Development of an Innovative Family Car Prototype through the Use of IDeS Method

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Abstract

The primary objective of this project is to create a family car that fills the gap in the market between station wagons and sedans through the technical feature of changing its length. Additionally, the project aims to achieve innovation that aligns with future trends. The presented methodology is based on IDeS, on which many design tools are implemented, such as Quality Function Deployment (QFD), Benchmarking (BM), Top Flop Analysis (TPA), stylistic design engineering (SDE), prototyping and planning. A market analysis follows to identify the major competitors and their key characteristics considering style and technology. The results are used to design an innovative car. Based on the most developed stylistic trends, the vehicle is first sketched and then drawn in the 2D and 3D environments for prototyping. This result leads to the possibility of 3D printing the actual model as a maquette using the Fused Deposition Modelling (FDM). This final application unveils the possibilities of Industry 4.0 as enrichment for SDE and in general rapid prototyping.

Keywords
Industrial Design Structure (IDeS), Quality Function Deployment (QFD), Benchmarking (BM), Stylistic Design.

1. Introduction
Industrial design is the most important phase in the lifetime of a product. The design stage controls the style of the components, the costs, the time of production, and the impact on the market. It is important to gather all the information possible from customers and start a new project to develop the right car concept from the beginning. Errors in this phase will lead to inefficiencies that will affect the budget. Using IDeS, it is possible to develop an innovative industrial product by deconstructing the process into phases concerning style, design, optimization, and production. Thanks to this methodology, errors are reduced, and the final product result is both innovative and relatively cheap since no changes need to be done after the application of the method. Moreover, the usage of technologies such as Additive Manufacturing (AM) show that non-expensive solutions for virtual prototyping can be implemented in the IDeS process. It is possible to divide the design process into three macro-phases: Setup, Development, and Production (Figure 1).

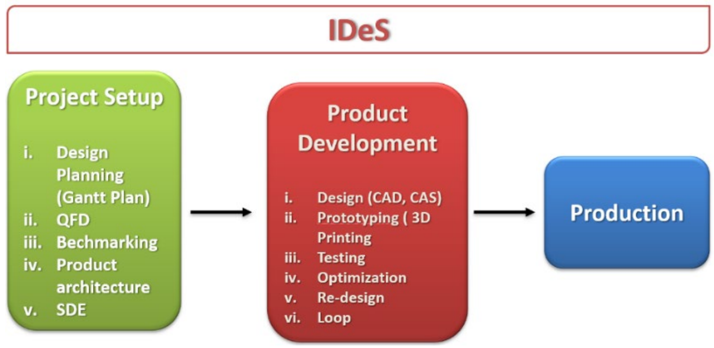


Figure 1. Setup, Development, and Production

The Project Set-Up analyses the background and objectives of the product design. First, Quality Function Deployment (QFD) is used to define the customer's requests then a Benchmarking analysis is done to identify the number of requirements that will allow the product to be innovative. This method is an evolution of the past known methodologies, being enhanced by a Top-Flop Analysis to find the number of the main characteristics of the best products on the market, which will set the level that needs to be overcome to achieve innovation in the new prototype. The SDE method consists in the sketches of a vehicle digital version to improve the classic freehand drawing. After finding the best shape (analysing and discarding the various proposals of the stylistic trends with a volume and CX evaluation), the proportions and dimensions of the final sketch are corrected through 2D CAD drawings before moving on to the second part of the IDeS, Product Development. This step begins with the 3D CAD modelling of the vehicle to obtain the three-dimensional shape of the product. Once the 3D model and all its details are completed, the realistic renderings of the product are displayed before proceeding with prototyping, which can take place physically with the creation of the model of the vehicle with 3D printing.

1.1 Objectives
The main aim of the project is to develop an innovative family car prototype based on the use of IDeS. Through the main tools of this method, it is possible to analyze all the factors that help to reach a solid result, filling an automotive market portion with unique and futuristic features. The last purpose is to achieve the step before production tests start. The final result is a physical maquette realized with 3D printed polymer.

2. Literature Review
Until the 2000s, the field of car design and styling was relegated to a mostly manual activity, without a mathematical and scientific approach, based mainly on the skills of individual specialists (Donnici et al. 2020). The change of course occurred after the work of Eng. Lorenzo Ramacciotti, former CEO of Pininfarina Spa and Mechanical Engineer and the activity of the Department of Industrial Engineering, University of Bologna, that has developed various research applying the SDE also for systematize the car design process and reduce costs (Frizziero, Donnici, et al. 2021) (Frizziero, Gimapiero Donnici, et al. 2019) (Frizziero, Liverani, and Nannini 2019) (Frizziero et al. 2018). Within the IDeS method one of the most relevant sections is the Stylistic Design Engineering, an approach consisting of successive steps: (1) Analysis of stylistic trends; (2) Sketches; (3) 2D Computer-Aided Design (CAD) drawings; (4) 3D CAD models; (5) Rendering; (6) Solid stylistic model (also called style maquette) (Donnici et al. 2019). With the SDE it is possible to insert the new concept into a real environment through renderings and augmented reality, taking the most of the style and characteristics of the product conceived. Moreover, most of the literature considered for this paper is related to approaches to realize an innovative and futuristic prototype of family car, starting from the engine (Graham Conway, Ameya Joshi et al 2020) and proceeding with the entire design settings.

3. Methods
3.1 Environmental Analysis
Throughout the decades up to today the philosophy of the family car stayed pretty much the same, while their design evolved enormously to better express it.

Today, when the term "family car" is used, it is difficult to imagine one single kind of car. Station wagons, SUVs, CUVs and even sedans are being used as family cars. Even though the popularity of crossovers and SUVs is steadily raising, in the European market station wagons are still the most popular kind: in 2017 in an analysis performed by JATO it was found out that Europe accounts for the 72% of global station wagon sales, the most of which are in Germany and Scandinavia (Figure 2).

Figure 2. European market station wagons

By a powertrain point of view, thanks to both the recent regulations introduced by the European parliament and the aftermath of the diesel-gate scandal, car manufacturers have started to research for solutions to try and reduce pollutions emitted by their products. The two main roads taken by manufacturers are fully electric vehicles (BEVs) and hybrid vehicles (HEVs). While emitting zero pollutants by the engine while in use, BEVs spread is limited by the infrastructure of many countries and a higher initial cost to the customer. On the other hand, HEVs offer the same range of traditional ICE vehicles while having a small electric engine to help the ICE at lower loads and engine speed thus increasing overall efficiency in the case of Mild Hybrids. Plug-in hybrids, on the other hand, have bigger electric engine (in series or parallel with the ICE) and battery capacity allowing the car to be driven fully electric for small distances at medium-low speed.

While the projections made using the data from previous years' sales show that mild hybrids will be more popular in Europe in the future, it is better to take in account also how regulations are designed and what manufacturers are doing right now with them. In the annex 8.4 of the Regulations and Homologation of OVC HEVs (EU R101), the way the formula for the Mass emission of pollutant is made allows for some exploits. For example, by guaranteeing 25km of range with the operation of the electric motor alone in the fully charged test cycle, the resultant mass emission of pollutant value is halved. Even though this regulation might seem badly formulated, its intention is to promote PHEVs, trusting that the owners of this type of car will mainly drive the short distances in urban areas using only the electric motor thus overall reducing the pollution. A manufacturer that wants to sell a car in the European market in the next five years should adopt PHEV or BEV solutions.

3.2 Market Analysis

To analyse the Market and understand the customer needs, the starting point of the Industrial Design Setting (IDeS) must be a criterion that allows for robust decision making. One of the methods that has become almost a standard in the automotive sector is the Quality Function Deployment (QFD), which combines evaluations made both qualitatively and quantitatively through the self-imposing of key questions and the use of matrixes of importance. The goal of this method is to get rid of any subjective bias and derive optimal project parameters aimed at customer satisfaction. The self-imposed questions of the QFD are six.

WHO: *Large families who need to travel in groups and a **high load** capacity for their movements. Somebody that needs comfort for medium/long range travel and a **large trunk.***
WHAT: *For everyday needs, for example going to work but also to go on vacation, all with a **high-tech car.***
WHERE: *Urban and extra-urban roads also to make **long journeys** in a **comfortable and safe** way and without frequent stops.*
WHEN: *In **everyday life** for shopping, given the large capacity, but also to go to work or make medium and **long trips** being able to load luggage without problems.*

WHY: ***Space available*** *to carry the family and load suitcases, strollers, groceries or pets, or for the comfort combined to the* ***performance.***
HOW: *Movement in maximum* ***comfort and security*** *even with several passengers despite they can also be children.*

From the answers given to the six questions, some key-points can be extracted and converted into customer requirements: size, comfort, consumptions, safety, manoeuvrability, performance, design, family friendliness, space on board, technology, loading space and price.
By having these parameters at hand, it is possible to compile the Relative Importance Matrix to extract the most important parameters and the Independence/Dependence Matrix to obtain which are the most dependent and independent requirements.

3.3 Relative importance matrix

This matrix is used to determine which customer requirements have greater relevance than the others. Each cell is filled with a numerical value, from 0 to 2, in relation to how much the requirement of the row is more or less important than the one in the column. 0 if the element of the row has less importance than the one in the column. 1 if the element of the row has the same importance as the column element. 2 if the element of the row has more importance than the one in the column. The highest value between the total sum of each row is the most important feature that should be designed, the proceeding is reported in Table 1.

Table 1. Relative importance matrix

CUSTOMER REQUIREMENTS	SIZE	COMFORT	CONSUMPTIONS	SAFETY	MANOEUVRABILITY	PERFORMANCE	DESIGN	FAMILY FRIENDLY	SPACE ON BOARD	TECHNOLOGY	LOAD SIZE	PRICE	TOTAL	IMPORTANCE
SIZE	1	1	1	1	2	2	2	1	1	1	1	2	16	84%
COMFORT	1	1	1	1	2	2	2	2	1	2	1	2	18	95%
CONSUMPTIONS	1	1	1	1	2	1	2	1	1	1	0	1	13	68%
SAFETY	1	1	1	1	2	2	2	1	1	2	1	2	17	89%
MANOEUVRABILITY	0	0	0	0	1	1	1	0	0	1	0	1	5	26%
PERFORMANCE	0	0	1	0	1	1	1	0	0	0	0	1	5	26%
DESIGN	0	0	0	0	1	1	1	0	1	1	0	1	6	32%
FAMILY FRIENDLY	1	0	1	1	2	2	2	1	1	1	0	1	13	68%
SPACE ON BOARD	1	1	1	1	2	2	1	1	1	1	1	1	14	74%
TECHNOLOGY	1	0	1	0	1	2	1	1	1	1	0	1	10	53%
LOAD SIZE	1	1	2	1	2	2	2	2	1	2	1	2	19	100%
PRICE	0	0	1	0	1	1	1	1	1	1	0	1	8	42%

3.4 Independence Matrix

This matrix is used to establish the possible dependency relations between different characteristics. Every cell is filled with a numerical value from 0 to 9 in relation to how much the requirement of the row is more or less dependent from the one in the column. 0 or none if the requirement of the row is totally independent on the one of the column. 1 if the requirement of the row is not so dependent on the one of the column. 3 if the requirement of the row is very dependent on the one of the column 9 if the requirement of the row is totally dependent on the one of the column. Calculating the sum for each row and column, it is possible to determine which parameters are more independent. In particular, the sum of the rows defines how much a feature is dependent on the others and the sum of the columns identifies the most influential parameters (Table 2).

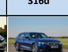
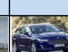
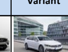
Table 2. Independence Matrix

CUSTOMER REQUIREMENTS	SIZE	COMFORT	CONSUMPTIONS	SAFETY	MANOEUVRABILITY	PERFORMANCE	DESIGN	FAMILY FRIENDLY	SPACE ON BOARD	TECHNOLOGY	LOAD SIZE	PRICE	TOTAL
SIZE	0	9	9	9	3	9	3	3	0	9	1	3	58
COMFORT	1	0	9	3	1	9	3	3	0	1	3	3	36
CONSUMPTIONS	1	9	0	9	9	1	3	9	9	9	9	9	77
SAFETY	3	9	9	0	1	9	3	0	9	1	9	3	56
MANOEUVRABILITY	0	3	9	3	0	1	3	9	1	1	9	9	48
PERFORMANCE	1	9	1	9	1	0	3	9	9	3	9	3	57
DESIGN	1	3	9	1	9	9	0	3	1	3	3	3	45
FAMILY FRIENDLY	3	3	9	3	9	3	1	0	9	3	9	3	55
SPACE ON BOARD	0	1	9	3	3	9	1	9	0	9	1	9	54
TECHNOLOGY	9	9	9	9	9	9	3	9	3	0	9	3	81
LOAD SIZE	0	3	9	3	9	3	1	9	1	9	0	9	56
PRICE	3	1	3	1	3	1	1	1	9	1	3	0	27
TOTAL	22	59	85	53	57	63	25	64	51	49	65	57	

3.5 Competitor analysis

To be competitive in the Market, it is mandatory to analyse what the competitors' products are offering to their customers, understanding their weaknesses and strengths and formulate a product capable of innovating in more areas than the rest. For this analysis are compared some of the most popular models made by various manufacturers that compete in the Family Car sector. For every proposal are compared the performances and characteristics and given a score of +1 when that model has the best characteristic in that parameter and a -1 when it has the worst one. From the sum of these scores, for each model is calculated a total score Top/Flop that gives indication of how much innovation and value is behind that product (Table 3).

Table 3. Competitor analysis

MODELS	Peugeot 308 Puretech Turbo 130	Fiat Tipo SW	BMW Series 3 Touring 316d	Skoda Octavia Wagon	Audi A4 Avant	Ford Focus SW	Ford Mondeo SW	Toyota Corolla Touring Sport	Volvo V60	Volkswagen Passat Variant	Mercedes Class C SW	Jaguar XF Sportsbrake	Tesla Model Y	Dacia Jogger	Mazda 6		
FAMILY CARS																	Innovative Family Car
LENGHT (cm)	436	439	471	469	476	469	487	465	478	477	475	496	475	455	466		496
WIDHT (cm)	185	182	183	183	185	185	185	179	185	183	203	188	192	178	180		203
HEIGHT (cm)	144	156	144	147	144	149	150	144	143	152	145	149	162	163	144		163
WHEELBASE (cm)	268	264	285	267	282	270	285	270	287	279	286	296	289	290	273		296
TRUNK SIZE (l)	412/1323	440/1440	410/1410	640/1700	495/1495	575/1620	525/1630	598/1730	519/1431	650/1780	455	481/1500	1841	160/1819	450/1138		1819
ELECTRIC TRUNK	No	No	Si	No	Si	Si	Si	Si	Si	Si	Si	Si	Si	No	Si		Si
HEATED SEATS	Si	No	Si	Si	Si	No	Si	Si	Si	Si	Si	Si	Si	No	Si		Si
COSUMPTION (l/100 km)	5,6	6	4	4	6	5,5	5	4	6,1	1,4	6,6	6	19,6	6	5,4		-
ENGINE DISPLACEMENT (cm3)	1199	1468	1995	999	1984	1000	1999	1987	1969	1395	1496	1997	-	999	1998		1999
ADAS/AD QUALITY (Max 5)	2	1	2	1	2	2	2	2	2	2	2	2	3	1	2		3
POWERTRAIN TYPE	Gasoline	Mild-Hybrid	Hybrid	Mild-Hybrid	Hybrid	Mild-Hybrid	Hybrid	Hybrid	Mild-Hybrid	Plug-in Hybrid	Mild-Hybrid	Mild-Hybrid	Electric	GPL	Mild-Hybrid		P.I.H/EV
TRACTION	RWD	RWD	RWD	RWD	FWD	FWD	FWD	FWD	4x4	FWD	FWD	RWD	RWD	FWD	FWD		4x4
EMISSIONS (g/km)	127	120	105	98	132	125	99	89	130	32	150	127	0	120	123		0
CRASH TEST SCORE (Max 5)	4	4	5	5	5	5	5	5	5	5	5	5	5	1	5		5
HEADLIGHTS	Led	Halogen	Led	Led	Led	Led	Led	Led	Led	Led	Led	Led	Led	Halogen	Led		Led
HORSEPOWER	131	131	122	110	150	125	140	153	163	156	224	204	208	100	122		224
TOP SPEED (km/h)	210	200	198	201	210	198	187	180	180	220	240	230	217	175	202		240
0-100 Km/h (sec)	9,6	9,3	10	10,6	9,2	9,5	9,2	8,1	8,6	7,6	7,5	7,8	6,9	13,2	10,4		6,9
RANGE (km)	928	833	1000	1125	900	854	1060	1125	983	1100	757	1133	270	1370	944		1370
MAX TORQUE (N/m)	230	240	300	200	270	210	173	190	283	250	300	430	355	170	210		430
SEATS	5	5	5	5	5	5	5	5	5	5	5	5	5	7	5		7
DOORS	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		5
PRICE	26870	28200	46750	29950	39700	32000	39000	32900	43954	57650	53177	70760	50970	18950	29500		18950
N°TOP	2	0	4	3	4	3	5	4	5	5	7	7	9	5	4		
N°FLOP	5	7	2	5	2	3	2	2	2	2	4	3	3	12	3		
TOP/FLOP	-3	-7	2	-2	2	0	3	2	3	3	3	4	6	-7	1		

The worst scoring competitors are the Dacia Jogger and the Fiat Tipo SW, while the best one is the Tesla Model Y with a score of 6. A new family car to be released in a market in which the Tesla Model Y is competing should feature an Innovation Index of 7 or higher. (Figure 3).

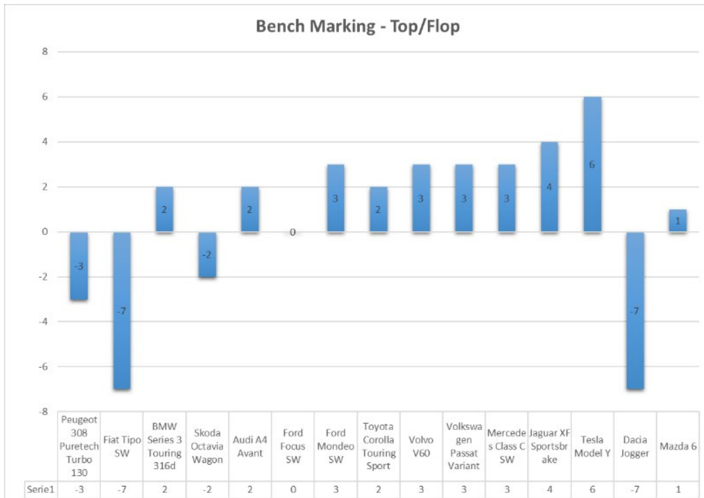


Figure 3. Tesla Model Y

3.6 What-How Matrix

To evaluate which are the most influenced parameters, an additional matrix can be compiled to relate the already determined most dependent and independent parameters to the specifications used to compare the various model from the competition. This helps deciding which of the 23 specifications should be the ones to invest on first to best the competition. Having to achieve an innovation index of 7 or higher, from the What/How matrix are determined the 7 best scoring elements, named most influenced parameters: Length, Width, Height, Trunk Size, Powertrain Type, Range and ADAS/AD Quality. Table 4 explains the What-How Matrix.

Each cell is filled with a number from 0 to 10 depending on the relationship between the customer's requirement and the performance of the vehicle as clear in Table 4 if there is no relation. 2 for weak relationship. 4-6 for medium relationship. 8-10, strong relationship.

Table 4. What-How Matrix

	LENGTH (cm)	WIDTH (cm)	HEIGHT (cm)	WHEELBASE (cm)	TRUNK SIZE (l)	ELECTRIC TRUNK	HEATED SEATS	CONSUMPTION (l/100 km)	ENGINE DISPLACEMENT (cm3)	ADAS/AD QUALITY (Max 5)	POWETRAIN TYPE	TRACTION	EMISSIONS (g/km)	CRASH TEST SCORE (Max 5)	HEADLIGTHS	HORSEPOWER (cv)	MAX TORQUE (Nm)	TOP SPEED (km/h)	0-100km/h (sec)	RANGE (km)	SEATS	DOORS	PRICE	**TOTAL**
SIZE	10	10	10	6	9	0	0	7	6	0	3	0	0	4	0	0	2	2	2	2	10	7	0	90
COMFORT	7	7	9	6	7	8	8	0	2	9	7	5	1	0	8	4	2	5	4	6	7	6	8	126
CONSUMPTIONS	0	4	0	0	2	0	4	10	8	6	10	2	10	0	4	8	8	8	9	10	0	0	4	107
SAFETY	4	2	5	2	2	0	0	0	0	10	4	5	3	10	8	2	2	0	0	0	2	6	5	72
PERFORMANCE	4	8	2	4	0	0	0	5	7	5	8	8	3	0	0	10	10	10	10	7	0	0	6	107
FAMILY FRIENDLY	5	5	5	5	7	3	7	0	0	7	2	0	7	8	3	0	0	0	0	6	7	5	3	85
LOAD SIZE	7	6	6	4	10	0	0	0	0	0	6	6	0	0	0	0	0	0	0	6	2	3	3	59
TOTAL	37	42	37	27	37	11	19	22	23	37	40	26	24	22	23	24	24	25	25	37	28	27	29	

3.7 Product Architecture
In the product architecture are analysed the technical and functional components that define the features of the new product.

3.7.1 Dimensions
In terms of size, LOKI is larger than its competitors to ensure more space on board and comfort for passengers, essential characteristics for a family car. At the same time to contain the length and provide good mobility on urban roads, it is characterized by a very innovative technology, called "Accordion System". This allows the car to become shorter and more competitive, through a translation of the trunk of about 400 millimetres (Figure 4).

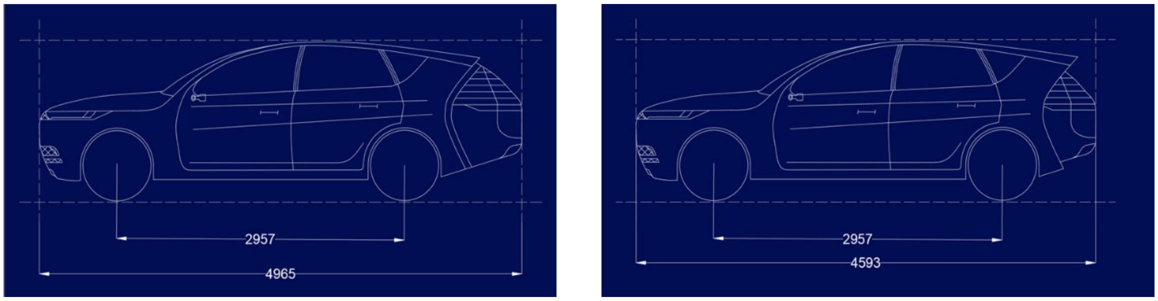


Figure 4. Dimensions

3.7.2 Propulsion System
Considering the restrictions imposed on the production of internal combustion engines and the limited autonomy of full electric cars, the propulsion system chosen is a Plug-in Hybrid engine (Figure 5). This allows to enjoy a high range to tackle longer journeys and at the same time enables driving in full electric mode, if the batteries are charged. Once empty, they can be recharged with the plug at charging stations.

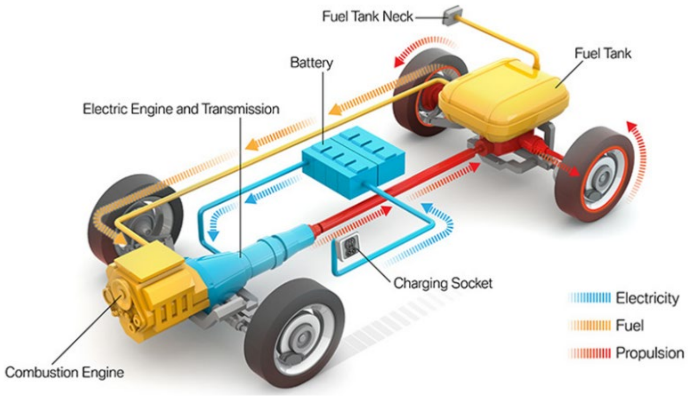


Figure 5. Plug-in Hybrid engine

3.7.3 Advanced Driver Assistance Systems
The technological equipment includes numerous cameras and sensors to achieve level four of autonomous driving. So, the vehicle is entirely managed by the autonomous system and the presence of the driver is no longer necessary. This system is conditional on meeting certain requirements and can, therefore, be activated only on predetermined routes and under specific conditions of use.

3.8 Sketching
To provide an idea of what the car will look like, freehand sketches were made including the innovative elements of product architecture just analyzed (Figure 6). In addition, the proposed designs were executed according to the main stylistic trends that can be identified today: Natural, Retrò, Advanced, and Stone. The different elements that characterize these currents affect the aesthetic appearance of the product and beyond.

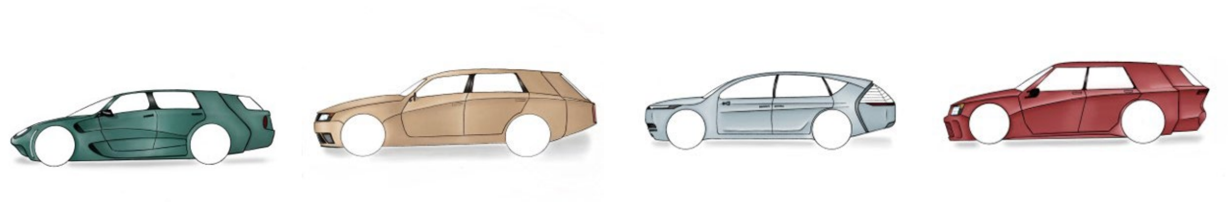


Figure 6. elements of product architecture

3.9 2D Drawings

The side view of the different stylistic trends was transformed into a 2D drawing with height and length dimensions (Figure 7). This operation is necessary because it prepares for the subsequent analyses, aimed at selecting the best trend, which will be then developed in the three dimensions.

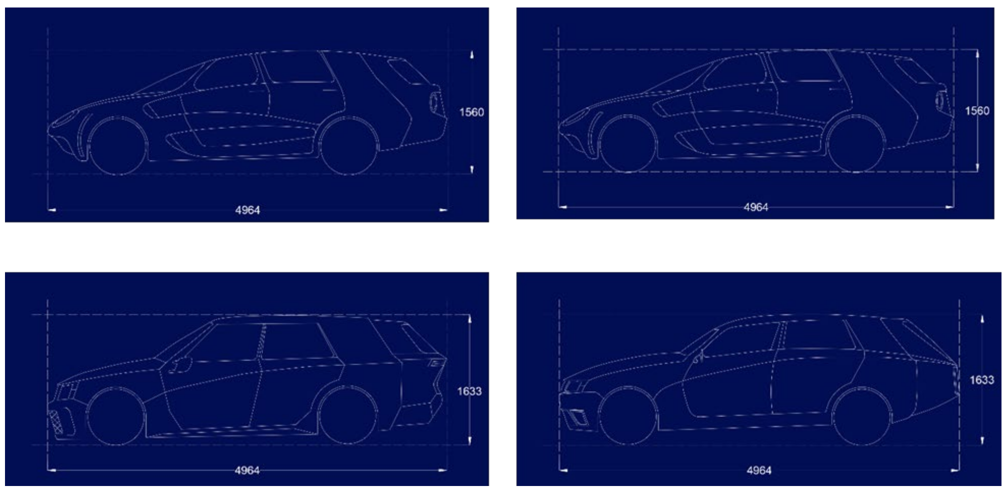


Figure 7. Height and length dimensions

3.10 Stylistic Trend Selection Criteria

The evaluation of which of the four concepts best meets the targets imposed by the product architecture is based on aerodynamic and volumetric analyses.

3.10.1 Volume Evaluation

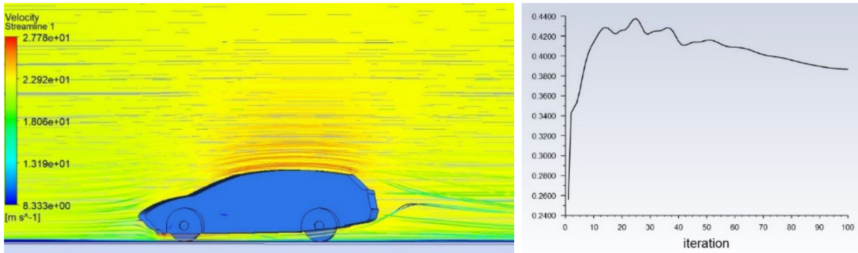
From the extruded models, the biggest volume is the one of the Stone proposal. This is a clear benefit to both passenger comfort and cargo capacity.

3.10.2 CFD Simulations

The simulations performed replicate a wind tunnel test where model, floor and walls were assumed to be fixed. Moreover, the speed of the airflow was set to 80 km/h to reproduce the aerodynamic behavior of the vehicle in Figure 8.

The best option in this case is the Natural one, since it has the lowest Drag Coefficient "Cx". In fact, it allows the lowest resistance to motion and thus best consumptions.

The best tradeoff, given by an overall analysis, is the advanced trend.



	Natural	Advanced	Retro	Stone
Cx	0,38	0,39	0,41	0,44

Figure 8. aerodynamic behavior

3.11 Design Check

At the end, it can be seen that the concept realized meets the dimensions required for road homologation.

- Height of the Vehicle (Figure 9):

Minimum height of the vehicle from the ground: 120 mm < 214 mm

- Headlight arrangement (Figure 9):

Minimum distance between dipped beam headlights: 600 mm < 1010 mm
Minimum ground clearance: 350 mm < 811 mm

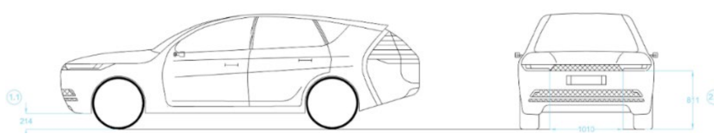


Figure 9. Headlight arrangement

- Minimum Angle of Visibility in Horizontal Direction (Figure 10):

Towards the left upright: 15° < 19°
Towards the upright right: 45° < 57°

- Minimum Angle of Visibility in Vertical Direction (Figure 10):

Along the vertical line: 7°+7° < 10°+90°

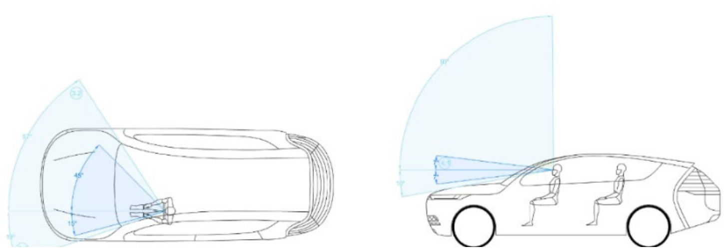


Figure 10. Visibility in Horizontal Direction

3.12 Final 3D Model

In the Figure11 is shown the result achieved after the Blender rendering session, which included the choice of materials, lighting and colours. This phase is very important because it adds organicity to the product, making it look natural in real environments and attractive for a customer. The images below show the studio renders in a blue version from different views. The car body colour is the result made up by a mix of different shades of blue and grey; moreover, it has been decided to opt for a metallic surface with a very low roughness that suggests an advanced look.

Figure 11. 3d Model

It is useful to show the most relevant technology that makes Loki a unique car, the Accordion System. The Figure 12 shows the space saving that is useful in an urban environment. Despite the geometrical change that the Accordion System brings, the aesthetic of the car keeps good lines in both the version.

Figure 12. Sapce saving

The contextualization in real environments is shown in the Figure 13. It is important to underline the usefulness of renderings of this kind, which give a faithful idea of what the finished product can look like, even though it does not physically exist yet.

Figure 13. contextualization in real environments

3.13 Prototyping

The model has always been a key point in the design phases, and it is used to test the final result of an SDE by reproducing a "physical object". This representation is needed to begin the technical phase and the industrialization of the product. With an eye on fast prototyping, it was useful to proceed with the 3D printing of the model through the FDM technology. The more complex surfaces have been simplified and after a careful study of the supports in slicing software, it has been possible to achieve the desired result.

To fully pursue the fast-prototyping philosophy, the model obtained from 3D printing was painted to give the idea of a scale reproduction faithful to a hypothetical real model (Figure 14).

Figure 14. Scale reproduction

5. Results and Discussion

By applying a stylistic development of a futuristic and highly innovative hybrid family car, a preliminary analysis was possible by means of Stylistic Design Engineering (SDE) and Quality Function Deployment (QFD). The customer requirements for vehicles in the family car sector were compared to benchmark models in the industry, achieving a set of innovative parameters known to be useful for mobility in the near future and in urban and extra-urban traffic. Fast prototyping applied in this work was used as a physical fit analysis to compare the dimensions of the scaled car (1:25). This prototyping solution is necessary to improve the design phase before pre-series production, aiding to avoid redesign steps which would produce high costs for the overall project management. This study was intended to describe the stylistic development of a hybrid, futuristic and highly innovative family car.

6. Conclusion

Interpreting this study, the applications of the IDeS method have achieved the following objectives:
• The analysis of the most convincing stylistic trends and the ability to compare them accordingly to established product innovation guidelines.
• A new stylistic idea for an elegant family car drawn using digital sketching.
• The solid stylistic model (maquette), produced using the Fused Deposition Modelling (FDM) to save time and resources, accurately reproduce the model for preliminary assessment to confirm the proportions, aesthetic guidelines, and other characteristics of the final product.
As future development it could be useful to create an augmented reality environment to be experienced through a virtual reality visor. This should be useful in evaluating ergonomics, view angles and to have an additional idea on the car real dimensions other than the one given by the scaled physical maquette.

References

Frizziero, L.; Donnici, G.; Liverani, A.; Alessandri, G.; Menozzi, G.C.; Varotti, E. Developing Innovative Crutch Using IDeS (Industrial Design Structure) Methodology. Appl. Sci. 2019, 9, 5032, 2019.

Donnici, G.; Frizziero, L.; Liverani, A.; Cacaci, L.; Costantini, N.; Pedrielli, G. Ides (Industrial design structure) and stylistic design engineering (sde) applied to the mobility of the future. In Proceedings of the International Conference on Industrial Engineering and Operations Management, Detroit, MI, USA, 10–14 August 2020.

Graham Conway , Ameya Joshi , Felix Leach , Antonio García , Peter Kelly Senecal. A review of current and future powertrain technologies and trends in 2020.

Cristiano, J.J.; Liker, J.K.; White, C.C. Key factors in the successful application of quality function deployment (QFD). IEEE Trans. Eng. Manag, 48, 81–95, 2001

Donnici, G.; Frizziero, L.; Liverani, A.; Buscaroli, G.; Raimondo, L.; Saponaro, E.; Venditti, G. A new car concept developed with stylistic design engineering (SDE). Inventions, 5, 30, 2020.

Ginting, R.; Ishak, A.; Fauzi Malik, A.; Satrio, M.R. Product Development with Quality Function Deployment (QFD): A Literature Review. IOP Conf. Ser. Mater. Sci. Eng., 1003, 012022. [CrossRef] Designs 2021, 5, 46 17 of 17, 2020.

Donnici, G.; Frizziero, L.; Francia, D.; Liverani, A.; Caligiana, G. Innovation design driven by QFD and TRIZ to develop new urban transportation means. Aust. J. Mech. Eng. 2019.

Brevi, F.; Gaetani, F. The Process of Surveying Maquettes in Car Design. Diségno, 7, 141–150, 2020.

Donnici, Giampiero, Leonardo Frizziero, Alfredo Liverani, Giulio Buscaroli, Luna Raimondo, Eleonora Saponaro, and Giorgia Venditti. “A New Car Concept Developed with Stylistic Design Engineering (SDE).” Inventions 5(3):1–22. 2020.
Donnici, Giampiero, Leonardo Frizziero, Alfredo Liverani, Giulio Galiè, and Federico Lelli. “A New SUV Conceived by Stylistic Design Engineering (SDE).” Proceedings of the International Conference on Industrial Engineering and Operations Management (July):2125–42. 2019.
Frizziero, Leonardo, Giampiero Donnici, Alfredo Liverani, Gian Maria Santi, Antonio Belsito, Carmelo Polito, and Michele Sdruccioli. “Stylistic Design Engineering (SDE) to Conceptualize a Futuristic Sports Car.” IEOM. 2021.
Frizziero, Leonardo, Gimapiero Donnici, Francia Daniela, Gianni Caligiana, and Annarita Gaddoni. “STYLISTIC DESIGN ENGINEERING (SDE) FOR AN INNOVATIVE GREEN VEHICLE FOLLOWING QFD AND TRIZ APPLICATIONS.” International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 2019.
Frizziero, Leonardo, Christian Leon-cardenas, Gabriele Colasurdo, and Alessandro Vicaretti. IDeS (Industrial Design Structure) Method Applied to the Au- Tomotive Design Framework : 2 Sports Cars with Shared Plat- Form .” 1– 21, 2022.
Frizziero, Leonardo, Gian Maria Santi, Giampiero Donnici, Christian Leon-Cardenas, Patrich Ferretti, Alfredo Liverani, and Marco Neri. “An Innovative Ford Sedan with Enhanced Stylistic Design Engineering (SDE) via Augmented Reality and Additive Manufacturing.” Designs 5(3), 2021.

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