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IDeS (Industrial Design Structure) Method Applied to the Automotive Design Framework: Two Sports Cars with Shared Platform

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Abstract: The present study was set to validate two different suburban-type sportscar bodies with shared common underpinnings. The chosen method to develop this project was the Industrial Design Structure (IDeS), which characterizes the ability to use the different innovative techniques known within the industrial field, across the whole organization. This method is embodied by following a series of structured analysis tools, such as QFD (Quality Function Deployment), Benchmarking (BM), Top-Flop analysis (TFA), Stylistic Design Engineering (SDE), Prototyping, Testing, Budgeting and Planning. This project aims to study the present-day car market and to foresee deployment in the near future. This attempt was confirmed by delivering the complete styling and technical feasibility characteristics of two different sports cars, obtained by the IDeS methodology. This approach of embodying design together with phases of product development would provide a better engineered, target-oriented product, that uses state-of-the-art style and CAD environments to reduce product development time and, hence, overall Time to Market (TTM).

Keywords: industrial design structure (IDeS); quality function deployment (QFD); benchmarking (BM); Top-Flop analysis (TFA); stylistic design engineering (SDE); suburban mobility; sportscar

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1. Introduction

This study illustrates the possibility to lay out a complete stylistic and technical product by means of applying the IDeS method, which allows one to optimize internal resources and speed up the time-to-market delivery of a product [1]. This begins with defining the different macro and micro phases comprised in the development, as shown on Figure 1. Each step was taken into consideration, from initial project setup, towards product development, throughout production set-up and market release. Moreover, a careful examination of the automotive industry environment was performed, as well as a global market analysis, adding up to the recent pandemic and the overall user trends that showed a sportscar-type vehicle only appeals to those who intend to use it during their free time, or as a leisure object [2].

Furthermore, the use of the Internal Combustion Engine (ICE) in vehicles is predicted to become more limited in the next few years [3,4] and ICE sportscars are up to become more of a recreational hobby [5], as electric-powered vehicles are becoming cost-effective [6–8]; the results stated that a niche market, filled with true car enthusiasts, will remain truly interested in the purchase of a sportscar and, therefore, it is important to capture the essence of a sportscar and transform their needs into ideas during the design process [9]. As reflected from the case studies, the core idea revolves around the creation of a small-sized, single-seat, lightweight vehicle. Combined with a medium-sized powertrain, the proposed car concept is focused more on maneuverability and control rather than raw power, thus, maintaining the essence of a sports car [10]. Following the case studies, a comparison between pre-existing engineering solutions was carried out to determine the best solution, in terms of powertrain position. A brand was assigned to each car body style based on the overall feel it transmitted.

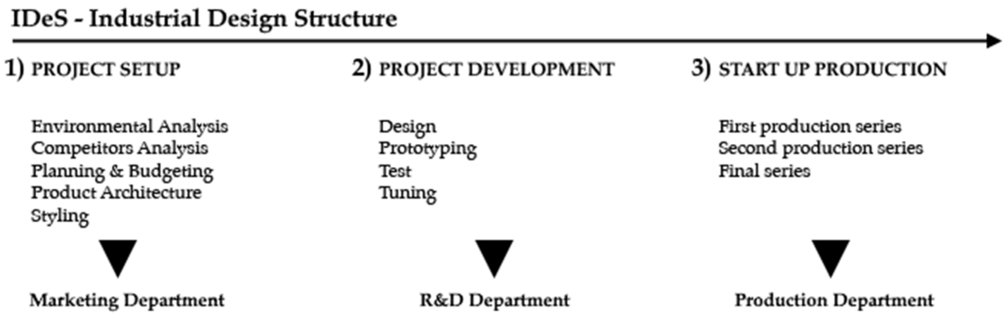

Figure 1. IDeS method outline.

2. Materials and Methods

The chosen methodology for product development is IDeS, which drives the whole organization structure in a development company by means of design, integrating both technical product design and stylistic design, from which Stylistic Design Engineering (SDE) [11,12] was conceived, first introduced by Lorenzo Ramacciotti, ex-CEO of Pininfarina design house [13], revealing a systematic style-oriented methodology to freeze style concepts in the world of car design [14], method of which was picked by young designers and educators [15] as a tool to portray the best design solution. Moreover, this solution combines innovative and logical product conception tools such as Quality Function Deployment (QFD), Benchmarking, Top-Flop Analysis [16], among others. The application of IDeS towards the present work can be structured in the following scheme, which summarizes the process involved (See Figure 1).

Nevertheless, the concept of IDeS was proven by research findings [1,17,18], to aid and seamlessly develop a product designed accurately for a specific market segment, and that needs to be put into production in a shorter time. In this way, this concept manages the industrial design phases for all ongoing projects, straightforwardly sharing resources and engaging the company organization with the design structure. Moreover, previous exercises with IDeS [19] proved to deliver a customer-centered product with the capability of considering the industrialization part, a key element towards reaching a high-quality product that is also cost-effective to the group. However, IDeS is generally structured into three main steps, i.e., project setup, product development, and production start-up. Designers are usually involved mostly in the first two steps, during which the new product is born and takes its shape throughout the project. Moreover, the validity of this method arises from research discoveries which nowadays submit their proposals of implementing industry 4.0 technologies straightforwardly through the organization to reach Six Sigma [20]. This modern interpretation of information sharing would support companies in reducing defects though lowering cycle time [21,22].

2.1. Project Setup and Development

The project setup stage is composed of distinct phases: (a) Environment analysis, (b) Market analysis, (c) Styling, (d) Architecture definition and (e) Budgeting and planning. Product development is composed of the following phases: (a) 3D Modelling (CAD), (b) Prototyping, (c) Testing and (d) Optimization and Final Tuning (See Figure 2).

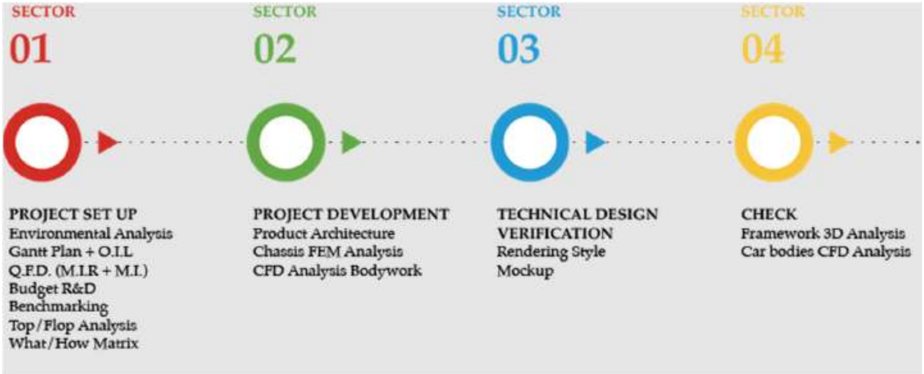

Figure 2. Roadmap.

2.1.1. Environment Analysis

The Environment Analysis allows the user to know the field in which they are going to operate. It requires a complete and full understanding of any field-related topics as well as thorough research.

2.1.2. QFD Method

QFD is a market analysis methodology that allows users to get to know the client's needs and subsequently work on them. Analyses have been broadly applied in product conception in most industries [23], from food industry [24], chemicals [25], and automotive [26], towards service quality [27], medical service sector [28] to information technologies [29]. Moreover, this method is based on the use of two main components: the "wh-questions" (who, what, when, where, why, how) and matrices (Relative Importance Matrix (R.I.M.) and Dependence/Independence Matrix (I.M.)). The 6 "-questions" are used to identify the client needs. The result of the 6 "-questions" in then used to properly set up the matrix analysis. The Relative Importance Matrix works on a range of numbers between 0 and 2, while the Dependence/Independence Matrix uses a fixed set of values (0, 1, 3, 9). In the first matrix type, numbers are assigned inside the matrix boxes depending on the importance value resulted from each interpolation between line and column: 0 is assigned if the row requirement is more important than the column requirement; 2 is assigned if the column requirement is deemed to be more important; 1 is assigned if they are both considered important. By adding up the values of each column, a ranking of the requirements is obtained. Those with greater numerical value are to be considered more important than the others. In the second matrix, the interpolated requirements are assigned values (0, 1, 3, 9) based on how much the row requirement depends (or doesn't depend) on the column requirement: 0 is assigned if the row requirement is completely independent from the column requirement; 1 is assigned if it is not very dependent; 3 is assigned if it is very dependent, and 9 is assigned if it is completely dependent on the column requirement. In this case, adding the values of each column gives us a classification of the requirements, from least to the most important requirements, extracted from the Relative Importance Matrix and the five most independent requirements (along with the five most dependent), taken from the Dependence/Independence Matrix. Combined, a list of requirements is formed.

2.1.3. Benchmarking and Top-Flop Analysis

Benchmarking is a very useful tool that allows one to analyze and compare products on the market. The technical and qualitative characteristics considered most relevant for each product are put side by side and evaluated. The TFA is carried out from the requirement for traceability technologies as considered by Murtazina and Avdeenko [30], Kchau et al. [31], or Saleem and Minhas [32] by highlighting the best and worst characteristics for each of the categories taken into consideration. The difference between "Tops" and "Flops" highlights the minimum number of innovative features that the new product needs to have to be considered innovative. This tool for scoring characteristics has been deployed in various product development exercises [33,34] to have a higher degree of innovation, the features used in benchmarking are interpolated with the requirements drawn from the first two matrices. This generates the What/How matrix. In the What/How matrix, cells contain a number ranging from 0 to 10 (0, 2, 4, 6, 8, 10) based on how each feature influences the individual requirements. By adding the values from each column, the design factors that need to be considered to improve innovation are obtained.

2.1.4. Planning

A Gantt timetable was set up to organize all the work activities that need to be completed along the path. It shows how time and resources are distributed amongst the various activities. In conclusion, this tool allows the users to visualize their workflow and overall progress as well as know which activities to prioritize over others.

2.1.5. Budget

Through budget planning it is possible to visualize the overall costs related to design activities such as: Raw Material Costs, Research Costs, Work-Hours Costs, Manufacturing Costs, Machinery Costs and Prototyping Costs.

2.1.6. Product Architecture

Product Architecture allows the designer to review the project (at a global level) both from the functional and aesthetics standpoint. This helps develop a solid base for the project, allowing an easier implementation of all parts included in the project [1,11]. Furthermore, the correct choice of this would enable the integration of customized modules for product personalization [35,36].

2.1.7. Stylistic Design Engineering (SDE)

The SDE process, described in Figure 3, concludes the project setting phase. It can be analyzed in different steps. The first is focused on determining the style that is then going to be brought to life (Colors, Shapes, etc.). The second step consists in making different sketches to lay out and materialize the product idea. The third step is carried out by making a 3D model based on the previously mentioned sketches (carefully edited and laid out as a blueprint/canvas base). A complete 3D model and photorealistic renderings will mark the end of the fourth and final step.

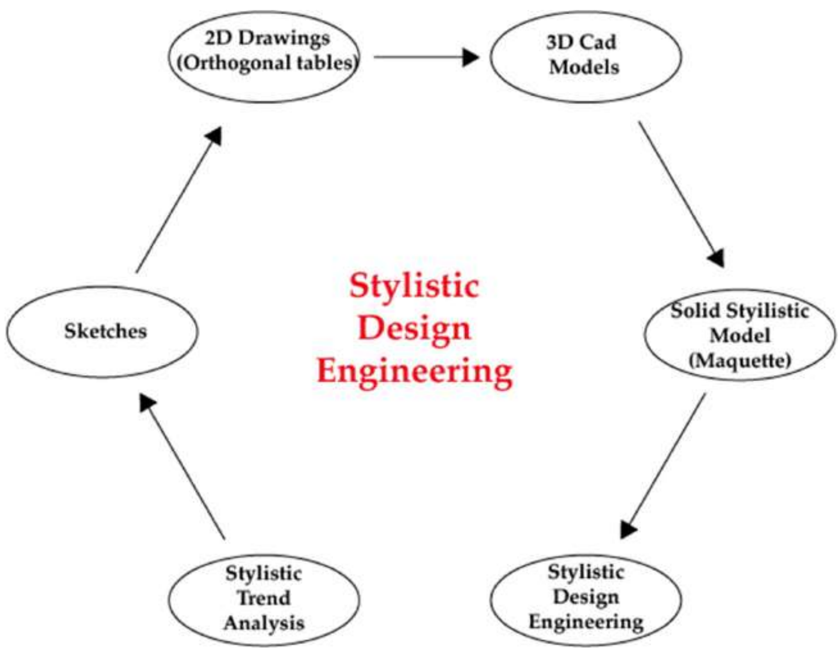

Figure 3. SDE method outline.

2.2. Design Phase

2.2.1. Design Engineering

This phase is comprised of different parts, for instance choosing shape, dimensions, and materials of the product. These operations can be carried out by using 2D and 3D CAD modelling software. Successively, the project is further developed into greater detail, diving aspects, including items and usability.

2.2.2. Virtual Prototyping and Scaled Model Mockup

Virtual Prototyping is a very important phase of SDE. By creating a virtual, rendered image and a physical object, a better understanding of the shapes, proportions, and body surfaces is given to the audience, as well as the ability to feel and touch the model.

The 3D model for prototyping was obtained with CAD (Computer Aided Design) software, which offers the advantage of quick editing thanks to the parametric modelling feature and the overall virtual environment. Said 3D CAD model can be used for creating virtual images with the use of a render engine and it can then be transformed into a real object though 3D Printing technology. Prototyping can also include a full scale 1:1 model made from clay or equivalent industrial plasticine. An alternative prototyping method, becoming ever more popular in recent years, relies on Virtual Reality environments and VR equipment. Its popularity can be mainly attributed to higher efficiency and inherent lower costs.

2.2.3. Testing

Testing phase is carried out to verify whether the previously set goal of innovation is met or not. An accurate examination of the prototypes as well as a full assessment of their characteristics allows one to compare the old highest value of Δ with the new one.

2.2.4. Setup

This phase consists of collecting data to modify and improve the project. It can be done by reviewing its features. This part, as well as the next one, can be repeated more than once even if the product is already undergoing production.

2.2.5. Redesign

The IDeS method is concluded with the redesign step. Sections 2.2.3 and 2.2.4 are reviewed to further improve the project.

2.3. Case Studies

2.3.1. Design Setup

Searching for information as well as reading reviews and exploring technical features allowed us to know in greater detail how the automotive industry operates. Everyday human habits were observed, and a better understanding of our client type was achieved. The search field was then narrowed in accordance with the established brief.

Environment Analysis

The environment analysis started off by analyzing different vehicle segments (City Car, Subcompact, Mid-Size, Compact, Full-Size, Full-Size Luxury, Supersport, Hypercar, Sports Coupé, etc.). Final choice ended up being the Sports Coupé segment. It was in fact determined that a Hypercar or Supersport-type vehicle would have fallen out of the price-requested price range and that a road legal sportscar with hypercar-like features would have been a good compromise. A nationwide analysis carried out by A.C.I. (Automobile Club of Italy) showed how since the year 2000, new car sales have been gradually going down (See Figure 4). Lowest selling points tend to coincide with major economic downturns or global pandemics; however, an overall decreasing trend can be seen even after filtering out these factors.

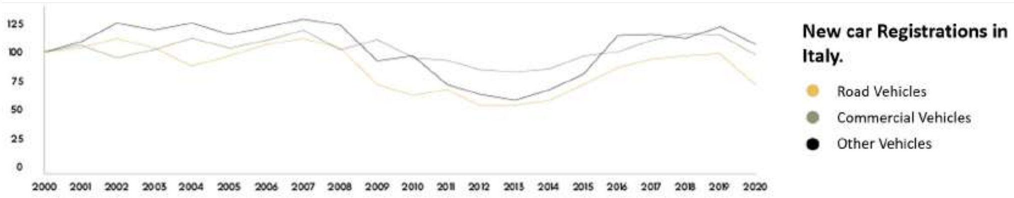

Figure 4. Brand new car sales. A.C.I. statistics.

Another important statistic laid out by JATO Dynamics [37] (See Figure 5) shows how over the last three years (2019, 2020, 2021) car sales have dropped for almost each of the car segment categories except SUVs. What really impresses from the graph is how small the sports car market is compared to others.

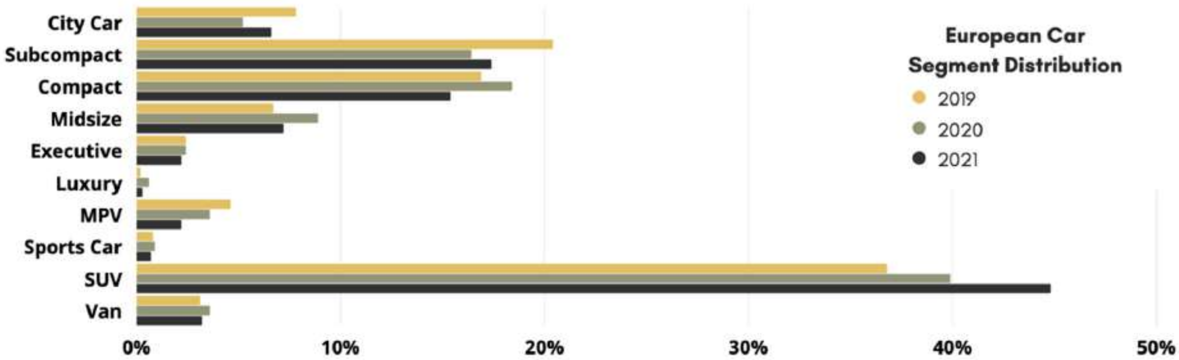

Figure 5. Car segments sales trends in Europe, JATO statistics.

These two factors, alongside the fact that regulations on combustion engine vehicles will become more excluding [38], makes it very easy to predict a shrinkage in the already relatively small sportscars market. When it comes to next decade, a three-stage hypothesis would be that by the year 2025 all diesel-powered cars are likely to start being banned [39] (or are likely to be banned entirely) from travelling inside city/urban areas. This ban is expected to be accompanied by an ever-increasing digitalization that is expected to peak around the year 2030, year where all combustion engine vehicles are likely going to be completely removed from the urban context [40] and autonomous driving is expected to become more and more predominant amongst hybrid/electric vehicles. By the year 2040 we imagine a future where the only combustion engine road vehicle remaining will likely be the sportscar. Its use would be exclusively suburban, and its purpose would be entirely recreational. The environment analysis was then further explored by researching a few case-study vehicles. The Alfa Romeo 4C, Lotus Elise, Toyota Supra Mk.5 and the Ford Mustang GT Fastback (See Figure 6) were taken into consideration.

Figure 6. Benchmark vehicles. from left to right: Alfa Romeo 4C, Lotus Elise, Toyota Supra Mk.5 and Ford Mustang GT Fastback.

The Alfa Romeo and Lotus were explored and considered to be very good examples of a sportscar: lightweight, agile and despite having a relatively small engine, very fast. The Ford Mustang GT Fastback was on the other hand regarded as a bad example of sportscar. Despite having a massive 5.0LV8 engine with very high power and torque output, it was deemed as heavy, bulky, with poor agility and little maneuverability. The Toyota Supra Mk.5 was a very interesting case that expanded our view on shared platforms and components across different brands. One of the biggest controversies and discussions among the car enthusiasts' community had to do with the Supra (an iconic Japanese car) using the same chassis, suspensions, transmission, and engine as the BMW Z4. According to one part of said community this strategic choice ruined the Supra's heritage, while the other part appreciated the work that was put in by Toyota into adapting and fine tuning the BMW engine as well as creating an aesthetically good design.

Quality Function Deployment (QFD)

The six "wh-questions" of the QFD were used to determine the list of requirements that would take part in the two-vehicle project.

Who will use the product?

Car enthusiasts, adults, and young adults.

When will the product be used?

During the weekend/holidays, during spare/leisure time.

Why will the product be used?

Allows the user to be independent.

The driving and use experience.

It is agile and fun to drive.

What is the product for?

Short and long journeys, events, competitions.

How will customers use the product?

As a new concept car for drivers, people with automotive knowledge ought to investigate and learn from the car.

Where will customers use the product?

Suburban roads, circuits and racetracks.

As a result, the list of features includes: (1) Performance, (2) Appearance, (3) Customization, (4) Performance Upgradeability, (5) Mechanical Reliability, (6) Practicality, (7) Safety, (8) Agility, (9) Use Experience, (10) Driving Experience, (11) Price Tag, (12) Usage Cost, (13) Sound, (14) Spaciousness, (15) Maintenance, (16) Digitalization, (17) Ergonomics.

The Relationship Matrix was then filled out with those characteristics, obtaining as a result the most important features of the product. The Relative Importance Relationship Matrix (See Figure 7) was filled in as described in Section 2.1.2.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Performance	**1**	1	0	2	2	1	2	2	1	2	2	2	2	2	2	1	1
2 Aesthetics	1	**1**	2	2	0	1	0	1	2	2	2	0	2	1	1	0	2
3 Customization	0	2	**1**	1	0	0	0	0	1	2	2	0	0	0	1	1	2
4 Performance Upgrade	2	1	2	**1**	2	1	2	2	2	2	2	2	2	0	2	2	0
5 Mechanical Reliability	2	0	0	2	**1**	0	2	2	2	2	2	2	0	0	2	1	0
6 Practicality	1	1	0	0	1	**1**	1	0	2	2	1	0	0	2	1	2	2
7 Safety	2	2	0	2	2	1	**1**	2	1	1	2	1	0	0	0	2	1
8 Agility	2	1	0	2	2	0	2	**1**	1	1	2	1	0	0	0	2	0
9 Usage Experience	1	2	1	2	2	2	1	1	**1**	0	1	2	1	2	2	2	2
10 Driving Experience	2	2	2	2	2	2	1	2	1	**1**	0	0	2	1	0	2	2
11 Price	2	2	2	2	2	1	2	2	1	0	**1**	1	1	1	2	2	2
12 Usage Prices	2	0	0	2	2	0	1	1	2	0	1	**1**	0	0	2	2	0
13 Sound	2	2	0	2	0	0	0	0	1	2	1	0	**1**	0	0	0	0
14 Spaciousness	2	1	0	0	0	2	0	0	2	1	1	0	0	**1**	1	0	2
15 Maintenance	2	1	1	2	2	1	0	0	2	0	2	2	0	1	**1**	2	1
16 Digitalization	1	0	1	2	1	2	2	2	2	2	2	2	0	0	2	**1**	1
17 Ergonomics	1	2	2	0	0	2	1	0	2	2	2	0	0	2	1	1	**1**
TOTAL	**26**	19	14	**26**	21	17	18	18	**26**	22	**26**	16	11	13	20	**23**	19

Most important characteristics

1 Performance
2 Usage Experience
3 Price
4 Performance Upgrade
5 Digitalization

Figure 7. Relative importance relationship matrix.

Afterwards, all the numerical values in the columns were added, and the highest values were highlighted. In our case, the characteristics with the highest value were Performance, Use Experience, Price Tag, Performance Upgradeability and Digitalization. These requirements will play a greater role in defining the design and overall characteristics of the product, after filling out the Dependence/Independence Matrix (See Figure 8). Likewise, a list of the most independent (Performance Upgrade, Mechanical Reliability, Performance, Ergonomics, Spaciousness) and dependent (Use Experience, Price Tag, Driving Experience, Appearance, Safety) was obtained.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	TOT. DIP
1	Performance	X	0	0	9	9	0	1	9	0	0	1	0	0	0	0	3	0	32
2	Aesthetics	3	X	9	3	0	0	0	0	0	0	3	0	9	0	0	3	9	39
3	Customization	0	9	X	9	0	1	0	0	1	0	3	0	0	0	1	3	0	27
4	Performance Upgrade	1	0	3	X	9	1	1	1	1	1	1	0	0	3	1	3	0	26
5	Mechanical Reliability	3	0	0	3	X	0	1	1	0	0	1	1	0	0	0	0	0	10
6	Practicality	1	1	0	0	1	X	1	0	0	0	1	0	0	9	3	3	9	29
7	Safety	9	0	0	3	9	1	X	9	1	0	1	1	0	0	0	3	1	38
8	Agility	3	1	0	9	9	0	1	X	0	0	1	0	0	0	1	3	0	28
9	Usage Experience	3	1	3	9	9	9	9	1	X	3	1	9	1	9	9	3	9	88
10	Driving Experience	9	3	3	9	9	3	9	3	1	X	0	0	3	3	0	3	3	61
11	Price	9	3	3	9	9	1	9	3	1	0	X	0	1	3	3	3	3	60
12	Usage Prices	9	0	0	9	3	0	1	0	0	0	1	X	0	0	9	1	0	34
13	Sound	3	1	0	9	1	0	0	0	1	1	1	0	X	0	0	0	0	17
14	Spaciousness	0	3	0	0	0	1	0	0	1	1	1	0	0	X	1	1	9	18
15	Maintenance	1	1	0	3	9	1	1	0	1	0	1	2	0	3	X	0	3	26
16	Digitalization	3	1	1	3	1	0	1	0	0	0	1	0	0	1	1	X	0	13
17	Ergonomics	0	3	3	0	0	3	3	0	0	0	1	0	0	3	1	3	X	20
	TOTAL	57	27	25	87	78	21	38	28	8	6	19	12	14	34	30	35	46	

Most dependent characteristics

1. Usage Experience
2. Price
3. Driving Experience
4. Aesthetics
5. Safety

Most indipendent characteristics

1. Performance Upgrade
2. Mechanical Reliability
3. Performance
4. Ergonomics
5. Safety

Figure 8. Matrix of dependence/independence.

Considering the requirements extracted from both matrices, the vehicle is supposed to be all about the performance and the excitement of being able to control the vehicle on the road. Major attention also goes to the driver and the overall driving experience.

Benchmarking and TFA

During the Benchmarking and Competitors Analysis (See Figure 9), a direct comparison was made among 10 vehicles (all belonging to the Sport Coupé category) and their features to choose those most suitable for the design. The vehicles in question are Alfa Romeo Giulia QV, Aston Martin Vantage, Porsche 718 Cayman GTS, Ford Mustang GT Fastback, Audi TT Coupé, Alpine A110, Toyota Supra, Nissan 350Z, Alfa Romeo 4C, Lotus Elise. As previously mentioned in Section 2.1.3, the best and worst value for each technical characteristic is highlighted in green and red respectively. The TFA, located at the bottom of the Benchmarking Table, enables us to specify the Delta between the number of "Tops" and "Flops". Highest values are highlighted with a green-colored cell, while the lowest value is distinguished by a red-colored one.

Moreover, a series of considerations and arguments were made in the Benchmarking Analysis table when choosing what to consider better or worse. When it came to dimensions (length, height, width, wheelbase), smaller values were considered better, since the main goal was to have a small and maneuverable car. An engine size that was either too big or too small was considered a negative aspect, while a medium-sized engine was positive. When considering the number of seats and doors, less was better. This was because the focus of the design process is on the driver as previously stated, and also because a lower number of seats and doors helps to keep the car compact, lightweight and keeps the price tag down.

The Top-Flop Delta for each vehicle used in the Benchmarking can be visualized below (See Figure 10).

	Alfa romeo Giulia QV	Aston Martin Vantage	Porsche 718 Cayman GTS	Ford Mustang GT Fastback	Audi TT Coupè	Alpine A110	Toyota Supra	Nissan 350Z	Alfa romeo 4C	Lotus Elise	
Lenght (mm)	4640	4470	4380	4790	4178	4180	4380	4247	3990	3820	< 3820
Width (mm)	1870	1940	1800	1920	1842	1800	1850	1849	1860	1720	< 1720
Height (mm)	1430	1270	1280	1380	1352	1250	1290	1318	1180	1120	< 1120
Wheelbase (mm)	2820	2700	2475	2720	2468	2420	2470	2550	2380	2300	≈ 2300
Boot Capacity (lt.)	480	350	425	408	305	196	290	235	110	112	≈ 110
Subur. Fuel Consumption (km/lt.)	16.6	8	10.7	8.5	16.4	19.6	16.6	12.8	20	12.9	> 20
Engine size (cm^3)	2891	3982	3995	5038	1984	1798	2998	3696	1742	1796	> 2992
Fuel	B	B	B	B	B	B	B	B	B	B	B
Horse Power (CV)	510	510	400	450	230	252	340	328	241	220	> 350
Max Speed (km/h)	307	314	293	249	238	250	250	250	258	233	> 265
Acceleration 0–100 km/h (sec)	3.9	4	4.5	4.6	6.2	4.5	4.3	5.7	4.5	4.6	< 3.9
Max Torque (Nm)	600	625	420	529	370	320	500	370	350	250	> 625
Seats' number	4	2	2	4	4	2	2	2	2	2	< 2
Doors' number	5	3	3	3	3	3	3	3	3	3	≤ 3
Price (€)	80,150	189,659	84,883	48,910	41,190	59,300	67,900	35,000	53,000	55,220	≤ 71,520
Emissions (grammi CO_2/km)	198	185	246	272	137	144	170	249	157	177	< 137
Breaking Distance (mt. 100 km/h)	38.9	30	30	41.7	35.2	34.7	38.5	42	35.1	34	< 30
Gear	M	M	M	M	A	A	A	M/A	A	M	M
Mass (kg)	1620	1499	1410	1743	1435	1103	1270	1496	895	904	< 904
Top	4	8	5	3	3	3	4	4	6	8	
Flop	5	3	0	5	3	1	1	1	2	3	
DELTA	-1	5	5	-2	0	2	3	3	4	5	**> 5**

Figure 9. Benchmarking table amongst concurrent productsAt the right-bottom corner we can find one of the most important indicators of the whole analysis. This value represents the minimum number of technological advancements that the design needs to be considered innovative. In the present case study, a minimum of 5 improvements over the competition needs to be achieved.

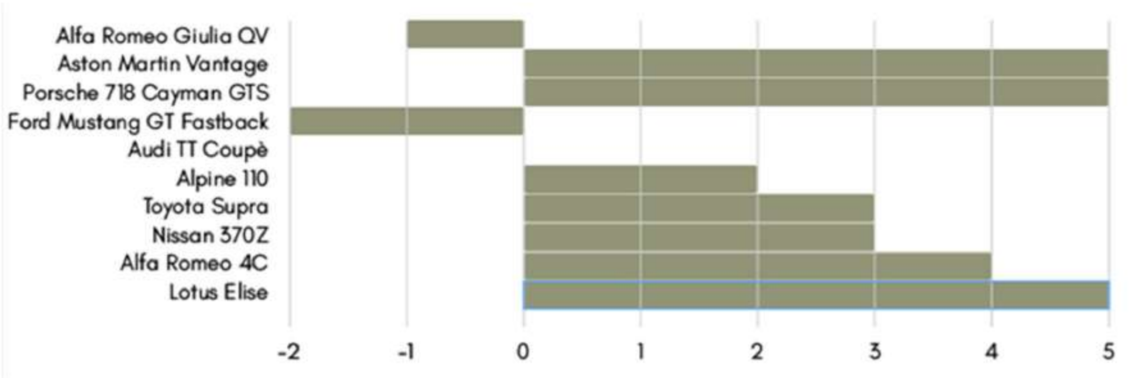

Figure 10. Visual representation of Top-Flop Delta for each vehicle.

After obtaining the Innovation Delta, the What/How Matrix (Figure 11) was used to determine which of the design factors were needed to be considered the most in order to obtain a positive innovation score.

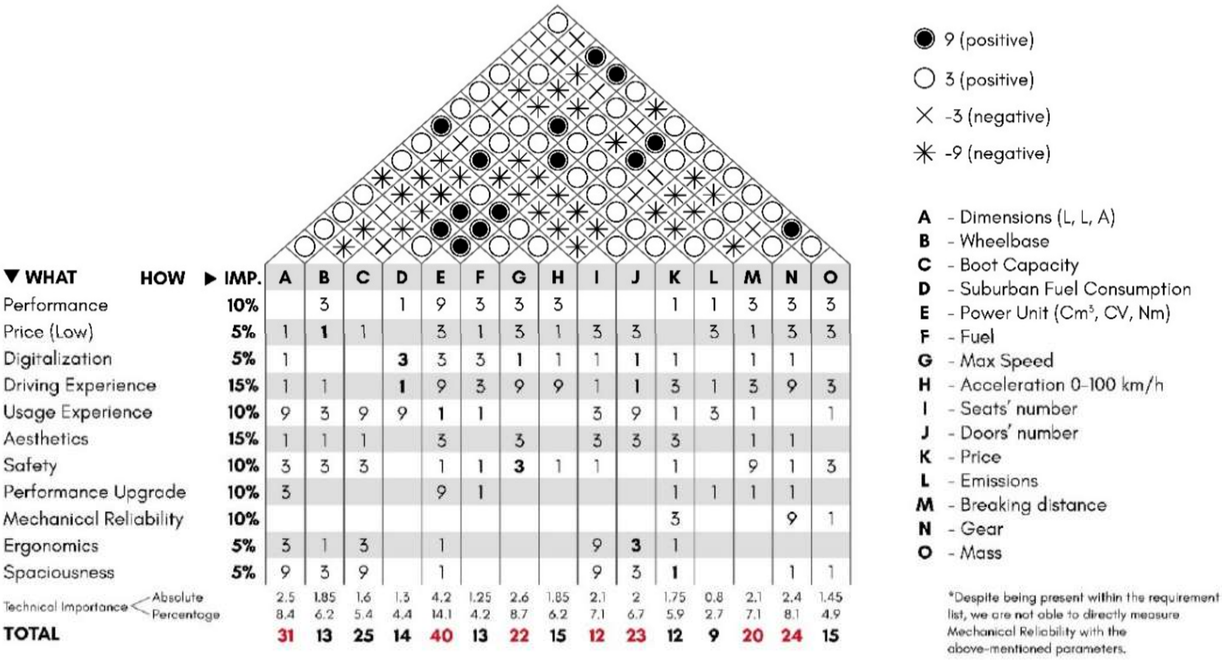

Figure 11. What/How matrix.

Activity Planning

Before starting the project, a Gantt Plan was defined. All of the different activities that needed to be carried out were added. The timeframe was set from September to December. During this period the team followed the so-called Work Breakdown Structure (WBS). It includes the 14 macro-phases seen in Figure 12, as well as the Gantt that establishes the time available for each activity, as well as which specific team member is assigned to carry out the various tasks. This allows the users to visualize their workflow and overall progress. It is also a very useful tool when it comes to increasing the deadline observance rate.

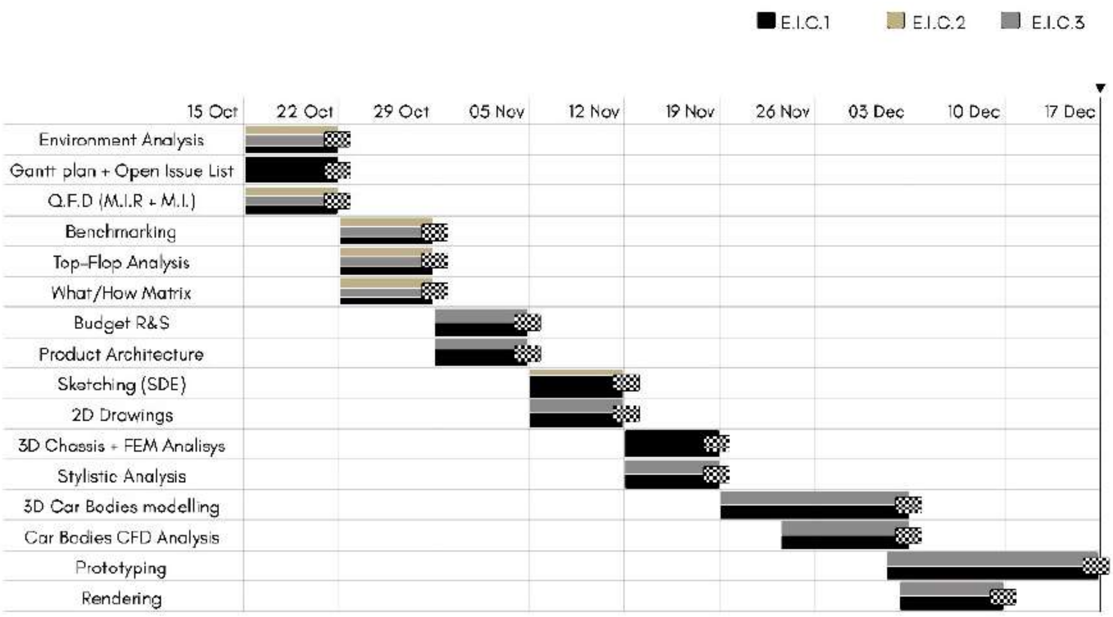

Figure 12. Gantt Plan.

Budget Planning—Research and Development Costs

Budget planning was divided into two parts: time based and a cost based. In the time-based budget planning (See Figure 13) a specific timeframe is allocated to each activity

(Project Setting, Project Development, Production) in a very similar way to the Gantt plan method. This is done in order to simulate and project the current case study into a real-world scenario.

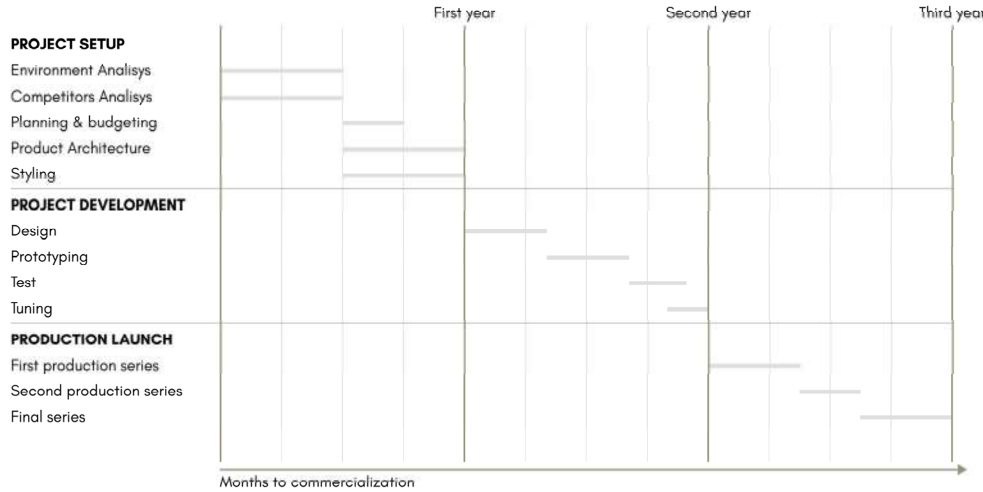

Figure 13. Time-based Budget Planning.

The cost-based budget planning is shaped out like a matrix (See Figure 14). Raw Material Costs, Work hours Costs and Equipment Costs are found in the column section. Environment Analysis, Competitors Analysis, Planning and Budget, Vehicle Architecture, Styling, Engineering, Prototyping, Testing and Follow-up Tuning are located in the rows area. An estimated cost is added into each cell. The total cost for each column is then calculated and a grand total alongside it.

	Materials' costs		Hourly wages			Equipment costs	
	n° models	unit cost	n° employees	n° hours	cost	total	
Environment Analisys	/	/	20 I	920	920.000 €	Frame	550.000 €
Competitors Analisys	/	/	10 E, 10 A	920	432.000 €	Mechanic and Engine	500.000 €
Planning & budgeting	/	/	15 E, 20 A	480	374.000 €	Electrical Components	120.000 €
Product Architecture	/	/	5 D, 8 E	920	224.000 €	Body	600.000 €
Styling	/	/	20 D	920	736.000 €	Windows	400.000 €
Design	/	/	20 E, 40 C, 20 D	640	920.000 €	Interiors	290.000 €
Prototyping	25	500.000 €	50 W, 10 E, 20 A	640	705.000 €	Interface/Software	200.000 €
Test	22	150.000 €	10 E	480	240.000 €		
Tuning	18	200.000 €	20 E	320	320.000 €		
	SUBTOT.	19.400.000 €	SUBTOT.		4.771.000 €	SUBTOT.	2.660.000 €
						TOTAL	26.831.000 €

Designers	40 €/h
Accountants	40 €/h
Engineers	50 €/h
Cad drawer	40 €/h
Workers	30 €/h

Figure 14. Cost-based Budget Planning.

Product Architecture

From the What/How Matrix a list of parameters was obtained. These are the parameters we need to act on in order to achieve the requirements previously determined with the Dependency Structure Matrix (D.S.M.) method. With Product Architecture (See Figure 15) we translated this list of parameters into a vehicle schematic. A quick visual comparison of the different architectures highlighted how a rear engine and rear traction was the most suitable displacement in terms of internal space. A manual transmission allows the driver a much more exciting driving experience. To further improve performance and to add a new element, previously seen in higher-end hypercarsonly, a Kinetic Energy Recovery System (KERS) system was implemented.

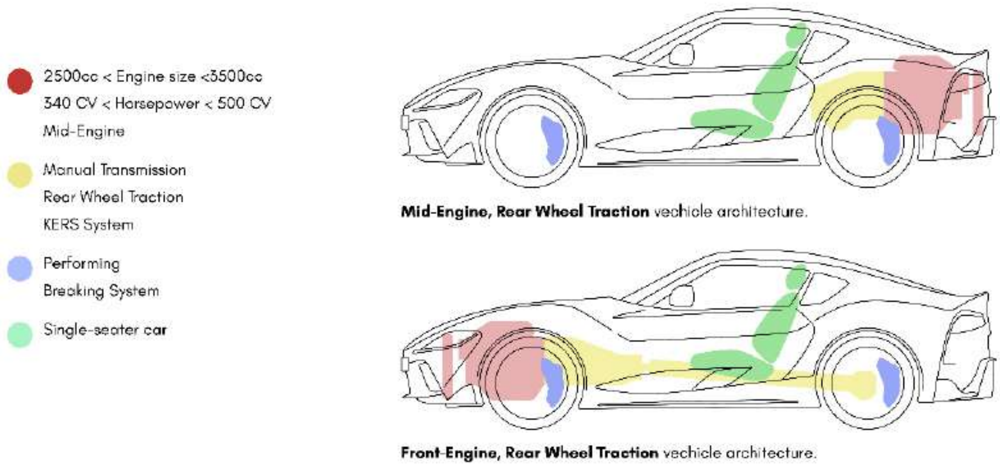

Figure 15. Product Architecture and comparison between different engine configurations.

In contrast with most of the vehicles used in the Benchmarking, a single-seat configuration allows one to further increase focus on the driver and comfort. The seat is situated in the center of the cockpit to give the driver equal visibility both on the left and the right side. This set of characteristics gives the sportscar a very eccentric and extreme note. The single seat configuration was chosen by taking into account pre-existing road-legal sportscars such as the BAC Mono [41], and the Ariel Atom [42] (See Figure 16b,c).

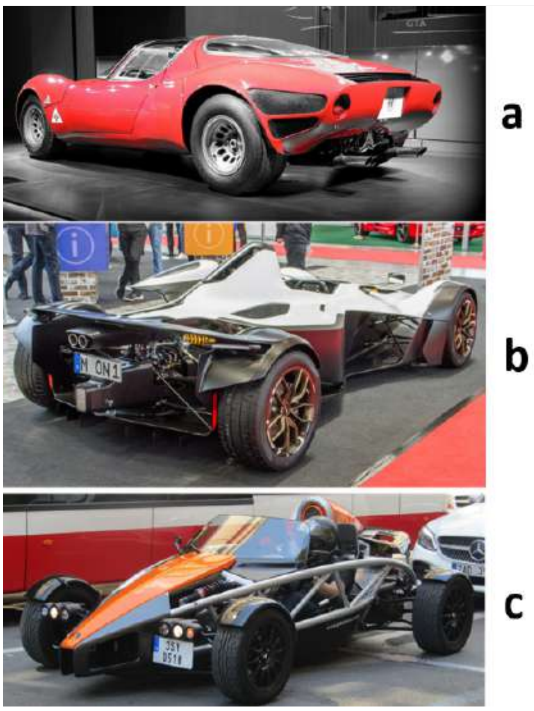

Figure 16. (**a**) Alfa Romeo 33 Stradale, (**b**) BAC Mono, (**c**) Ariel Atom.

Once the overall vehicle architecture was defined, the final dimensional values were assigned. Total length being 3700 mm, no more than 1200 mm for the Height, 1850 mm for the Width and a wheelbase not exceeding 2400 mm.

Stylistic Design Engineering (SDE)

By taking inspiration from other sportscars, four different concepts were sketched, each in a different style (Advanced, Retro, Stone, Natural) (See Figure 17). What distinguishes these four types of sketches from each other is the overall shape given to each one of them.

Based on the feel that the concepts transmitted to the viewer, a car brand was associated with each one of them. The Advanced-Style Concept was associated with Toyota, the Retro Concept was associated with Lamborghini, the Honda Brand was assigned to the Stone Concept and the Natural Concept resembled an Alfa Romeo.

Figure 17. Sketches and assigned brands for Different Styles.

Common elements between the different concepts are the side air vents and the exposed rear. The rear was purposefully uncovered so as to uncover some of the mechanical elements and the frame, which both hold an inherent aesthetic value. Examples of vehicles where the bodywork is exposed and shows mechanical components were the a. Alfa Romeo 33 Stradale, b. BAC Mono, and c. Ariel Atom (Figure 16).

2.3.2. Product Improvement

Before beginning 3D modelling operations, a comparison between the finished sketches and the 2D drawing was carried out to visually display the area difference between hand-drawn sketches and "scaled to true proportion" 2D drawings (Figure 18).

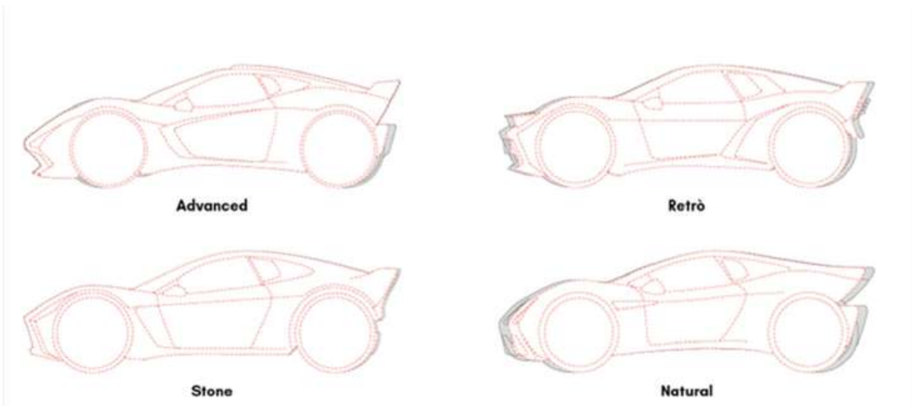

Figure 18. Direct overlay comparison between sketches and scaled 2D drawing.

Stylistic Analysis

A stylistic analysis was carried out to gain an idea regarding the advantages/disadvantages of each concept type. The main subject of this analysis concerned visibility angles and overall Field of View (FoV) that each concept could provide. A driver's silhouette (obtained from a 3D mannequin) is placed in the 2D drawings inside the cockpit and FoVs are determined by drawing lines and subsequently measuring the angle in between (See Figure 19).

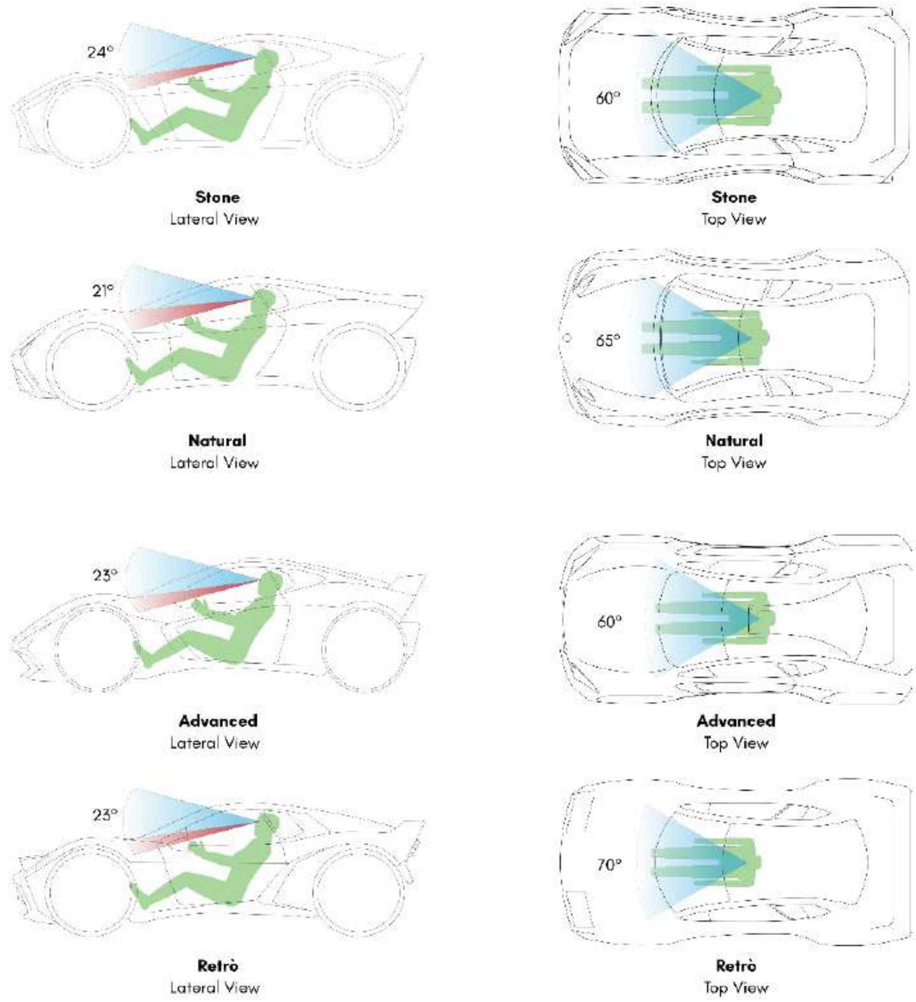

Figure 19. Simulation and measuring of visibility angles for each concept.

A Benchmarking between the four concept types was performed (See Figure 20) to determine which one was better suited for development and modelling. The Benchmarking Matrix features the four concepts in the column section and Field of View/Visibility Angle parameters in the rows area. The Advanced concept turned out to be the worst in this comparison, while both the Stone and Natural concept ended up being joint winners.

The Stylistic Analysis was further expanded by studying the human–vehicle relationship, specifically from a dimensional standpoint. A 2D standing mannequin was placed alongside different 2D views of the Stone and Natural car concepts (See Figure 21).

	Advanced	Retrò	Stone	Natural
Length DELTA (Absolute Value, mm)	7,15	69,78	0	12,01
Height DELTA (Absolute Value, mm)	46,26	48,62	16,60	18,92
Wheelbase DELTA (Absolute Value, mm)	98,87	26,34	16,48	15,30
CX (m²)	1,83	1,82	1,88	1,77
F.O.V. Lateral (grad)	23°	23°	24°	21°
F.O.V. Top (grad)	60°	70°	60°	65°
Top	0	1	3	2
Flop	2	2	2	1
DELTA	-2	-1	1	1

Figure 20. Stylistic Analysis Benchmarking.

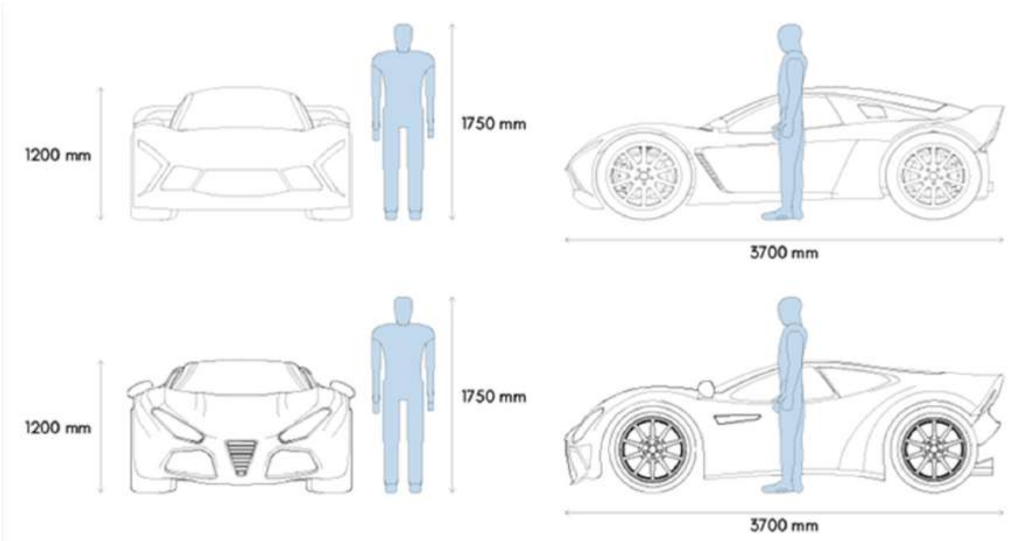

Figure 21. Vehicle/Human dimensions relationship.

3. Results

3.1. Chassis Design

The Chassis was modelled with Solid Edge (Academic Version) on the premise that it was going to be shared between the Stone and the Natural concepts. To ensure that the frame would fit underneath both bodies, its length, height and width were made smaller than the overall car volume. The overall chassis shape was kept very simple. Instead of constructing it with tubular section subframes, a square or double-T section was adopted. Swing arms, suspensions, wheel hubs and disc brakes were modelled and added to the virtual assembly (See Figure 22).

FEM Analysis

Various FEM-type analyses were carried out using the Solid Edge (Siemens PLM Software, Plano, TX, USA) built-in tool, in order to study frame deformation while under a certain load. For the purpose of the FEM analysis, the material chosen was Aluminum 6061-T6. The first type of analysis with 2400 N load was distributed on the four attachment points of the frame, resulting in a 1 mm maximum deformation, located towards the rear of the chassis (See Figure 23). A higher load of 6000 N (distributed in the same way) was then applied, which resulted in a 3 mm maximum deformation, also located towards the rear end of the chassis (See Figure 24). Both deformations were underneath the 10 mm imposed safe limit and, therefore, chassis design was deemed satisfactory.

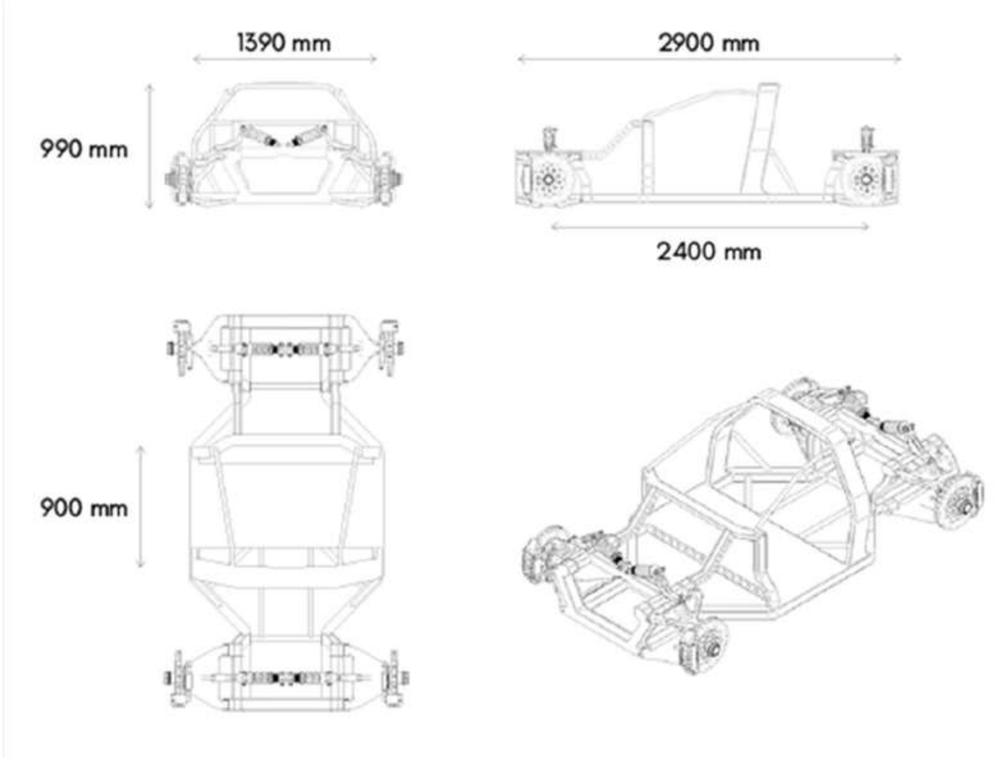

Figure 22. Chassis Assembly 2D Drawings.

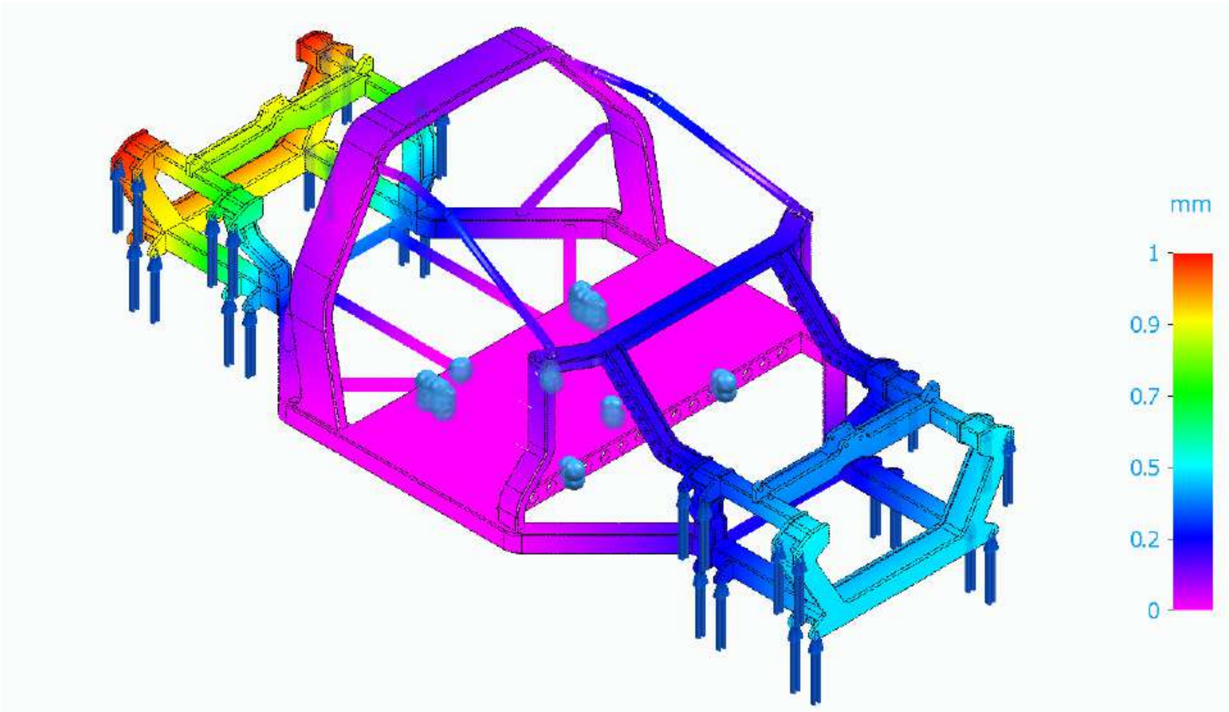

Figure 23. FEM Analysis with 1200 N load and 0.9 mm deformation.

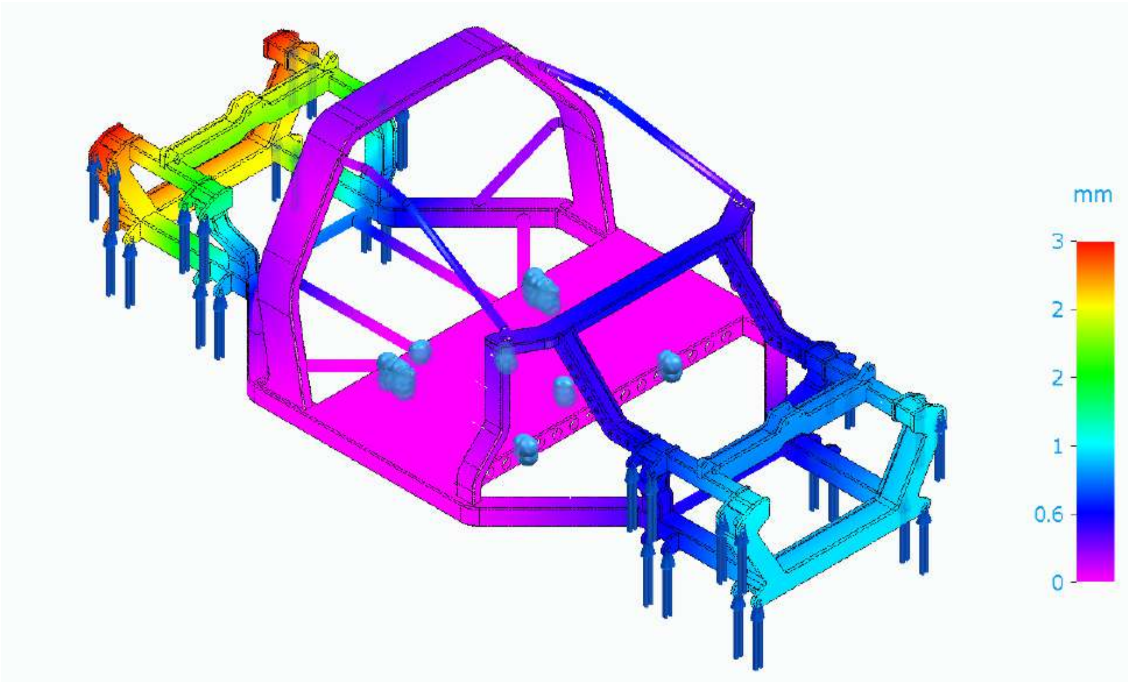

Figure 24. FEM Analysis with 6000 N load and 3 mm deformation.

In the second FEM analysis, the Euro NCAP Frontal Impact with Full Width Rigid Barrier was simulated. Vehicle mass was hypothesized at 900 Kg and vehicle speed was taken straight from the Euro NCAP test at 50 Kph (or roughly 14 m/s). With those elements, an axial impact force of 12,600 N was derived. To such force corresponded a maximum Von Mises stress of 40 MPa (See Figure 25).

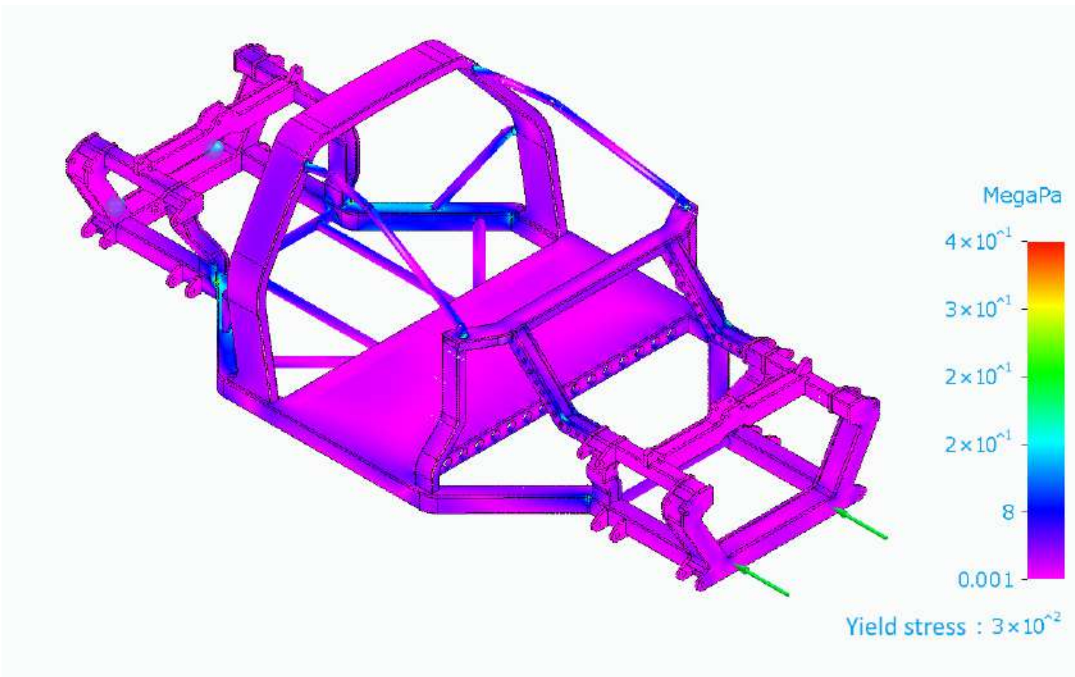

Figure 25. FEM Analysis simulating Euro NCAP frontal impact at 50 Kph.

A third FEM Analysis was carried out in order to verify torsional stiffness of the chassis. A force couple of 1000 N was applied to the front and the rear of the chassis, resulting in a 2 mm maximum deformation and a maximum Von Mises stress of 50 MPa (See Figure 26).

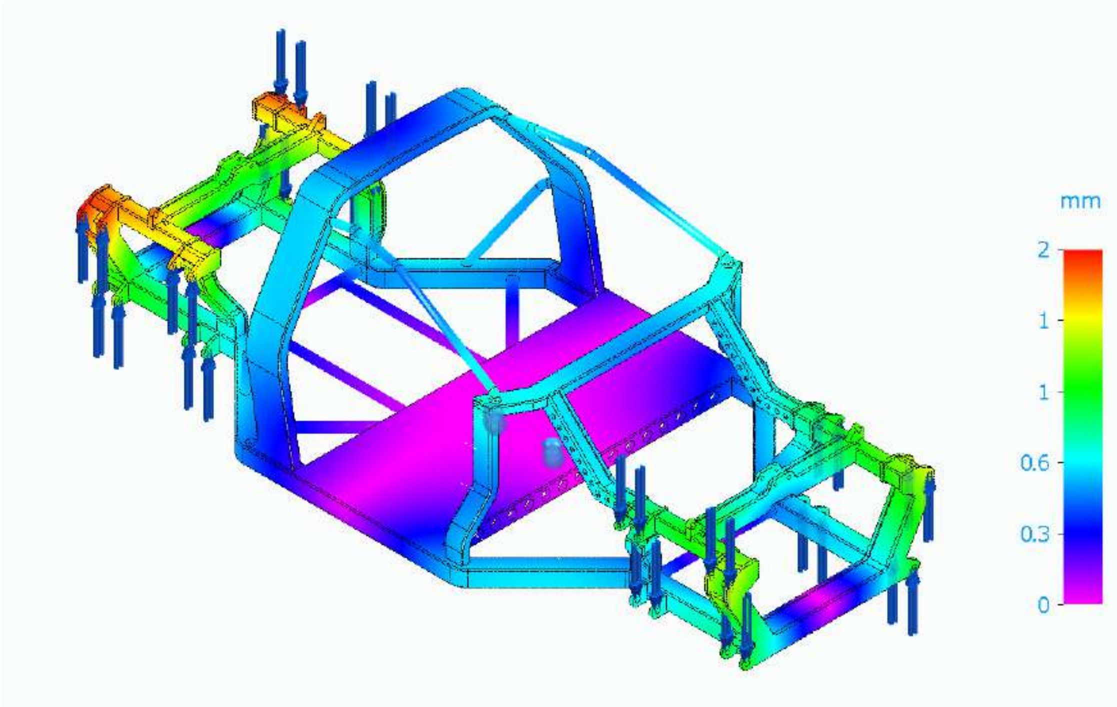

Figure 26. FEM Analysis for torsional stiffness.

Moreover, a 3D model for engine and transmission was added to the chassis assembly, as well as a double wishbone suspension system. With those elements, an initial virtual render was made using KeyShot (See Figure 27).

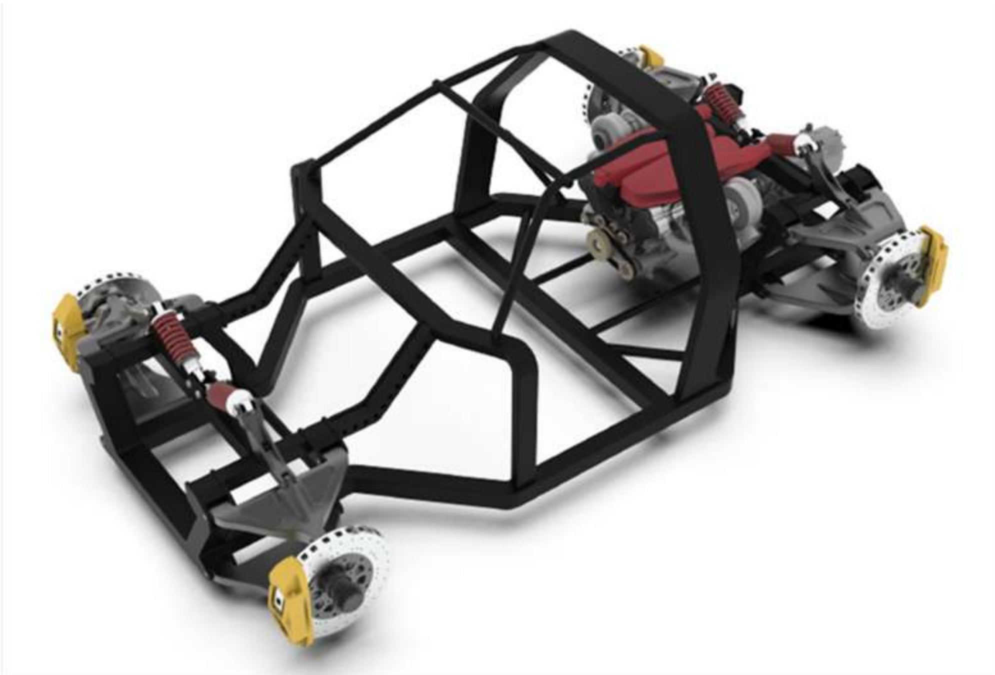

Figure 27. Rendered Chassis assembly.

3.2. Car Body 3D Modelling

Once the specific guidelines were specified, the 3D Modelling phase could begin. The scaled 2D Drawings became blueprints inside the 3D modelling software (See Figures 28 and 29). Nevertheless, true car proportions could be maintained intact. Using two separate modelling software meant splitting the original task into two. The Stone Concept was modelled using Autodesk Alias Studio (See Figure 30), while the Natural Concept was modelled with Rhinoceros (Robert McNeel & Associates, Seattle, DC, USA) (See Figure 31). Both software required a Class-A level of modelling, which focuses its attention on surface layout and surface continuity. Once the 3D modelling was complete, the 3D chassis (and the relative suspensions, brakes, engine, and transmission) was applied, underneath both car bodies (See Figure 32), ultimately fulfilling what was the original premise of the project.

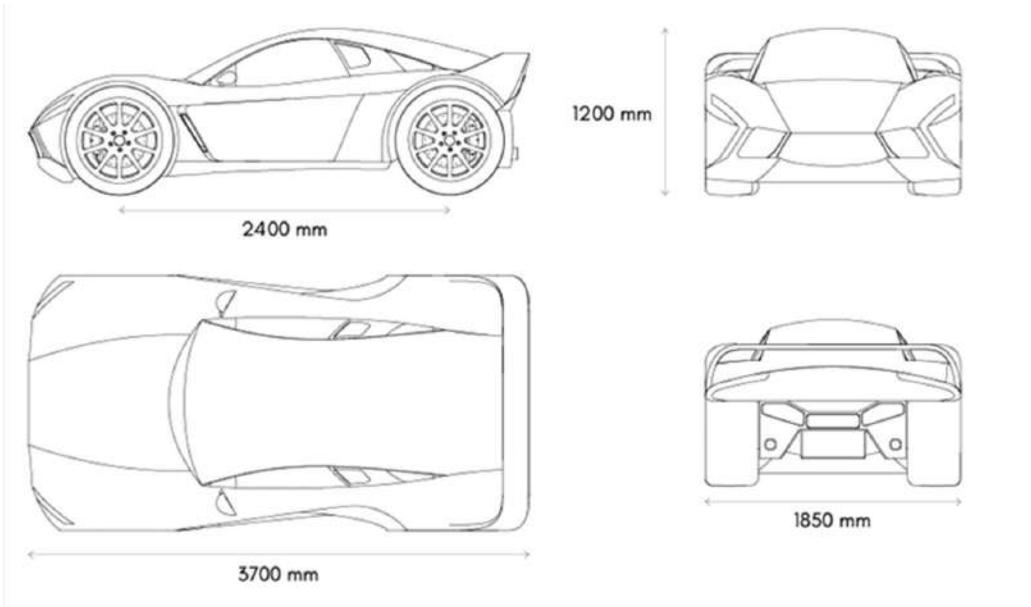

Figure 28. Stone concept 2D Drawings.

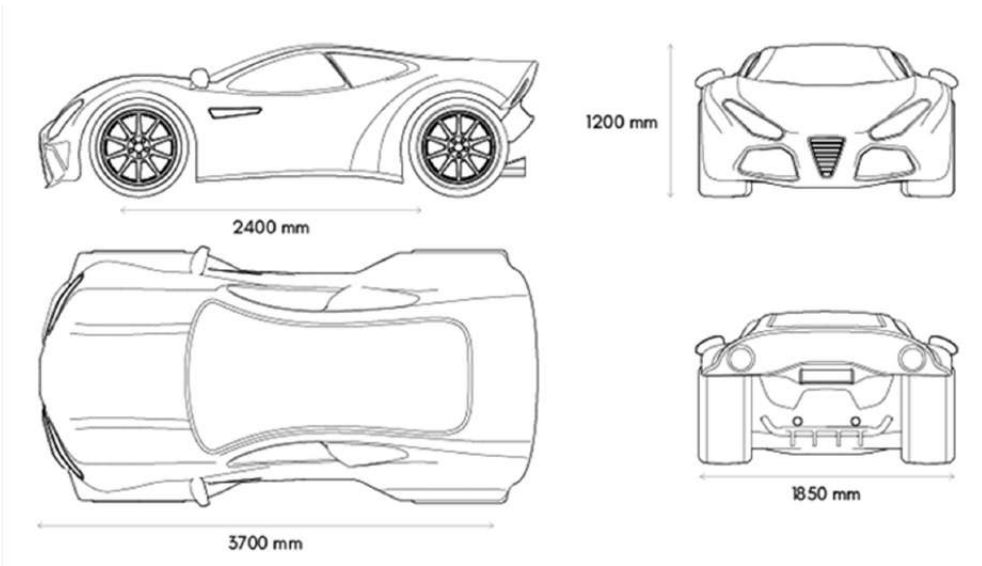

Figure 29. Natural concept 2D Drawings.

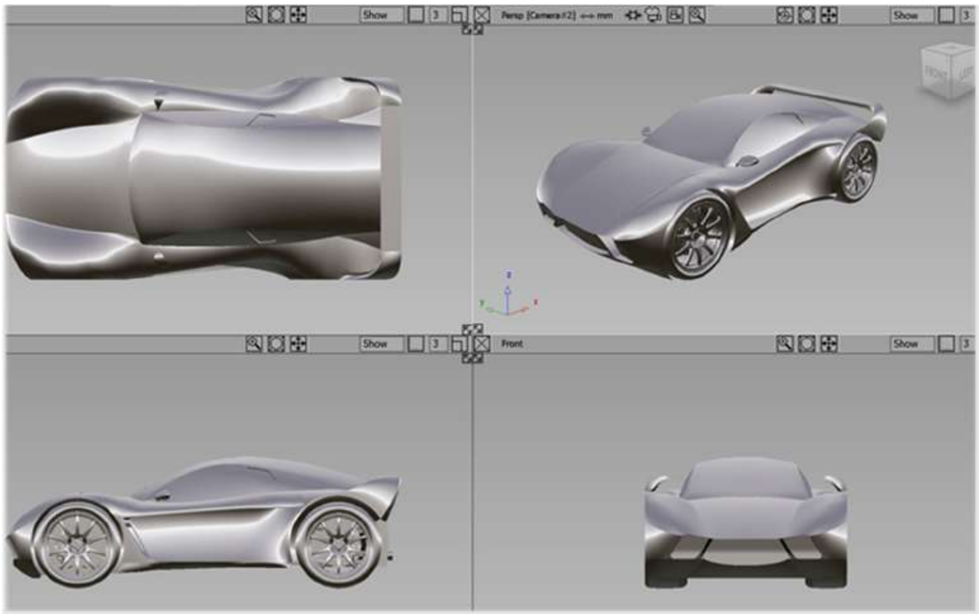

Figure 30. Stone concept 3D Modelling via Autodesk Alias Autostudio.

Figure 31. Natural concept 3D Modelling via McNeel Rhinoceros.

Figure 32. Car bodies showing the shared Chassis.

3.2.1. Car Body CFD Analysis

Computational Fluid Dynamics (CFD) is the analysis of fluids carried out by numerical solution methods. It permits one to analyse problems related to fluids interacting with the product, in order to define the value of its aerodynamical efficiency profile. Parameters within this analysis to be taken into consideration are pressure, air density, drag coefficient, frontal area.

Such a method was used to save both time and money through the design process. This analysis has been made by using the software Autodesk CFD. A CFD analysis was conducted to gauge the aerodynamic performance of the car bodies. Both models were imported into Autodesk CFD and an airflow simulation was run. Results showed how the Stone Concept had relatively lowered front pressure area compared to the Natural Concept, but a higher rear turbulence wake. Drag coefficient were calculated at 0.27 for the Stone and 0.29 for the Natural, seen in Table 1 and in Figures 33 and 34.

Table 1. CFD Parameters and Results.

Design A: Stone		Design B: Natural	
Area (m^2)	1.29	Area (m^2)	1.33
Drag Force (N)	670	Drag Force (N)	730
Speed (Km/h)	55.5	Speed (Km/h)	55.5
Air Density (Kg/m^3)	1.225	Air Density (Kg/m^3)	1.225
Cd	0.27529	Cd	0.29092

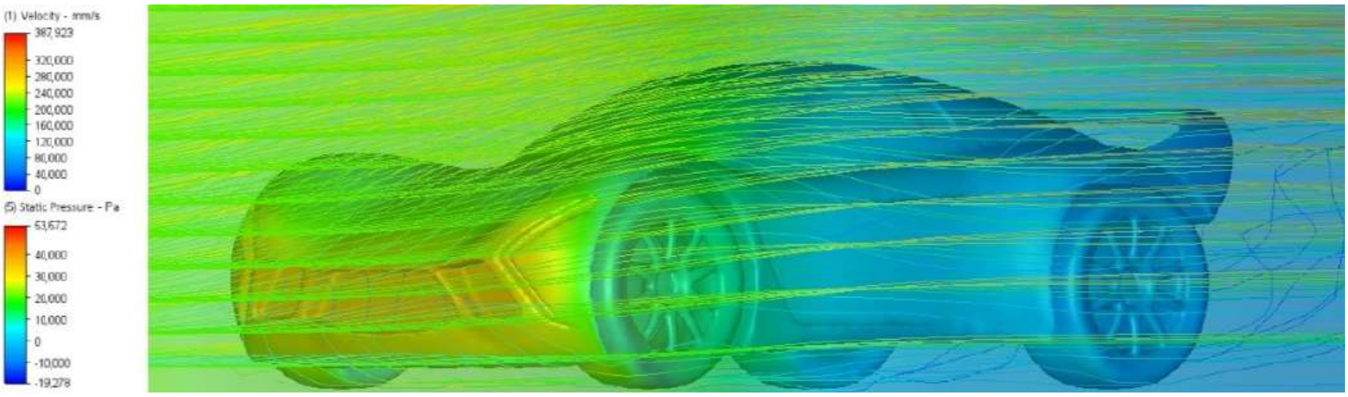

Figure 33. Stone concept CFD Analysis.

Figure 34. Natural concept CFD Analysis.

3.2.2. Real-Life-Inspired Renderings

Realistic renderings were created using KeyShot's HDRI environment (Figures 35 and 36). This process allows one to get a wider understanding of the product in real-life scenes and completes the car body modelling phase.

Figure 35. Stone concept rendering.

Figure 36. *Cont.*

Figure 36. Natural concept rendering.

3.2.3. Physical Models at Scale

Physical ABS models at scale were 3D printed using the Anycubic Mega X printer (Fused Filament Fabrication technology) and the CURA slicing software. Upon completing the 3D printing process, the models underwent post-process operations. To decrease the stair-stepping effect (created by the slicing of the .slt file) and increase smoothness, surfaces were sanded down and a layer of Tamiya White Putty was applied. Lastly, a coating of acrylic white paint was sprayed onto the models (See Figure 37).

Figure 37. Mockup model in the post-process phase (**left**) and completed mockup models (**right**).

3.2.4. Dashboard View and ADAS

IDeS methodology is applied through the SDE (Stylistic Design Engineering) process that was used to realise sketches and develop accurate ideas, in order to establish the most suitable elements to furnish for the driver in their experience. Such a dashboard was studied by analysing different case studies on the market, mostly used over Mercedes vehicles. The whole project was implemented by analysing a dashboard on the vehicle that was made by taking into consideration many different parameters, in order of importance. Firstly, the principal decision was made by considering, as a primary item, the safety of the driver. Secondly, it has been relevant to make a distinction among all the suitable elements, based on the human needs through the driving. By sticking to the criteria, three displays were arranged on Figure 38, subdividing all the icons into three principal groups of elements:

- Traditional and mandatory on-vehicle information (RPM, speedometer, GPS, etc.);
- Advanced driver assistant systems (lane warning, parking support, adaptive cruise control, etc.);

- Entertainment and telematics functions (calls, music, address book, etc.).

Figure 38. Dashboard and steering wheel rendering.

An internal dashboard was conceived, featuring three main screens. The center screen is dedicated to the traditional and mandatory on-board information (RPM counter, Speedometer, etc.). The right screen hosts all the entertainment functions (Radio, Music, Bluetooth, Phone Connectivity) and Telematic Functions (Navigation System, Phone, Emergency Calls, Traffic Information, etc.). The left screen holds all Advanced Driving Settings, such as ABS level setting, Traction Control level setting, KERS output flow rate, Launch Control. A smaller screen was added on the steering wheel to display live wheel temperature and pressure values and other track/race-related information (See Figure 38).

4. Discussion

The efficacy of the industrial design structure (IDeS) was demonstrated in the development and application of this case study. The IDeS method, through the usage of other development tools, such as QFD and SDE, has shown that it is able to outline the phases of product management. The straightforward usage of design and engineering applications, across both areas, gave the ability to better organize the flow of information to the organization, starting from the product design area. Digital models, part simulations and overall assembled components information, provided by design and engineering departments, could be shared straightforwardly with all other departments across the organization, thanks to dedicated software for event simulation and real-life-inspired renderings, which ought to enhance the physical perspective of the product before its actual production. Therefore, the IDeS method guarantees the reaching of both technical and stylistic targets, and this has demonstrated a reduction in time and resources, in order to give a final delivery with a lower likelihood of additional changes before starting production; therefore, delivering a quality product ought to please a target market segment.

Moreover, this method has the ability to expand its coverage of application beyond product development and reaching production set-up. This would allow technical and style designers to fully implement a new project easily and systematically with the IDeS roadmap. Management, technical and control phases are all included in the IDeS, the most complete way to design an entire industrial project. Design for Six Sigma guidelines must be included in product research and design, in order to achieve process sustainability [22,43]. DMADV needs to be guided, and supplemented with guidelines from lean productivity [21]. In this way, the IDeS methodology supports a major part of the organization, and information sharing leads to a reduction in waste execution time, aiding the systematic achievement of sustainability [44]. Moreover, this exercise also delivered the opportunity of brand differentiation, which could be achieved by fine tuning, suspension set-up and by experimenting with the exhaust sound design. The single seat configuration increases the focus on the driver's needs and increases space alongside comfort.

5. Conclusions

This concept attempted to preserve the traditional racing driving style towards a future world, likely to be surrounded by fully electric, autonomous driving vehicles. This was done after an integrated product conception started from the stylistic point of view. Both revealed models, with a shared, common platform, together with already existing, reliable, powertrain and mechanical parts, that would greatly reduce development times and costs. The entire product set-up was conceived with the tools and parameters provided by the IDeS method, by which the target was to create a small, niche market product, with the aim to satisfy clients from the shrinking sportscar market and the increasing cost that sportscars will have in the future.

The methods included in the IDeS lead us to gather a fully technical layout of the product, including mechanical and CFD assessments, mandatory factors needed to satisfy today market's minimum requirements. Additionally, updated product information sourced from the product design department will help stakeholders, from internal and external parties in the organization, to have a clear, immediate understanding about change decisions in the main design, saving valuable resources and helping to freeze the technical definition of the project in a lower time.

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