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IDeS Method Applied to the Concept of a Sports Car

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Abstract

The following paper aims to take a detailed look at the various stages of IDeS (Industrial Design Engineering), a prime example of a modern, cutting-edge methodology useful for laying the groundwork for new product development within an organization. Its general outline interfaces with any type of product and is applicable in almost any context, from food production to the world of cosmetics, from the biomedical sector to car design. The methodology described is orderly and perfectly schematic, so it can govern all departments of a generic company with the goal of product development, to the point that its very architecture could be built following the logic of IDeS. From an initial market analysis useful for understanding the needs required by the future users of the product, through benchmarking applied to competitors in the target market segment, arriving at the study of the actual architecture of the product, all the steps of the IDeS will be considered. In detail, the steps of "Stylistic Design Engineering," a purely design approach to develop automotive design projects in the industrial world, will be applied to arrive at the final product configuration. Serving first Quality Function Deployment (QFD), a methodology involving market and competitive analysis, and SDE, the goal was to design a new sports car model that can be competitive and aesthetically cutting-edge. The model creation process is divided into several stages that required in-depth knowledge in the use of various programs. Both the aesthetics and performance of the vehicle must be perfectly optimized. To top it off, a scaled prototype printed in PLA was also made to offer a first impression of the final model to the future customer.

Keywords
IDeS (Industrial Design Structure), Stylistic Design Engineering (SDE), Quality function Deployment (QFD), Car Design and Prototyping.

1. Introduction
The definition of "sports car" refers to a type of automobile designed to achieve an elevated level of performance, typically geared toward a high end of the market (Rentzmann and Wuthrich, 2019). Sports cars are works of high engineering that fall between "normal" cars, used as "everyday" vehicles, and track racing cars, which prioritize performance over functionality (Ingenbleek and. Lemaire 1988). Thus, designed to give the driver an experience on the road or on the track of a high degree of luxury and performance, they have special characteristics: an extreme and avant-garde design, with lines with attention to detail and certified beauty; they are often halfway between tradition and innovation, giving rise to extremely modern and sophisticated solutions, while also managing to represent the history of their car manufacturer at its best; they have a strongly sporty connotation, proven by average performance out of the ordinary; they are very original mechanical means, different from the cars usually seen in cities for everyday use. The purchase of a sports car requires a well-calculated evaluation given the amounts of money they require (Katz and Cain, 2011). So, it was decided to identify what are the advantages and disadvantages in owning one of these marvels. The main advantages are those for which these cars are specially designed: Speed, Exclusivity, Driving, Safety. However, owning a "luxury" car leads to disadvantages, which are often related to its maintenance (Cannon and Rucker, 2019). Price, Parts, Repairs, Insurance, Consumption, Limits, Emissions. As can be seen, most of the advantages are associated with the driving experience the car offers, while the disadvantages are mainly associated with the costs of buying and maintaining it on the road (Okulicz-Kozaryn et al, 2015). At this point, the choice will depend on the preferences of the customer who will have to put all these factors on the scales.

2. Literature Review

2.1 Market analysis

The last period, marked by the COVID-19 pandemic, has negatively affected the sports car market simply because those interested in buying such a product have for one reason or another decided to postpone their purchase. However, as this situation has gradually been resolved, sales related to this narrow part of the market have also resumed growth. In 2021, sales of luxury and sports cars showed a slight increase over 2020 (+5.8 percent) and continue to account for 0.3 percent of the total registered market. Automakers such as Bentley, Ferrari, Lamborghini, Porsche, and Rolls-Royce enjoyed the best year of their existence in 2021, with production and sales records broken and deliveries never before. In addition to the classic cars that have made history for these brands, credit for this economic upswing must also be given to models that have only recently taken the motorsports stage: SUVs and electric cars. The brand with the highest number of registrations in 2021, Porsche, with a total of 301,915. The reason for this success is dictated by the fact that this automaker caters to a wide variety of audiences, thanks to numerous customizations to create models tailored to its customers. The Porsche 911 (Farris et al, 2021) is confirmed as the best-selling sports car in Italy, with a total of 1,218 registrations in 2021, representing a +5.5 percent over 2020. In addition to this iconic model that continues to dominate the sports car market, the Zuffenhausen company owes a slice of its success to the switch to electric. Indeed, the Taycan has won 41,296 customers worldwide, including 617 in Italy alone. On the strength of its flagship models, the Aventador and Huracan, Lamborghini owes its latest successes to an "out-of-the-box" model: the famous Lamborghini Urus. The Sant'Agata Bolognese-based company ended 2021 as its best year ever with an impressive 8,405 units delivered worldwide, of which the Urus SUV has 5,021, while 2,586 for the Huracan and 798 for the Aventador. Regarding the main customers, the United States remains the first market for Lamborghini (2,472 units, +11%), followed by China (935, +55%), which rises to second place, Germany (706, +16%) and the United Kingdom (564, +9%). Numbers are also up for the House of the Bull in Italy: +4%, with a total of 359 cars delivered. Finally, Ferrari also reported a historic leap in registrations with 11,155 cars sold and +22% compared to last year, +13.4% if 2019 is considered, surpassing the figure of 10,131 registrations of 2 years ago and marking a new historic sales record. This is due to a product range that has never been so rich, driven by the performance of the SF90 family and the new releases, including the SP3 Daytona, as well as customization programs that have generated strong added value. The market for the Rossa is growing steadily and will be fueled by a series of model launches that will perhaps mark a turning point, such as the already announced and long-awaited Purosangue SUV that will aim to dominate the current international automotive scene, or the first electric Ferrari in history, on which the Maranello-based company is already committed. In conclusion, in a market aimed at a small, privileged clientele, where, however, new "competitors" try to impose themselves every day, the race for innovation and perfect aesthetics is vital (Vaz et al, 2017). This same competition drives automakers to project future designs on the search for new technologies that can be used to manufacture cutting-edge mock-ups and evolved car models (del Pero et al, 2018).

2.2 Stylistic Design Engineering (SDE)

A method called Stylistic Design Engineering (SDE) is very useful to design a new car. It is one of the phases of industrial design setting, a part of the macro area of Design Engineering. It is aimed at defining the aesthetic form of a new product (not necessarily automotive) by taking an engineering approach. The qualities of this method lie in the fact that it is the most cost-effective, it is simple and effective to use, and it can open up great spaces for research because each of its steps can be adapted to new emerging technologies. The main objectives of Stylistic Design Engineering are: a) to analyze historical and innovative stylistic trends; b) to provide new stylistic ideas for new products potentially suitable for any field; c) to offer as an end result a technical stylistic study that can lead to a final physical prototype; and d) to carry out stylistic designs using an engineering method.

Analyzing the structure of Stylistic Design Engineering (SDE), the following phases are denoted: 1) Analysis of stylistic trends; 2) Making multiple sketches according to different styles; 3) Making the first 2D drawings bearing the main information about the overall dimensions; 4) Designing the 3D virtual model of the product (digital mockup); 5) Rendering of the finished product; 6) Manufacture of a first final prototype, typically 3D printed (physical mockup). The first phase consists of the study of the stylistic features that characterize its product line, so as to set the design of the car in accordance with the brand's history; this phase includes the study of both the body and particular functional components such as the rims, headlights, and air intakes. Based on the results of the study, multiple freehand sketches are drawn, each with its own defined style: typically, the styles analyzed are Natural, Advanced, Stone and Retro. These models are used to be able to identify, through their fusion, the final sketch of the car, which can then have stylistic features belonging to all models. Having arrived at the final design, one moves on to work on a CAD in two dimensions, such as AutoCAD, in which orthogonal projections of the model are made. Using the best views, usually top and side, the driver's visibility cones while driving are derived, and, if it is required, the structure of the car is modified to allow an optimal view. In addition to this, a rough estimate is made of the interior volume of the vehicle that is to accommodate passengers, assessing its suitability. The two-dimensional references obtained from making the first views of the model serve as an important reference for the actual modeling of the vehicle surfaces, a particularly lengthy and tedious procedure given the level of quality required for the exterior. Advanced design and engineering software such as Siemens Nx or Alias Studio are among the few that can actually meet the quality requirements at this stage of applying the method. Not all CADs, in general, are suitable for the purpose. The design of the body is therefore made in accordance with the surface quality requirements demanded by company standards and with those relating to the interface with the remaining parts of the vehicle, prominent among which is the chassis, the vehicle's load-bearing structure. For optimal rendering and to have well-defined light reflections on the car, the continuity and curvature of the surfaces is studied by making initial test renders on software such as Keyshot, for example, to correct any imperfections again on the CAD. The study of surface curvature is basic to avoid the emergence of defects on the finished product (such as dents) that often arise at the very stage of its virtual modeling. Rendering software, such as Blender, V-Red, Keyshot, allow a multitude of textures associated with realistic materials and natural colors to be attributed to the surfaces, so that very detailed and truthful renders of the car can be made. The scenario in which the product is placed contributes to its presentation. Indeed, it determines the final appearance of the model's light reflections and shadows. Finally, it ends with the fabrication of the solid styling model: this is normally the result of an SDE Project and is the "product" delivered to the engineers to start the technical process of industrialization. Made by 3D printer, it usually consists of one or more of the following materials: Ureol, Polyurethane, Clay. A simplification of the latter phase may concern 3D printing the model to scale, then painting and updating it with all the elements that help it look as similar as possible to the real thing (wheels, mirrors, body colors, and so on).

3. Methods

The IDeS (Industrial Design Engineering) methodology should be considered in all its major phases to govern the process of developing a new product within a company, from the industrial to the medical-health field. This is even more necessary in cases where such a product is complex and requires the collaboration over long periods of time (months or years) of multiple company departments and hundreds of operators. Too often this process is approached in companies in a crude and unmethodical manner. This turns out to be very dangerous, as well as completely inefficient. It is precisely in companies where prior experience is still the cornerstone of product development that time and economic losses occur due to multiple causes. The realization of one or more errors in the design phase, difficulties related to the manufacture of an overcomplicated part encountered too late, not realizing that the product being developed does not have the basis to be competitive in the market, poor dialogue skills with future customers, and so on. The IDeS lays the foundation for a schematic and effective method that is summarized in the following steps: a) Initial market analysis; b) Study of the product architecture; c) Study of the characteristic style trend; d) 2D and 3D modelling; e) Analysis of the mechanical performance of the product (based on the context); f) Rendering and first presentation to customers; g) Making the first physical prototype.

3.1 Quality Function Deployment (QFD)

The QFD methodology is employed early in the development phase of a new product. It requires the initial execution of market research with the purpose of gathering information inherent in the needs of potential users of the finished product. This is needed because without sound documentation describing exactly what the primary needs required by the market are, the basis for design cannot logically be laid. There is no alternative. Despite this, this step is often neglected or completely overlooked, especially in small to medium-sized enterprises. The company uses this step to determine which product features are considered important by the customer and how he or she evaluates the offering compared to that of competitors. In this way, they can clearly identify which are the salient aspects on which to invest more time and money to make their product successful over that of competitors. The other fundamental step takes place through involvement in analysis brainstorming to gather ideas from company personnel; very often, in fact, the best ideas can arise directly within the company, the place where one generally expects greater judgment relative to one's ability to innovate, to make a product, to lay the groundwork for its development by organizing the company hierarchy itself according to the characteristics of the project to be completed. Having mapped customer requirements and identified the areas of intervention to meet them, the development of the product according to the qualitative and technical specifications derived is the following step, as a stage-gate approach.

3.2 The 6 "Wh" questions

The now well-known in the literature "6 questions" are used to get an initial indication of the type of product to be developed and what the main technical specifications will be. These questions are answered by two different sources, one internal to the company and one external. Both in the company's internal personalities and in future consumers specific market surveys and polls must be conducted with the aim of laying the foundation for the entire project. The final feedback obtained from this process is therefore presented as hybrid. The six questions to be asked are generally as follows:

Who? Who will be interested in the purchase? The car is aimed at sports car enthusiasts who seek a combination of power, performance and aesthetic elegance in their cars.

When? When will it be used? Its use should be suitable for any location and activity. However, given the typical characteristics of the car analysed, use on suburban roads or at the track is recommended.

Why? Why should one purchase it? There are various motivations that can drive one to buy this car, from a passion for sports cars, through a real business necessity that requires driving them, to the simple desire to collect them.

What does one get from buying it? Good feelings due to its driving both on the road and on the track, the possession of a product characterized by an aggressive but elegant design, which not everyone can afford. Also, a comfortable product customized to one's taste.

How? How is it used? The car has the characteristic of being able to adapt to different roads and conditions. The normal driving mode, combined with a comfortable driving position allows the driver to enjoy the road while with the sport mode the car unleashes the full power of its engine, pushing the car's performance to the next level.

Where? Where can it be used? Being versatile and adapting to any situation, it can be used on urban and suburban roads as well as on the track.

Interpreting the answers to the questions just asked, we can see that the goal is to create a car with high performance and a sleek, elegant design that allows the driver a complete driving experience.

4. Data Collection

4.1 Matrices

Based on what was derived from the previous questions, twelve characteristics were chosen as the most important for the car and put into a matrix as rows and columns. These are: *top speed, acceleration, braking, suspension, aerodynamics, comfort, road holding, design/aesthetics, weight, cabin capacity, safety, and emissions*. The purpose of this matrix is to compare all these properties with each other by going to assign a value based on the following yardstick: 0 = line more important than column; 1 = line and column have equal importance; 2 = column more important than row (Figure 1).

	1	2	3	4	5	6	7	8	9	10	11	12
Top speed 1	1	2	1	0	1	0	1	1	0	0	2	0
Acceleration 2	0	1	1	0	0	0	0	1	0	0	1	0
Braking 3	1	1	1	0	1	0	1	1	0	0	2	1
Suspension 4	2	2	2	1	2	1	2	2	1	0	2	1
Aerodynamics 5	1	2	1	0	1	1	1	1	1	1	2	1
Comfort 6	2	2	2	1	1	1	2	1	0	1	2	1
Road holding 7	1	2	1	0	1	0	1	1	1	0	2	1
Design/aesthetics 8	1	1	1	0	1	1	1	1	0	0	1	1
Weight 9	2	2	2	1	1	2	1	2	1	1	2	1
Cabin capacity 10	2	2	2	2	1	1	2	2	1	1	2	1
Safety 11	0	1	0	0	0	0	0	1	0	0	1	1
Emissions 12	2	2	2	1	2	2	2	2	1	1	2	1
TOTAL	15	20	16	6	12	9	14	16	6	5	21	4

Figure 1. Relative importance matrix

When the results for each characteristic are summed vertically, the four that scored the highest are chosen and are therefore the ones deemed most important for the car: ACCELERATION, BRAKING, DESIGN/AESTHETICS,

SAFETY. In the second matrix, the elements in the rows and columns remain the same as those used in the relative importance matrix.
In this one the comparison is made on the basis of how dependent the characteristic belonging to the row is on the characteristic belonging to the column:
0 = the feature in the line is independent of the feature in the column.
1 = the feature in the line is almost independent of the feature in the column.
3 = the characteristic in the line is highly dependent on that in the column.
9= the characteristic in the line is completely dependent on the one in the column (Figure 2).

	1	2	3	4	5	6	7	8	9	10	11	12
Top speed 1	/	0	0	1	9	0	1	0	3	0	0	0
Acceleration 2	0	/	0	1	3	0	3	0	3	0	0	0
Braking 3	3	0	/	1	3	0	1	0	3	0	0	0
Suspension 4	0	0	0	/	1	0	0	0	3	0	0	0
Aerodynamics 5	0	0	0	1	/	0	0	3	0	3	0	0
Comfort 6	0	0	0	0	1	/	0	1	1	3	0	0
Road holding 7	9	9	3	3	9	0	/	0	3	0	0	0
Design/aesthetics 8	0	0	0	0	9	1	0	/	0	9	3	0
Weight 9	0	0	0	0	0	1	3	0	/	3	3	0
Cabin capacity 10	0	0	0	0	3	3	0	0	0	/	0	0
Safety 11	9	3	9	3	3	0	9	0	3	0	/	0
Emissions 12	9	3	0	0	3	0	0	0	3	0	0	/
TOTAL	30	15	12	10	45	5	17	4	23	18	6	0

Figure 2. Dependence/independence matrix.

This matrix identifies which characteristics are the most influential and the most influenced. Going, as before, to sum the values for each column, the 4 with the highest score are chosen, thus the most influential: TOP SPEED, AERODYNAMICS, WEIGHT, CABIN CAPACITY.

Then, the following goal is to analyze the market into which the car is to be introduced, studying its competition and target segment. This comparison procedure is called 'benchmarking' in industry jargon [9]. The most innovative models were selected from the leading car manufacturers in the industry: Ferrari Roma, Aston Martin Db11, Audi R8 coupe quattro, Porsche 911 Turbo, Maserati MC20, McLaren GT Coupe, Lamborghini Huracan, Alfa Romeo Giulia GTA. In choosing cars, an effort was made to select models that were in the same price range so as not to create advantage or disadvantage for certain brands. In fact, a comparison built between a luxury car and one designed for the lower-middle market segment would hardly make sense. This makes it clear that the choice of the target market segment is crucial from the outset. A comparison was made on the basis of fifteen characteristics typical of sports car data sheets: length, width, height, wheelbase (distance between rear and front axle), weight, tank capacity, engine horsepower, displacement, maximum torque, CO2 emissions, seats, top speed, 0-100 km/h acceleration, fuel consumption per 100 km, and price.

Once the comparison is made, the cars with the best value (TOP) and those with the worst value (FLOP) are identified for each parameter, and for each model a "Delta value" is calculated as the difference between TOPS and FLOPS to identify the car that, presenting the greatest Delta, is the most complete and competitive (Figure 3).

	Ferrari Roma	Aston Martin Db11	Audi R8 coupe quattro	Porsche 911 Turbo	Maserati MC20	McLaren GT	Mercedes Amg GT Coupè	Lamborghini Huracan	Alfa Romeo Giulia GTA
Length [m]	4.65	4.75	4.43	4.53	4.67	4.68	4.55	4.52	4.64
Width [m]	1.97	1.95	1.94	1.90	1.96	2.05	1.95	1.93	1.91
Heigth [m]	1.30	1.30	1.24	1.30	1.22	1.21	1.29	1.16	1.43
Wheelbase [m]	2.67	2.80	2.65	2.45	2.70	2.67	2.64	2.62	2.82
Weight [kg]	1472	1760	1670	1715	1500	1466	1650	1389	1560
Tank capacity [l]	272	270	112	128	150	570	350	100	450
Horsepower [CV]	620	510	580	580	630	620	510	610	540
Engine Displacement [cm3]	3855	3982	5204	3745	3000	3994	3982	5204	2891
Max Torque [Nm]	760	700	580	750	730	630	650	560	600
CO2 Emissions	245	270	289	280	262	270	291	332	245
Number of seats	4	4	2	4	2	2	2	2	4
Max speed [km/h]	320	300	330	320	325	326	310	325	315
Acceleration 0-100 km/h [s]	3.40	3.80	3.10	2.80	2.90	3.20	3.80	3.30	3.60
Consumption [l/100km]	11	9.9-13	13.1-12.9	12.3-12	11.50	12	9.4-13	13.08	10.08
Price [Euros]	200'000	187'432	217'800	201'190	216.318	203'000	145.000	195.000	185.000
TOP-FLOP	3	-4	-1	3	0	1	-2	-3	5

Figure 3. Benchmarking Matrix.

As can be seen (Figure 3), the car with the highest Delta is the Alfa Romeo Giulia GTA with a value of 5. This suggests that the model that will be presented in the market, in order to be competitive, will have to have at least 5 features better than those in the benchmarking. The last matrix compares the characteristics used in benchmarking with those obtained from the relative importance and dependence/independence matrices. The latter are placed on the rows. Values are assigned based on how much the column influences the row:0 if the column does not influence the row; 2 if the column influences the row little; 4 if the column partially influences the row; 6 if the column influences the row quite a bit; 8 if the column influences the row a lot and 10 if column completely influences the row (Figure 4).

	Length	Width	Heigth	Wheelbase	Weight	tank capacity	Horsepower	Engine displacement	Max torque	CO2 emissions	Number of seats	Top speed	0-100 km/h acceleration	Consumption [l/100 km]	Price
Top speed	4	6	6	6	8	0	10	10	8	0	0	10	4	0	0
Aerodynamics	6	8	8	0	0	0	0	0	0	0	0	0	0	0	0
Braking	0	0	0	0	6	0	0	0	0	0	0	8	0	0	0
Weight	6	6	6	0	10	2	0	4	0	0	6	0	0	0	0
Acceleration	4	2	2	4	8	0	10	10	0	0	0	0	10	0	0
Design / Aesthetic	8	8	8	6	0	4	0	0	0	0	8	0	0	0	0
Safety	6	4	0	4	6	2	0	0	0	0	0	6	4	0	0
Cabin capacity	10	10	10	0	0	0	2	0	0	0	6	0	0	0	0
TOTAL	44	44	40	20	38	8	22	24	8	0	20	24	18	0	0

Figure 4. What/How Matrix.

By summing the column values, the seven most influential features are identified: LENGTH, WIDTH, WHEELBASE, WEIGHT, ENGINE HORSEPOWER, DISPLACEMENT, TOP SPEED.

Defining the product architecture before starting the design is a critically important step because it lays the foundation for how the model should be designed.
Initially, two basic elements must be defined: the type of drive and the location of the engine. From an initial study of the most famous sports cars, it jumps out how almost all models feature all-wheel drive with a rear engine giving the car a particular forward arrow shape.

Also, it must be remembered how from the previous matrices we derived that the fundamental elements for the car are: length, width, braking, weight, engine horsepower, displacement and top speed. This indicates that one should aim for a type of structure that is compact but can deliver high performance; this recommends opting for an all-wheel drive model with a rear engine.

4.2 Sketching

Having thus defined the general features that must be considered during the design of the model, it is possible to proceed by making a series of sketches each characterized by a unique style (Delbridge et al, 1995). The first is marked by a futuristic style that gives the idea of a car with simple but aggressive lines, large and aesthetically advanced headlights that can blend harmoniously with the figure of the car. For its realization, an attempt was made to take to extremes the features presented by the new sports car models: aerodynamics is one of the salient aspects of these cars; therefore, the idea was to create an arrowhead car shape with a very low front end that could cleave the air. Very important and distinctive elements are the headlights, which are designed to blend with the aesthetics of the car. They opted for a long, slim shape that follows the curves of the chassis and conveys an idea of futurism and avant-garde (Figure 5).

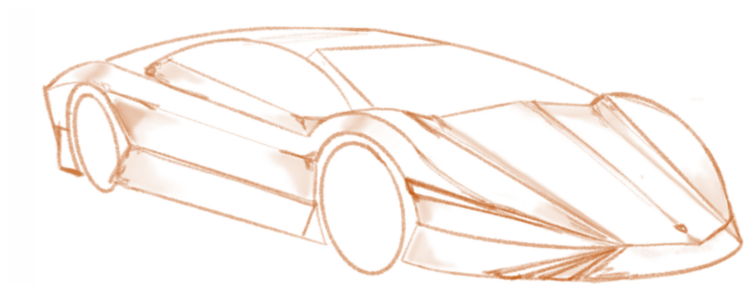

Figure 5. Advance Style Sketches

This sketch captures the history of sports cars with an eye to early successful models, for example cars such as the Lamborghini Miura and the Ferrari 250 GTO that are still considered undisputed icons of motorsports today. This style involves a shape configuration typical of a historic car. Initially, in fact, car manufacturers produced models with the trim shifted to the rear and the engine positioned at the front. The lines and shapes used turn out to be the opposite of those of the advanced sketch, favoring more harmonious and rounded surfaces. The headlights and other details also echo the retro style of the car by recalling characters typical of models of the past (Figure 6).

Figure 6. Retro Style Sketches

The Stone style is conceived to give the conceived car a rugged, gritty and massive design. For this, angular surfaces and strongly marked corners were used, creating a discontinuous but overall simple chassis. These characteristics can also be found in the secondary elements: the air intakes, windows, and front and rear headlights have elementary, angular geometric shapes. The importance of this style, which can also be called by the name "Solid," is that its compact and heavy features provide the customer with a sense of "protection" from the dangers of the road environment and safety when driving. Therefore it is increasingly present in the automotive field (Figure 7).

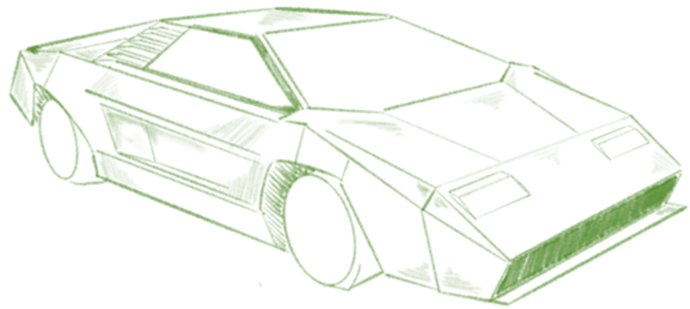

Figure 7. Stone Style Sketches.

The last style analysed is the Natural style. As the word "Natural" says, the goal is to create an elegant and refined design that blends perfectly with its surroundings. In this case, lines with soft and harmonious curves are preferred, which gives the car a sense of simplicity and lightness in form (Figure 8).

Figure 8. Natural Style Sketches

The final shape of the car is a fusion of the four sketched prototypes: Advanced, Retro, Stone, Natural. The model will have details and features from all the sketches so as to give the car a complete and versatile style.

In this case, in each element of the model, an attempt was made to merge as many styles as possible: in modelling the surfaces, softer and more harmonious lines were alternated with harder and more angular ones, trying to find the perfect combination. The front headlights present an Advanced style but are positioned in the car as those of the Retro style, while the rear ones are born from a union between the Advanced and Natural styles. Various details from all previous designs have been carried over into this design, such as the air intakes, windows, and exhausts (Figure 9).

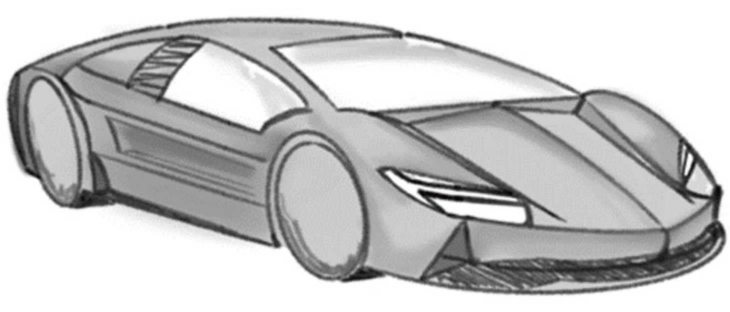

Figure 9**.** Final sketch obtained at the end of the trend analysis.

5. Results and Discussion

After completing the drawing phase of the design and deriving the final model, one can move on to making the first 2D views of the model. It is interesting to point out that, usually, when modelling a component in 3D on a CAD only then does one proceed with making the 2D views in an appropriate drawing. This procedure is different and cannot work that way. In fact, it is necessary to define in detail the 2D views of the exterior of the car to preserve the pure design work done up to the previous stages. In addition, all the information about the overall dimensions that must be respected in the subsequent design stages enters the 2D drawings.

5.1 Orthogonal projections

Having defined the geometry of the machine, we moved on to make orthogonal projections of the model on the program. For completeness in representation, four views were used: side, front, rear, and top. This phase is extremely important and requires special attention since the elements present in one view must be aligned and well positioned in the others as well, so that the shapes present in all projections match.

In fact, during the three-dimensional design phase they will be used as reference views, so they must be correct for proper modelling. The entire surface construction of the car model will be done, initially, precisely based on these drawings (Figure 10).

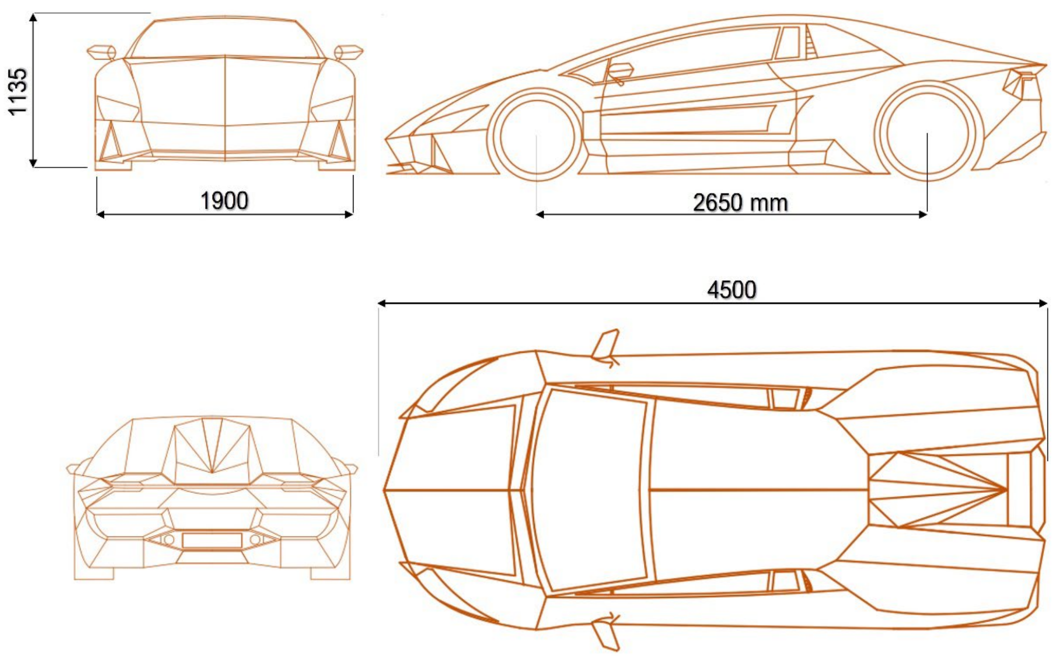

Figure 9. Main dimensions of the vehicle.

5.2 Modelling the surfaces on Alias

As anticipated, the four views drawn previously on AutoCAD 2D: front, back, side, top were taken as reference for the creation of the constituent surfaces of the vehicle body. The process is to create and model the surfaces, taking the projections as reference, to build the outer "skin" of the car. At this stage it is important to carefully check the continuity of the curvature of the surfaces since the presence of imperfections will create, in subsequent renders, discontinuous reflections that will highlight incorrect workmanship. The issue is again much more complex. The presence of surface areas with concavities facing the outside of the vehicle, not found on the virtual model, can cause numerous problems, including that of several possible losses of time and money for the company. The same dents, if not corrected, will in fact appear on the fabricated vehicle. Even noticing this series of defects from observing the first physical prototype made already constitutes an economic loss. CAD software presents several useful tools precisely for performing a series of checks related to the geometry of surfaces and their quality. These include analysis of the curvature of the isolines in a particular direction under consideration, calculation of the maximum and minimum curvature at a particular point, and checking the zebra pattern, which is useful for highlighting defects related to the lack of continuity of tangency or curvature on the edge common to two surfaces. It started by creating the entire area of the car using as few surfaces as possible so that curvature and continuity could be accurately checked. Once this was completed, we moved on to the introduction of the other elements: the air intakes, the rear-view mirrors, and the front and rear lights, always checking their correct modelling. Then follows the creation of all other details (Figure 11).

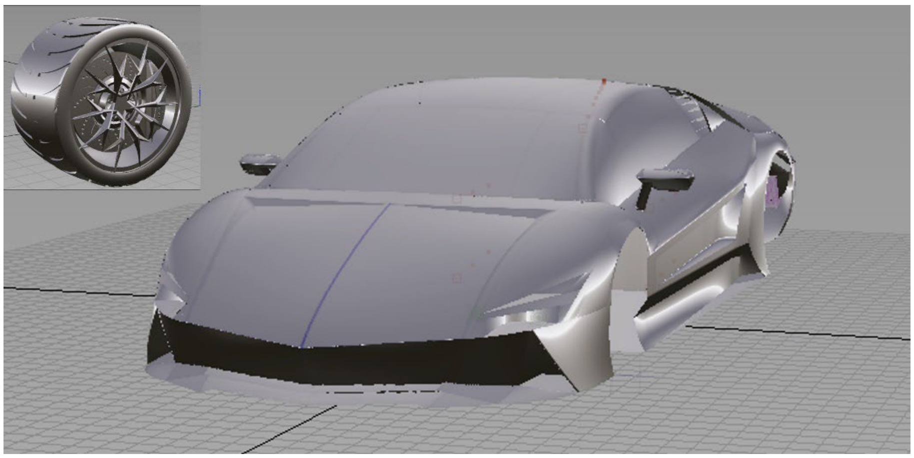

Figure 10. Main surfaces of the car and virtual model of the rim and wheel with details

5.3 Vehicle performance calculation

A fundamental element in sports cars is aerodynamics, in relation to how well the shape of the car succeeds in reducing the resistance of the air it passes through while in motion (Pache and Lindemann, 2003, Dumas 2008, Ding et al. 2006). To be able to assess whether the design so far has the appropriate aerodynamics, the coefficient cx of drag is calculated using suitable engineering simulation software, for example Ansys Fluent. When the 3D model is completed, it is possible to proceed with a simulation of the true aerodynamic values of the car (Nichols 2019). We proceeded in this way: the model was imported into Ansys and after setting a speed of about 30 m/s (speed at generally at which aerodynamic tests are carried out) and all the conditions for proper evaluation, the calculation of the coefficient was carried out. In addition to this, it was decided to map other parameters onto the surface of the car: air pressure, its speed and direction in contact with the surface of the car, and the kinetic energy generated by the fluid on it. To have the most accurate result possible, the program was set to perform 1,000 iterations; however, after about one hundred the curve had already stabilized at a certain value of 0.31. Comparing it with what are typical cx of sports cars, the value obtained conforms. Instead, the images below show the air pressure, its speed and direction in contact with the surface of the car, and the kinetic energy generated by the fluid on it. The performance estimation step described here serves only as an example. Top companies invest a lot of time and money in structural and fluid dynamics tests on their vehicles in the build phase. This is also used for the final validation of the design. Every single component must be found to be fit for operation. The chassis design of such a vehicle alone takes weeks and weeks of work to define and implement. Equally important is the study related to the interface between the chassis and the car body, which is not addressed here. The chassis itself forms the skeleton of the vehicle; it must be lightweight but at the same time provide structural support for every part of the vehicle. There are many structural simulations and integrity tests to be performed on chassis, covering multiple fields of study in mechanical engineering, from fatigue life to mechanical vibration. Impact tests are never lacking, as they are the ones that best simulate the risk passengers may incur in the event of a crash. A vehicle that does not pass the suitability check of a crash test cannot for obvious reasons be produced and marketed (Figure 12).

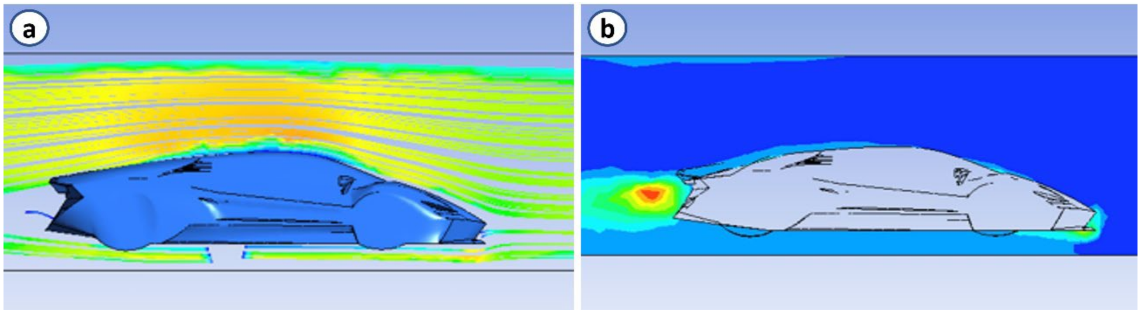

Figure 11. CFD results concerning a) Streamlines; b) Turbulence.

The values obtained from the study of pressure mapping due to high-speed air impact are interesting (Figure 12). Maximum values of 254 Pa are those recorded at the front of the vehicle, a resistance factor that is difficult to improve given the small size of the vehicle. Although it may seem high, it must be said that for this type of vehicle it is among the lowest ever.

5.4 Rendering

The objective of this phase is to visualize the designed model in as realistic a key as possible (Figure 13), so that any flaws in the design can be checked and to see how it behaves when placed in a series of settings with different lighting and shadows.
In addition to this, the potential of renders is harnessed to be able to give the consumer a first impression of the product and allow them to "customize" and personalize before proceeding to production.

Taking a cue from the presentations that automakers make of their models, two new and exclusive colors were designed specifically for the car by matching a second one consonant with the first one for details and rims. The first is a midnight blue coloration paired with a second coppery color. The second picks up the coppery but slightly darker, matching it with carbon details and rims.

Figure 12. Rendering of the product in two different scenarios.

5.5 Prototyping

The use of 3D printing is already heavily employed in the automotive field for multiple reasons. One of these concerns the creation of scale models of the final vehicle to provide both the company and future customers with a solid idea of what the model of the new car will look like . The last phase concerns the creation of a physical prototype in scale, here 1:20, according to several possible modes.. In this case, a 3D printer using a biodegradable plastic (Figure14), PLA, as the material was used. In order to send the car to print, it is necessary for the model to be perfectly closed, with all surfaces aligned and matching so that it can be considered by the program as a solid. The time period required by the process was 32 hours. Highlighted in the next image is the presence of supports needed to support the parts of the material lacking support. The classic stepped surface due to the overlapping of the various layers during the printing process can also be seen. For the first problem, a cutter and pliers were used, removing all superfluous elements from the model as soon as it came out of the printer, trying to be as precise as possible so as not to damage the main surfaces. Removing supports can often also do damage to the surfaces to be retained in the model.

Figure 13. Views of the prototype post support removal.

The surface machining phase was the most challenging and time-consuming of the entire process and was divided into several stages in order to ensure proper continuity that would render best once painted. The quality of the model delivered directly into the customer's hands should best represent the finished product. For this reason, the fine-tuning steps described next become essential. The first concerns the elimination of the main and most visible imperfections. The part was grouted using a special metal putty so as to fill the "steps" left by the printer. After allowing the putty to dry for the necessary time, a sandpaper with high roughness (P120) was used to remove the excess material, thus leaving a continuous surface thanks to the putty filling the various interstices ((Figure 15).

Figure 14. Model with grouted surfaces.

For smaller imperfections, another type of putty should be used, this time spray, which creates a full-bodied patina that highlights the discontinuities present, allowing them to be worked on with sandpaper. It also serves as an aggravating base for the subsequent painting. In this case, after giving repeated coats of filler in order to cover the entire machine, a finer sandpaper (P1200) was used to allow more precise work without risking ruining the surface with grooves (Figure 16).

Figure 15. Model ready for painting.

In order to really see if the work so far was done well, it was decided to give a first coat of sapphire blue spray paint, which brings out the curvature of the surfaces and any imperfections to the eye. The windows of the car were covered with tape, so that it could be painted later having already the shape well demarcated.

In case the work is already satisfactory, one can proceed with the colouring of the details. In the opposite case, the previous steps can be repeated, as happened with the prototype described here (Figure 17).

Figure 16. 3D physical prototype completed.

Once the base coat of sapphire blue paint had been allowed to dry, we moved on to working with a brush for greater precision, going on to colour the various details of the car. Taking the renders on V-Red as a reference, an accurate job was attempted so as to make the prototype as realistic as possible. The final result is in this case obtained after several hours of work, but it offers added potential for the company. In fact, unlike an exclusively virtual prototype, this can be delivered directly to the customer, making it more effective to observe details that would not stand out from the CAD model alone.

6. Conclusion

The sports car market is very competitive and staying ahead of the times requires continuous design studies and product innovation. For this reason, the design process of a car is of utmost importance and must be executed as meticulously as possible in order to bring a product to the market that meets customer demands. The application of the IDeS methodology proves to be effective and is already being developed for application in various business settings. Its effectiveness stems from the methodical schematization it allows to offer even in the case of the development of a complex product such as an automobile. It makes no distinction as to the economics of the company, in terms of budget, production capacity or market segment in which it operates. Any business, from small to large, can exploit the potential of this methodology to follow the development of a product from its conceptualization to physical prototyping and commercialization, with very high probability of success.

References

Cannon C. and D. D. Rucker, "The Dark Side of Luxury: Social Costs of Luxury Consumption," *Pers Soc Psychol Bull*, vol. 45, no. 5, pp. 767–779, 2019, doi: 10.1177/0146167218796790

del Pero, F. M. Delogu, and M. Pierini, "Life Cycle Assessment in the automotive sector: a comparative case study of Internal Combustion Engine (ICE) and electric car," *Procedia Structural Integrity*, vol. 12, pp. 521–537, 2018, doi: 10.1016/J.PROSTR.2018.11.066.

Delbridge, R.J. Lowe, and N. Oliver, "The process of benchmarking: A study from the automotive industry," *International Journal of Operations and Production Management*, vol. 15, no. 4, pp. 50–62, 1995, doi: 10.1108/01443579510083604/FULL/XML.

Dumas, L. "CFD-based Optimization for Automotive Aerodynamics," *Optimization and Computational Fluid Dynamics*, pp. 191–215, 2008, doi: 10.1007/978-3-540-72153-6_7.

Ding, W. J. Williams, D. Karanth, and S. Sovani, "CFD Application in Automotive Front-End Design," *JOURNAL OF PASSENGER CAR: MECHANICAL SYSTEMS JOURNAL*, vol. 115, no. 6, pp. 244–252, 2006, Accessed: May 22, 2022. [Online].

Farris, P., E. Kang, and J. Mitchell, "Product-Line Strategy at Porsche: The Effect of New Models on the Porsche Brand and the 911," *SSRN Electronic Journal*, 2021, doi: 10.2139/SSRN.2974666.

Katz J. and Cain, K. P. "Rapid, Low-Cost, Aerodynamic Development of a High-Performance Sports Car," *SAE Technical Papers*, 2011, doi: 10.4271/2011-01-2821.

Lim, C. W. J. K. Q. Le, Q. Lu, and C. H. Wong, "An Overview of 3-D Printing in Manufacturing, Aerospace, and Automotive Industries," *IEEE Potentials*, vol. 35, no. 4, pp. 18–22, 2016, doi: 10.1109/MPOT.2016.2540098.

Nichols, M. R. "How does the automotive industry benefit from 3D metal printing?," *Metal Powder Report*, vol. 74, no. 5, pp. 257–258, 2019, doi: 10.1016/J.MPRP.2019.07.002.

Okulicz-Kozaryn, A. Nash, T. and N. O. Tursi, "Luxury car owners are not happier than frugal car owners," *Int Rev Econ*, vol. 62, no. 2, pp. 121–141, 2015, doi: 10.1007/S12232-015-0223-2.

Pache M.and U. Lindemann, "Sketching in 3D What should Future Tools for Conceptual Design look like?," *Human Behaviour in Design*, pp. 243–252, 2003, doi: 10.1007/978-3-662-07811-2_24.

Rentzmann and M. v. Wuthrich, "Unsupervised Learning: What is a Sports Car?," *SSRN Electronic Journal*, 2019, doi: 10.2139/SSRN.3439358.

Ingenbleek J.-F. and. Lemaire, J "What is a Sports Car?," *ASTIN Bulletin: The Journal of the IAA*, vol. 18, no. 2, pp. 175–187, 1988, doi: 10.2143/AST.18.2.2014951.

Vaz, C. R. T. R. Shoeninger Rauen, and álvaro G. Rojas Lezana, "Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis," *Sustainability 2017, Vol. 9, Page 880*, vol. 9, no. 6, p. 880, 2017, doi: 10.3390/SU9060880.

Zhang M. and C. Yao, "Construction of Digital Model of Auto Parts Based On 3D Printing Technology," *J Phys Conf Ser*, vol. 1744, no. 2, p. 022016, 2021, doi: 10.1088/1742-6596/1744/2/022016.

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