesel	2	2759	1500	425	500	3,1
Aixam Crossover Premium	Diesel	2	3000	1500	425	500	3,1
JS50 CLUB Progress	Diesel	2	2890	1500	420	486	3,6
JS50L DCI Sport Ultimate	Diesel	2	3000	1500	425	486	3,6
DUE5 Progress Initial	Diesel	2	2870	1500	400	486	3,6
MGO5 DCI HIGHLAND X	Diesel	2	2870	1500	420	486	3,6

Another company that is entering in the market of the small cars is the Micro Mobility, with the model Microlino, Figure 25. It is an electric car that starts at €12150,00 with the standard range of 125 km up to €17450,00 with the extended range of 200 km and all the accessories. The Microlino is not inserted in the L6eBP category.



Figure 25 – Microlino (Micro Mobility 2019)

Analyzing the Microcar market, the price of these vehicles goes from €7999,00 to €15598,00. This project intends to be in the same range of prices.

Car concept

After the Moodboard and market analysis, some sketches were made searching for the basic shape of the car. The car conceived to be as simple as possible for a cheaper manufacturing and a lighter car. Therefore, a three wheeled vehicle was initially sketched, Figure 26.



Figure 26 - Sketches of a three wheeled car

For reduced weight and better performance, the car is projected with a double wishbone suspension in the front and a motorcycle type of suspension in the back, having a tubular steel frame for cheaper manufacturer and lighter result.

The 3D process started with the steel tubular frame, with the dimensions of the L6eBP category and with space for two seats, because of the results presented in Table 8.

In Figure 27, the initial tubular steel body frame with the front wheels and double wishbone suspension is presented.

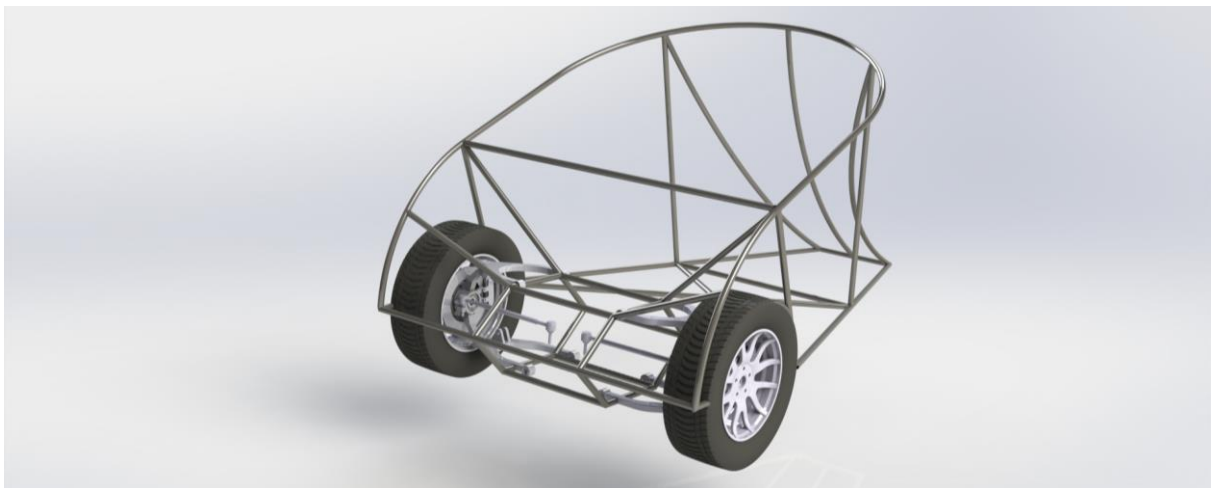


Figure 27 - First Designed Tubular Frame

After positioning the two seats, the driver and passenger, some adaptations in the frame were made in order to fit the two seats and passengers comfortably, Figure 28.

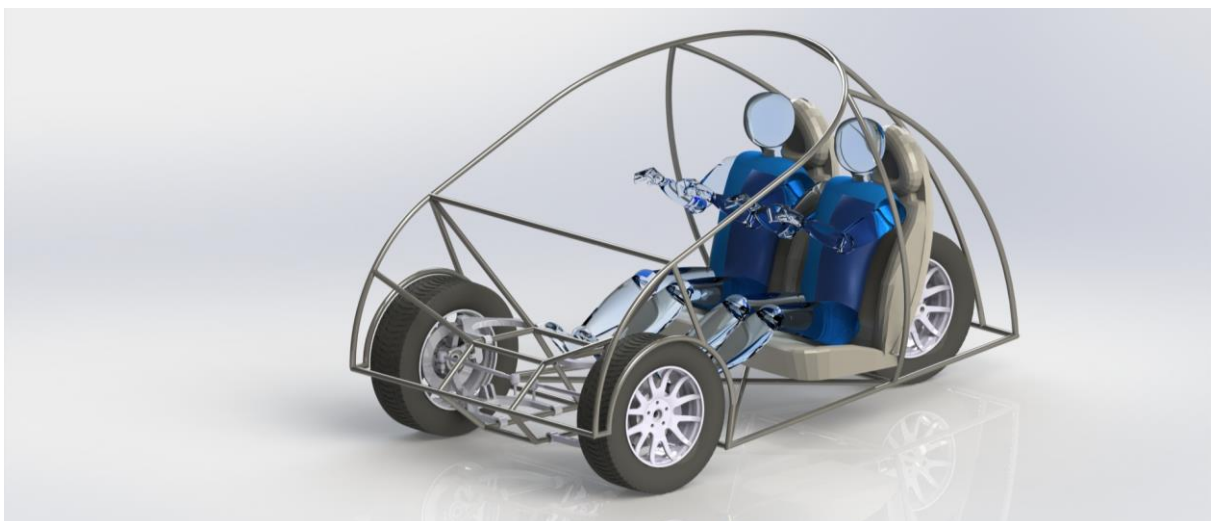


Figure 28 - Second Design of Tubular Frame with passengers

After the Design of the Tubular frame, the car fairing was designed. Firstly, the surfaces of the frame were connected forming the form presented in Figure 29.



Figure 29 - First design of car fairing

After this first form, the frame and fairing were modified for a more appealing design; other details like the door and side glasses were added, the shapes were more rounded having a more cohesive design. The result is in Figure 30.

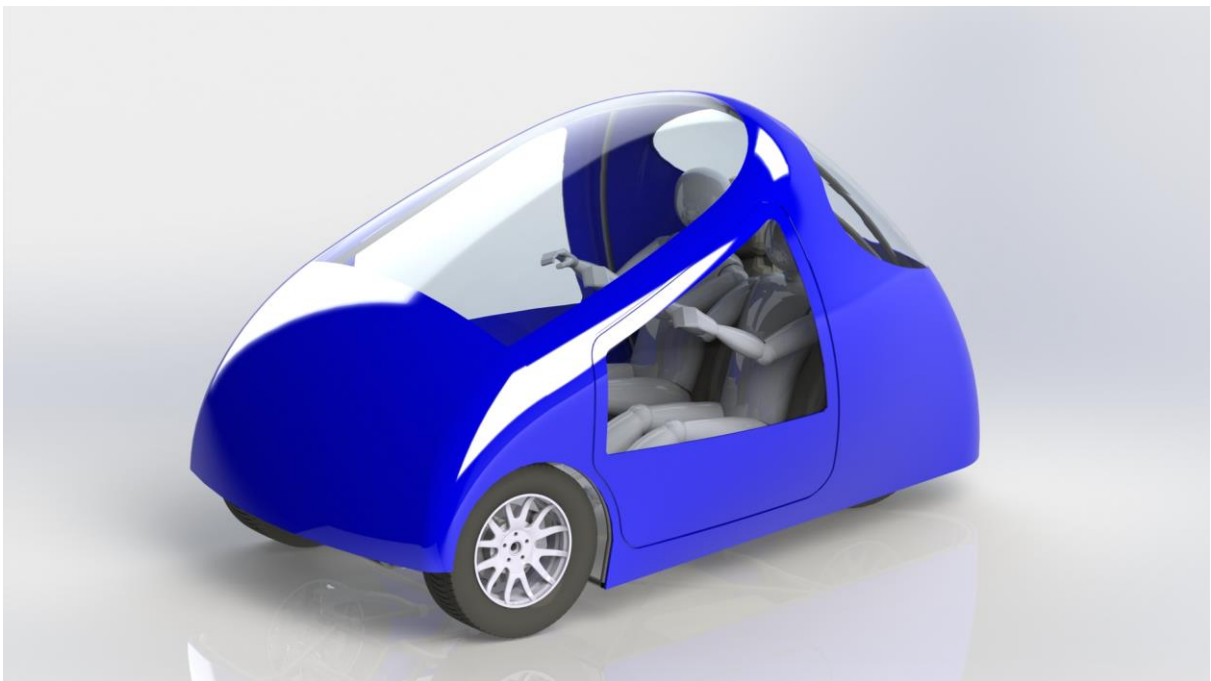


Figure 30 - Improvement of the fairing

After those improvements, the fairing and frame were again improved and all the other details like turn signals, brake light and headlamp were added. The results are in Figure 31 to Figure 34.



Figure 31 - View from the back-right of the vehicle



Figure 32 - View from the left side of the vehicle

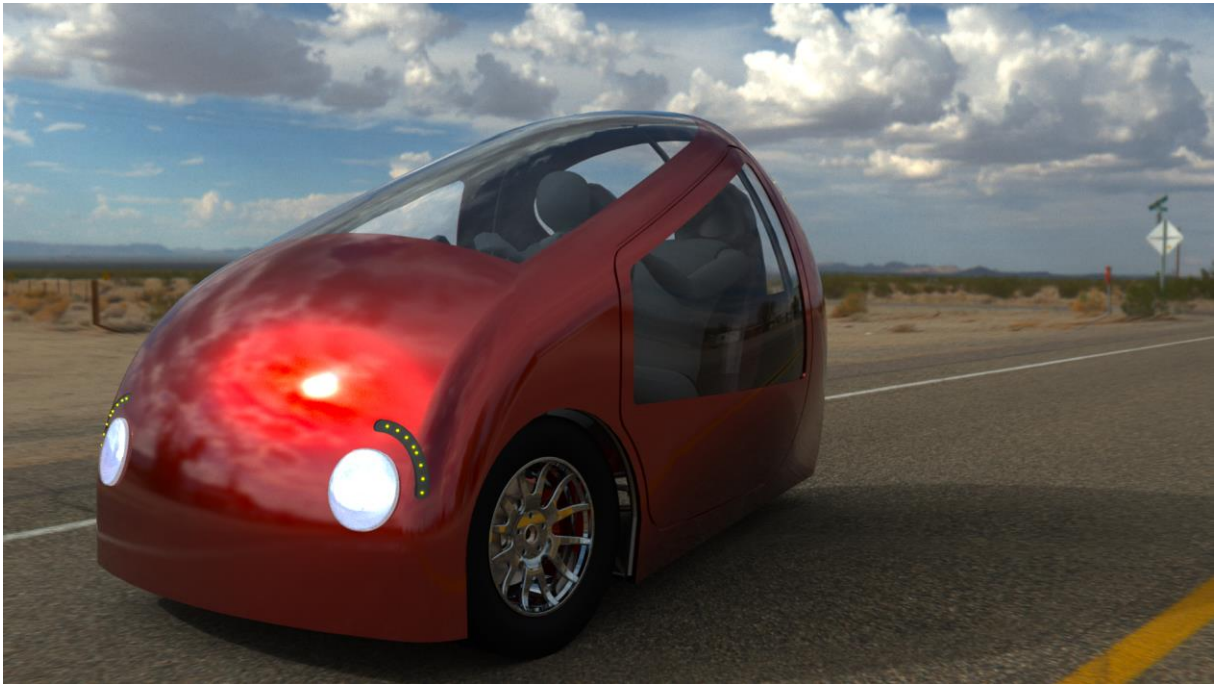


Figure 33 - View from the front-left of the vehicle

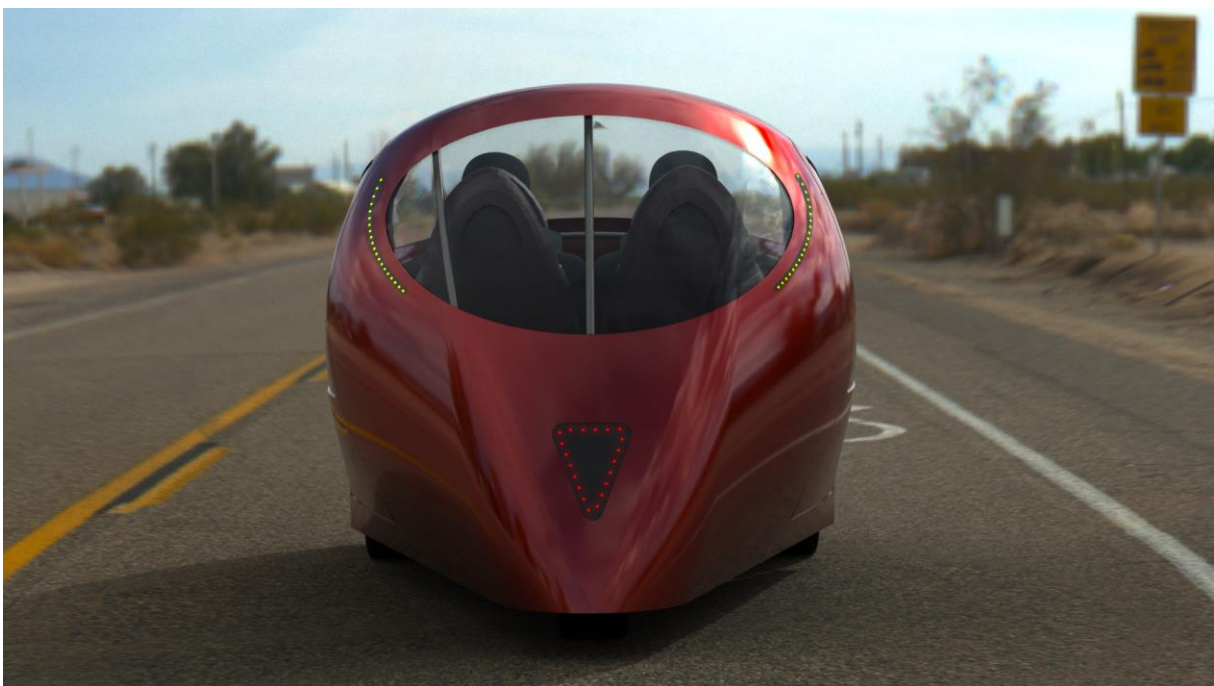


Figure 34 - View from the back of the vehicle

Utilizing a feature from Solidworks, Figure 35, the weight of the vehicle was calculated. This value does not consider the electrical motors neither battery, is a simplified analysis to verify if it was possible to design a car with less than 425 kg.

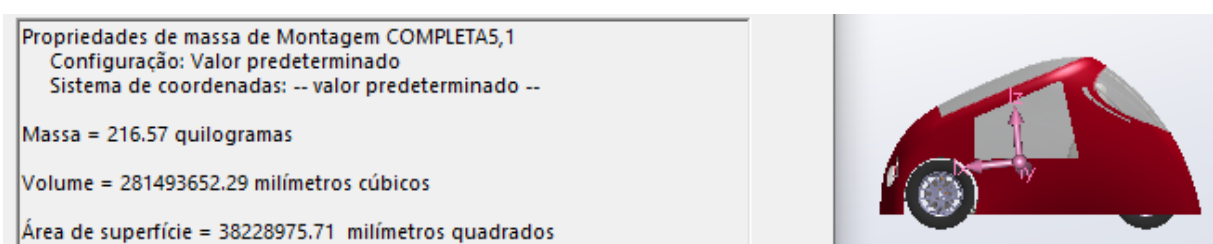


Figure 35 – Simplified analysis of car weight

Calculation of implied forces

As the car is electrical, the batteries needed dimensioning for the usage in the car. Firstly, a simulation of the airflow was made in Solidworks to determine the Drag force, Figure 36, Figure 37 and Table 10. Then, the other forces applied in the car were calculated, so the quantity of batteries could be selected.

6.1 Drag analysis

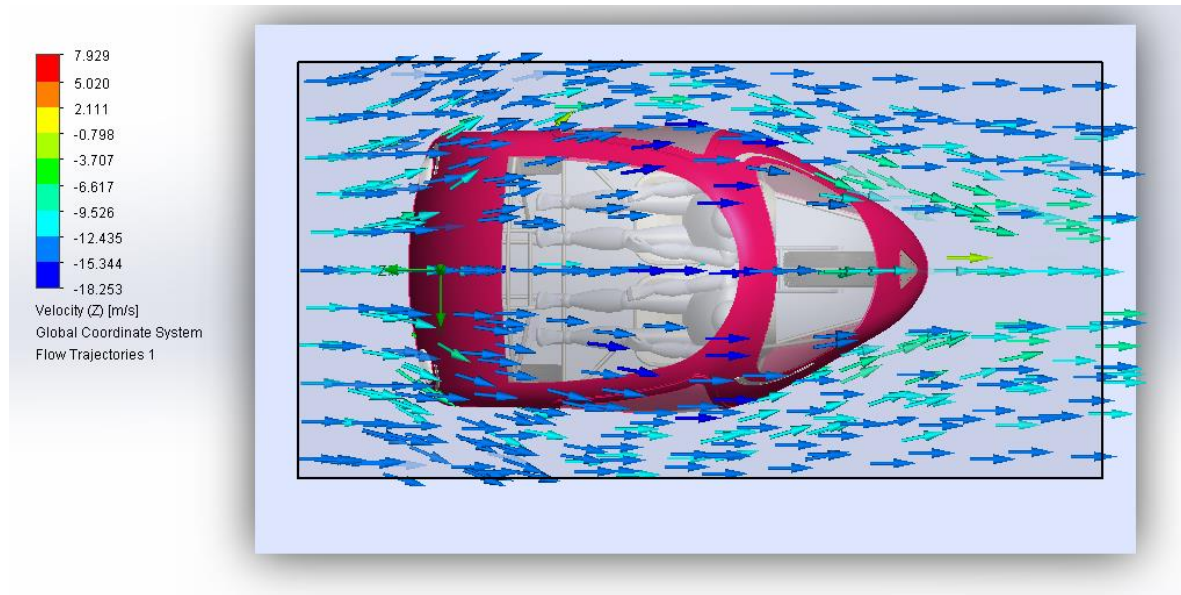


Figure 36 - Upper view of wind displacement analysis at 45km/h (12,5 m/s)

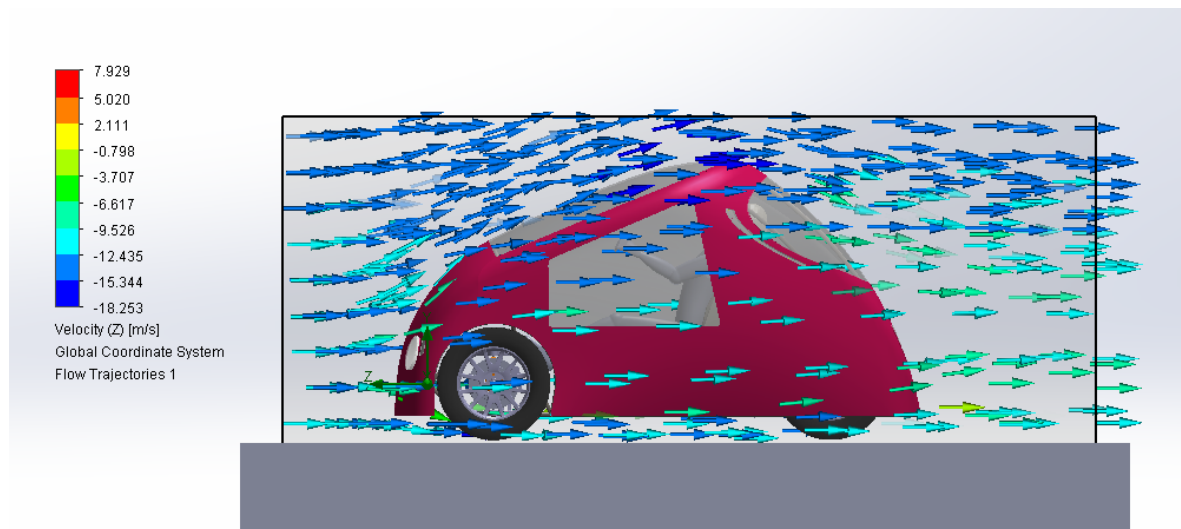


Figure 37 - Side view of wind displacement analysis at 45km/h (12,5 m/s)

Table 10 - Drag analysis result from SolidWorks

Drag Analysis		
Goal Name	Unit	Averaged Value
Drag force at 45 km/h	[N]	110
Drag force at 90 km/h	[N]	440

6.2 Rolling resistance force

The second analysed force was the rolling resistance, which is relevant to calculate the amount of force generated by the rolling of the tires against the floor.

The rolling resistance can be expressed as:

$$Fr = c * W \quad (3)$$

Where

Fr = rolling resistance force or rolling friction (N)

c = rolling resistance coefficient

$W = m * ag$

W = normal force – or weight – of the body (N)

m = mass of body (kg)

ag = acceleration of gravity (9,81 m/s²)

In Table 11 are presented the values of the rolling resistance coefficient in several conditions. The values of the rolling resistance coefficient depend on the tire/wheel and the type of track that the vehicle is installed.

Table 11 - Rolling Resistance Coefficient of different tires and pavements (Engineering ToolBox 2015)

Rolling Resistance Coefficient	Condition
0,001 – 0,002	railroad steel wheels on steel rails
0,001	bicycle tire on wooden track
0,002 – 0,005	low resistance tubeless tires
0,002	bicycle tire on concrete
0,004	bicycle tire on asphalt road
0,005	dirty tram rails
0,006 – 0,01	truck tire on asphalt
0,008	bicycle tire on rough paved road
0,01 – 0,015	ordinary car tires on concrete, new asphalt, cobbles small new
0,02	car tires on tar or asphalt
0,02	car tires on gravel – rolled new
0,03	car tires on cobbles - large worn
0,04 – 0,08	car tire on solid sand, gravel loose worn, soil medium hard
0,2 – 0,4	car tire on loose sand

6.3 Rolling coefficients for cars

As presented in Table 11 the rolling resistance coefficient, depend on the road and tire conditions. For a more precise measurement in a car analysis, this value can be calculated with the speed of the car and the tire pressure. The rolling coefficients for air-filled tires on dry roads can be calculated as (Sastry e S.V.Y.Sastry 2013):

$$c = 0,005 + (1 / p) (0,01 + 0,0095 (v / 100)^2) \quad (4)$$

Where

c = rolling coefficient

p = tire pressure (bar)

v = velocity (km/h)

The rolling coefficient of the project car can be calculated:

Taking into account the tire pressure of 32 PSI or 2,2 bar and the speed of 45km/h

$$c = 0,005 + (1/2,2)(0,01 + 0,0095 (45/100)^2)$$

$$c = 0,01042$$

Taking into account the tire pressure of 32 PSI or 2,2 bar and the speed of 90km/h

$$c = 0,005 + (1/2,2)(0,01 + 0,0095 (90/100)^2)$$

$$c = 0,01304$$

Calculating the rolling resistance force for a 650kg car (450kg car + 150kg passengers + 50kg of batteries):

$$Fr = 0,01042 * 650 * 9,81$$

$$Fr = 66,44 \text{ N}$$

Calculating the rolling resistance force for a 750kg car (450kg car + 150kg passengers + 150kg of batteries):

$$Fr = 0,01304 * 750 * 9,81$$

$$Fr = 95,96521 \text{ N}$$

Table 12 – Rolling coefficient and rolling resistance for the selected situations

	650 kg 45km/h car	750 kg 90km/h car
Rolling coefficient	0,01042	0,01304
Rolling resistance force (N)	66,4	96,0

6.4 Calculation of batteries

For the calculation of the batteries, six different situations will be analysed. Round trip from Porto to Coimbra and the European and USA (United States of America) average trips for both the L6eBP and L7eCP vehicles.

Considering the average of 252 working days (Working days in Portugal 2019) and the data in chapter 3.4, Range, the average daily distance travelled in Europe was 47,6 km and in USA 85,6 km.

For calculating the total energy needed to go from A to B, we used the following parameters: speed, drag resistance, roll resistance, potential energy and accessory use.

The speed for this calculation would be the max speed of the L6eBP and L7eCP vehicles, 45 km/h and 90 km/h respectively. The drag resistance depends on the speed and the distance can be calculated multiplying the values of the Table 10 by the distance. The Roll resistance is also depending on the speed and the distance and can be calculated multiplying the values of the rolling resistance of Table 12 to the distance, The potential energy is calculated considering 77,5 % of regeneration. The accessory usage is considering a medium use of power, 0,5 kWh.

6.4.1 Drag resistance

The Drag resistance depend on the Drag force and the travelled distance:

Drag force at 45km/h is 110 N

Drag force at 90km/h is 440 N

The Drag resistance can be calculated using the following formula:

$$Dr = Df * d * fc \quad (5)$$

Where

Dr = Drag resistance in kWh

Df = Drag Force in N

d = distance in m

fc = factor of conversion from N*m to kWh = $1/(3600*1000)$

Therefore, the drag Resistance in kWh for a certain route can be calculated, Table 13.

Table 13 – Drag Resistance in kWh for the selected distances and speeds

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	US average 85,6 km
Drag resistance for 45km/h in kWh	7,7	1,5	2,6
Drag resistance for 90km/h in kWh	31,1	5,8	10,5

6.4.2 Rolling resistance

Similar to the calculation of Drag resistance is the calculation of Rolling resistance in kWh:

Rolling resistance force at 45 km/h and 650 kg car is 66,4 N

Rolling resistance force at 90 km/h and 750 kg car is 96,0 N

The Rolling resistance can be calculated using the following formula:

$$Rr = Rf * d * fc \quad (6)$$

Where

Rr = Rolling resistance in kWh

Rf = Rolling resistance Force in N

d = distance in m

fc = factor of conversion from N*m to kWh = $1/(3600*1000)$

The Rolling Resistance in kWh for a certain route and weight is in Table 14.

Table 14 – Roll resistance in kWh for the selected distances and speeds

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Rolling resistance for 650 kg car at 45km/h in kWh	4,7	0,9	1,6
Rolling resistance for 750 kg car at 90km/h in kWh	6,7	1,3	2,3

6.4.3 Potential energy

From Porto to Coimbra, there is an upslope of 1120 m and a downslope of 1168 m (Ecalc s.d.). For EU, it would be used a 200 m upslope and downslope. And USA 300 m for upslope and downslope, the efficiency in the regeneration would be 77,5 %.

$$Pe = w * h * fc \quad (7)$$

Where

Pe = Potential Energy in kWh

h = the Slope in m

fc = factor of conversion from N*m to kWh = $1/(3600*1000)$

The Potential Energy in kWh is shown in Table 15:

Table 15 – Potential Energy in kWh

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Potential Energy for 650 kg car in kWh	0,9	0,1	0,1
Potential Energy for 750 kg car in kWh	1,3	0,1	0,2

6.4.4 Accessories energy

The accessory usage depend upon the time of usage and intensity of use, consequently the distance, speed and average accessory usage, for these calculations the use would be 0,5 kW.

$$Au = Iu * t \quad (8)$$

Where

Au = Accessory Usage in kWh

Iu = Intensity of accessory use in kW (in this case 0,5 kW)

t = time of usage in hours

$t = d/(v*1000)$

So, the Accessory Use in kWh can be calculated, Table 16:

Table 16 – Accessory Use in kWh

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Accessory Energy for 45km/h car in kWh	2,8	0,5	1,0
Accessory Energy for 90km/h car in kWh	1,4	0,3	0,5

6.4.5 Total energy use:

The Total Energy Use can be calculated summing all the Energy contributions:

$$Te = Dr + Rr + Pe + Au \quad (9)$$

Where

Te = Total Energy in kWh

Dr = Drag resistance in kWh

Rr = Rolling resistance in kWh

Pe = Potential Energy in kWh

Au = Accessory Usage in kWh

So, the Total Energy Use in kWh can be calculated, Table 17:

Table 17 – Total energy use in kWh for selected speeds and distances

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Total energy Use for 650 kg car at 45km/h in kWh	16,1	2,9	5,3
Total energy Use for 750 kg car at 90km/h in kWh	40,6	7,5	13,4

Considering the values of Table 13 to Table 17, one can calculate the percentage relative to the total energy expenditure, Table 18.

Table 18 - Percentage of use per factor per trip

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Drag resistance for 45km/h in % of the total	48%	49%	50%
Drag resistance for 90km/h in % of the total	77%	78%	78%
Rolling resistance for 650 kg car at 45km/h in % of the total	29%	30%	30%
Rolling resistance for 750 kg car at 90km/h in % of the total	17%	17%	17%
Potential Energy for 650 kg car in % of the total	6%	3%	2%
Potential Energy for 750 kg car in % of the total	3%	2%	2%
Accessory Energy for 45km/h car in % of the total	17%	18%	18%
Accessory Energy for 90km/h car in % of the total	3%	4%	4%
Total:	100%	100%	100%

Selecting the battery model, the weight of these battery packs is calculated. For the Panasonic NCR18650B (SANYO Energy Corporation 2012) model, with a gravimetric energy density of 243 Wh/kg the weight of the battery packs in kg is, Table 19:

Table 19 – Weight of battery packs for selected speeds and distances in kg

	Porto – Coimbra round trip 252,8 km	EU average 47,6 km	USA average 85,6 km
Battery weight for 650 kg car at 45km/h in kg	66,3	12,1	21,7
Battery weight for 750 kg car at 90km/h in kg	167,1	30,8	55,2

As some factors of the calculation depends upon the weight of the car, and this weight depends upon the quantity of batteries, another analysis can be made, taking into account the variable weight of the batteries and, consequently, the car. So, the range for a variable weight can be calculated: considering a base weight of the car plus passengers as 600 kg the range of the car, varying with the capacity of the battery pack and, consequently, its weight, Table 20.

Table 20 – Range in km of a 600 kg car at selected speeds and battery packs capacities

Battery pack Capacity in kWh	Range at speed of 45km/h in km	Range at speed of 90km/h in km
10	167,0	66,4
20	327,7	131,6
30	482,2	195,5
40	631,1	258,1
50	774,6	319,7
60	913,0	380,0

With the quantity of batteries needed, the cost analysis of the car can be made.

6.5 Cost analysis of first solution

The Body frame is made of 51 tubes, the indicative of each tube, the respective length, and cutting angles can be verified in APPENDIX B: Technical Drawings and Table lists. For producing each car, it is necessary 37,1 meters of tube, Solidworks estimates the cost of the chassis as €382,57, utilizing the process of cutting, bending and soldering the tubes. In Figure 38, the estimative of the steel frame cost is presented.

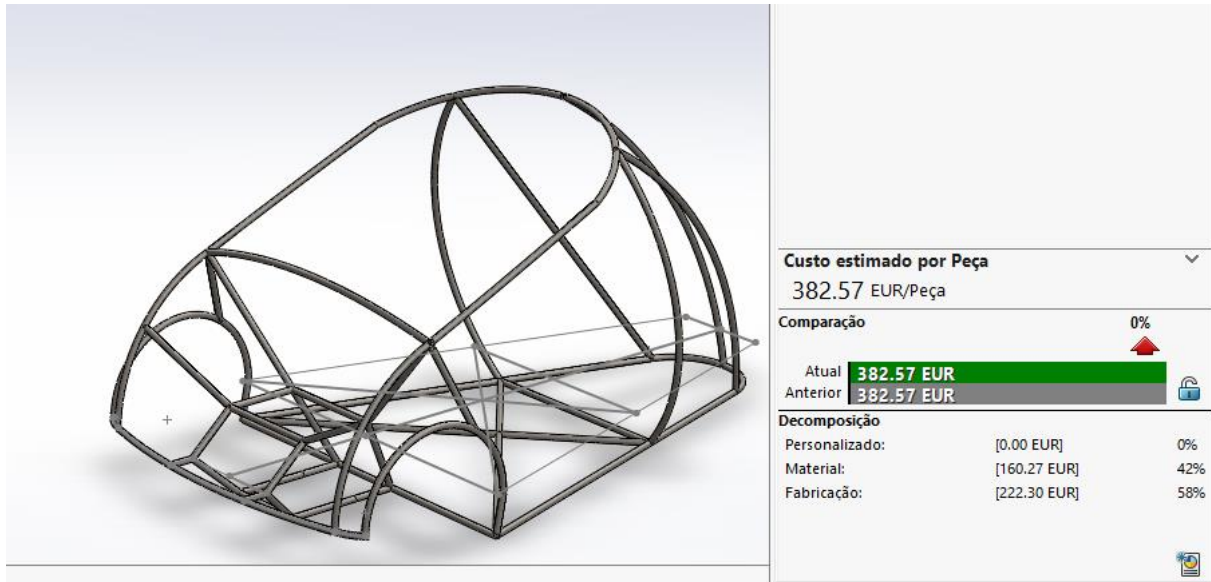


Figure 38 - Body frame made of 1020 steel

For the price calculation of cast iron parts, the data from CES EduPack was accessed, the price of cast iron was verified and varies from 0,35 to 0,95 EUR/kg. For a conservative calculation, it was considered the price of 1 EUR/Kg of the cast iron, the price of the mold was 1000 per piece, in a batch of 100 units. The pieces made of cast iron are in Figure 39 to Figure 43 utilizing the process of casting.

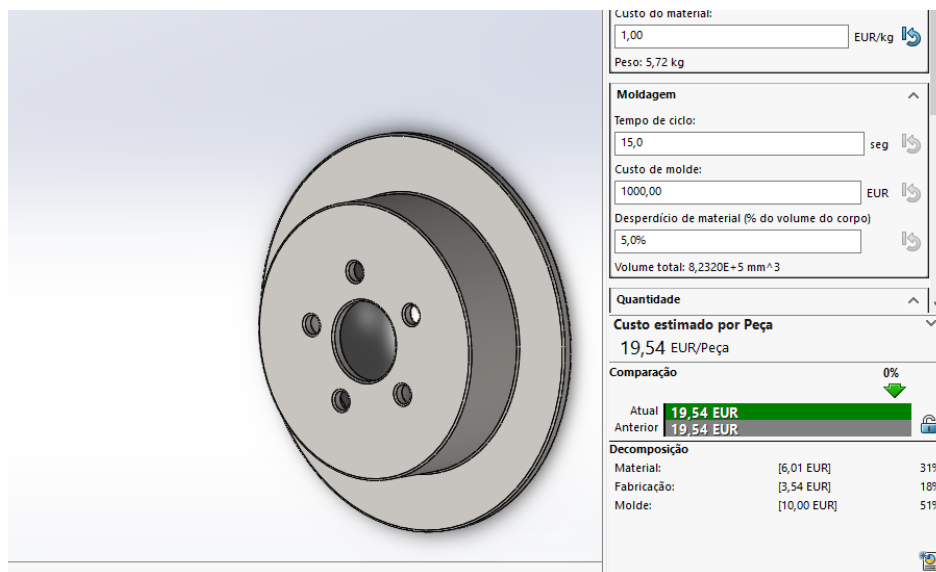


Figure 39 - Cast iron disk brake

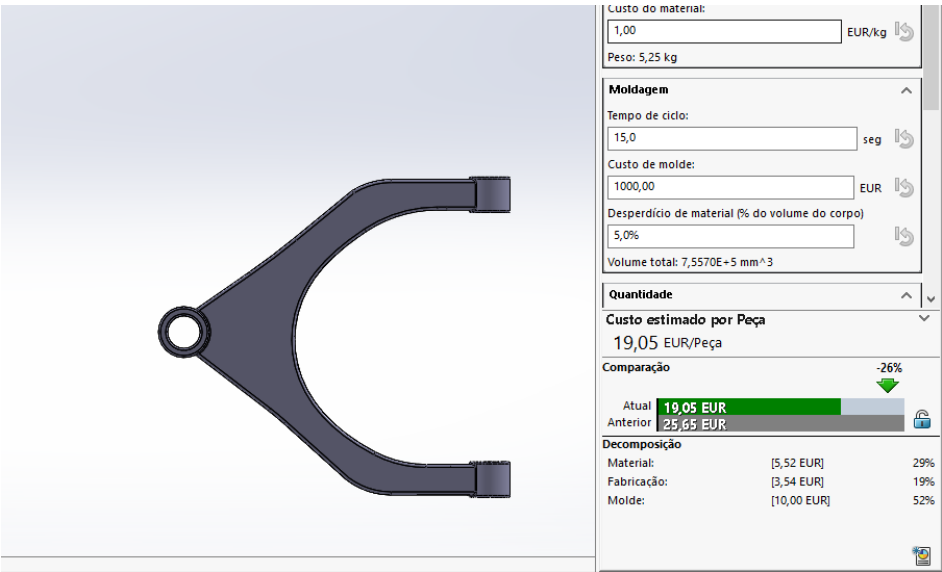


Figure 40 - Cast iron upper arm

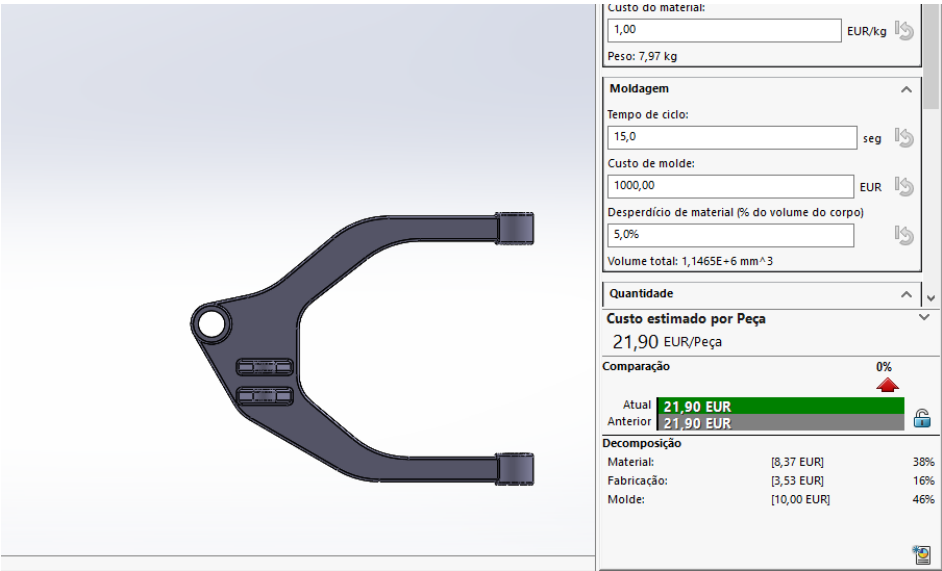


Figure 41 - Cast iron lower arm

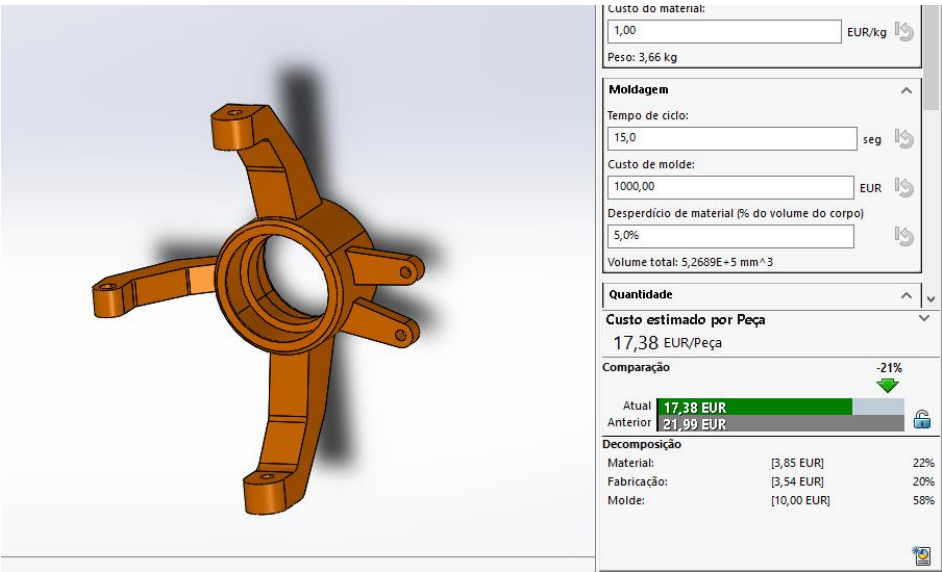


Figure 42 - Cast iron steering knuckle

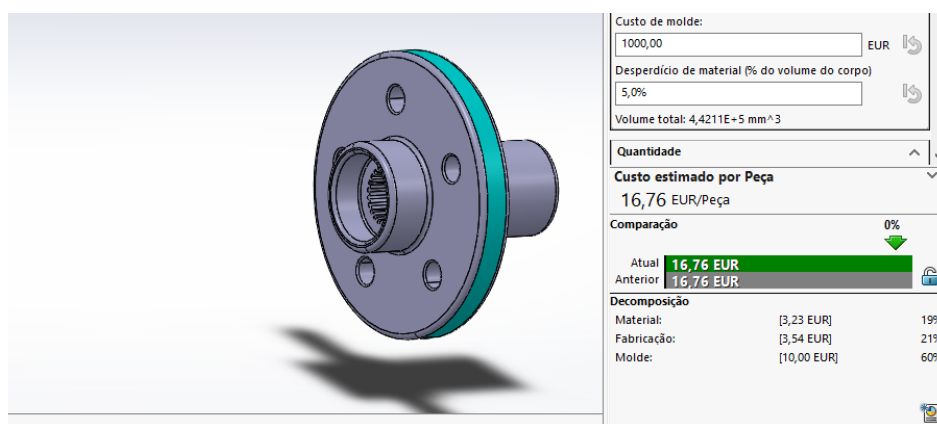


Figure 43 - Cast iron hub

For the RIM, it was considered a Magnesium Alloy, the price in CES Edupack is 2,42 to 2,61 but, for a more conservative estimative, it was considered the suggested price of SolidWorks: 3,62 EUR/kg, Figure 44. For the rim was also utilized the process of casting.



Figure 44 - Magnesium alloy rim

After estimation, the price of each individual part of the suspension, Table 21, was created, with all the components quantities and prices, to summarize the suspension price.

Table 21 - Estimative of Suspension parts for the first solution

Suspension			
Name	Qt	Price per unit	Total price (€)
HUB	2	16,76	33,52
Steering knuckle	2	17,38	34,76
Low Arm	2	21,90	43,8
Up Arm	2	19,05	38,10
Disk brake	2	19,54	39,08
SKF 33010 bearing (123Bearing 2019)	4	39,66	158,64
Rim	3	26,06	78,18
Tire (Pneus Online 2019)	3	25,44	76,32
Shock Absorber (Louis 2019)	4	50,00	200,00
Total (€)			702,4

After the estimative of the suspension, it was made an estimative of the interior parts, considering the values of the market; these values are presented in Table 22.

Table 22 - Estimative of interior parts for the first solution

Interior			
Name	Qt	Price per unit	Total price (€)
Steering Wheel (Alibaba 2019)	1	25,00	25,00
Seat (Alibaba 2019)	2	55,00	110,00
Synthetic Leather (Alibaba 2019)	3	3,00	9,00
Total (€)			145,00

After the estimative of interior parts, was made an estimative of the plastic parts. The major plastic parts are the fairing of the vehicle, the panel and the headlight case and lens. This estimative is presented in Figure 45 to Figure 48. The fairing of the vehicle will be made of Acrylonitrile Butadiene Styrene (ABS) with an automotive painting.

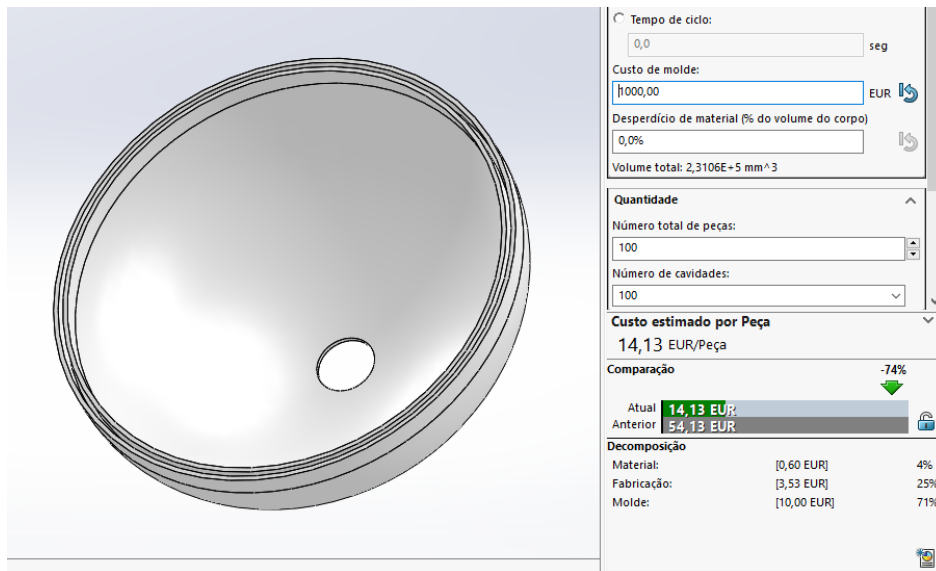


Figure 45 - Headlight case made of Acrylonitrile Butadiene Styrene (ABS)

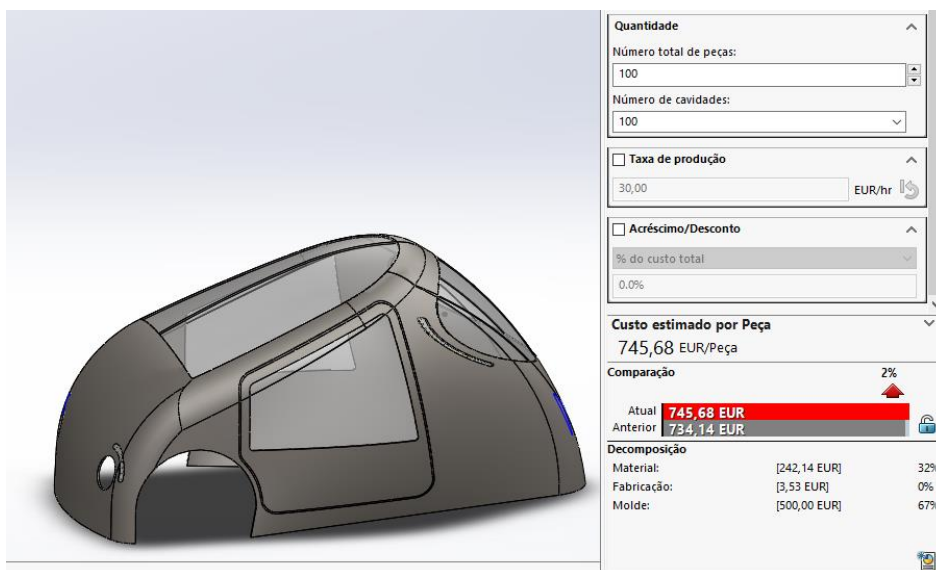


Figure 46 - Fairing made of ABS

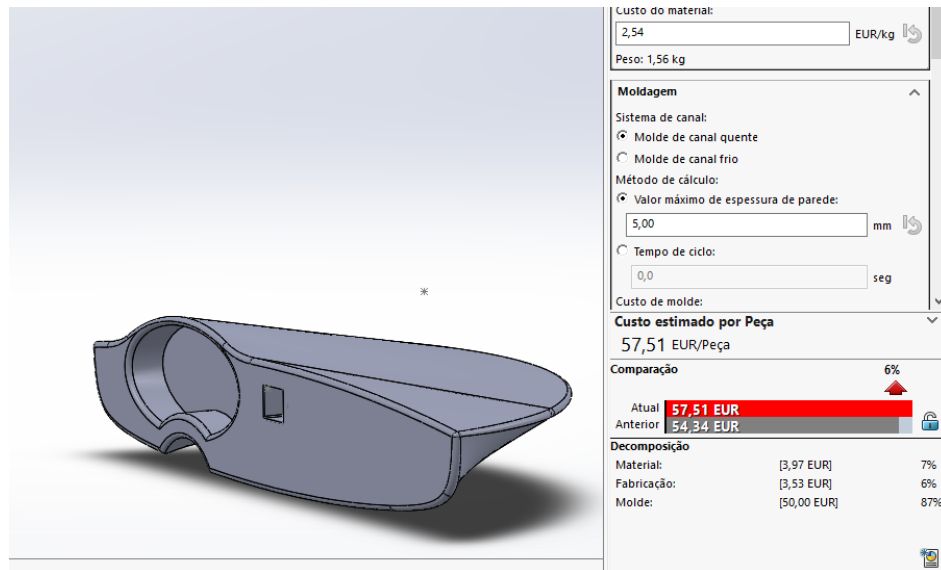


Figure 47 – Panel made of ABS

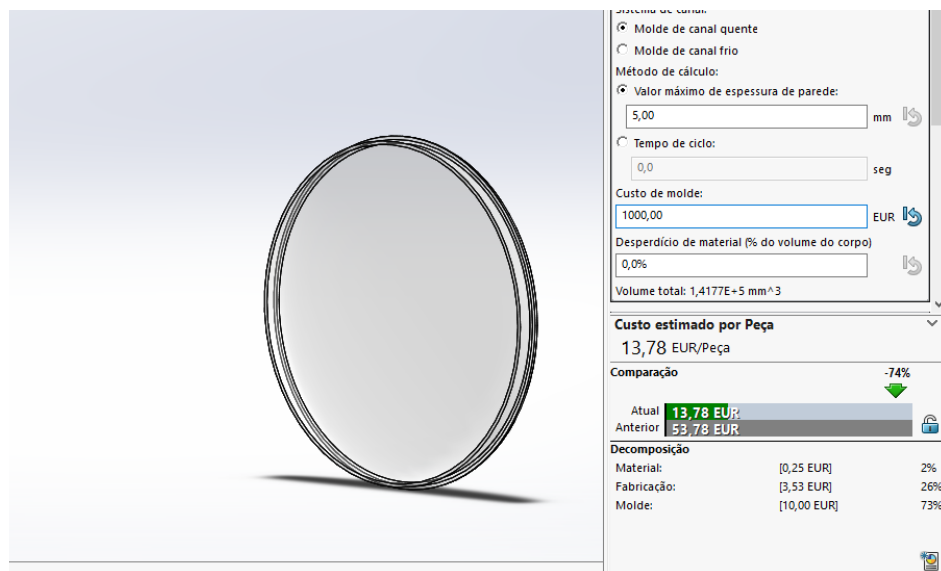


Figure 48 - Headlight Lens made of Polycarbonate (PC)

In Table 23, all the estimative of the plastic parts are presented and summed, giving a total cost of €859,01.

Table 23 - Estimative of plastic parts for the first solution

Lights			
Name	Qt	Price per unit	Total price (€)
Fairing ABS	1	745,68	745,68
Panel ABS	1	57,51	57,51
Headlight ABS	2	14,13	28,26
Headlight PC	2	13,78	27,56
Total (€)			859,01

As the car is totally electric, all the lights of the car will be using LED for a lower usage of energy. The Table 24 shows the cost of each part.

Table 24 - Estimative of LED parts for the first solution

Lights			
Name	Qt	Price per unit	Total price (€)
LED lightbulb (Alibaba 2019)	2	3,50	7,00
LED strip (Alibaba 2019)	3	2,25	6,75
Total (€)			13,75

The quantity of batteries can be calculated with the total energy needed, gravimetric density of the batteries and the weight of each battery. The number should be even for easier assembly.

$$Qt = Te / (Gd * Wb) \quad (10)$$

Where

Qt = Quantity of batteries in units

Te = Total energy, in this case 10.000 Wh

Gd = Gravimetric density in Wh/kg, in this case 243 Wh/kg

Wb = Weight of each battery, in kg in this case 0,0485 kg

$$Qt = 10000 / (243 * 0,0485)$$

$$Qt = 848,5 \text{ units}$$

Considering all parts of the car and an even number of batteries, 848 units, an estimate of the total cost can be made, and the car will have a total cost around €7000,00 for the basic version as presented in Table 25.

Table 25 - Estimative of total cost of the car for the first solution

Total			
Name	Qt	Price per unit	Total price (€)
Frame	1	382,57	382,57
Suspension parts	1	702,40	702,40
Interior parts	1	145,00	145,00
Plastic parts	1	859,01	859,01
LED parts	1	13,75	13,75
Motor (MiroMax 2019)	2	398,00	796,00
Controller (MiroMax 2019)	1	156,00	156,00
18650 Battery (NKON 2019)	848	2,25	1908,00
Painting	1	500,00	500,00
Assembly	1	500,00	500,00
Other electronic equipments	1	500,00	500,00
Other minor pieces (screws, nuts, glue...)	1	500,00	500,00
Total (€)			6962,73

6.6 Second solution

As seen in Table 18, the most representative force to determine the car range is the Drag force, being responsible from 48 % up to 78 % of the total energy needed in the solution one. In order to develop a better car, with less drag and more space, several drag analyses were carried out in SolidWorks with different profiles, being the width constant in all of them, only the profile and the fillets were changed.

These drag analyses can be seen in APPENDIX C: Drag Analysis, the selected solution is the one with less drag and with a “flat” roof in order to be possible to make an extendable car, Figure 49.

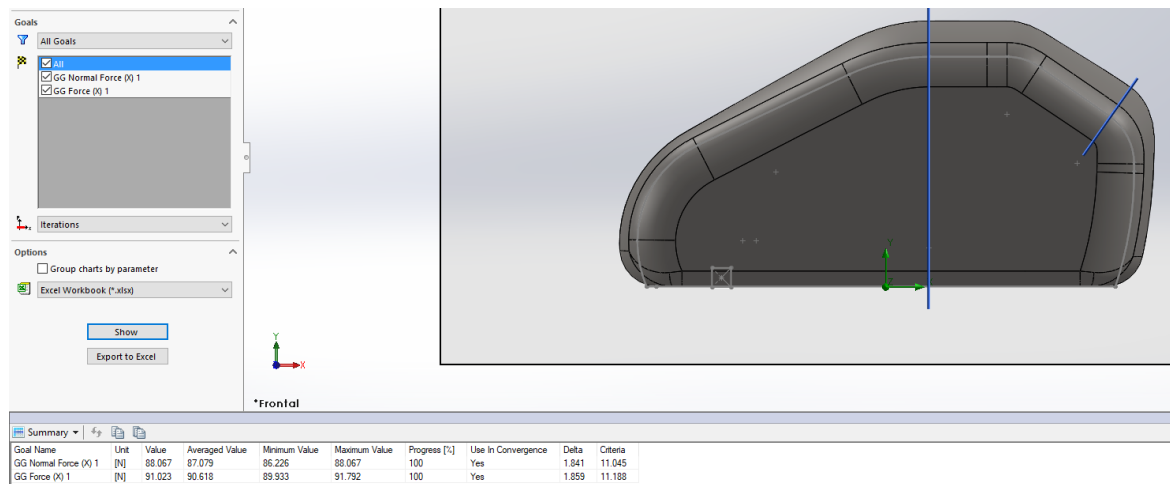


Figure 49 - Selected shape of body

It was created a different solution, instead of using a tubular chassis and fairing, it was developed a body on frame chassis, which could enhance the quality of the final product, such as safety, noise cancelation but is not viable for a small amount of unities.

With the final shape of the car and added other components like suspension system, another drag analysis was made, Figure 50.

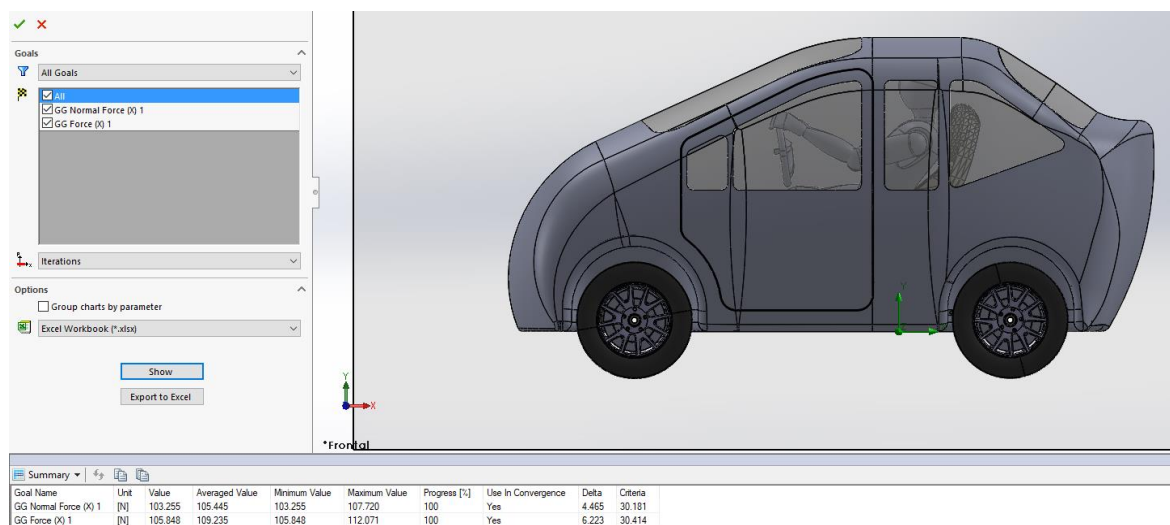


Figure 50 – Drag Force at 45km/h (12,5 m/s)

6.7 Third solution

The third solution is an improvement in space usage of the second solution. With a higher roof in the rear part of the car, it is possible to fit a third passenger if the car is shortened or more two passengers if the car is extended.

Even though the car is bigger, due to the shape of the third solution the drag force is similar to the second solution, Figure 51 and Figure 52.

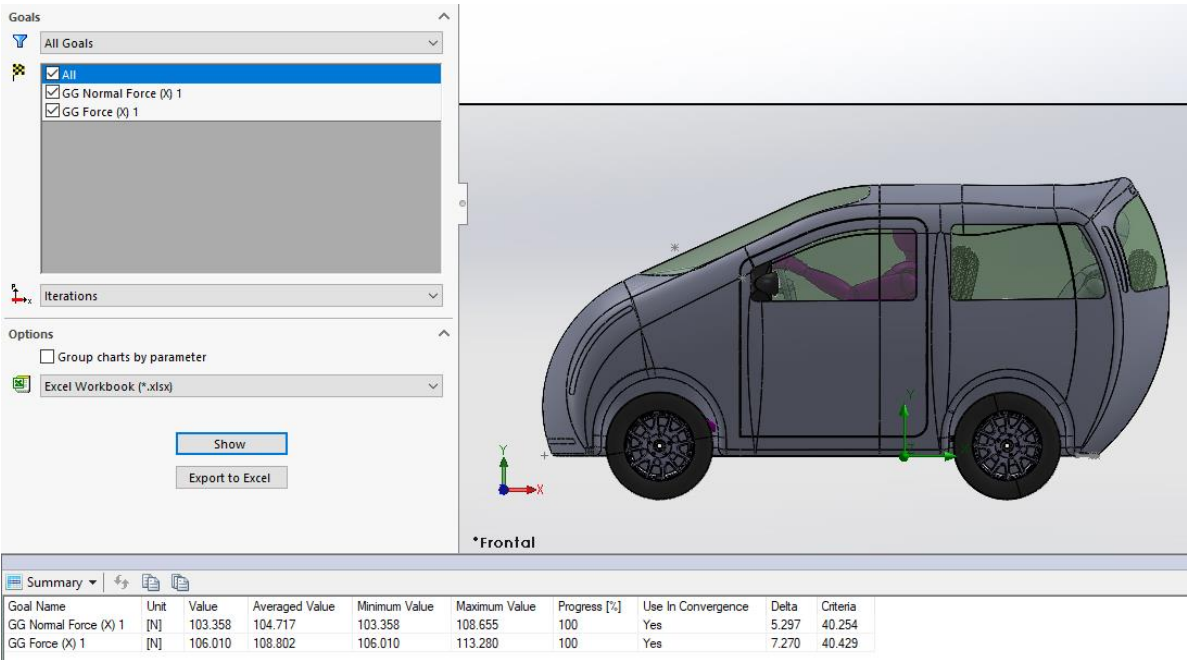


Figure 51 - Drag Force at 45 km/h (12,5 m/s)

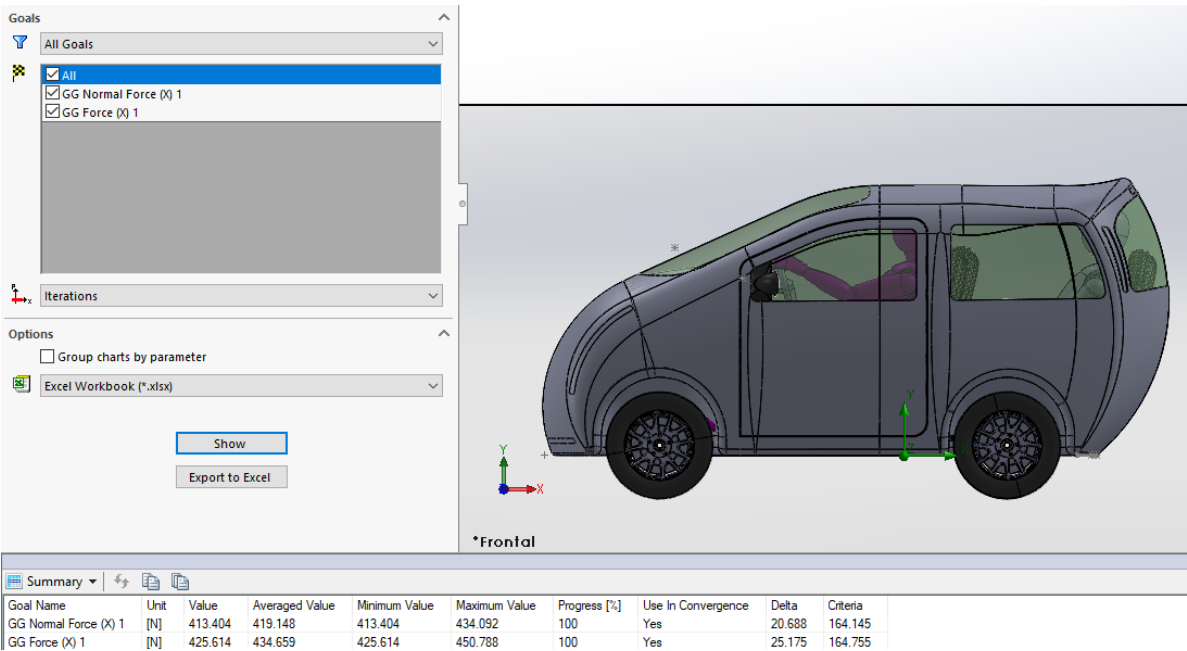


Figure 52 - Drag Force at 90 km/h (25 m/s)

6.7.1 Calculation of batteries for the third solution

Using the values of the drag Force generated by a finite-element analysis and utilizing the same process at the chapter 6.4, Calculation of batteries, the uses of energy can be calculated for the Third solution. In Table 26 are presented each factor of the total energy needed and in Table 27 is presented the range with the variable weight of the battery packs.

Table 26 – Energy used for the third solution

	Porto - Coimbra round trip 252,8 km	EU average 47,6 km	US average 85,6 km
Drag resistance for 45km/h in kWh	7,2	1,4	2,4
Drag resistance for 90km/h in kWh	29,2	5,5	9,8
Roll resistance for 650 kg car at 45km/h in kWh	4,7	0,9	1,6
Roll resistance for 750 kg car at 90km/h in kWh	6,7	1,3	2,3
Potential Energy for 650 kg car in kWh	0,9	0,1	0,1
Potential Energy for 750 kg car in kWh	1,3	0,1	0,2
Accessory Energy for 45km/h car in kWh	2,8	0,5	1,0
Accessory Energy for 90km/h car in kWh	1,4	0,3	0,5
Total energy Use for 650 kg car at 45km/h in kWh	15,6	2,8	5,1
Total energy Use for 750 kg car at 90km/h in kWh	38,7	7,1	12,8

Table 27 – Range in km of the third solution at selected speeds and battery packs capacities

Battery pack in kWh	Range at max speed of 45km/h in km	Range at max speed of Max 90km/h in km
10	172,6	69,0
20	338,4	136,7
30	497,8	203,0
40	651,1	268,0
50	798,7	331,8
60	940,9	394,3

6.8 Adaptive features

All the features presented in this part of the chapter can be adapted to all the presented models unless, due to a characteristic of the car, it is not possible to apply.

6.8.1 Size adaptive car

Due to the shape of the First solution, it is not possible to adapt this solution for it, but the second and third solutions were designed with this feature in mind. These cars can be equipped with an extensible frame and chassis that is capable to make the car 30 cm longer.

The selected technology for the extension of the frame is using a threaded rod screw-nut assembly, due to the fact that is not necessary to add an oil pump and due to simplicity of the assembly.

The same solution is utilized in gates mechanism. In Figure 53, the number 40 represents the threaded rod and the number 2 the nut.

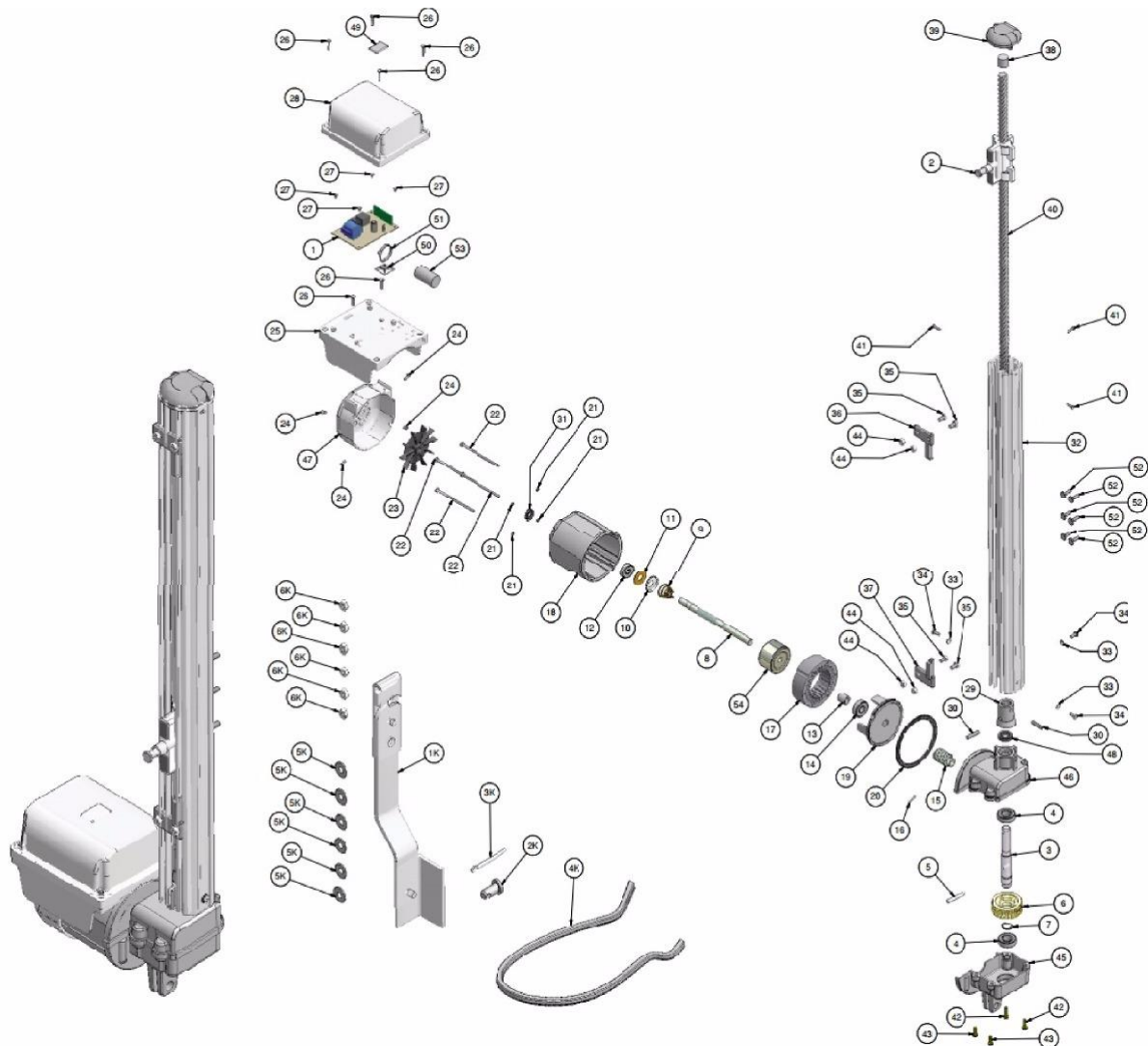


Figure 53 - Scheme of a gate mechanism (Garen 2019)

Figure 54 shows the shortened frame and Figure 55 after the extension. Figure 56 presents a detailed view of the extension mechanism. Figure 57 presents this extension feature applied to the second solution.

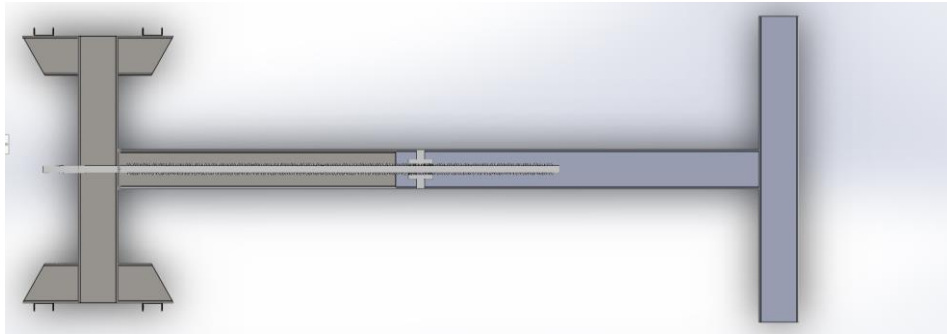


Figure 54 - Shortened Frame

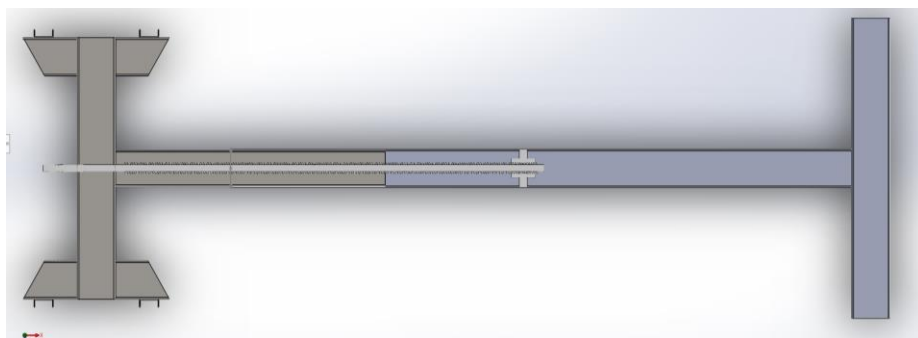


Figure 55 - Extended Frame

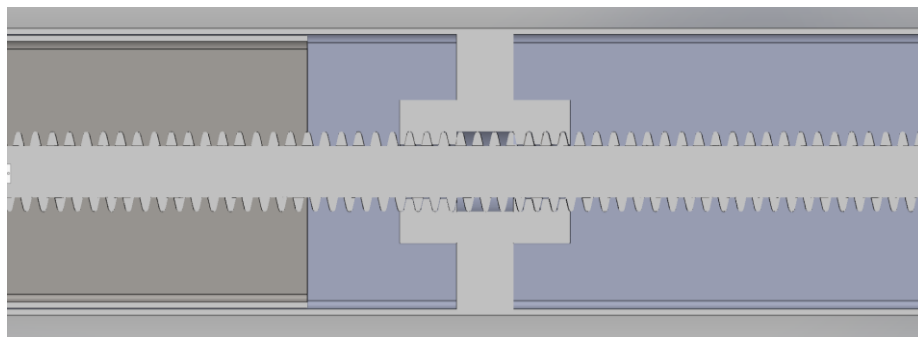


Figure 56 - Detail of the worm gear assembly of the extension system



Figure 57 - Extendable Chassis and Frame adapted to the Second Solution

6.8.1 Driver adaptive car

This feature can be easily applied to all the solutions, the additional hardware needed for it is only an ID card reader, Figure 58. With this feature, the car will be able to identify the driver and with this adapt to the Driver license limitations. If the person is able only to drive a L6eBP or L7eCP the driver will not be able to go faster than 45 km/h and 90 km/h respectively, or the car extension of the car cannot go further than 3 and 3,7m respectively. This feature can also be used in a car sharing service, easily identifying the costumer and, consequently, charging the exact amount for each driver.



Figure 58 - ID card reader

The use of an ID card can also improve the safety against robbery due to the identification, by the card, of the driver of the vehicle.

6.8.1 Range adaptive car

Since the legislation for the Microcars in Europe considers the weight of the car without the batteries, the amount of batteries in a car depends only in the size/weight limitations and the project aims. Considering that the average travelled distance in Europe is 47,6 km per day, and considering the Survey that 90,2 % of the people that drive car drives less than 60 km per day, the car could have an initial battery of 10 kWh. This will provide a range of 66,4 km at the worst scenario, first solution at 90 km/h, and 172,6 km at the best scenario, third solution at 45 km/h.

The range can be also adapted utilizing driving profiles, limiting the acceleration, the top speed or improving brake regeneration efficiency (using less the disk brakes).

Figure 59 presents the left battery “drawer”. There are two “drawers” in the car, one each side, each drawer can fit two banks of batteries. Figure 60 shows in detail the battery bank, each of them has 280 batteries with an additional of 3,3 kWh.

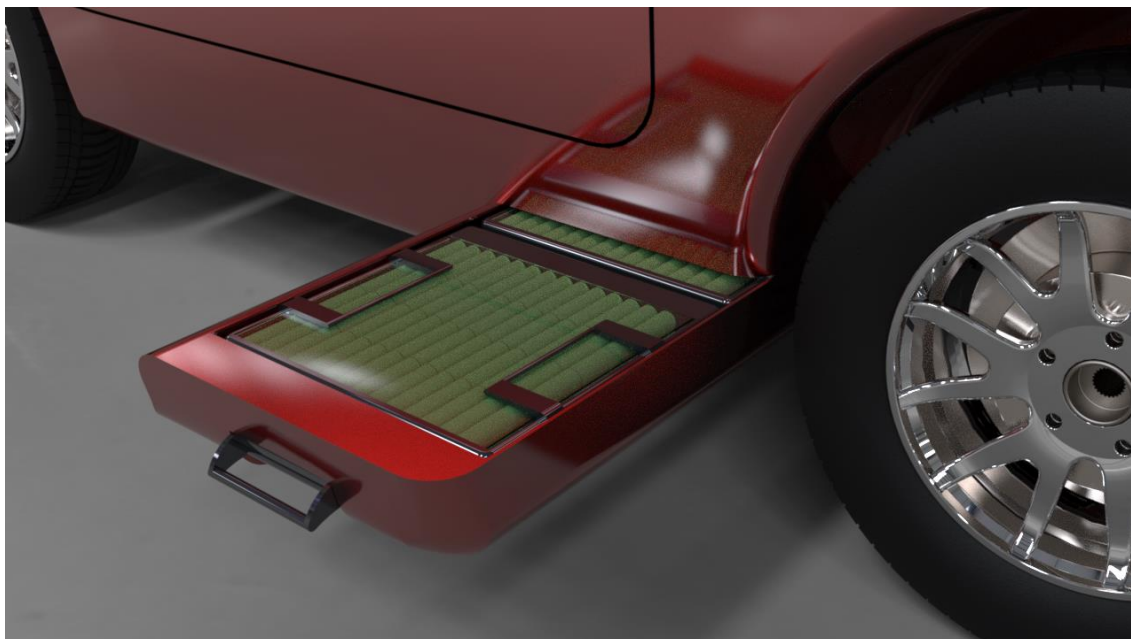


Figure 59 - Left battery drawer

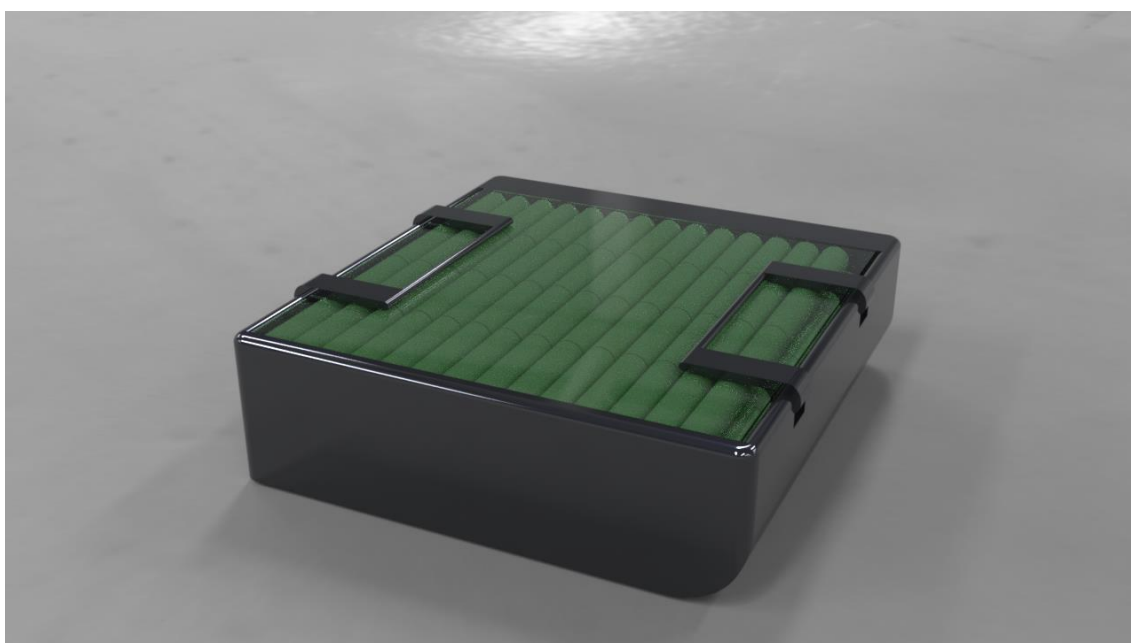


Figure 60 - Adaptive Battery

Already considering the added weight of the batteries, each pack will add 53,7 km of range for the car limited at 45 km/h and 21,4 for the car limited at 90 km/h, each pack has a weight of 13,6 kg, being light enough to be carried by the average costumer.

If the costumer adds the four packs, considering the extra weight, the final range would be 377,8 km for the 45 km/h and 150,4 km for the 90 km/h car, an additional of 211 km and 84,8 km for the 45 km/h and 90 km/h respectively considering the initial battery of 10 kWh. In Table 28, the range for each battery configuration is presented.

Table 28 - Range for each battery configuration

	Stock	1 extra battery pack	2 extra battery packs	3 extra battery packs	4 extra battery packs
Range at 45km/h in km	167,0	220,7	273,7	326,1	377,8
Range at 90km/h in km	65,6	87,0	108,3	129,4	150,4

6.8.2 Battery charger

For the electrical charging of the car, it was thought in a solution that could be as friendly-user as possible and with less interaction as possible, so a wireless pad, Figure 61, was conceived to charge the car. Due to the distance-related efficiency of the wireless charger, as soon as the car stops in the top of the charger and turn off, the charger will verify the car, elevate the pad, and start to charge the vehicle, everything automatically, Figure 62 and Figure 63.

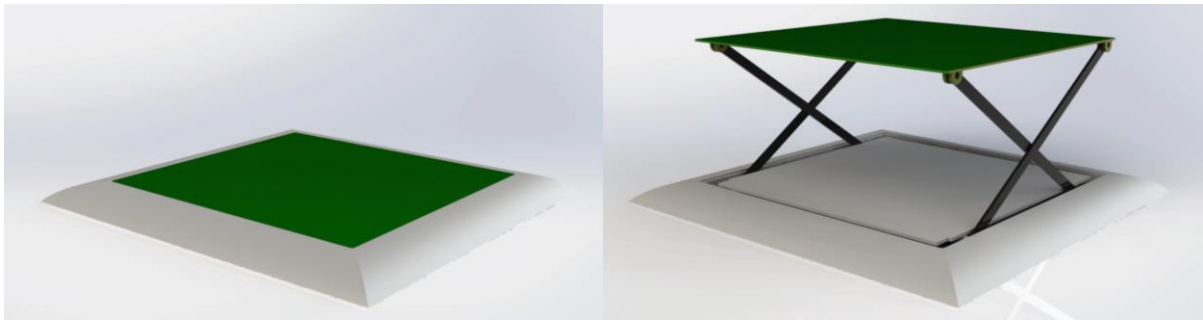


Figure 61 - Charger pad in the lower and higher position



Figure 62 – Charge pad below the vehicle before and after the car turn off



Figure 63 - Charge pad charging

A wirelessly charger solution is already being developed by some companies. The Japanese company TDK partnered with the U.S. startup WiTricity, to develop a wireless charger, Figure 64, and they intend to ship by 2020 (Nikkei 2018).



Figure 64 - WiTricity wireless charger at the 2015 CES expo in Las Vegas (Nikkei 2018)

In Figure 65 to 71, the third solution can be appreciated. In these renderings, the car takes with one driver and two passengers, one at the side of the driver and one centered in the back of the car.



Figure 65 - Driver view for the Third Solution



Figure 66 - Rear passenger view for the Third Solution



Figure 67 - Front-right view of the Third Solution



Figure 68 - Side-left-bottom view of the Third Solution



Figure 69 - Side-left-upper view of the Third Solution



Figure 70 - Front view of the Third Solution



Figure 71 - Front view of the Third Solution



Figure 72 - Detail of side mirror and panel of Third Solution



Figure 73 - Front-right view of the Third Solution



Figure 74 - Right side view of the Third Solution



Figure 75 - Rear-right view of the Third Solution

6.9 Cost analysis of third solution

The third solution has a simpler frame and the suspension, for reducing the cost. It utilizes a squared tubular frame of 100x100 mm profile. The cost of this frame is estimated by Solidworks as € 57,69, Figure 76.

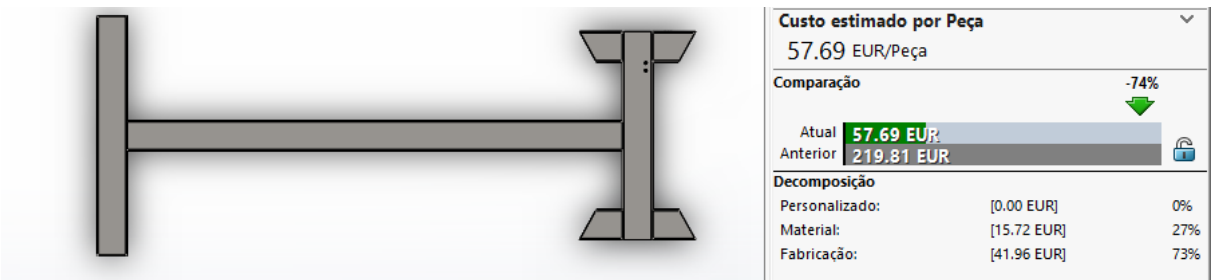


Figure 76 - Body frame made of 1020 Steel

The Lower and Upper arms now are made of a tubular profile for a lower cost, reducing the cost from around € 20,00 to € 9,36, Figure 77.

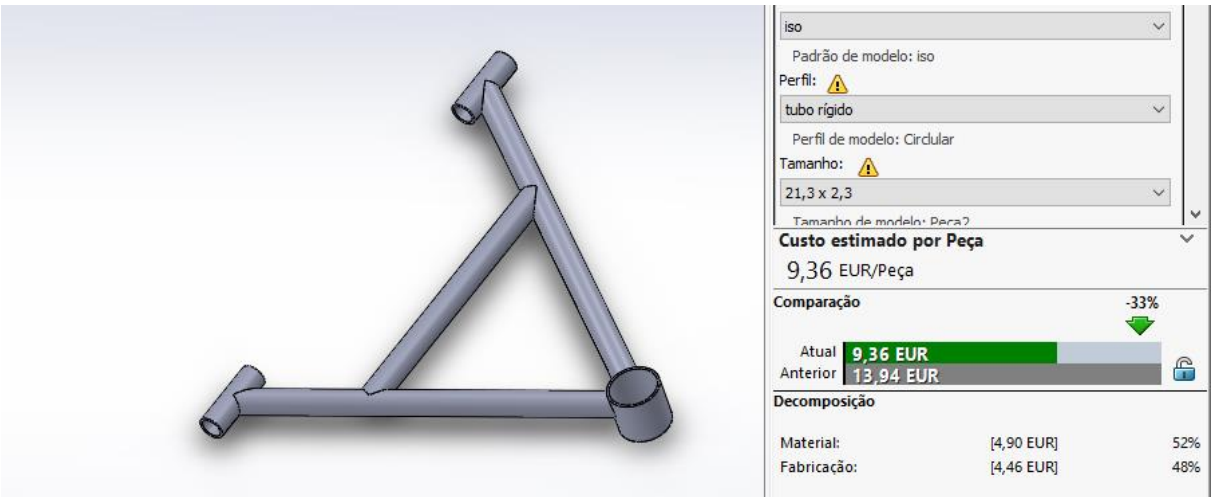


Figure 77 - Suspension arm made of 1020 steel tube

The steering knuckle now have a more optimized form reducing the cost in 10 % from the previously version, Figure 78.



Figure 78 - Cast iron steering knuckle

The rear axis is now made from cast iron, the cost of the rear axis is € 31,23, Figure 79.



Figure 79 - Cast iron rear axis

The HUB, bearings, rim, tire, shock absorbers and disk brakes kept the same as the solution one. In addition, Table 28 presents the total estimative of the suspension of the third solution.

Table 29 - Estimative of Suspension parts for the third solution

Suspension			
Name	Qt	Price per unit	Total price (€)
HUB	4	16,76	67,04
Steering knuckle	2	15,79	31,58
Rear axis	1	31,23	31,23
Low Arm	2	9,36	18,72
Up Arm	2	9,36	18,72
Disk brake	4	19,54	78,16
SKF 33010 bearing (123Bearing 2019)	8	39,66	317,28
RIM	4	26,06	104,24
Tire (Pneus Online 2019)	4	25,44	101,76
Shock Absorber (Louis 2019)	4	50,00	200,00
Total (€)			968,73

The interior parts, Table 22, and lights, Table 24, kept the same as the first solution, with the estimative of € 145,00 and € 13,75 respectively. Since the car does not have a fairing, the cost of the plastic parts is reduced, Table 30, being only needed for the panel and headlights.

Table 30 - Estimative of plastic parts for the third solution

Panel ABS	1	57,51	57,51
Headlight ABS	2	14,13	28,26
Headlight PC	2	13,78	27,56
		Total (€)	113,33

As the steel body and glasses are extremely complex forms, it was estimated a value of € 1000,00 each. Table 31 presents the total estimative cost of the third solution.

Table 31 - Estimative of total cost of the car for the third solution

Total			
Name	Qt	Price per unit	Total price (€)
Steel Body	1	1000,00	1000,00
Glasses	4	250,00	1000,00
Frame	1	57,59	57,59
Suspension parts	1	968,73	968,73
Interior parts	1	145,00	145,00
Plastic parts	1	113,33	113,33
LED parts	1	13,75	13,75
Motor (MiroMax 2019)	2	398,00	796,00
Controller (MiroMax 2019)	1	156,00	156,00
18650 Battery (NKON 2019)	848	2,25	1908,00
Painting	1	500,00	500,00
Assembly	1	500,00	500,00
Other electronic equipments	1	500,00	500,00
Other minor pieces (screws, nuts, glue...)	1	500,00	500,00
		Total (€)	8158,40

For the adaptive solutions, the estimated cost is listed in Table 32.

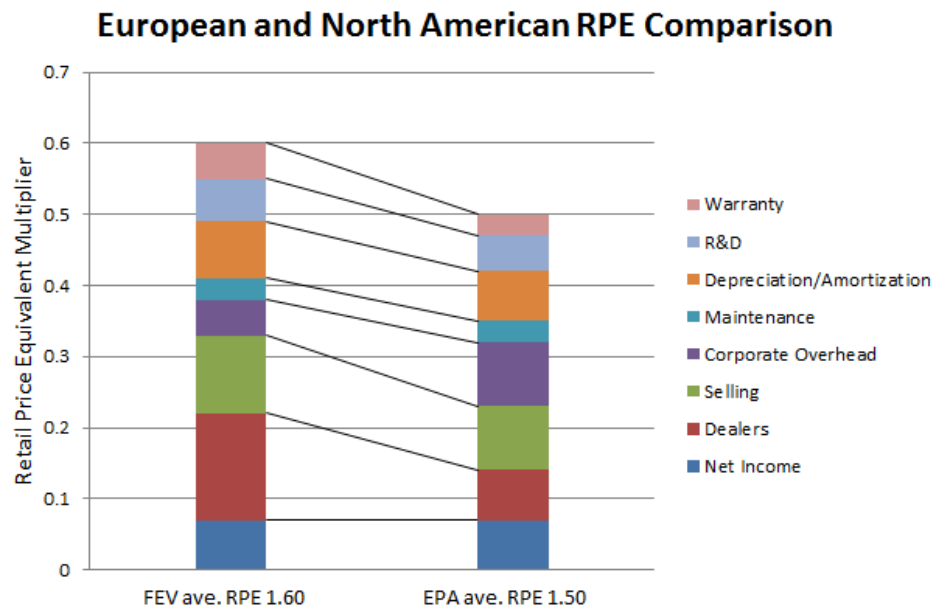
Table 32 - Estimative of Adaptive Solutions

Feature	Qt	Price (€)
Extension system	1	Est. 2000,00
ID Card reader (ID reader + mod) (Worten 2019)	1	50,00
Wireless charger and receiver (Wireless Power & Communication 2019)	1	-
Battery pack (280 batteries + case + electronics)	1	800,00

The total cost of the car can vary due to the estimative for the calculations, but in overall this values represents a realistic cost of the vehicle.

6.10 Feasibility analysis

Considering the FEV corporation report from 2013 that calculates a factor called RPE or Retail Price Equivalent multiplier, the retail price of car for the European market is 1,6x the cost of production, considering the American market this value is 1,5x the cost, Graph 10. For a retail price of € 15.000,00 the costing price should be lower than € 9.375,00.



Graph 10 - Retail Price Equivalent multiplier (FEV 2013)

Taking into account the influence that the car cost has in the purchase decision, presented in the Survey, as the factor that most influence the purchase decision, a cost analysis of the car is important to determine if the project is feasible and attend to the market expectations prices for electrical vehicles.

As presented in Table 25, the total cost of the solution one is around €7000,00. With the price of € 9375,00 there is a margin of profit of €2375,00 and the car would arrive for the costumers reaching the low cost goal of a price below €15000,00.

For the third solution, the cost it is around € 8150,00, with a margin of profit of € 1225,00. The car will arrive for the costumers reaching the low cost goal of a price below €15000,00.

Considering the cost analysis of both solutions, it is possible to infer that this adaptive car can be extremely successful as a product to substitute the ICEV vehicles that are currently in the market, producing way less pollution during the lifetime use.

7 Conclusion and Future Research

During the last years, the growth in sales of electric cars was enormous and, supported by the survey, there is a marketing with a lot of space to grow. The questions presented in the first chapter could be answered during the development of the project, either in form of the research presented in the report, sales reports, survey or as the Design and adaptive solutions presented for the car. The great complexity of designing, project and consequently build a car could be verified in this report.

As was verified in the report, the future of the cars seems to be definitively electric, at least considering a future of 10 – 20 years. It is a big opportunity for small and big companies to invest in the Electrical sector, and these companies are already making huge investments in the BEV sector (Reuters 2018).

Also with this report, we could verify that for a small and lightweight vehicle, the Drag Force is the most representative in the usage of energy. An improved design with a better tool to analyse the Drag, such as wind tunnel, can have significant gains in efficiency of energy.

It is possible to implement, with small adaptations for the installation, in other Electric Vehicles most of the adaptive features presented in this report.

In summary, a lot of the research needed to design a car was made during the process. It can be concluded, that is likely possible to develop an Electric low cost car, utilizing the Adaptive factor to reduce the price. Hence, more people could access the technology of Electric vehicles. It will enhance the quality of life of the costumers and, at the same time, reduces the usage of fossil fuels and, consequently, the emissions of pollutants.

The overall concept of an Adaptive car is to buy a bare bone car with less unnecessary features, and adapt this car to the usage of the consumer. Reducing the price for the people that just need a car to go from A to B safely and find a spot to park, since the car is smaller than the average.

7.1 Future work:

It is highly recommended to make more drag analysis to improve the car efficiency, utilizing 3D printed models and wind tunnel. A more complete cost analysis is also recommended, considering the initial costs of investments, the loans and all the related costs to the production of the car. Also, consider the price of the components as wholesale buying.

Investigations in how the car can adapt and be part of the public transport should be approached, as the Airbus concept designed to enter in a train. Furthermore, it is highly suggested to focus in the car-sharing sector, since the vehicle could easily go in the big cities, due to the small dimensions.

Bibliography

- 123Bearing. *Tapered roller bearing 33010-Q-SKF - 50x80x24 mm*. 2019. <https://www.123bearing.eu/bearing-33010-Q-SKF.php> (accessed May 5, 2019).
- 1950s Car Had An Extra Wheel To Help With Parking. YouTube video, 1:30,"Tech Insider" 18 June 2017. Retrieved from <https://www.youtube.com/watch?v=ki9otMeiRP0> (accessed October 21, 2018).
- Joe DeMatio, Evan McCausland, David Zenlea, Rusty Blackwell, Amy Skogstrom, Donny Nordlicht, ed. *2011 Smart ForTwo Passion Coupe*. Matt Tierney. 4 May 2011. Retrieved from <https://www.automobilemag.com/news/2011-smart-fortwo-passion-coupe/> (accessed February 2, 2019).
- Aixam. *GALERIA - CROSSOVER PREMIUM -*. 2019. Retrieved from <https://www.aixam.pt/pt/crossover/premium#tarifs> (accessed June 5, 2019).
- . *GALERIA - MINAUTO ACCESS*. 2019. Retrieved from <https://www.aixam.pt/pt/minauto/access> (accessed June 5, 2019).
- Alibaba. *350 mm Real Leather Pinhole Racing Car Steering Wheel With Rivet Spoke*. 2019. https://www.alibaba.com/product-detail/350-mm-Real-Leather-Pinhole-Racing_1311061899.html?spm=a2700.7724838.2017115.166.97697c9effYxne (accessed May 5, 2019).
- . *DC12V IP65 Waterproof Flexible Light LED Strip 5050 White Blue Green Red Yellow RGB led light*. 2019. https://www.alibaba.com/product-detail/DC12V-IP65-Waterproof-Flexible-Light-LED_60424509372.html?spm=a2700.galleryofferlist.normalList.1.165359d83Z188K&s=p (accessed May 5, 2019).
- . *Factory PU Coated Synthetic Leather for Clothing Fabric*. 2019. https://www.alibaba.com/product-detail/Factory-PU-Coated-Synthetic-Leather-for_60764723152.html?spm=a2700.7724838.2017115.53.39e83809Sy8S89 (accessed May 5, 2019).
- . *H7 H4 H8 H11 30W 60led 4014 smd Car Light Source LED Bulb Car Auto Light Source Projector DRL Driving Fog Headlight Lamp 12VDC*. 2019. https://www.alibaba.com/product-detail/H7-H4-H8-H11-30W-60led_60663833120.html?spm=a2700.7724838.2017115.35.5abb1b46mwirdg (accessed May 5, 2019).
- . *High Quality PVC Leather Racing Seat Black with red stitch for auto car use sports racing seat*. 2019. https://www.alibaba.com/product-detail/High-Quality-PVC-Leather-Racing-Seat_60828749136.html?spm=a2700.7724838.2017115.54.104351e9xq27P7 (accessed May 5, 2019).
- Antonelli, Luiz. *Volkswagen Expand*. 2012. Retrieved from <https://www.techtudo.com.br/noticias/noticia/2012/11/carro-conceitual-da-volkswagen-tem-rodas-removiveis-e-cabine-extensivel.html> (accessed April 12, 2019).

- Arthur D Little. "Battery Electric Vehicles vs. Internal Combustion Engine Vehicles." 2016. *Automobile Inspection & Registration Information Association*. n.d. <https://www.airia.or.jp/info/system/02.html> (accessed October 24, 2018).
- Autovista Group. 28 February 2019. <https://autovistagroup.com/news-and-insights/state-autonomous-legislation-europe> (accessed May 7, 2019).
- BloombergNEF. *A Behind the Scenes Take on Lithium-ion Battery Prices*. 5 March 2019. <https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/> (accessed May 5, 2019).
- BreatheLife. 2016. <https://breathelife2030.org/the-issue/> (accessed November 24, 2018).
- British Parking Association. "Parking Know How Bay Size." Haywards Heath, 2016.
- Bullard, Nathaniel. *Electric Car Price Tag Shrinks Along With Battery Cost*. 12 April 2019. <https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost> (accessed May 4, 2019).
- Business Insider. *15 major cities around the world that are starting to ban cars*. 12 January 2019. <https://www.businessinsider.com/cities-going-car-free-ban-2018-12> (accessed March 6, 2019).
- Cameron, Duncan. *British Microcars 1947 - 2002*. Bloomsbury Publishing, 2018.
- Ecalc. *Charger & Trip Information*. n.d. <https://ecalc.ch/evcalc.php> (accessed March 5, 2019).
- EHang. *EHang*. 2018. <http://www.ehang.com/ehang184/> (accessed February 5, 2019).
- . *YouTube*. 5 February 2018. Retrieved from <https://www.youtube.com/watch?v=Mr1V-r2YxME&t=> (accessed January 10, 2019).
- Engineering ToolBox. *Rolling Resistance*. 2015. https://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html (accessed January 15, 2019).
- Euro NCAP. *Quadricycles & Microcars*. n.d. <https://www.euroncap.com/en/ratings-rewards/quadricycle-ratings/> (accessed December 12, 2018).
- Eurostat. *What is the share of renewable energy in the EU?* n.d. <https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-4c.html> (accessed April 24, 2019).
- FEV. "Light-Duty Vehicle Technology Cost Analysis European Vehicle Market Updated Indirect Cost Multiplier (ICM) Methodology." Analysis Report, Auburn Hills, MI, 2013.
- Garen. *Garen Seg*. 2019. Retrieved from: https://produto.mercadolivre.com.br/MLB-1091578564-pecas-motor-basculante-pivotante-seg-garen-garcia-unisystem-_JM?quantity=1 (accessed June 10, 2019).
- Geoscientific Model Development. "Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS)." 29 January 2018: 382.
- Gray Ridge. *The Traditional White Egg*. 2019. <http://grayridge.com/our-brands/gray-ridge/white-eggs/> (accessed February 2, 2019).

- Hounshell, David. *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States*. Baltimore: JHU Press, 1985.
- InContext Enterprises Inc. *WHAT IS CONTEXTUAL DESIGN?* n.d. <https://www.incontextdesign.com/cd/> (accessed March 12, 2019).
- Infoupdate. *Body On Frame Vs Unibody*. n.d. <http://infoupdate.org/body-on-frame-vs-unibody/> (accessed March 2, 2019).
- INRIX Research. "The Impact of Parking Pain in the US, UK and Germany." July 2017: 18-20.
- Interaction Design Foundation. *User Centered Design*. 2018. <https://www.interaction-design.org/literature/topics/user-centered-design> (accessed April 24, 2019).
- International Energy Agency. "Global EV Outlook 2019." 2019.
- Italdesign and Airbus. *Pop.Up*. 2017. Retrieved from <https://www.italdesign.it/project/popup/> (accessed January 15, 2018).
- JASIC. "GRSP Inf. Group on on a Pole Side Impact GTR PSI-4-XX." Japanese Proposal and Research Plan, 2011.
- JATO. 21 February 2019. <https://www.jato.com/wp-content/uploads/2019/02/2018-Full-Year-Global-Sales-Release-Final.pdf> (accessed April 5, 2019).
- Lavrador, Alfredo. *Observador*. 18 July 2016. <https://observador.pt/2016/07/18/mata-velhos-e-novos-tambem/> (accessed November 4, 2018).
- Levine, David M., David F. Stephan, and Kathryn A. Szabat. *Statistics for Managers Using Microsof Excel*. 7th. 2017.
- LigierGroup. 2019. <https://www.ligiergroup.com/> (accessed June 5, 2019).
- Louis. *Universal Shock Absorbers in black and Chrome pair*. 2019. <https://www.louis.eu/artikel/universal-shock-absorbers-in-black-and-chrome-pair/10046112?list=99fe8163588bfcbb58fc886992c3af8b> (accessed May 5, 2019).
- Micro Mobility. *Microlino*. 2019. Retrieved from <https://microlino-car.com/en/microlino> (accessed June 5, 2019).
- MiroMax. *Eco Transport*. 2019. <https://www.miromax.lt> (accessed May 5, 2019).
- National Chamber of Commerce Inc. "Hand Book of Automobiles." 129 - 132. New York: Redfild-Kendrick-Odell Co. Inc, 1919.
- National Geographic. *National Geographic Kids Ladybug*. 2019. Retrieved from <https://kids.nationalgeographic.com/animals/ladybug/> (accessed March 2, 2019).
- Nikkei. *TDK to develop wireless charging system for electric vehicles*. 23 February 2018. <https://asia.nikkei.com/Editor-s-Picks/Japan-Update/TDK-to-develop-wireless-charging-system-for-electric-vehicles> (accessed May 6, 2019).
- Ning Ai, Junjun Zheng, Wei-Qiang Chen. "U.S. end-of-life electric vehicle batteries: Dynamic inventory modeling and spatial analysis for regional solutions." *Resources, Conservation & Recycling*, 2019: 208-219.

- Nissan. *Exterior and Interior*. n.d. Retrieved from https://www3.nissan.co.jp/vehicles/new/dayzroox/exterior_interior.html (accessed October 24, 2018).
- . *New Mobility Concept*. 1 November 2010. Retrieved from https://www.nissan-global.com/EN/DESIGN/NISSAN/DESIGNWORKS/CONCEPTCAR/NEW_MOBILITY/ (accessed February 2, 2019).
- NKON. *Samsung INR18650-25R 2500mAh - 20A*. n.d. <https://eu.nkon.nl> (accessed May 5, 2019).
- Odyssee-Mure. n.d. <http://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html> (accessed October 15, 2019).
- Participate in Design. n.d. <http://participateindesign.org/approach/what> (accessed April 24, 2019).
- Pneus Online. *Pneu Auto Minerva F209 145/70 R13 71 T*. 2019. https://www.pneus-online.pt/pneu-auto/minerva/f209/145-70-r13-71-t.html?partnerDomain=adwords.google.pt_gps_pt_pt_199750_f209&xtor=AD-144&gclid=CjwKCAjw0N3nBRBvEiwAHMwvNpx19Q1oAqpObAPjNalCGuuvUG1U6KzF06Ia8aTfd8cY9nHsXVnibhoC0ncQAvD_BwE (accessed May 5, 2019).
- Product Tribe. *User-Centered Design: Process And Benefits*. SERGEY GLADKIY. 2018. <https://producttribe.com/ux-design/user-centered-design-guide> (accessed February 1, 2019).
- Qinyu Qiao, Fuquan Zhao, Zongwei Liu, Xin He, Han Hao,. “Life cycle greenhouse gas emissions of Electric Vehicles in China:Combining the vehicle cycle and fuel cycle.” *Energy*, 2019: 222-233.
- “Regulation (EU) no 168/2013 of the European parliament and of the council of 15 January 2013.” *Official Journal of the European Union*, January 2013: 60/94.
- Reuters. *Global carmakers to invest at least \$90 billion in electric vehicles*. Paul Lienert. 15 January 2018. <https://www.reuters.com/article/us-autoshow-detroit-electric/global-carmakers-to-invest-at-least-90-billion-in-electric-vehicles-idUSKBN1F42NW> (accessed May 4, 2019).
- Road Traffic Act*. London: Eyre and Spottiswoode, LTD, 1930.
- SANYO Energy Corporation. “NCR18650B DataSheet.” Data Sheet, 2012.
- Sastry, S.V. A. R., and S.V.Y.Sastry. “Comparison of the Overall Efficiency of the Cars At Different.” *International Journal of Emerging Technology and Advanced Engineering* 3, no. 5 (May 2013): 509.
- Society of Automotive Engineers. *Vehicle Dynamics Terminology*, SAE J670a: *Report of Vehicle Dynamics*. SAE, 1952.
- Statista. *Number of licensed quadricycle microcars in the United Kingdom (UK) between the 1st quarter of 2010 and the 3rd quarter of 2018*. 2019. <https://www.statista.com/statistics/310552/number-of-quadricycle-microcars-in-the-united-kingdom/> (accessed March 15, 2019).
- Tesla. 2019. <https://www.tesla.com/models> (accessed May 5, 2019).

- The World Bank*. 2019. <https://web.archive.org/web/20140209114811/http://data.worldbank.org/indicator/IS.VEH.NVEH.P3> (accessed May 5, 2019).
- U.S. Energy Information Administration. *What is U.S. electricity generation by energy source?* 1 March 2019. <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3> (accessed April 24, 2019).
- United States Department of Transportation - Federal Highway Administration. *Office of Highway Policy Information*. 29 March 2018. <https://www.fhwa.dot.gov/ohim/onh00/bar8.htm> (accessed October 15, 2018).
- Walker, Brooks. Motor vehicle lifting and traversing device. United States of America Patent US3061028A. 30 October 1962.
- Walker, Brooks. Vehicle lifting and traversing device. United States of America Patent US2139341A. 6 December 1938.
- Walker, Brooks. Vehicle mounted parking device for use on front wheel drive vehicles. United States of America Patent US4516653A. 14 May 1985.
- Wikipedia. *Ackermann steering geometry*. n.d. https://en.wikipedia.org/wiki/Ackermann_steering_geometry (accessed February 10, 2019).
- Wireless Power & Communication. *2kW and High Speed Data*. 2019. https://www.wpc.no/products_2kw.html (accessed June 1, 2019).
- Working days in Portugal*. n.d. http://www.dias-uteis.pt/EN/dias-uteis_feriados_2019.htm (accessed February 15, 2019).
- Worten. *Leitor Cartões BIT4ID*. 2019. https://www.worten.pt/informatica-e-acessorios/armazenamento-de-dados/leitores-de-cartoes/leitor-cartoes-bit4id-4647960?LGWCODE=4647960;129031;9295&gclid=Cj0KCQjwxYLoBRCxARIsAEf16-vDc5uuWXctNk9EAqXKpDZJX3rGZnZpxi-2M5LFTSoQlsB8b5oPW0YaAnXREALw_wcB (accessed June 2, 2019).

APPENDIX A: Survey

Mail Dinamico SIFEUP <Mail.Dinamico@fe.up.pt>



para Matheus ▾

No âmbito do projeto de dissertação de mestrado em Design Industrial e do Produto da Universidade do Porto, que visa desenvolver um veículo adaptativo, peço a vossa colaboração para preenchimento de um questionário simples, com tempo de preenchimento de 3 minutos.

O questionário pode ser acedido em:

https://docs.google.com/forms/d/e/1FAIpQLSeXuzWwfYpKL_7kaoWyGaPBvxEbaa-ndRMH0KY1Qmjv43X2mw/formResponse

Esta mensagem foi enviada a pedido de 201700253 - Matheus Borges Dias para potencialmente 47830 pessoas.

Sistema de Email Dinâmico do SIGARRA - FEUP

Registo:

Enviado para 43216 endereço(s).

4614 pessoa(s) sem endereço(s) de email válido.

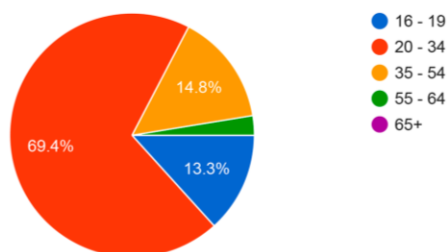
Pode consultar o detalhe do envio em http://sigarra.up.pt/feup/mail_dinamico_geral_ver_detalhe?p_id=271907

Carros Adaptativos

271 responses

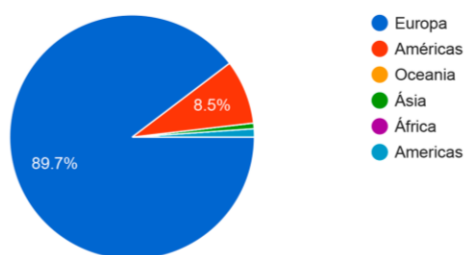
Qual a sua idade?

271 responses



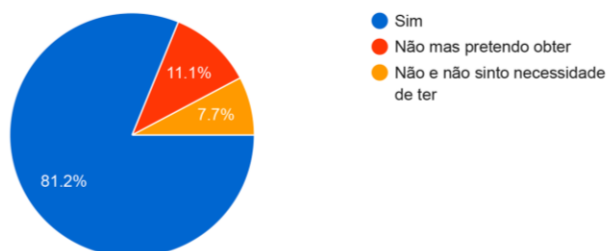
Onde você mora?

271 responses



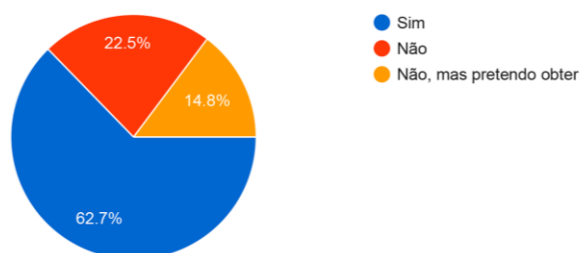
Você possui carteira de motorista?

271 responses



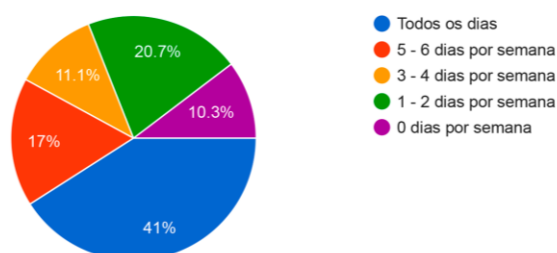
Possui carro próprio

271 responses



Em média, quantas vezes por semana você utiliza carro? (carro próprio, táxi, uber...)

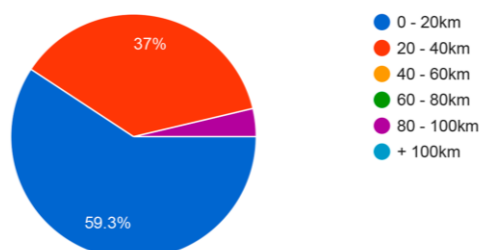
271 responses



Trajetos

Se você utilizasse CARRO PRÓPRIO, quantos km em média utilizaria o veículo? (Trajeto casa - trabalho..etc)

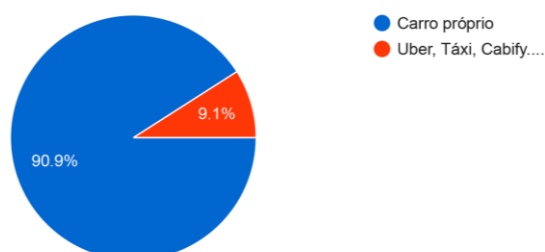
27 responses



Hábitos

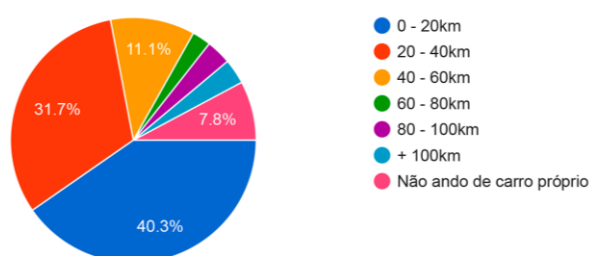
Anda mais de carro próprio ou de carona?

243 responses



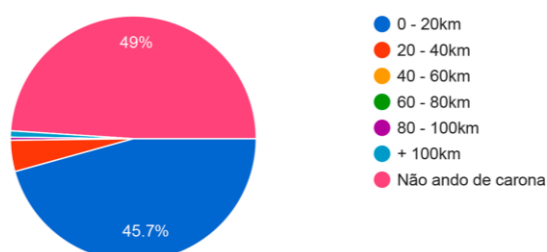
Nos dias que usa CARRO PRÓPRIO, quantos km em média utiliza o veículo?

243 responses



Nos dias que anda de CARONA, quantos km em média utiliza o veículo?

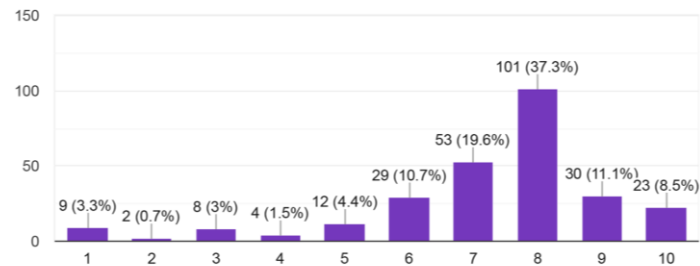
243 responses



Compra de carro próprio

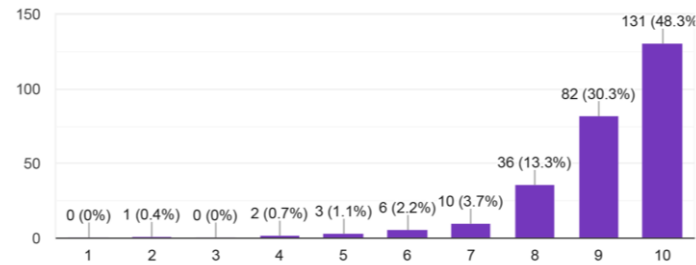
Numa escala de 1 a 10 quanto o DESIGN do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



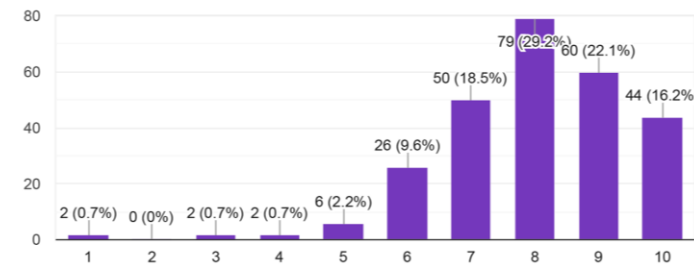
Numa escala de 1 a 10 quanto o PREÇO do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



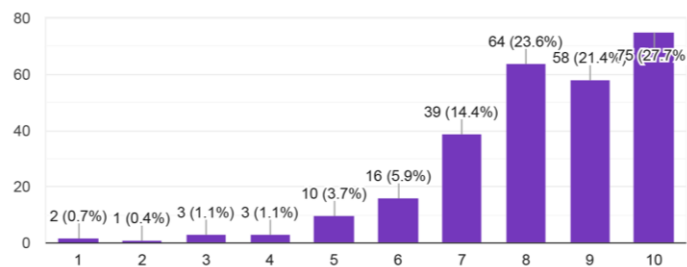
Numa escala de 1 a 10 quanto o CONFORTO do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



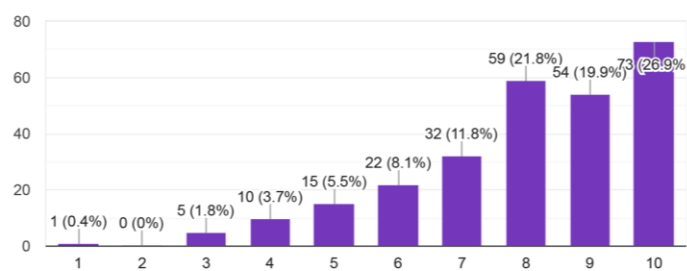
Numa escala de 1 a 10 quanto o ECONOMIA do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



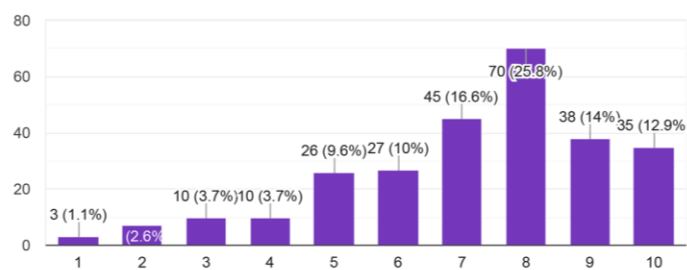
Numa escala de 1 a 10 quanto o SEGURANÇA CONTRA ACIDENTES do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



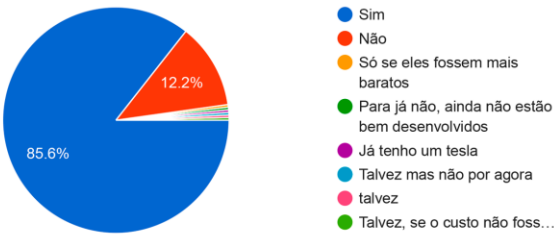
Numa escala de 1 a 10 quanto a AUTONOMIA do carro influenciou ou influenciaria na compra do carro próprio?

271 responses



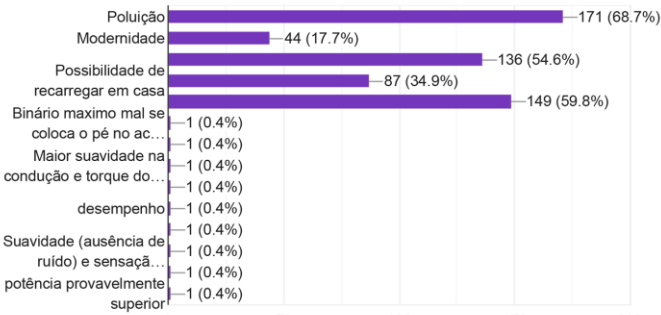
Você compraria um carro elétrico?

271 responses

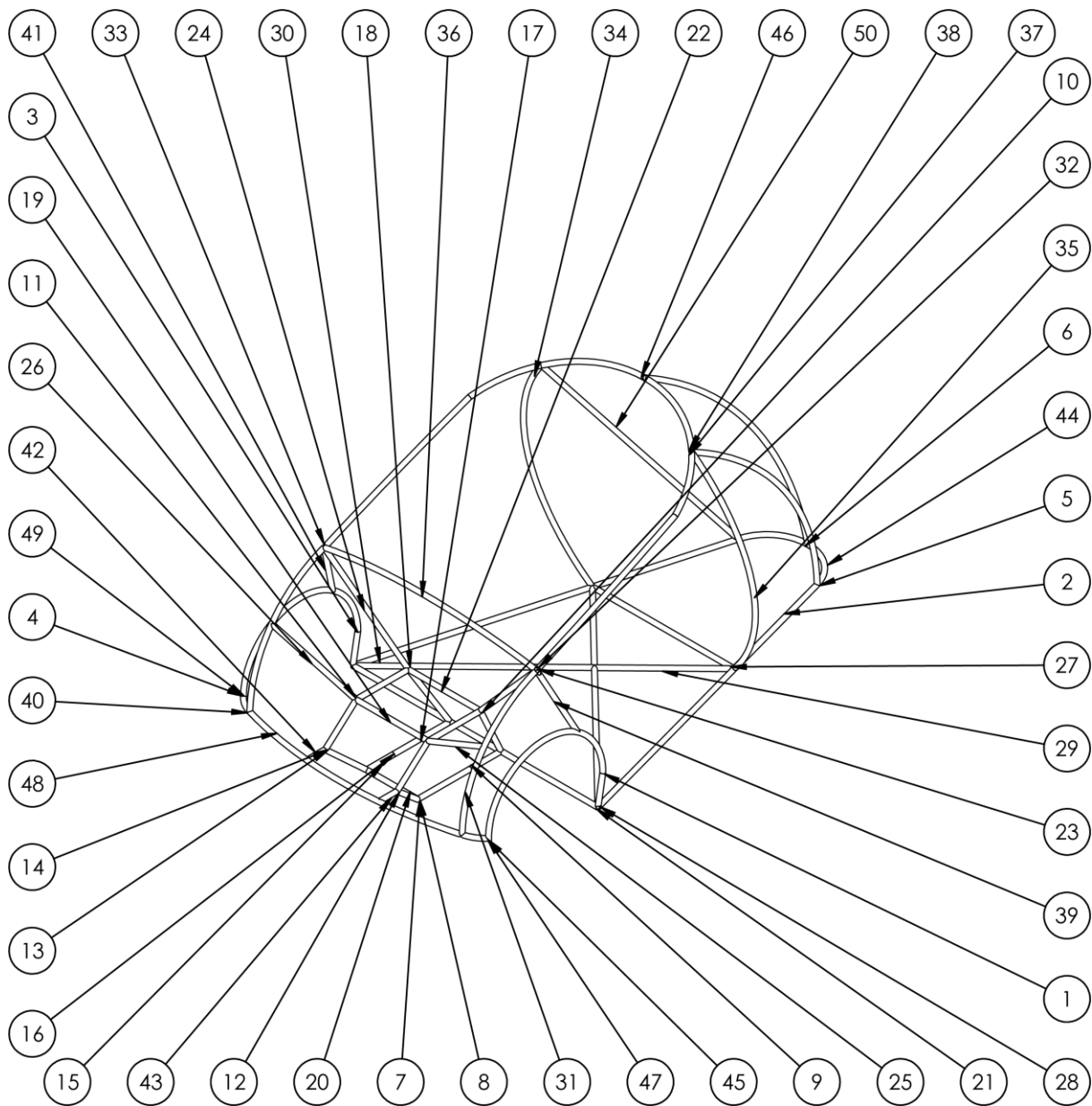


Por qual motivo compraria um carro elétrico?

249 responses



APPENDIX B: Technical Drawings and Table lists



Item Number	Qt..	Cutting Angle 1	Cutting Angle 2	Length
1=3	1	5	49,82	169,3
2	1	-	49,82	1919,43
4 = 45	2	-	-	1127,27
5	1	-	-	1699,7
6	1	-	-	1755,98
7 = 14	2	21,86	48,08	282,1
8	1	-	21,86	325,09
9 = 17	2	59,39	-	190
10 = 18	2	30,61	59,39	402,22
11	2	20,91	30,61	332,37
12 = 13	2	48,08	20,91	273,95
15	1	-	21,86	165,09
16	1	-	-	160
19 = 22	2	-	-	440
20	1	-	-	312
21	1	-	-	1500
23 = 24	2	-	-	643,81
25 = 26	2	-	-	492,32
27	1	-	-	867,5
28	1	-	-	1650,38
29	1	-	-	604,73
30	1	-	-	1045,65
31 = 40	2	-	-	841,76
32 = 33	2	-	-	958,22
34 = 35	2	-	-	1457,85
36	1	-	-	1326,75
37	1	-	-	350,54
38	1	-	-	513,57
39	1	-	-	390,7
41	1	-	-	386,52
42 = 43	2	-	-	110,85
44	1	-	-	2572,6
46	1	-	-	862,04
47 = 49	2	-	-	133,1
48	1	-	-	1332,24
50	1	-	-	1647,67

APPENDIX C: Drag Analysis

