Product Development by Means of Industrial-Design Structure (IDeS) Method. Studies for Future Mobility Solutions

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Abstract

The aim of this research is to enlighten the methodology model of Industrial Design Structure (IDeS), and validate it through the design of different mobility solutions focused on the state of the art technology, as well as offering updated product and service characteristics according to the present offerings. IDeS integrates both internal and external feedback and exemplifies the application of known methods like QFD, and Design for Six Sigma to systematically bring the information across the entire organization, resulting in important time and resources gain in the overall product development process. The IDeS methodology is sequentially composed of Quality Function Deployment (QFD), Benchmarking (BM), Top-Flop analysis (TFA), Stylistic Design Engineering (SDE). Then planning the whole product development, including the prototyping and testing phases, budgeting, aiming to reach production-related decisions. The present work illustrates how the IDeS method manages to integrate the abovementioned design methods to achieve a convincing result. As a result, different sustainable mobility solution proposals are exposed, both for personal and mass transportation, that combine speed, comfort and eco-sustainability with the purpose of replacing the current means of transport and moving towards future technologies for vehicles, and after the assessment to the observed problematic on urban and extra-urban transport systems, as well for new vehicle development requirements.

Keywords
Style Engineering, QFD, Product Development, Future Mobility

1. Introduction
This work proposes to analyze the IDeS method in its overall complexity, going to show, by breaking it down into its various parts, how its application will help designers in the realization of complex projects. During the development of a project there are many complexities and problems that occur, the application of this methodology allows with proven ease to keep an eye on all these aspects in one place, with obvious increase in overall efficiency in terms of time invested and final quality of work. One of the main problems is to be able to follow in an organic and in-depth way the whole chain of the project, being able to have the possibility to go down in the development of individual details while being able to have an overview, which is essential to have the highest level of innovation as a track for the project. Thanks to the IDeS method this problem is significantly reduced, thanks to the structure of the succession of the various steps that make the whole design very scientific and repeatable.

The Industrial Design Structure (IDeS) method is organized according to a well-defined analytical scale and is useful for designing a valid product within the reference market. Several case studies were taken for practical application of this method, and the foundations were laid for the design of a concept for the development of a new hybrid vehicle, with technologies available nowadays, combining the functions of an electric minibus with those of a magnetic levitation train, with the aim of reducing travel times over long distances, as well as managing to guarantee a widespread service within the city. The projects presented here seeks to help to reorganize the mobility network, which thanks to this innovative project will be able to provide a sustainable and at the same time practical alternative, capable of replacing all highly polluting, inconvenient, and slow public means of transport.

This work is structured following the Industrial Design Structure method (IDeS), which combines innovative and systematic design methodologies such as Quality Function Deployment (QFD), Benchmarking (BM), Top-Flop analysis (TFA), and Stylistic Design Engineering (SDE) (Frizziero, Liverani, Donnici, Giuliano, et al., 2021), (Frizziero, Donnici, Liverani, et al., 2019), (Frizziero, Santi, et al., 2021). Moreover, the roadmap on Figure 1 establishes the steps proposed in order to create a product using this method.

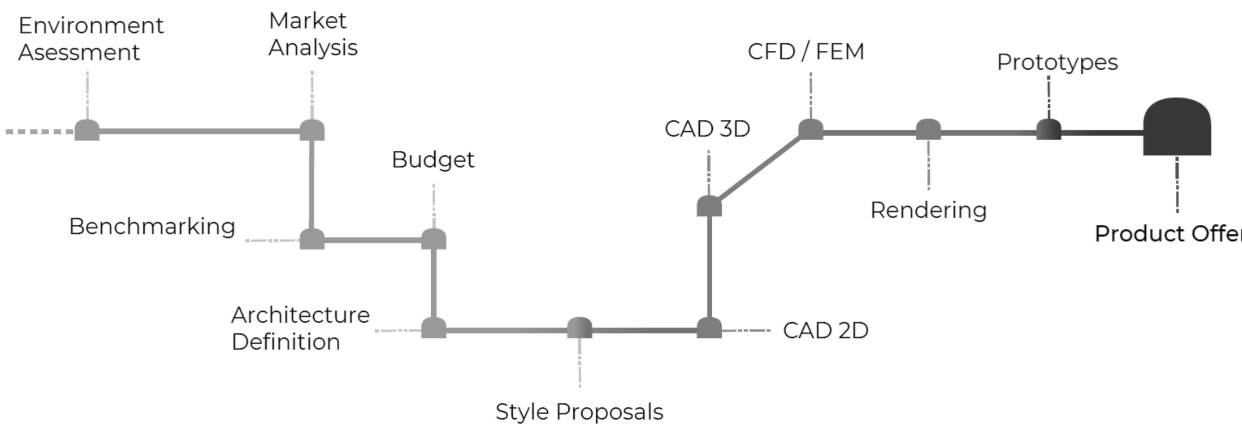


Figure 1. IdeS Practical Project Outline

Moreover, to create a product for a mobility solution, the designer must take into account the general social paradigms, as the current social perception of sustainability, which is constantly changing making it an issue of ever-increasing importance, has led to the need to develop products that require less energy to move and operate (Esposito et al., 2018), making the continuous search for efficiency a crucial added value in every field of new product design and development. Current mobility problems in the urban and suburban scenarios of housing realities (Diamond et al., 2021) that have been on a trend of increasing growth and accentuation of services in recent decades have increased the focus on finding alternative answers to large metropolises overcrowded with expensive rents, and plagued by a multitude of problems among which some of the major ones are crowding traffic congestion (Kelbaugh, 2019), inefficient public and private travel given the large mass of people moving simultaneously (Hannon et al., 2019) , and great pollution of the air given to large quantities of vehicular traffic and the antiquity of many home heating systems. From this data has emerged the demand for the implementation of micro sharing mobility products or services (Populus, 2018), (Boglietti et al., 2021), (Campisi et al., 2020); diversification of which is a reality with Industry 4.0 technology, which allows more elements to be added to the overall product offered (Barata et al., 2020). The market today is very likely to demand a product with an included application to help them better use the service. This technology can be leveraged both to maximize the offering to customers and to control the total progress of the project during the development stages, at the industrial level. In general, it is possible to say that within today's landscape, more and more in the area of design, the goal is the realization of a product-service, rather than simply the design of an independent untethered physical product, as was the case until a few years ago, all in order to fully grasp the various new possibilities for interconnection and value creation, given by Industry 4.0.

1.1 Objectives

To enlighten application of the IDeS method through the practical use of Design for quality tool of QFD and the SDE method, within the mobility sector landscape, in particular to conceive sustainable urban public transport solutions for the nearby future.
To establish mobility solutions using new technologies and methods given by Industry 4.**0.**

2. Literature Review

The decision to decrease the impact of transport systems on the environment comes from the considerable increase in environmental pollution (Zhang et al., 2021). In addition, a variety of problems have been observed on urban and extra-urban transport systems, making them less efficient(Letnik et al., 2018), nor inclusive to people with disabilities (Medina-Molina et al., 2022). Afterwards, there is social pressure to act about greenhouse gas emissions (Chapman, 2007), public health concerns and social equity implications (Mackett & Thoreau, 2015), that make current transport systems unsustainable (Banister, 2005, Hrelja, 2011). Consequently, there are growing efforts to develop innovations that can supply individual mobility whilst addressing these challenges (Pangbourne et al., 2020). It has been suggested that trends such as an apparent levelling off in the rise of car use, and the social change exemplified by the 'sharing economy', represent a window of opportunity for a sustainability transition in the mobility system (Geerlings et al., 2012), (Kemp et al., 2012). Various smart mobility solutions were analyzed and discussed by (Šurdonja et al., 2020), in a mobility survey conducted in Italy and Croatia in 2017. many of these solutions are based on IT and they include a vehicle navigation system, e-parking, e-ticket, info-mobility signalization, demand-responsive transport, car sharing, bike sharing, public transport live tracking among others. These results shown that efficiency in future mobility solutions require a positive tradeoff between product and service, and both of these could be improved by exploiting Industry 4.0 tools. Moreover, mobility requirements for extra urban areas was first studied by (Milbourne & Kitchen, 2014), and further discussed by (Gogola & Sitányiová, 2020). mobility is highlighted as an important shaper of rural lifestyles and rural places. A community study in rural Wales oversaw the difficulties linked with involving everyday mobility in rural settings. Some studies (Rogers, Dufty-Jones, Steele, 2015) examined the problems and role of housing in rural areas.

Moreover, the concept of smart cities has established transportation as one of the key aspects that could be benefited with Industry 4.0 (Campisi et al., 2021). Emerging technologies toward a connected vehicle-infrastructure-pedestrian environment and big data have made it easier and cheaper to collect, store, analyze, use, and spread multi-source data (Sumalee & Ho, 2018). Therefore, Artificial Intelligence enabled several strategies for smart mobility like e-mobility, smart parking, and autonomous mobility solutions have been developed over the years and can contribute to the definition of smart cities, but transport supply (i.e., mobility service, infrastructure details, ICT), demand (socio-demographic aspects), and the size of the city are key factors that define the actual path. Nevertheless, service quality and environmental attitude affect individuals' intention toward sustainable mobility (Mugion et al., 2018).

However, Micro mobility solutions for disabled people have encountered many barriers to access them such as the price and availability of the device (Kett et al., 2020), and available technological assistance elements for the passenger is ultimately needed (Sulistiyawan et al., 2020). Therefore, the solutions existing on the market may not be entirely focused on ensuring a good transport service for disabled people.

3. Methods

The chosen methodology to analyze with this study is IDeS, which is the latest evolution of innovative combining and systematize design methodologies such as Quality Function Deployment (QFD), Benchmarking, Top-Flop Analysis (Frizziero et al., 2018), Stylistic Design Engineering (SDE) (Donnici et al., 2020), (Frizziero, Donnici, Francia, et al., 2019), among others. The application of IDeS towards the present work can be structured in the following road map, which summarizes the process involved [See Figure 2].

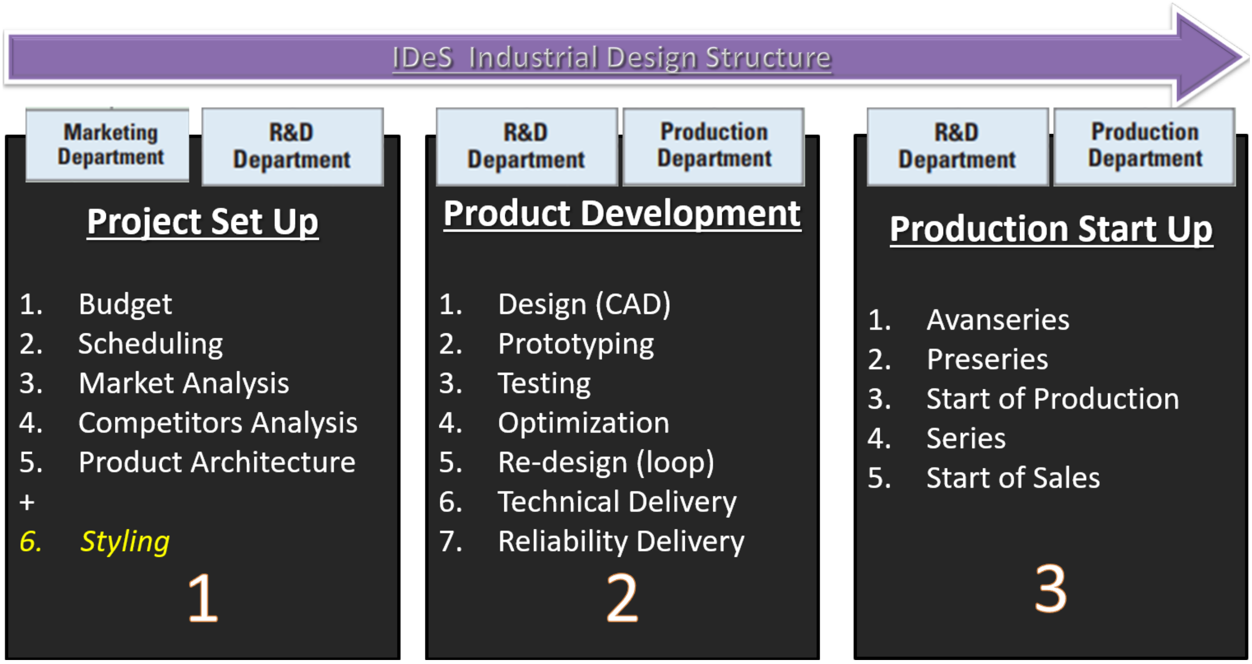


Figure 2. IDeS Methodology Outline

IDeS structure comprises three main Phases: Project Setup, Product Development, and Production Start-up. Main involvement from all areas inside an organization is given mostly in the first two phases, during which the new product is conceived and takes its shape throughout the project. Moreover, the validity of this method stands from research findings that nowadays propose to implement industry 4.0 technologies through the organization to help to obtain Six Sigma (Butt, 2020). This modern interpretation of information sharing would support companies both at reducing defects by lowering overall product development cycle time (Ikumapayi et al., 2020), (Gijo et al., 2021).

3.1. Project Setup and Development

The project setup stage is composed of distinct phases: (a) Environment analysis,
(b) Market analysis, (c) Styling, (e) Architecture definition and (f) 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.

3.1.1. 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 a thorough research.

3.1.2 Quality Function Deployment Methodology (QFD)

QFD (Quality Function Deployment) is a market analysis methodology that allows users to get to know the client's needs and subsequently work on them. It is based on the use of two main components: the six "wh-questions" (Who, What, When, Where, Why, How) and matrices (Relative Importance Matrix and Dependence/Independence Matrix). The 6 "wh-questions" are used to identify the client needs. Results of which are displayed on Table 1, and then are going to be used to properly set up the matrix analysis.

Table 1. Results of 6 questions for a bike sharing system

WHO	WHAT	WHERE	WHEN	WHY	HOW
Comfort Safety Stylish design Convenient price Adaptability	Performance Comfort Italian design	Performance Safety Eco-design Smart accessibility	Autonomy Smart accessibility	Comfort Convenient price Safety Eco-design differentiation Italian design	Comfort Safety Flexibility Smart Accessibility

Moreover, the market analysis begins with the Relative Importance Matrix. This is valuated with 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; and 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 are extracted from the Relative Importance Matrix (Table 2) and the five most independent requirements (along with the five most dependent) are taken from the Dependence/Independence Matrix (Table 3). Combined, a list of requirements is formed.

Table 2. Relative Importance Matrix for an extra-urban mobility system.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Ergonomics	1	0	0	0	1	0	2	1	1	2	1	0	0	2	0	2	0	2
2. Ticket cost	2	1	1	0	1	1	2	1	2	2	1	1	1	2	1	2	0	2
3. Comfort	2	1	1	0	0	1	2	1	2	2	1	1	1	2	1	2	1	2
4. Entertainment	2	2	2	1	2	1	2	1	2	2	1	1	1	2	1	2	0	2
5. Quietness	1	1	2	0	1	1	2	1	2	2	2	1	1	2	1	2	2	2
6. Capacity	2	1	1	1	1	1	2	1	2	2	1	0	1	2	0	2	1	2
7. Safety	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	0	1
8. Dimensions	1	1	1	1	1	1	2	1	2	2	2	0	1	2	1	2	1	1
9. Speed	1	0	0	0	0	0	1	0	1	1	1	0	1	2	0	2	1	2
10. Endurance	0	0	0	0	0	0	1	0	1	1	1	0	0	1	0	1	0	1
11. Sustainability	1	1	1	1	0	1	2	0	1	1	1	1	1	2	0	2	0	2
12. Cleanliness	2	1	1	1	1	1	2	1	2	2	2	1	1	2	1	2	2	2
13. Practicality	2	1	1	1	1	1	2	1	1	2	1	0	1	2	1	2	1	2
14. Maintenance	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	1	0	1
15. Aesthetics	2	1	1	1	1	2	2	1	2	2	2	0	1	2	1	2	1	2
16. Aerodynamics	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	1
17. Multiple seats	2	2	1	2	0	1	2	1	1	2	2	0	1	2	1	2	1	2
18. Stability	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	1
Total	21	13	13	9	10	12	30	12	23	29	19	8	12	31	9	31	11	30

Table 3. Dependence/Independence Matrix for an extra-urban mobility system.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1. Ergonomics	x	0	0	0	0	1	1	0	0	0	1	1	0	0	0	1	3	0	0	1	9
2. Comfort	9	x	0	0	1	3	3	0	1	0	0	9	1	1	0	0	1	1	3	9	42
3. Entertainment	0	1	x	3	1	0	3	0	0	0	0	1	1	0	0	0	1	0	1	3	15
4. Inclusiveness	3	1	1	x	0	1	3	1	0	0	0	3	1	0	0	0	1	0	1	3	19
5. Quietness	9	0	1	0	x	0	0	0	3	0	1	0	0	1	0	3	3	0	0	1	22
6. Modularity	3	0	0	0	0	x	9	0	0	0	0	0	0	0	0	0	3	0	0	1	16
7. Customizable	1	0	0	0	0	3	x	0	0	0	0	0	0	0	0	0	3	0	1	3	11
8. Security	3	0	0	0	0	0	0	x	3	9	0	0	0	9	1	3	1	1	0	1	31
9. Speed	3	0	0	0	0	0	1	1	x	0	3	0	0	1	0	0	1	0	1	3	14
10. Endurance	3	0	0	0	0	1	1	0	1	x	1	0	0	3	1	9	1	1	0	0	22
11. Sustainability	1	0	0	0	3	1	1	1	1	1	x	0	0	0	1	1	0	0	0	0	11
12. Functionality	9	9	1	1	3	0	1	1	1	0	0	x	3	3	3	0	3	3	1	3	45
13. Practicality	1	1	0	0	0	3	3	0	3	0	0	0	x	0	0	0	0	0	0	1	12
14. Stability	3	0	0	0	0	0	0	0	9	1	1	0	0	x	0	1	0	1	1	1	18
15. Cleaning	1	0	0	0	0	0	0	0	0	0	1	0	0	0	x	1	0	0	0	0	3
16. Maintenance	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	x	0	0	0	0	3
17. Aesthetics	3	0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	x	0	0	1	9
18. Safety	3	0	0	0	0	0	0	1	3	3	0	1	1	1	0	0	0	x	0	0	13
19. Capacity	3	3	1	0	1	3	3	0	0	0	3	1	1	1	0	0	0	0	x	1	21
20. Multifunctionality	3	0	1	3	0	9	9	0	0	0	0	1	3	0	0	0	0	0	1	x	30
Total	61	15	5	7	9	26	39	5	26	15	11	18	11	21	7	20	21	7	10	32	

3.1.3. Benchmarking and Top Flow Analysis (TFA)

Benchmarking is a very useful tool that allows 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. A top-flop analysis is carried out 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. 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 (Table 4), cell 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.

Table 4. WHAT / HOW MATRIX for an extra-urban mobility system.

		Length		Wagons		Technology		CO_2 Emissions		Power		Speed		Passenger capacity		Ticket's cost	
Security	9%	1	0,09%	0	0%	3	0,27%	1	0,09%	1	0,09%	1	0,09%	1	0,09%	0	0%
Digitization	8%	0	0%	0	0%	9	0,72%	0	0%	0	0%	0	0%	0	0%	0	0%
Multiple seat	7%	3	0,21%	3	0,21%	1	0,07%	0	0%	0	0%	0	0%	9	0,63%	1	0,07%
Ergonomics	7%	3	0,21%	3	0,21%	3	0,21%	1	0,07%	1	0,07%	1	0,07%	3	0,21%	0	0%
Dimensions	7%	9	0,63%	3	0,21%	1	0,07%	0	0%	1	0,07%	0	0,%	3	0,21%	0	0%
Comfort	6%	3	0,18%	3	0,18%	9	0,54%	1	0,06%	0	0%	3	0,18%	3	0,18%	1	0,06%
Total	44%	19	**1,32**	12	**0,81**	26	**1,88**	3	**0,22**	3	**0,23**	5	**0,34**	19	**1,32**	2	**0,13**

Table 5. Competitor analysis – Top – Flop table

	FRECCIAROSSA	.italo		SMT		N700A	
Origin	Italy	Italy	Italy	Germany/Japan	China	Japan	innovation:
Length (mm)	202000	202000	51900	153600	48000	216500	>202
Width (mm)	2920	3000	2950	3700	2800	3380	>3,5
Wagons	8	11	3	6	3	8	>11
Technology	Electric	Permanent magnet electric motors	Diesel	Magnetic levitation	Magnetic levitation	Electric	Magnetic levitation
CO2 emissions (g/km)	25,3	29,22	26,9	0	0	24	=0
Power (kW)	9800	7600	1250	4000	3000	13000	>9800
Max speed (km/h)	360	300	160	431	249,5	330	>431
Passenger capacity	457	462	345	440	-	1300	>462
Ticket price (€)	20-140	10-100	10-100	6,75	10,54	1,45-3	0<x<50
TOP	0	1	0	4	2	4	
FLOP	1	1	5	0	3	0	
Delta	-1	0	-5	4	-1	4	

3.1.4. Planning

A Gantt timetable is 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. It also visually shows weather activities are carried out singularly (In-Series activities) or simultaneously (In-Parallel activities). Each activity has a specified deadline to abide by. In conclusion, this tool allows the users to visualize their workflow and overall progress as well as know which activities to prioritize over others.

3.1.5. Budget

Through budget planning it's 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.

3.1.6. Product Architecture

Product Architecture allows the designer to review the project (on 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 on it(Frizziero, Liverani, Donnici, Conti, et al., 2021), (Donnici et al., 2019). Further while, the correct choice of this would integrate customized modules for product personalization (Tan et al., 2020), (Meissner et al., 2021).

3.1.7. Stylistic Design Engineering (SDE)

The SDE process 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 (Figure 3). 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.

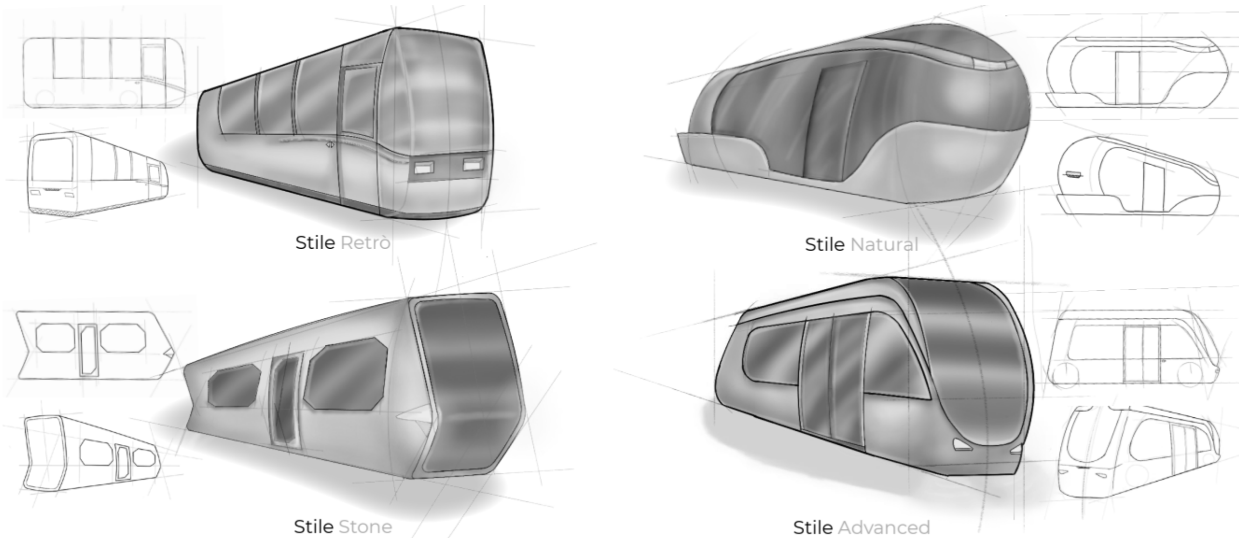


Figure 3. Style Definition for the extra urban sustainable mobility system

3.2. Design Phase
3.2.1. 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 into aspects like items and usability.

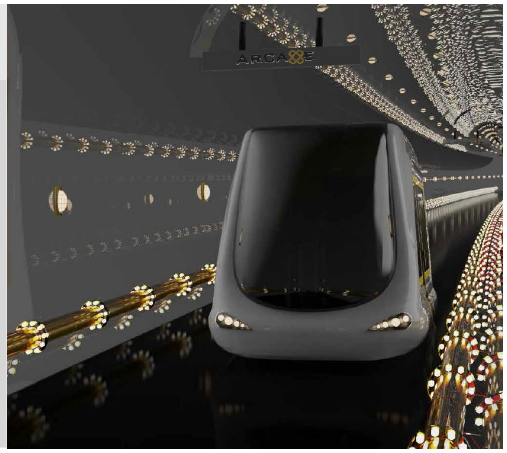
3.2.2. Prototyping
Prototyping is one of the most important phases of SDE. By creating a physical object, the sense of touch is added to the vision, giving wider understanding of the shapes and body surfaces.

The 3D model for prototyping is obtained with a CAD (Computer Aided Design) software, which offers the advantage of quick editing thanks to the parametric modelling feature and the overall virtual environment. It is the 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 the latest years, relies on Virtual Reality environments and VR equipment. Its popularity can be mainly attributed to higher efficiency and inherent lower costs, examples in Figure 4, 5.

(a) (b)

Figure 4. AM Prototype on Disabled People mobility solution: a: AM physical object, b: Rendering

(b)



(b)

Figure 5: Prototyping with: a: AM physical object, b: Rendering

3.2.3. 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 to compare the old highest value of Δ with the new one. Testing product feature might include all technical (Figure 6) and quality testing phases, capable to be carried out according to Six Sigma.

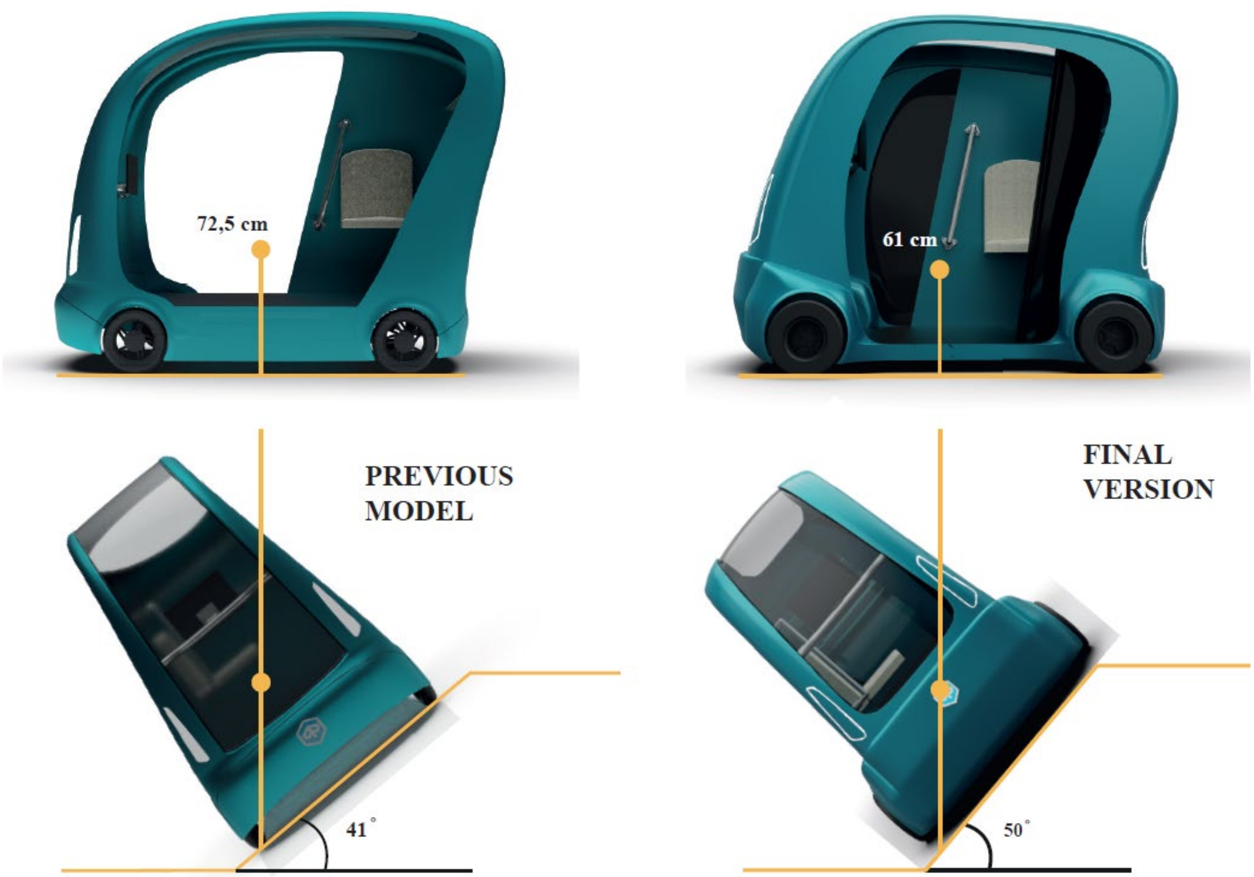


Figure 6. Center of Gravity modification on Disabled People mobility solution

3.2.4 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. Step 2.2.3. and 2.2.4. are reviewed to further improve the project.

4. Results and Discussion
A total of four mobility solution proposals were gathered by applying the IDeS method: Arcade, an extra-urban bimodal transport system; Proxima, a mini electrical bus with an external, mobile recharge system; Omnio, an individual mobility solution for handicap users; and Bicy, an e-bike, sharing system platform. Results of each proposal were gathered after a careful market research, benchmark, and state of the art analysis, as well as following a language style definition right for every single product.

4.1 Numerical Results
Accurate Finite Element Model (FEM) and CFD analysis were performed in the obtained product structures to convey a more solid technical design result. With aid of specialized software for FEM analysis like ANSYS, the mechanical internal structure could be validated for the designed product structures as seen in Figures 7 and 8. C.F.D. stands for Computational Fluid Dynamics, which is the set of techniques that allow fluid dynamics to be simulated using computational systems, it solves efficiently the problems of flow and thermodynamics of fluids: it calculates the properties of fluids (forces, pressures, velocities, temperatures, etc..) and allows access to knowledge of the phenomena through graphical representations and numerical values, simulating, according to a simplified model, the trajectories and behavior of flows that hit a 3D model given an initial velocity.

Given the analysis made to each design concept for project Arcade (Figure X), Here's what was noticed:

- **Retro** style it can be observed that the frontal surface, which is perpendicular to the flow, generates a zone of low velocity and high pressure that produces a relative resistance (drag), conveying the flows towards the external surfaces and upwards, hence accelerating them. Looking at the upper flow pattern, there is a low-pressure zone on the top of the vehicle (indicated by an orange flow in [Figure 7, top]). This leads to a negative lift effect in accordance with the lift principle explained above. The back, on the other hand, due to the sudden cut of the surface generates a significant volume of turbulence (marked by the dark blue lines), as the air seems to be pulled in from the back. This results in a mechanical loss of energy.

- **Natural** style, which was found to be the best, unlike the Retro style, the acceleration of the fluid on the front has a gradual variation due to the more rounded shape of the surface; therefore, the resistance and pressure of the fluid are lower. From the pressure of the flow on the top, it can be assumed that the vehicle is exposed to neither lift nor downforce, resulting in neutrality. Turbulence generated at the rear is also less severe, as it tends to flatten out.

- **Stone** style is the best for the front surface, since the more pointed shape makes the acceleration of the fluid gradual, the intensity of the flows better, and in general the flows are homogeneous. The same is not so for the back, where a vacuum zone is created in which the area of external flows is pulled inwards. This results in a high volume of turbulence, especially in the upper corner, which makes the vehicle unstable.

- **Advanced** style on the front the pressure intensity and flow velocity are reduced and more stable, giving greater aerodynamic stability. However, turbulence is generated at the back, which can be balanced by optimizing the track by reducing the speed of the vehicle on bends and increasing it on straight stretches.

The results deriving from these analyses have been put together in order to determine the most advantageous choice. It 'was finally selected then the Advanced proposal as it resulted the best compromise between the various requirements and constraints of the project imposed. In fact, the aspects taken into consideration for the final choice turned out to be multiple, not exclusively technical and motivated by the individual CFD argument set out above, but also taking into consideration the requirements extrapolated from the QFD analyses and matrices, also bringing into system aspects considered important for this project, such as, habitability, efficiency and exploitability of the space between the external footprint and the internal capacity, an aspect certainly favored by the regularity of the lines, ease of entry and exit, visibility, view cones and blind zones, and so on.

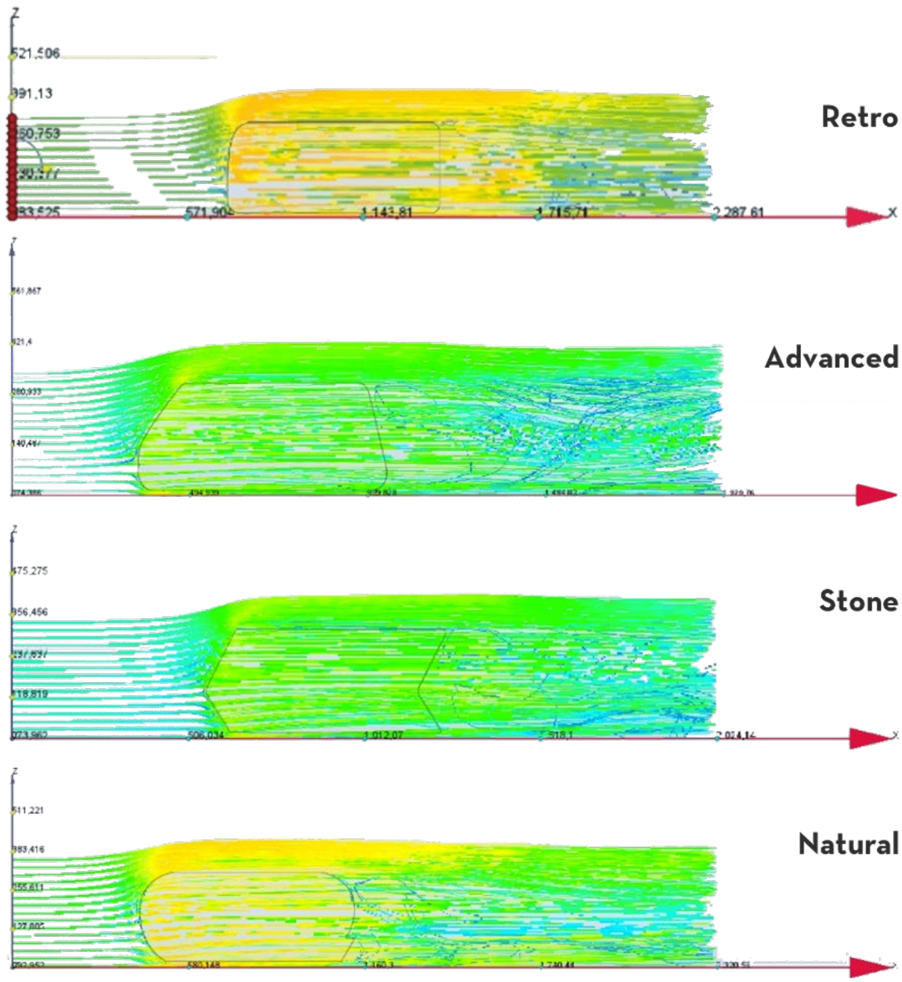


Figure 7. Example of CFD Analysis used to select the main style – ARCADE Project

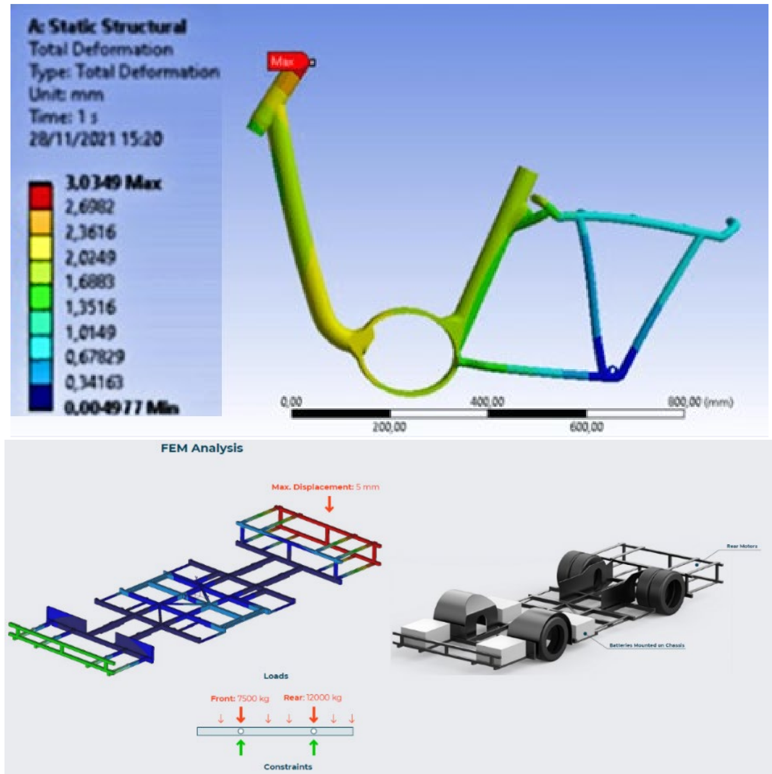


Figure 8. Above: Frame FEM simulation – E-Bike sharing system; Bottom: FEM Analysis from Proxima

5.2 Graphical Results

ARCADE – Extra-Urban Mobility

Based on what emerged from the analysis process, it was possible to identify a rather precise product characteristics. In particular, the IDeS methodology suggested the use of the QFD method for the initial research and analysis, which as always were essential for the subsequent development of the project. Thanks to these analyses it has been possible to define in a precise way the architecture of the product, and all the indispensable qualities to be able to fully satisfy the requirements placed at the beginning and deepened in the problematic analyses (Figure 9).

Figure 9. Actual Problematic Analysis

In this way it has been possible to define in a general way all the technical characteristics to be developed within the working of the project. This type of study has also led to the creation of a brand image for the project with the design of a logo and the definition of a service in the form of a working prototype application to allow you to manage all the various possibilities offered by the product [Figure 10]. A summary of all transport service amenities is displayed on Figure 11.

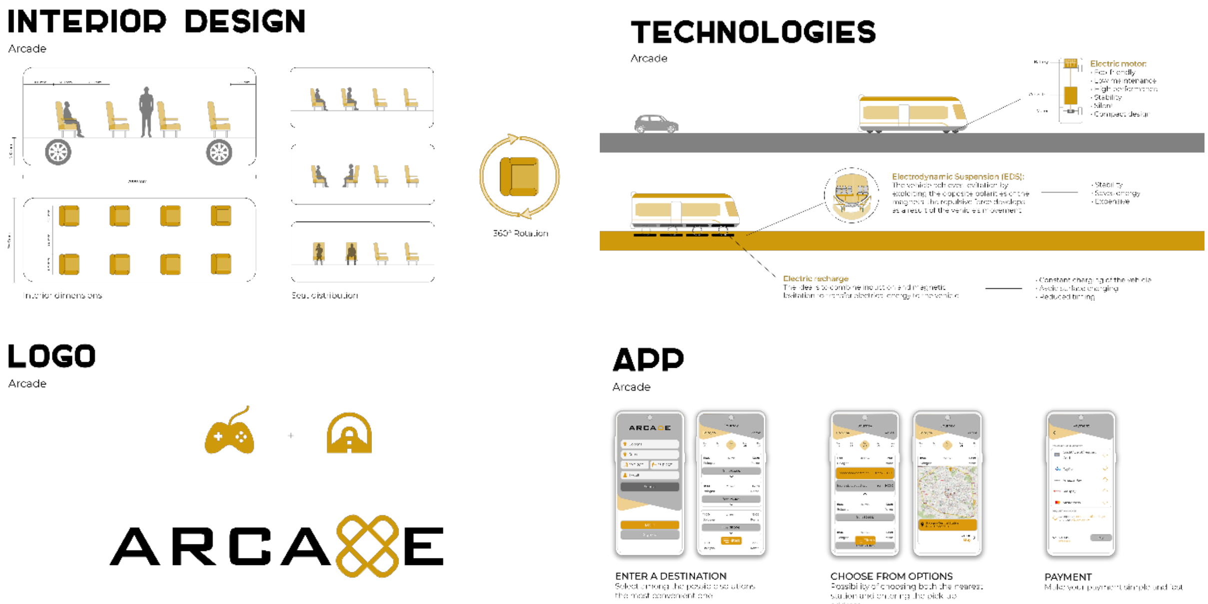


Figure 10: Examples of deepened aspects of the project.

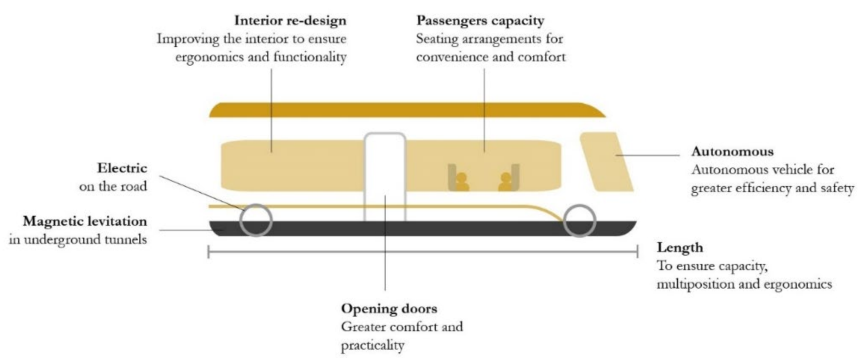


Figure 11. Product Characteristics Summary

Based on the sketches created, product concept sketches were translated into simplified 3d shapes to identify the best one. The idea is to go to select the best proposal not only through a purely stylistic selection based on market trends, but also from a functional point of view, internal habitability, and aerodynamic efficiency, necessary in order to contain consumption and therefore pollution (given that even if the vehicle is electrically powered, a part, for now still substantial, of the electricity is obtained from fossil fuels), and extend the range. To this end, a CFD analysis was carried out for each proposal, in order to predict and anticipate the fluid-dynamic behavior for each style. The purpose is therefore not to obtain realistic and complete model calculations, but to obtain basic indications through this type of analysis to take into account in the final selection of the model. Overall, this project managed to have a preliminary technical assessment, by which the specifications were gathered according to a budget target. Final product dimensions (Figure 12) and visual renderings of the final 3D object (Figure 13).

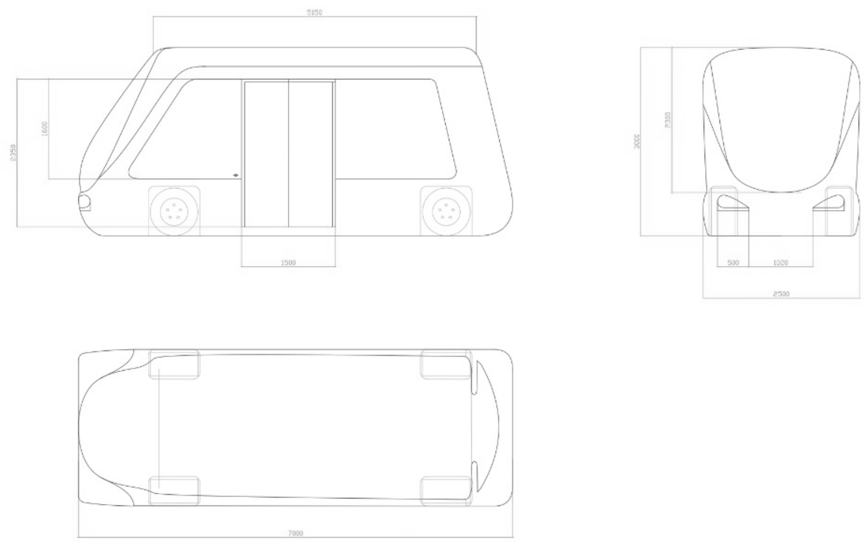


Figure 12. Arcade overall dimensions

(a) (b)

Figure 13. View of the designed vehicle: a) on the street; b) on the subway

OMNIO – Autonomous Solution for the Disabled

We can then proceed to the description of the next project, "**Omnio**", concerning the design of an autonomous electric urban mobility vehicle, extremely compact, intended for sharing and accessible also to people with disabilities.

As in the previous project, thanks to the IDeS methodology it was possible to put together the various requirements and quickly and accurately find the technical characteristics necessary for a correct definition and development of the project. The focus in this case was dictated by the very stringent requirements decided for this project in the very early stages (Figure 14). The main idea derived on the fact that, just in Italy alone, about 300,000 disabled workers move to the workplace every day, from this total, 74.9% use the own-property car and 7.4% use public transport. In fact, it is not a conventional compact vehicle for urban transport, but rather a product that can bring in reality an innovative concept of movement, no longer focused on the private, but on the sharing of the means and, most importantly, not designed as a great way to aggregate people who make the same route, as it could be a public urban service, but rather designed to give greater freedom to the individual user, providing a means of reduced size and potentially able to move without problems within the daily difficulties of an average urban center. Accessibility was also important, including people with disabilities and therefore with different needs due to difficulties in movement or different encumbrances of equipment. As a futuristic concept, there are fewer constraints due to the legal aspect of the regulations, and it was also natural to imagine a significant technological progress in the field of driving assistance, allowing us to imagine as feasible a complete autonomous driving device, therefore level 5, which can operate safely within a closed context such as the city, and that goes to exempt the passenger from the actual driving of the vehicle, making irrelevant the physical condition or health of the occupant transported. The product also included a novel, charging induction Pod (Figure 15).

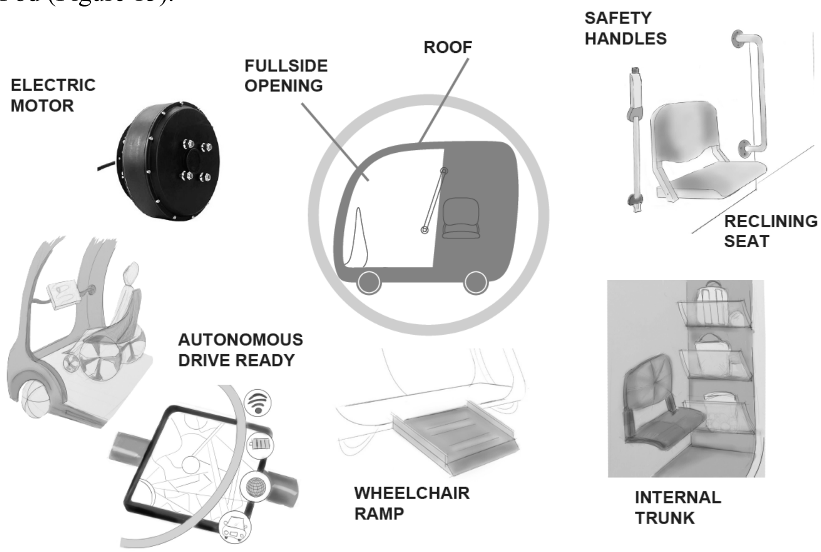


Figure 14. Product Requirements Arrived from What-How Matrix

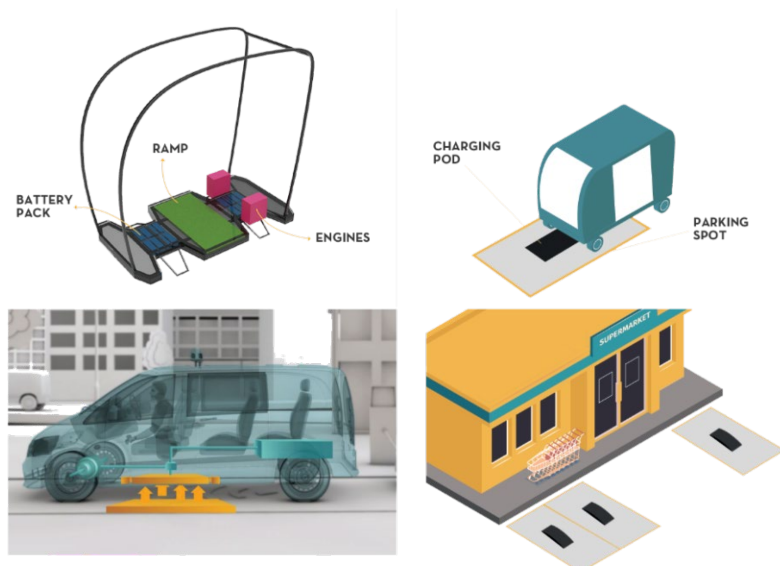


Figure 15. Proposed Charging Induction Pod Detail

The 3D model of the vehicle was fully designed according to the specific functionality (Figure 16) and comfort needs. On (Figure 18) it is possible to see various renderings of the vehicle in its working environment, and its external dimensions (Figure 17).

The project consists of a small vehicle characterized by autonomous driving, which allows passengers to be transported within the urban context without having to be actively involved in driving. This aspect is crucial for the purposes of the project as it makes the passengers' disabilities totally irrelevant to the proper operability of the vehicle. In addition, this vehicle makes it possible to transport more than one person, and since it is not exclusively related to the world of people with disabilities, it makes it possible to offer a service of interest also to people of an elderly age, with motor difficulties, or simply to offer significant help to those who find themselves shopping in places that can be reached on foot, but are difficult to return home with loaded bags. This makes it possible to offer a socially useful service that is both open to people with difficulties and suitable for accommodating the changing needs of future society in urban areas, promoting movement unencumbered by private transportation, and consequently avoiding all the problems associated with it.To allow easy boarding and alighting from the vehicle, a retractable ramp was designed to have a maximum slope of no more than 8 percent and allow wheeled vehicles to be able to move safely.

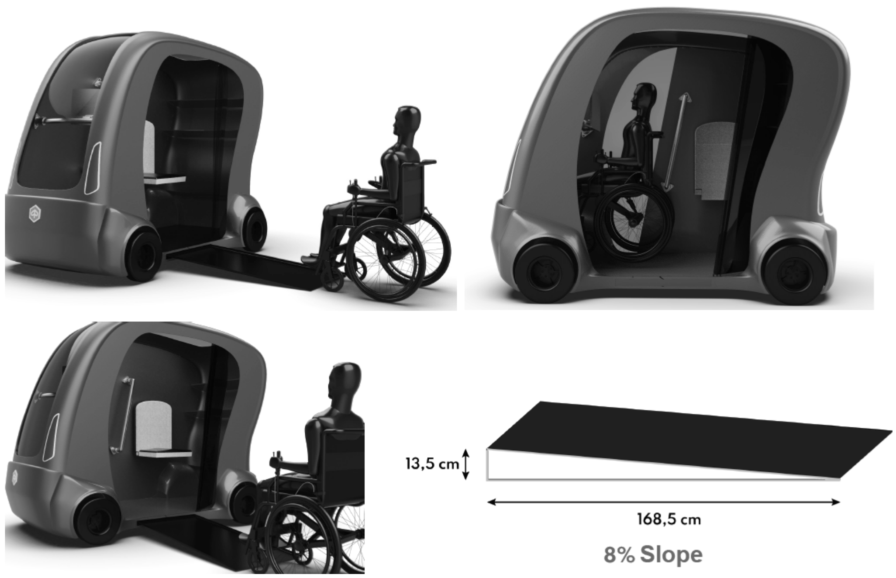


Figure 16. Vehicle with Passenger Chair - Visual Render

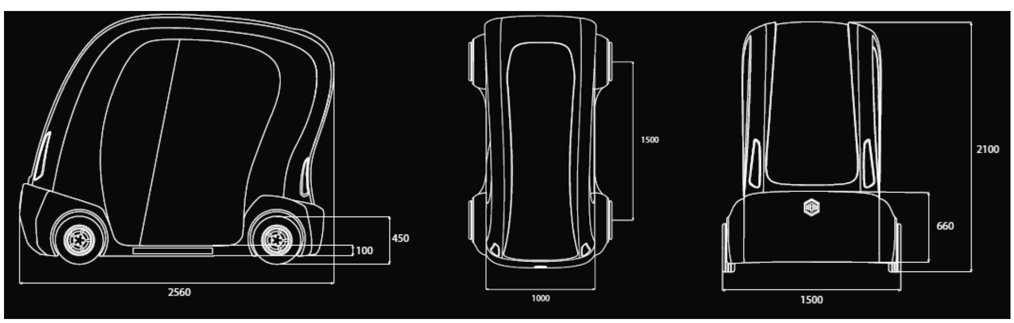


Figure 17. External Dimensions of the Vehicle

Figure 18. 3D Vehicle model Visual Renders

Table 6. Vehicle Technical Specifications

Property	Description
Dimensions	(2500 x 1600 x 2100) mm
Trunk	3 internal storage shelves
Door	Automatic side opening by bellows sliding system, operated by button
Motor power	2 electric motors of 4 kw, integrated in the wheels
Wheels	14", alloy
Brakes	Electromagnetic for energy recovery in braking and / or downward (regenerative braking)
Batteries	10 kw / h lithium
Ramp	(1685 x 135) mm
	Slope (135/1685) * 100 = 8% compliant with the regulations in force on ramps
Entertainment / navigation	Touch screen adjustable by tilt
Safety features	Front, curtain airbags
	Stainless steel safety handles
	Reclining seat
	Security belt
	Windshield in polycarbonate
	Rear window in polycarbonate
	Side door: polycarbonate sheets with bellows closure
	Front and rear led lights
Charging device	Pod placed in the underbody of the vehicle for induction charging

PROXIMA – Road Urban Public Transportation

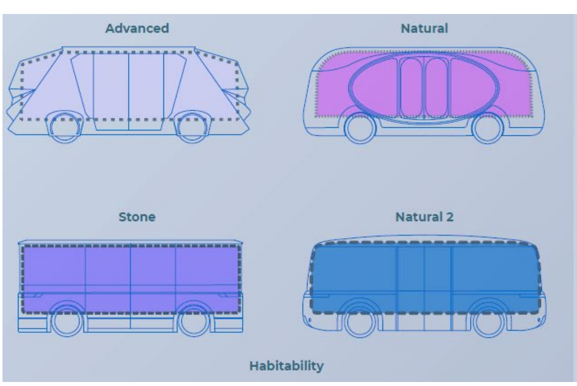
This project proposes to solve a very similar problematic but in a different way from what has already been seen with previous works. The same problems are always analyzed with the IDeS method, but through a different QFD approach, they are seen from different requirements. Therefore, the resulting product is different, given the diverse interpretation of the various critical issues.

Conceived from the desire to provide transport of people in an urban context, The ways in which this is carried out move away from the sharing theme seen in the previous project to get closer to that of urban transport, where therefore a large vehicle is able to provide for the transport of a given number of passengers in one or more urban sections. pre-established. In order to better cater for future urban scenarios that are certainly different and evolved from contemporary ones (Figure 19), the product architecture developed within the IDeS has been differentiated from contemporary forms, closely linked to current and past needs. A more widespread form of connection was then proposed, which exploits the space and ergonomics advantages provided by electric traction, combining them with the possibilities offered by an integrated autonomous driving system (Figure 20). This vehicle was conceived after analyzing the vehicle usage on restricted routes, such as trams and subways, partially restricted vehicles, vehicles on the road, such as buses, trolley buses, minibuses, or vehicles on wire ropes, such as cable cars or cable cars. Following some evaluations, it was decided to choose "road" transport as the object of study, taking into account the advantages and disadvantages of this.

Figure 19. Future Mobility Scenario

Figure 20. Product render

The vehicle does not need a suspended cable network for power supply, as happens with current electric buses, but has its own battery pack capable of providing it with sufficient autonomy to reach the end of the day without problems in an urban environment. The low weight contributes to this, given by the significant reduction in size compared to a conventional bus, dimensions that also allow it to be more effective in traffic and in narrow areas of urban areas, such as historic centers, which it can enter with a low impact. sound and low space occupation (Figure 21).



Property	Advanced	Natural	Stone	Natural 2
Aerodynamics (CX)	0,76	0,74	0,98	0,72
Aestetics Value	Good	Good	Mid	Best
Habitability	Low	Mid	Best	Good
Factibility	Low	Good	Best	Best

(a) (b)

Figure 21. (a) Habitability assessment for design options, (b) Comparison chart among style versions

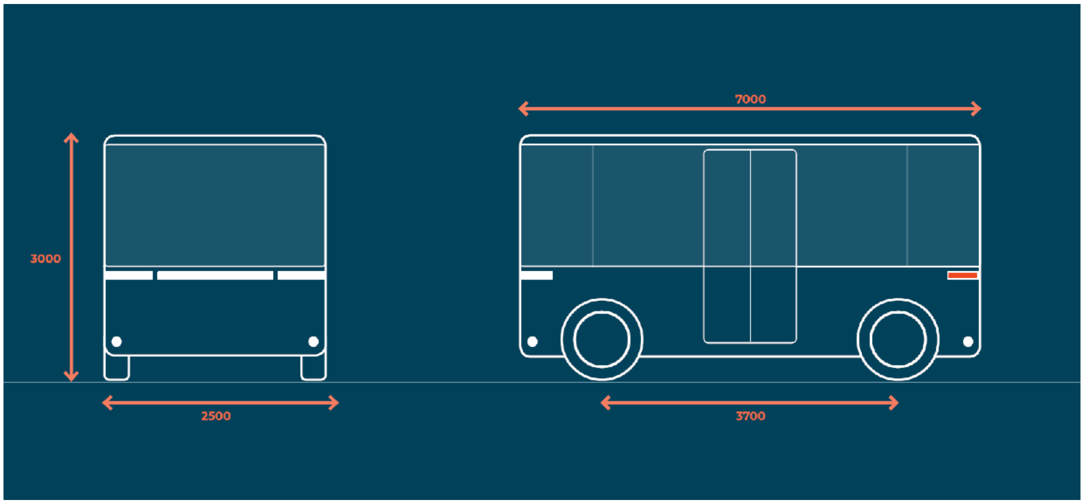


Figure 22. Product dimensions

Figure 23. Visual Interior Render

Since the vehicle was designed with a view into the future, innovation was the key differentiator, therefore the choice to design a compact, self-driving set of trailers parked in strategic areas of the city, constantly connected to the electricity supply, through an integrated control system, with which depending on the need for the individual vehicles, they can autonomously disconnect from the power supply and drive until they intercept the nearest vehicle with a lack in power reserve, hooking onto the rear, and charge it for few tens of minutes, when the their function is to go to the nearest collection and recharge point to restore their autonomy, thus making the vehicles potentially capable of continuously circulating night and day without the need to stop for charging (Figure 22, 23). This vehicle design was accompanied with the appropriate technical analyzes carried out such as CFD and FEM simulations, integrated into the workflow to have the possibility of making a more complete choice also based on other types of definition data.

Moreover, Figure 24 displays the planned range extender, the battery trailer, having finished its autonomous driving path and finally reaching the bus, hooks onto it at the rear and is passively transported. The type of connection between the two provides for the possibility of passing an adequate supply of electricity to be able to quickly charge the batteries of the bus for continuous operation, or alternatively to function as a range-extender if the bus is you find yourself taking longer distances in the suburbs than the classic urban route. Once the charging operation of the bus is complete, the trailer maintains a reserve of residual charge thanks to which it can uncouple and autonomously return to the nearest dedicated charging station, recharge, and be ready for the next task.

Figure 24. Trailer at work

BICY – Bicycle City Share

The next project is "BICY", in which the problem of future urban mobility is analyzed from a still different point of view, this time focused on the single user, rather than on collective transport.

In this project, the IDeS methodology is used to break down and analyze all the urban transport needs associated with the movement of a single person. A case study was taken to associate the development of the project in order to be more specific and arrive at a level of detail of a satisfactory depth. The case study of the selected urban context was the city of Bologna, where the University that carried out the project is based. The city of Bologna is an excellent setting in which to set this studio as it offers optimal features for the studio. In fact, it has a large historic center, one of the largest in Italy, but still easily visited on foot or by bicycle. Most of the services can be easily found in the center, thus making it important to have a fast, widespread movement, and with the possibility of being able to cross areas with limited or prohibited access to normal vehicles, given the pedestrian nature of various areas. At the same time there is a strong relationship between the center and the surrounding areas, highly urbanized, as a large part of the residents live here, like many commercial activities, and these areas, although very close, can be slightly cut off. from what is the life of the center without a means of transport that makes journeys temporarily short. The union between the convenience of walking and the speed of a vehicle has been found in e-bikes. As a result, it was possible to note that for the type of needs selected, the bicycle was the type of means of transport that guaranteed the greatest overall efficiency, and together with the aid of a pedaling aid from an electric motor, it made it possible to cover effortlessly distances that are difficult to cover on foot, while maintaining the ability to travel any type of zone or pedestrian area, not even having to worry about the problem of parking.

Through an in-depth benchmark analysis, contained within the QFD methodology applied to the project, the solutions proposed so far by companies that have found themselves advising products in this same range, that of applied e-bikes, were taken into consideration. sharing, trying to understand which the most beneficial solutions were proposed, which are the most interesting aspects, such as the critical issues, and what to focus on in order to offer innovative solutions, which could go to provide a higher quality and possible interest for the user. In this way, key negative aspects of the existing solutions were discovered that undermine the goodness of the solutions proposed so far, decreasing the degree of user experience and consequently the rate of use of the systems.

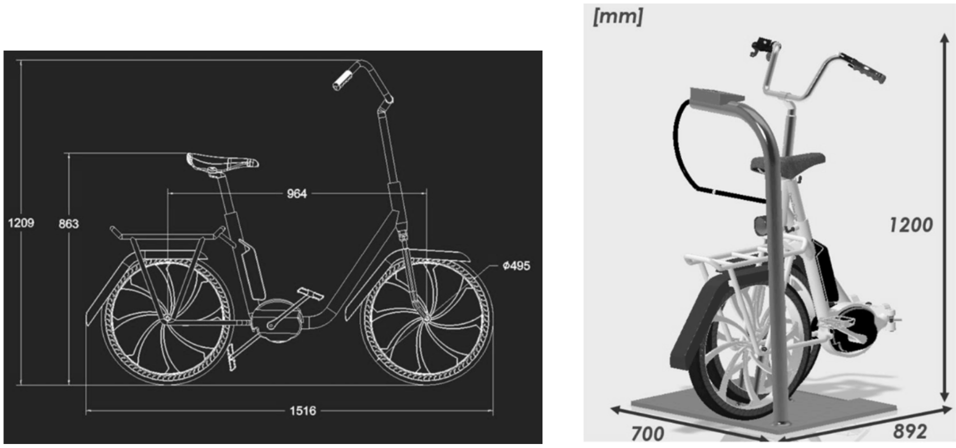


Figure 25: Product and station dimensions (in mm)

The idea is based on an iconic bike model among European cities. This model of bicycle, invented in the 60s, has experienced a very strong popularity over the decades that continues today, with very famous personalities from the entertainment world who over the years have decided to being seen with this model, which has therefore become iconic and sometimes even true collector's item. The basic idea of this bicycle was completely based on the ease of use by anyone and the agility of the vehicle. The wheels were small to facilitate an agile use at low speeds, the monorail frame very low to allow for an up and down without any commitment even by elderly people and women with skirts, and in the center of the same there is a hinge, easily operated by hand, which allows you to open and close the vehicle, obtaining a minimal footprint, allowing you to take it anywhere (Figure 25). To complete the equipment there were practical luggage racks placed above the wheels, easy to use, helping to make this bike a means of pure utility. This type of product is the opposite of classic bicycles designed for sharing, which for reasons of strength and resistance to vandalism are very heavy, squat and very not very agile, thus compromising usability and user experience. Thanks to the IDeS methodology, the idea developed is therefore to try to combine the positive aspects of both these categories, generating a service based on a fleet of robust, easy to use, agile and efficient vehicles (Figure 26).

Figure 26. Rendering of the final design

From this process, BICY (Bike In the CitY) was born, able to satisfy the needs found on the basis of the analyzes carried out and on the competitors analyzed. Furthermore, thanks to the very compact shape and geometries, it was possible to significantly reduce the overall weight of the vehicle, to the great advantage of agility, aided by the small diameter wheels.

5.3 Proposed Improvements

To include additional technical proposals to ensure the entire technical offering feasibility, and budget compliance. Have additional studies that help to include developing technologies as Autonomous Driving.

6. Conclusion

State of the art review noticed the increase of demand of sustainable mobility solutions in order to solve current environmental and mobility challenges in our societies. Industrial Design Structure Method was successfully applied to the conception, and feasibility analysis of four mobility solutions for the near future. This case studies of a probable product conception were developed by the information gathered from knowledge of the design department, which allowed to oversee main product use and shapes. This information also was useful to gather the understanding that mobility solutions often require a physical plus a service product offering, and every detail can be solved on time from the first product requisites gathered at this point. The obtained models were subjected to physical and virtual validation through CAM technologies such as AM and visualization tools through rendering such as VRed and Keyshot. Through these tools, it turned out to be possible to have photorealistic three-dimensional images from the previously made 3D models, so as to provide a clear idea of the product, and to be able to make photo-insertions, so as to place it in a credible usage environment. Using Unity, it was possible to create an augmented reality environment in which to verify the use and proportions of the product.

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Biographies

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