GIAN ANDREA GIACOBONE

Human-Centred Design & sustainable mobility: Envisioning the future concept of a hybrid sports vehicle

FERRARIAE UNIVERSITAS · EX LABORE FRUCTUS · 13 91
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Candidate
Gian Andrea, GIACOBONE

(UniFe Matr. N. 131773)
(Polis Univ. Reg. N. PL581N050006)

Supervisor DA
Giuseppe, MINCOLELLI

Supervisor POLIS
Loris, ROSSI

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Let's Begin

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Preface

Abstract

English version

This thesis is part of a multidisciplinary project named "Automotive Academy: a learning-by-doing project for innovation engineering automotive", a strategic industrial programme financed by Emilia-Romagna region, Italy. The project is made by a collaborative research network composed by several universities, research centres and local industries scattered on the territory.

The overall research aims to gather many engineering and design solutions, developed by the network, which can be transferred from academia to the automotive industry. In particular, the main goal of the project is to develop a "fun" and "eco" concept car as an R&D platform, which aspires to become a starting point and a demonstrator for future technical or technological innovations – in terms of sustainable and high-performance solutions – that will be developed within the network in the coming years. In particular, the objective is to design the future concept of a hybrid sports vehicle, which must be characterized by low environmental impact and high-performance features.

Five independent work packages constitute the research program. Each area refers to a specific field of expertise that deals with a particular system of the vehicle: (1) automotive product design and human-centred methodologies; (2) propulsion and powertrain; (3) vehicle body and dynamics; (4) smart materials and innovative components; (5) drive-by-wire

instruments. This specific research refers to the first work packaging and it focuses its attention on the automotive design or styling design, namely the specialized discipline that is specifically implicated in giving a shape to the car during the early stages of the automotive product development. Unlike the other engineering work packages, this research is design-driven and human-centred oriented.

The contribution, indeed, constitutes the framework of the overall project because it has the task to envision and conceptualize both architecture and styling of the expected sports car by using specifically a human-centred design approach. In fact, starting from identifying the context of use, the research analyses the main users and their behaviours to transform their wishes or needs into an innovative solution, which will be capable of satisfying their demands.

The peculiarity of the research lays on the use of two specific human-centred approaches – that are Quality Function Deployment (QFD) and Vision in Product Design (ViP) – but also on its exploratory combination for experimenting a new design methodology. QFD is a human-centred tool based on a mathematical correlating matrix that is able to orient product design toward the real exigencies of the end-users. While ViP is a conceptual and strategic methodology that enables innovation by envisioning new ideas for the future. Both models are selected for this research because they are perfectly suitable in automotive for structuring idea-generating throughout the styling process. They are also able to support the design process in making significant decisions for product development.

The main purpose of the exploratory combination is to develop the concept vehicle in a unique design process, in order to come up with a novel and integrated concept solution. At the end of the research, the proposed vehicle and its properties expect to become a technical layout for developing the automotive R&D platform in the coming years within the multidisciplinary network. The final solution will provide several technical and styling guidelines to the overall project that will be necessary not only to design the final vehicle prototype but also to promote the use of a human-centred design approach to the other engineering researches.

Italian version

Questa tesi è parte integrante del progetto multidisciplinare chiamato "Automotive Academy: a learning-by-doing project for innovation engineering automotive", un programma strategico industriale finanziato dalla Regione Emilia-Romagna. Il progetto è costituito da un network di ricerca collaborativo composto da diverse università, centri di ricerca e industrie locali diffuse sul territorio.

L'intera ricerca prevede di ottenere dal network diverse soluzioni ingegneristiche e di design che possano essere trasferite dal mondo accademico all'industria automobilistica. In particolare, l'obiettivo principale del progetto è sviluppare il concept di un'autovettura "fun" ed "eco", che possa fungere da piattaforma di ricerca e sviluppo e da dimostratore per presentare le future innovazioni tecniche e tecnologiche (in termini di soluzioni sostenibili e ad alte prestazioni) che saranno sviluppate all'interno del network nei prossimi anni. L'obiettivo è quello di ideare il concept futuro di un veicolo ibrido e sportivo, il quale sarà contraddistinto da caratteristiche tecniche a basso impatto ambientatale e ad alto livello prestazionale.

Il programma di ricerca è costituito da cinque gruppi di lavoro indipendenti, dove, in ognuno di loro, è trattato un particolare aspetto del veicolo: (1) architettura del veicolo e metodologie centrate sull'utente; (2) propulsione e modulo di trasmissione; (3) dinamica del corpo veicolo; (4) composti innovativi e materiali intelligenti; (5) sistemi di guida elettronica e assistita. Questa specifica ricerca si riferisce al primo gruppo di lavoro, la quale è principalmente focalizzata sull'automotive design, ovvero la disciplina che si occupa dell'intera progettazione del veicolo, della sua architettura e del suo stile, durante le prime fasi di sviluppo di un prodotto automobilistico. Diversamente dagli altri gruppi di lavoro che riguardano gli aspetti più ingegneristici del progetto, questa ricerca è prettamente legata al design e mantiene un approccio centrato sull'utente.

Infatti, il contributo costituisce la spina dorsale dell'intero progetto, in quanto il suo compito è quello di immaginare e concettualizzare, sia l'architettura, che lo stile finale del concept automobilistico atteso, tramite l'uso di una metodologia human-centred. Pertanto, a partire dall'identificazione del contesto d'uso, la ricerca cerca di analizzare gli utenti principali del progetto e i loro comportamenti in modo da trasformare i desideri o i bisogni di questi ultimi in soluzioni inedite che siano in grado di soddisfare le proprie esigenze.

La peculiarità di tale ricerca risiede nell'utilizzo di due specifici approcci centrati sugli utenti, come il Quality Function Deployment (QFD) e il Vision in Product Design (ViP), ma anche sulla loro inconsueta combinazione, la quale è servita a sperimentare una nuova e integrata metodologia. Il QFD è uno strumento human-centred basato su una matrice matematica di correlazione che è capace di orientare lo sviluppo di un prodotto verso le reali esigenze degli utenti finali. Mentre il ViP è un metodo strategico concettuale che promuove l'innovazione attraverso l'ideazione di nuove idee per il futuro. Entrambi i modelli sono stati selezionati per la ricerca perché tutti e due sono perfettamente orientati verso l'ambito automotive nel strutturare la generazione di idee lungo tutto il processo di stilizzazione del veicolo. Inoltre, i due metodi sono capaci di affiancare la fase di design nel momento in cui è necessario prendere decisioni significative per lo sviluppo finale del prodotto.

In questo caso, lo scopo principale della combinazione tra i due metodi è quello di sviluppare il veicolo attraverso l'uso di un inedito processo di design che possa elaborare il concept in una nuova e integrata soluzione. Alla fine della ricerca, il veicolo proposto e le sue caratteristiche prevedono di essere utilizzate come layout tecnico per lo sviluppo della piattaforma R&D nei prossimi anni, all'interno del network multidisciplinare. La soluzione finale provvederà a fornire all'intero progetto diverse linee guida, tecniche e stilistiche del veicolo, non solo per ideare il prototipo finale, ma anche per promuovere l'uso della metodologia human-centred nelle altre ricerche ingegneristiche.

Manuscript structure

This contribution aims to describe the entire research process of this thesis through a step-by-step narration. The content of the manuscript is structured essentially in six chapters and each of them explains an essential part of the process. The first four chapters serve: introduce the topic of the multidisciplinary project and the principal objectives of this research; describe the research theme; understand the proposed methodology that has been used to drive the design process; identify and analyse the main context. The other two last sections provide the complete description of the design activities that have been conducted to accomplish the goal of the entire multidisciplinary project: developing the concept of a hybrid sports car.

The chapter number 3 presents the goals and the expectations of the overall multidisciplinary project, especially reporting the role of this research within the regional network. The chapter number 4 describes the topic of the research that corresponds to the field of automotive. In particular, it gives an overview of the discipline of styling design and why it is important for this project. The chapter number 5 provides an in-depth understanding of the two proposed human-centred design approaches that have been adopted to perform the research. The chapter number 6 explains the research context and it describes the state-of-the-art about the main potential competitors of the project. The section number 7 is the core of the overall thesis because it reports the practical activities of this research, in particular describing every step – that have been necessary to develop the expected concept vehicle – in a sequential and linear narration. In the end, the last chapter number 8 presents concludes the thesis with an evaluation of the achieved and final results and an in particular, with an examination of the proposed exploratory methodology that was used to develop the project.

◆ **End of Preface**

CHAPTER III

Acknowledgements

As Marc Augé, a famous French anthropologist wrote in one of his books, our future has always a social dimension. For the author, every stage of our life depends to a large extent on other individuals. In my case, this step of my life and this thesis are the overall result of all the people who influenced and supported my career and thinking during my educational training, giving me the chance to achieve this important result.

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I would like to thank all the people who offered me their precious time while I was conducting many interviews for my research. In particular, I want to thank Professors Francesco Leali, the coordinator of my project, who provided to me a series of significant contacts in the University of Modena and Reggio-Emilia, which were important to perform my studies. Within this network, I would like to thank Professors Matteo Giacopini, Enrico Stalio and Sara Mantovani, the researcher Andrea Fregni and all the students of the Formula Student programme, who were available to provide to me important data that I needed to conduct my research activities. They gave me also the chance to learn more about the automotive development program.

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Gian Andrea

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PART 1:
INTRODUCTION TO THE DOMAIN

CHAPTER 1

Introducing the project

1.1 Introduction

This chapter describes the purpose of the presented thesis, which is part of a multidisciplinary automotive project financed by the Emilia-Romagna region. The overall project is divided into five individual work packages, which together aim to develop the concept of a hybrid sports car. The activities of this research are related to the first work package of the overall project: automotive styling and design methods. The main goal is to envision and design the vehicle's architecture and styling using a human-centred design approach. The final outputs become design guidelines for the other engineering partners to develop the final prototype.

1.2 The project: automotive academy

This thesis is part of a multidisciplinary project named “Automotive Academy: a learning-by-doing project for innovation engineering automotive”, a strategic industrial programme financed by Emilia-Romagna region, Italy. The scope of the project is related to the regional automotive industry. It aims to institute a specialized international network between universities, research centres and industries of the territory to develop new technologies for the next-generation sport vehicles. In particular, the goal of this overall project is to develop a “fun” and “eco” concept car as a R&D platform, which aspires to become a starting point and a demonstrator for future technical or technological innovations – in terms of sustainable and high performance solutions – that will be developed by the network in the coming years.

The aim of the research is to gather many engineering and design solutions from those activities, which can be transferred at the end of the project in the automotive industry. The project expects to produce the concept of a hybrid sports car, which must be characterized by the combination of sustainable and low environmental impact solutions and high-performance features.

Innovation technology is particularly addressed to the development of an efficient internal combustion engine (ICE) and advanced systems for electric or hybrid layouts. The project involves also the study of new materials and the use of additive manufacturing for producing automotive lightweight components. Besides, the research investigates new solutions to improve aerodynamics, vehicle dynamics and stiffness of the chassis in order to increase the efficiency of the vehicle's carbon emissions and fuel consumption. Another research examines car safety through the study of the advanced driver-assistance systems (ADAS) which permit the entire project to explore parallel lines of research related to smart mobility and autonomous driving. Furthermore, specific design research, which is focused on human-centred methodologies, guarantees a solid design strategy to ideate the expected concept according to customer demands. The design process provides also a technical framework to combine the other engineering researches together with new potential market trends in order to create a product that is able at the same time to accomplish the expected goal of the overall project and satisfy the users' requirements.

1.3 The regional network

The project is made by a multidisciplinary and collaborative network

Img. 01 • The overview concerning all of the partners involved in "Automotive Academy: a learning-by-doing project for innovation engineering automotive",the strategic industrial programme financed by Emilia-Romagna region, Italy.

composed by several universities, research centres and local industries scattered on the Emilia Romagna region. The purpose is mainly focused on technology transfer from academia to industry. The project aims to create a large automotive hub that can be used by the regional partners to collaborate together or exchange project in the field of automotive.

The project involves 4 universities, 8 research centres and 12 small-medium enterprises **Img. 01 •**. The 4 institutes drive the main research and they are:

- Department of Mechanical Engineering "Enzo Ferrari", University of Modena & Reggio Emilia (UniMoRe), which is the head of the overall project;
- Department of Architecture and Industrial Design, University of Ferrara (UniFe), which is the author of this thesis;
- Department of Mechanical Engineering, University of Bologna (UniBo);
- Department of Industrial Engineering University of Parma (UniPr);

The research centres are spin-offs of the university and all of them participates in the regional R&D network named "Rete Alta Tecnologia", which already is a meeting-point between academia and local industry for promoting industrial development, technology transfer and innovation. They are:

- Mech-Lav and Teknehub laboratories, which are associated with UniFe. In particular, Teknehub supports this thesis providing its background and expertise on human-centred design methodologies;
- Intermech Mo.Re., Kaitek, Raw Power and Softech-ITC, which are directly connected to UniMoRe;
- CIRI MAM laboratory and CIRI Aeronautica, which are related to UniBo;

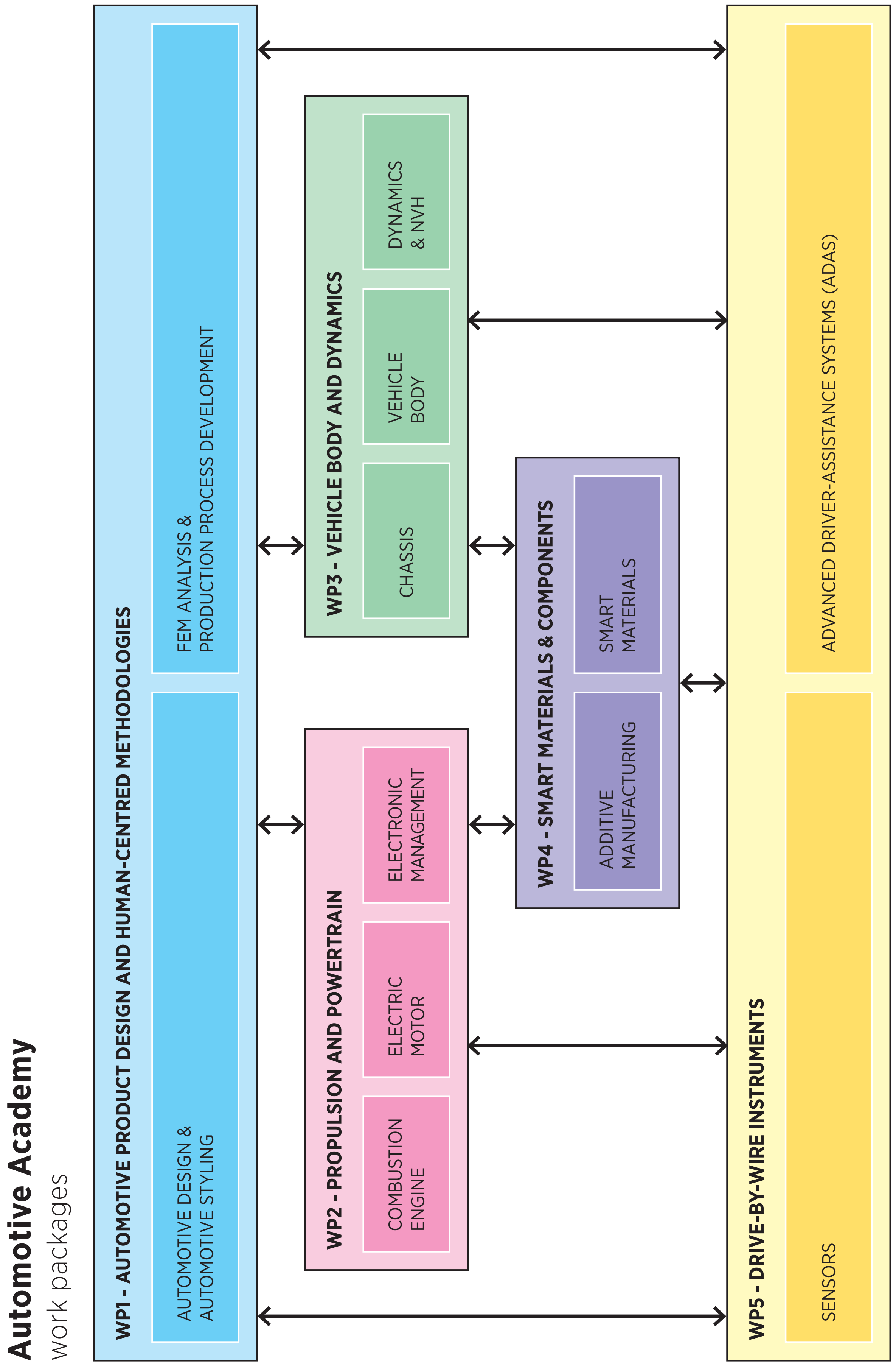
Lastly, the research completes its network involving several local automotive industries that collaborate for many years with the academic institutes and their R&D centres. This partnership aims to transform academic researches into tangible industrial projects. The main enterprises are:

- Astra Research;
- Curti Aerodinamica;
- Ferrari;
- Magneti Marelli;
- Maserati;
- Marzocchi;
- Riba Composites;
- Voltaide;
- Pulsar Dynamics;
- R&D CFD;
- Mat3D

1.4 Work packages

The overall project produces multidisciplinary scientific research, which expects to generate several and diverse contributions (theoretical and practical) in the field of automotive, especially in motorsports. The activities among partners are based on a learning-by-doing approach in order to produce many solutions that can be immediately applied in the industry or transferred directly on the automotive market. Collaboration among partners converges different backgrounds to solve the same problems by utilizing different perspectives. It permits to better manage also the complexity of the automotive product development in all its aspects.

Five independent work packages constitute the research program. Each



area refers to a specific field of expertise that deals with a particular system of the vehicle: (1) automotive product design and human-centred methodologies; (2) propulsion and powertrain; (3) vehicle body and dynamics; (4) smart materials and innovative components; (5) drive-by-wire instruments **Img. 02** •. The work packages present their distinct goals and tasks. They are:

- WP1 - Automotive product design and human-centred methodologies: the section belongs to this thesis and it constitutes the framework of the overall project. Unlike the other engineering work packages, this research is design-driven and human-centred oriented. The work package utilizes human-centred design methodologies to converge the users' needs with the technological solutions developed by the other partners in order to generate an innovative and inclusive sports vehicle. The research expects to delineate the final shape and architecture of the proposed car to provide several design guidelines for the other partners in order to develop the final concept according to customer demands. Simultaneously, another two transversal types of research are addressed to the analysis and the assessment of the vehicle's aerodynamics and to the optimization of the production process development through the study of smart manufacturing;
- WP2 - Propulsion and powertrain: the area regards the development of new hybrid systems, especially investigating advanced technical solutions to reduce carbon emissions and fuel consumption. The purpose is to ensure not only sustainable electronic management of the Internal Combustion Engine (ICE) but also to combine the ICE synergically with an electric source. Indeed, another research is specifically related to the study of efficient solutions for electric motor architecture. In

Img. 02 • Representation of the "Automotive Academy" network and all of the work packages that are involved in the project. Each area is related to specific system of the sports vehicle. This specific research is associated to the first work package, in particular automotive design.

particular, the purpose is to improve the battery pack optimizing its size, weight and autonomy, as currently, it is the most critical element of the electric drivetrain;

- WP3 - Vehicle body and dynamics: the work package examines the application of new innovative materials on the vehicle structure to improve the quality of both driving experience and vehicle dynamics in terms of handling, stability, weight distribution and NVH (Noise, Vibration, Harshness). Simultaneously, virtual simulations and FEM analysis (Finite Element Method) analyse and evaluate the vehicle's cinematic behaviours to reduce costs, resources and optimize Time-To-Market (TTM);
- WP4 - Smart materials and innovative components: the section experiments new materials through the use of additive manufacturing. The research expects to design new innovative polymers, especially incorporating in them metal particles, which can improve vehicle performance by realizing lightweight and resistant components for the vehicle chassis;
- WP5 - Drive-by-wire instruments: the area is focused on the study of drive-by-wire instruments, data capture systems, machine learning, sensor fusion, artificial perception, road planning, computer vision and all of the sensors – such as camera, IMU system, radars, ultrasound and lidar – that are necessary to realize advanced driver-assistance systems (ADAS) and autonomous driving. The research aims to develop new innovative and affordable electronic solutions to improve vehicle safety.

1.5 WP1: automotive design

Regarding the contribution of this thesis, the research addresses to the first work package of the project, which refers to the discipline of "automotive design and automotive styling". The main objective is to give proper vision and shape to the overall project by defining a successful design strategy to develop the concept vehicle.

The research aspires to envision and conceptualize both architecture and styling of the expected sports car, specifically using human-centred design approaches. In particular, the methodology is context driven, human-oriented and interaction-centred. Starting from identifying the context of use, the research, indeed, analyses the main users and their behaviours to transform their wishes or needs into an innovative solution, which will be capable of satisfying their demands. During the process, the final and expected outcomes will define the functional requirements and technical specifications of the vehicle that they will be successively used as design guidelines to develop the final concept.

For this reason, this contribution wants to illustrate also the human-centred design method that is utilized to drive the styling design process. The latter is faced up by utilizing two specific approaches, which are Quality Function Deployment (QFD) and Vision in Product Design (ViP). This because both models are perfectly suitable in automotive for structuring idea-generating throughout styling process, while supporting the entire research in taking significant decisions for the product development.

◆ End of
Chapter 1

CHAPTER 2

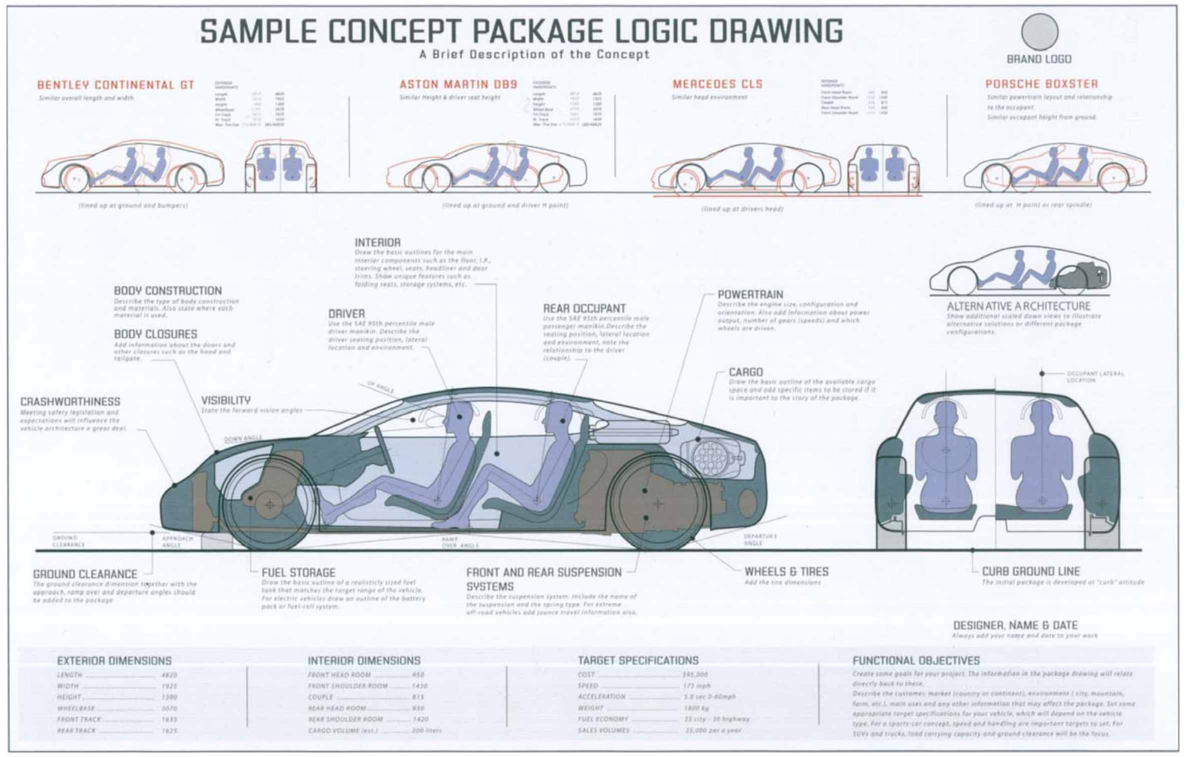
Research theme

2.1 Introduction

Designing a vehicle is a harmonic balancing between engineering functions, technologies, and designing activities. The design process is laborious because the convergence between styling and engineering needs to find constant compromises. This task is conducted by automotive design, the specialized discipline that is implicated in managing the complexity of the car. Therefore, this chapter explains the characteristics of this practice, when and how it is performed during the development of an automotive product and what are the main techniques that lead the design process to translate ideas in the final concept vehicle.

2.2 Designing a car

The development of an automotive product is a highly complex undertaking. Its design process requires many resources in terms of time, investments, technologies and specialists because the nature of the car itself is very complex (Bhise, 2013). A car is a system that involves several lower-level systems (body system, powertrain system, safety system, driving control system and so on), which must work simultaneously together in different context conditions to satisfy wants of drivers with varied characteristics, capabilities, and limitations (Bhise, 2017) **Img. 03 •**. Considering its commercial acceptance, a car must include a wide series of requirements that are directly dictated by production constraints, by standards or regulations (for example emissions, fuel consumption and safety) and



Img. 03 • Architecture of a vehicle and its packages. It shows all technical elements that make the car a very complex system. Source: H-Point (Macey & Wardle, 2014).

more than anything else by market trends. In the latter case, most of the attention is focused on customer demands, as they can force – in terms of safety, look and comfort – its development program in changing vehicle properties or design strategy formulations (Stadler, Hirz, Thum, & Rossbacher, 2013).

In this case, automotive product is not only a set of functional elements organized to satisfy specified objectives, but it is also a basic element of social life (Freund & Martin, 1993). A car is characterized by a particular appearance, shape, or better to say 'style', which evokes on people aesthetic, emotional and sensory sensations **Img. 04** •. Those elements are directly experienced during the interaction with the vehicle itself (Sheller, 2004). Any car has a stance, a look and proportion that together tell a distinct story that creates desirability and specific identity of that vehicle (Macey & Wardle, 2014). Through 'style', car acquires personality and it is able to

Img. 04 • BMW Vision M NEXT. The vehicle communicates the new BMW's future sports vehicle through a combination of functional, emotional and aesthetics sensations that are evoked by its styling. Source: BMW.

surround itself with many sing-values (such as power, speed, individual freedom, sexuality, career success, genetic breeding, etc.), which in turn, they provide specific status to its owner (Sheller & Urry, 2000) and a subjective and personal experience of driving (Mitchell, Borroni-Bird, & Burns, 2010).

Based on the above assumptions, all of those aspects transform a car into an intricate amalgam of functional, technological and styling properties. Final design and architecture of the car are the results of holistic thinking (Tovey, 1986), which is determined by a harmonic balancing between engineering (function, technology) and designing (emotion, style) activities that make the vehicle itself unique (Chandra, 2015; Lewin & McGovern, 2017). Technical requirements or quantitative values derive from engineering design and they ensure that the vehicle has quality, reliability, is well made and does not break down (Tovey, 1992)t. Whilst styling properties or qualitative values come from styling processes and they must be designed to deliver to the vehicle perceived added value, which is able to produce both substantial differential advantage over competitors (important for its commercial success), and strong effect on the long-term strategy of the company, in terms of corporate branding or technologies choices (Van Grondelle & Van Dijk, 2004).

Though, the entire design process is laborious because the convergence between styling and engineering needs to find constant compromise (Feldinger, Kleemann, & Vietor, 2017; Macey & Wardle, 2014), to acquire the satisfactory holistic solution that will determine the expected car model.

2.3 Automotive Design

Design leadership is crucially important for successful vehicle design. For this reason, specific design discipline possesses the task for elaborating the correct harmony between emotional and engineering aspects. This great effort is generally performed by 'automotive design' or 'automotive styling'. The specialized discipline is specifically implicated in giving a form to the car, encompassing package design and negotiating engineering constraints such as technologies, size, performance, ergonomics and so on (Van Grondelle & Brand de Groot, 2016).

Automotive design is one of the key roles of the automotive development program and it takes place during the conceptual and early stages of the design process (Feldinger et al., 2017). All intellectual decisions – that regard technical and morphological aspects of the vehicle – are carefully taken at that point to delineate an efficient strategy for achieving the expected accomplishments of the company, in terms of revenues and return of investments **Img. 05** •.

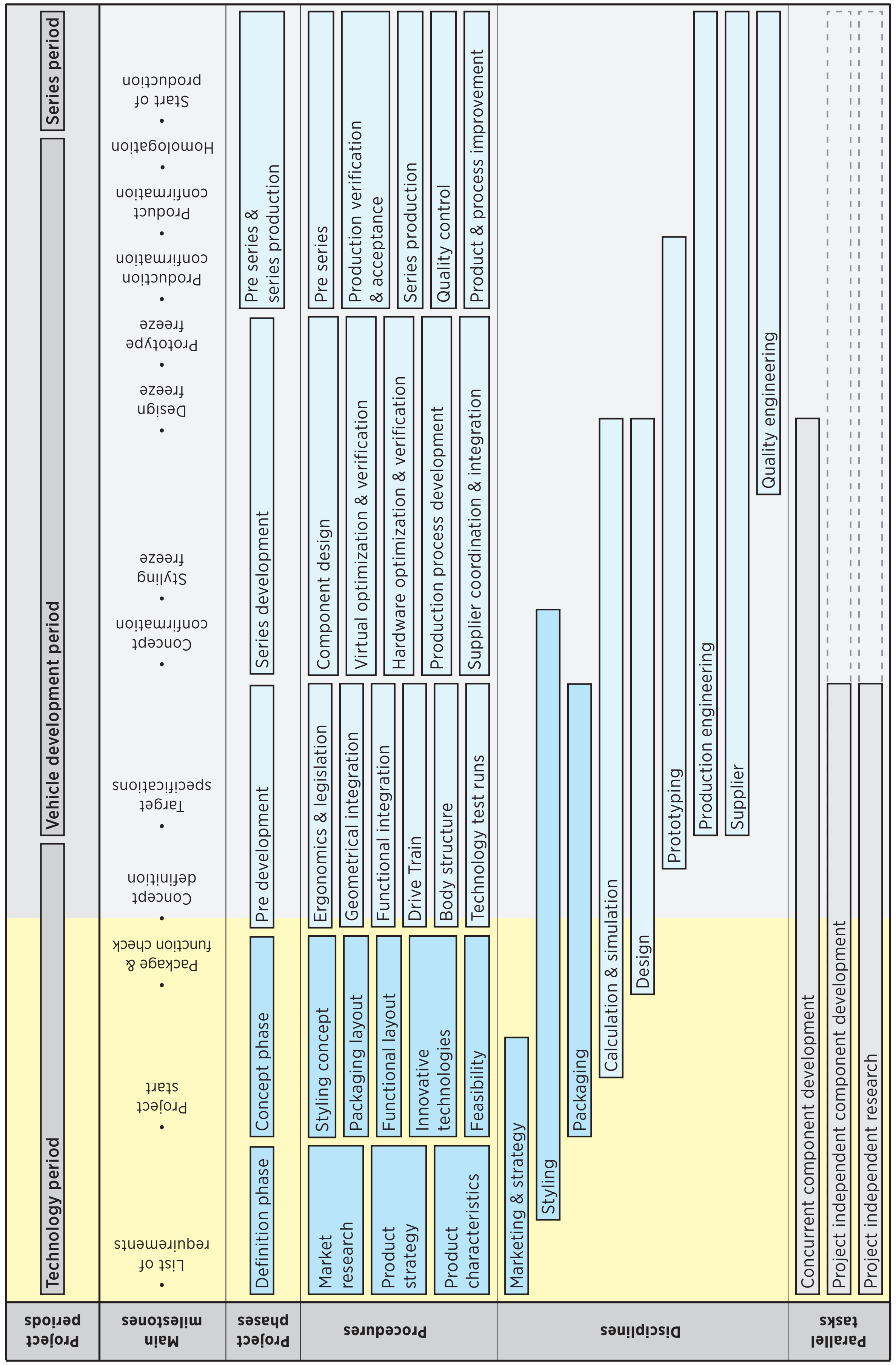
Img. 05 • A design team is working on the development of a new car model during the concept phase. In this phase, all of the decisions about the character of the car determine the design strategy of the final project. Source: Mercedes.

However, developing a vehicle means uncertainty (Brem, 2008), because strong competitiveness of global market implies investing high sums in advance – and nowadays, towards a shorter time-to-market process (Brunner, Hirz, & Wurzer, 2017) – without knowing if the final solution will be successful after its launch (Gerhard, Brem, & Voigt, 2008). Therefore, it is fundamental that the styling process must be well executed to reduce management risks that may stem from an exceeding of budget, time scheduled or from the failure in satisfying costumer demands. The latter is the most important factor for ensuring the successful development of the expected vehicle that end-users will enjoy in driving. Generally, the main problems derive from the failure of understanding wants, translating them into vehicle properties or assessing if the final solution coincides properly with customer expectations (Bhise, 2017). If all these aspects are not faced up within proper solutions, they could create a real gap between the level of satisfaction desired by end-users and the strategy utilized by design process to accomplish the goals of company.

To avoid negative outcomes, one of the potential and successful strategies proposed by the paper is adopting a multidisciplinary practice that embraces a human-centred approach in initial phase of development program. Considering this, the research examines the exploration of a design methodology that can support styling design to ensure that every need of both company and people are met, adopting a human-centred methodology. In particular, the research studies the exploratory combination of two particular approaches that usually are utilized individually during design process: Quality Function Deployment (QFD) and Vision in Product Design (ViP). The goal of the research is to define a strategic styling design process that can be able to utilise this methodological combination as decision-making tool to properly integrate designing aspects together with engineering requirements expressed by the developed program. Therefore, using this exploratory practice, styling strategy can achieve the expected desirability of final product, not only through technical properties of the vehicle, but also with its design, including appearance, functions, and operations which in turn determine qualitative level of the total product experience (Hekkert, Mostert, & Stompff, 2003; Hekkert & Schifferstein, 2008).

2.4 Automotive Product Development

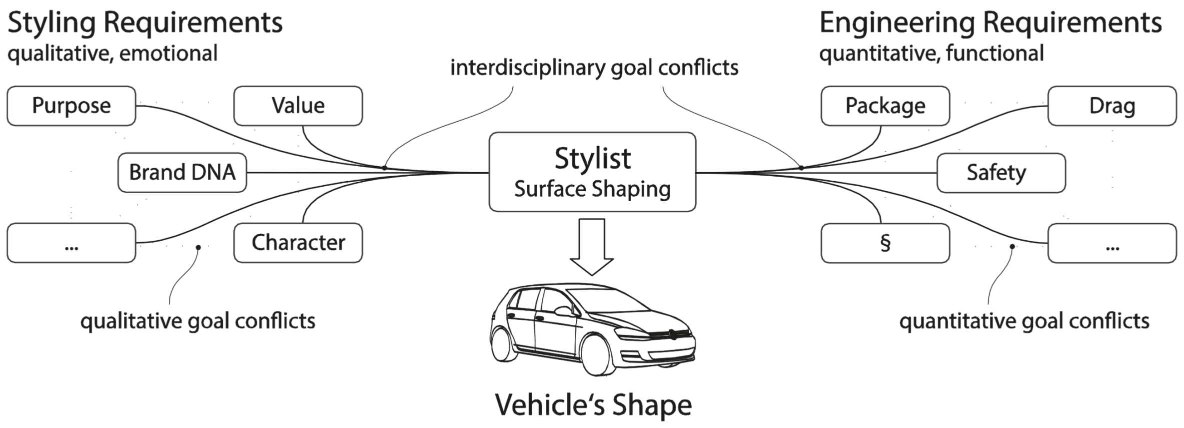
A product development process is the sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product (Ul-



Img. 06 • Representation of the full-vehicle development program (Brunner, Rossbacher, & Hirz, 2017). Automotive design is responsible particularly for the yellow area. The latter indicates the definition and concept phases, the two main steps in which this research is involved.

rich & Eppinger, 2011). Regarding the automotive industry, as described in the literature (Brunner, Rossbacher, & Hirz, 2017), the full-vehicle development program is defined by five main process phases: the definition phase, the concept phase, the pre-development, the series development and early stages of the production phase **Img. 06 •**. Each of these phases is performed by undertaking specialized processes and many of these steps and activities are intellectual and organizational rather than physical. The output of the early conceptual stages (definition and concept phases) is the automotive product's mission statement, which is the input required to begin the concept development step (pre-development phase and series development) and which serves as a guideline to the engineers for realizing the expected vehicle. The conclusion of the product development process is the product launch, at which time the product becomes available for purchase in the marketplace (Ulrich & Eppinger, 2011).

The activities of this specific research touch the first two steps, in which particular emphasis is placed on concept phase, especially on the transition from the first visions or ideas (delineated by the product strategy) to the final and detailed concept solution. At this stage, automotive design is responsible for the initial conceptual thinking in the creation of the new automotive product, and it takes that to a fairly detailed stage with fully defined surfaces before other engineering specialists assume control (Tovey, 1992). For doing this, the specific discipline conducts many activities to define vehicle styling and its preliminary architecture. The overall practice can be considered as iterative process of synthesis and analysis (Bürdek, 2015), in which many trade-offs between emotional goals and functional factors are simultaneously managed while elaborating the shape of the vehicle (Sareh & Rowson, 2009) **Img. 07 •**. Iteration, indeed, enables the research to learn about different design issues and improve their designs constantly reviewing the concept during the process.



Img. 07 • Automotive design is an iterative process of synthesis, in which styling and engineering requirements converge in a unique solution, which in turn generates the correct harmony between emotional and functional aspects (Feldinger, Kleemann, & Vietor, 2017).

The initial definition phase starts defining the requirements that must be taken into account for successful vehicle design. The elements includes all boundary conditions targeting legislative, consumer- or company- related aspects. Usually, the challenge to the vehicle development program is to understand: (a) the needs of the customers, (b) design and technological trends, (c) future government requirements (such as minimum and maximum limits on vehicle dimensions, weight, fuel consumption, greenhouse gas emissions, and safety systems and features), and (d) company's business considerations (such as mission, state of the market, plans of major competitors availability of suppliers and internal resources in terms of budget, processing equipment, production and assembly capacities, and available manpower) (Bhise, 2017).

The definition phase is followed by the concept phase. Within this process step, first visions and ideas of the concept are conceived determining, at the same time, its characteristics such as vehicle body-style type, size, proportions, vehicle packages, type of powertrain, location of the drive wheels, performance characteristics and so on. During the early part of the concept development phase, many alternate vehicle concepts are elaborated to understand how various vehicle characteristics and new

Img. 08 • Stylists are designing a full-scale physical mock-up to represent visually the proposed vehicle during the concept-generation process. The model is very useful to acquire a better feel of the size, space, and configuration of the expected product. Source: Land Rover.

features can be incorporated in the design. Conceiving different concepts also reveals a number of technical issues and problems that may occur in creating such expected vehicle. In addition, the properties created to illustrate the vehicle concepts can be used to conduct design reviews to qualitatively assess the feasibility and risks associated with transforming the concept into a real product.

The concept-generation process is produced by utilizing different design techniques that support the research in representing visually the proposed vehicle. They are: vehicle sketches, drawings, computer-aided design (CAD) models, computer-generated 3-D renders, and physical mock-ups (foam-core, clay, wooden, or fibreglass bucks to represent the exterior and interior surfaces of the vehicle) (Bhise, 2017) **Img. 08** •. At the end of the concept development process, the best solution that suites to fulfil the

stated requirements at the beginning of the process is selected. The final concept sketches must function as devices for communication and evaluation of design proposals and they must be understood by other company divisions.

2.4.1 The role of sketching

Regarding this particular research, to facilitate the management of every design decision during the concept process, sketching was used as a main form of expression to represent the vehicle ideas and their details in a formal and intuitive visual form **Img. 09** •. This because appearance design problems are frequently ill-defined, not being describable in words, and hence, sketching is a technique that supports the process in envisaging the overall design solution as a visual entity (Tovey, 1997). In fact, the sketches are languages for handling design ideas because they reproduce the designer's mental images in physical representations (Tovey, Porter, & Newman, 2003).

Sketching is also intended to provide quicker communication and retrieval at the early stages of concept phase, by providing combined visual and factual descriptions for improved evaluation and concept selection (McGown, Green, & Rodgers, 1998). The roles of sketching in the automotive design include: generating concepts; externalising and visualising problems; facilitating problem-solving and creative effort; facilitating perception and translation of ideas; representing real-world artefacts that can be manipulated and reasoned with; revising and refining ideas.

Their approach is certainly solution-focused and involves constructive thought processes. Different visual codes are used to employ visual and graphic languages to communicate and model vehicle's representations among every team involved in the project. The principal forms of codification are: monochrome line drawing to express the vehicle shape; line

Img. 09 • Students are generating concept vehicles by using the sketching technique. Technology and digital sources can offer new and different forms of expression to represent vehicle ideas. Source: Skoda.

thicknesses vary to give emphasis; rough shading to suggest form; colour illustration to show what the product looks like (Rodgers, Green, & McGown, 2000).

The process starts with an initial vague concept and concludes with a detailed design proposal by generating numerous ideas (Tovey et al., 2003). Sketches play an important role in the creative, explorative, open-ended phase of problem-solving and this is facilitated by two types of activity: lateral transformations: movement from one idea to a slightly different idea; vertical transformations: movement from one idea to a more detailed and exacting version of the same idea. Moreover, some of the sketches does not follow ideas in the mind but instead precedes them. Thus, the visual thinking of sketching is often used not to record an idea, which is not there yet but to help generate it. The main purpose of the sketching activity is primarily to enable the design process to identify clues that can be used to form and to inform emerging design concepts.

As previously mentioned, automotive design is an iterative process, and hence, rapid sketching helps it to transform images in a cyclic manner: each sketch generates images in the mind, which drive the development of the themes embodied in the design (Goldschmidt, 1994). In this case, sketching practise is able to transform the previous images by additions, deletions and modifications.
This is possible also because the nature of visual representations created by sketching imposes both order and tangibility on the one hand, while on the other hand, its ambiguity stimulates reinterpretation (Garner, 2001). The sketching process can also be supported by the use of influence boards and sources of inspiration. In fact, communication by reference to other vehicle shapes and/or other sources of different designs can support the process in expressing complex ideas quickly because the new design can inherit both details and context from the objects of inspiration (Eckert & Stacey, 2000).

Considering all described considerations about automotive design and the importance of sketching, the next chapters will report the final sketches of the expected vehicle that will be used, not only to represent the guidelines of the final concept (in terms of functions, technology and form) but also to describe visually the methodological design process.

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◆ End of Chapter 2

PART 2:
THEORY AND CONTEXT ANALYSIS

CHAPTER 3

Research methodology

3.1 Introduction

This chapter explains the human-centred methodology that has driven the research throughout the overall product development process. In particular, the research describes the scientific theory of two different human-centred approaches that have been selected to develop the project: Quality Function Deployment and Vision in Product Design. Lastly, the chapter introduces also the exploratory combination of both approaches as new methodological design tool to develop the concept vehicle of this research.

3.2 Human-Centred Design approach

Every design process needs to satisfy numerous constraints – which include shape, forms, costs, efficiency, reliability, effectiveness, understandability, usability, the pleasure of the appearance, the pride of ownership and the joy of actual use – and over the time, a large number of strategic approaches and tools have been developed to manage and fulfil the complexity of those requirements. The major movements that have lead the design process of design since today are usually based on two main approaches, which usually lead to distinguishably different results, despite working within the same contextual and economic constraints: technology driven or human oriented.

In this particular case, the automotive sectors has always been characterised by an highly efficient scientific orientation and technological innovation, in which there was far less agreement regarding the human-centred requirements and approaches (Braess & Seiffert, 2013).

However, in recent years many industries, which have traditionally been considered to be technological oriented, have recently shifted their emphasis away from matters of pure technology, moving toward a human-centred approach (Von Hippel, 2005) due to the benefits in terms of sales and revenue (Verganti, 2009). This has been supported also by the progression of the study of human beings on a scientific basis for designing physical products (such as engineering design, ergonomics, human factors) has evolved to become the measurement of metaphysical factors and modelling of how people interact with the world (Moggridge, 2007) and what meanings they create, which include the big umbrella of Human-Centred Design (Giacomin, 2014): usability, user centred design, inclusivity, interaction design, design for product or customer experience, design for emotion and so on.

The term of Human-Centred Design (HCD) means a specific approach or a philosophy that puts human needs, capabilities, and behaviour first and then it designs a proper solution to accommodate those needs, capabilities, and ways of behaving (Norman, 2014). Nowadays, HCD is a common design practise among designers and it is spreading in many sectors (such as academia, industry and policy) as a framework for innovation because it is able to solve wicked problems according to the human perspective (Lockwood, 2009). Indeed, HCD ensures that the needs of people are met guaranteeing at the same time that the resulting artefact is understandable, usable and its user experience is positive, enjoyable and reliable in accomplishing the desired tasks.

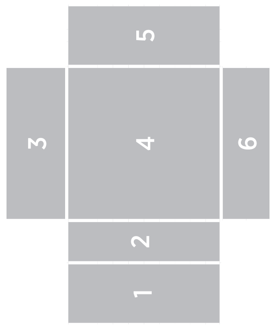
HCD consists of gathering human factors issues from an appropriate community of users who are anticipated to act on the system being designed (Guy, 2011). Considering this, HCD starts with a good understanding of people and the wants or needs they wish to accomplish (Norman, 1999). This understanding is primarily conducted by observing people in their context because they are often unaware of the difficulties they are encountering every day, even they produce a myriad of "thoughtless acts" that act as invaluable clues (insights) from which their range of unmet needs is identified (Brown, 2015).

Only when the needs of end-users are recognized and determined, the design research can generate several potential solutions to satisfy those requirements. Getting the specification of the thing to be defined is one of the most difficult parts of the design process, so much so that the HCD principle is to avoid specifying the problem as long as possible but instead to iterate upon repeated approximations (Norman, 2014). This process is done through rapid tests of ideas, and after each test modifying the approach and the problem definition. If the research is performed correctly, the final result is able to truly meet the needs of people.

The practices deployed by the Human-Centred Design include many different techniques that grows constantly, sometimes by borrowing from other scientific fields such as psychology, ethnography or sociology, and sometimes by delineating new analogies and approaches. Considering this, several design methods and tools can be found in the literature (IDEO, 2015; Kumar, 2012; Sanders & Stappers, 2013; Van Boeijen, Daalhuizen, Zijlstra, & Van Der Schoor, 2014) to drive an Human-Centred Design research depending of the scope and the characteristics of a specific problem or challenge.

For this particular project, the research proposes to develop the concept vehicle by using a human-centred methodology, which lays specifically

	RELEVANCE OF NEEDS	% RELEVANCE OF NEEDS	1. PRODUCT SPECIFICATION	2. PRODUCT SPECIFICATION	3. PRODUCT SPECIFICATION	4. PRODUCT SPECIFICATION	5. PRODUCT SPECIFICATION	6. PRODUCT SPECIFICATION	7. PRODUCT SPECIFICATION	8. PRODUCT SPECIFICATION	9. PRODUCT SPECIFICATION	10. PRODUCT SPECIFICATION	1. COMPETITOR	2. COMPETITOR	3. COMPETITOR	4. COMPETITOR	5. COMPETITOR
1. COSTUMER NEED	4	6%	0	3	0	0	0	3	1	0	0	3	2	1	3	3	3
2. COSTUMER NEED	1	1%	0	3	0	0	0	3	0	3	0	0	2	1	1	2	3
3. COSTUMER NEED	5	7%	0	9	3	0	1	1	1	3	3	1	5	3	4	2	4
4. COSTUMER NEED	3	4%	0	3	0	1	0	3	0	1	1	1	2	1	1	3	4
5. COSTUMER NEED	3	4%	0	3	0	9	0	3	0	1	1	3	2	3	3	3	4
6. COSTUMER NEED	2	3%	3	3	3	3	3	1	9	3	3	1	1	1	2	1	2
7. COSTUMER NEED	1	1%	0	3	3	1	1	3	1	3	3	1	1	2	2	3	1
8. COSTUMER NEED	2	3%	0	1	1	1	1	9	1	1	0	1	2	2	3	3	3
9. COSTUMER NEED	4	6%	3	9	3	3	3	1	3	3	3	1	3	3	2	4	5
10. COSTUMER NEED	5	7%	0	3	0	0	0	1	0	1	0	1	3	2	3	4	5
ABSOLUTE TECHNICAL IMPORTANCE			65	280	188	142	68	216	72	164	129	87					
% TECHNICAL IMPORTANCE			5%	20%	13%	10%	5%	15%	5%	12%	9%	6%					



Img. 10 • An example of the House of Quality, the scientific tool of the QFD.

on two distinct approaches: Quality Function Deployment (QFD) and Vision in Product Design (ViP).

This because, compared to other approaches, the Quality Function Deployment is a scientific tool that is able to combine the qualitative aspects of user demands with the quantitative properties required by a technical design process such as the automotive industry. Vision in Product, instead, is a useful model for automotive innovation because it uses the HCD principles to design a vehicle in a future scenario. For this reason, ViP can be fundamental to create a sustainable strategic advantage on the other competitors by predicting and anticipating new technological or sociological trends in the future ahead.

3.3 Quality Function Deployment

Quality Function Deployment (QFD) is a human-centred tool that is able to orient product design toward the real exigencies of the end-users, because customer satisfaction is placed first within the product development strategy (Al-Mashari, Zairi, & Ginn, 2005) **Img. 10** •. QFD is an inclusive model that is capable of acquiring feedback from end-users to elaborate many design specifications for the final products according to their needs (Mincolelli, 2008). The primary purpose of QFD is to ensure a qualitative product development process with a great emphasis on designing stage (Akao, 1990). QFD, indeed, intervenes before starting on the activities of a new artefact's development, engineering, and production (Clausing & Pugh, 1991; Franceschini, 2001) and it is a useful management tool to model the design process (Govers, 2001).

Quality Function Deployment is also considered a powerful and proactive decision-making tool applied in relationship-wise contexts, because it enables multidisciplinary working among different corporate sectors or divisions of the same company, engaged in a common project (Maritan, 2015). The involvement includes all of the company areas addressed to the planning process: marketing, design, quality, technical assistance, technologies, production and suppliers (Franceschini, 2001; Sullivan, 1986).

3.3.1 QFD history

QFD is methodological tool elaborated at the end of the sixties, in Japan, as a new approach to develop products, amongst the various activities of Total Quality Control (Akao & Mazur, 2003). The development of QFD came up from the necessity to both to design a project that can meet customer requirements and to control quality of the process, before actual production (Cristiano, Liker, & White, 2001).The official birth date of QFD is 1972, when the quality chart was applied during the design of large cargo vessels in the shipyards of Mitsubishi Heavy Industries (Nishimura, 1972). In the same year, Akao introduced a concept summarized by four Japanese ideograms, in which the first guidelines of the method were explained (Re Velle, Moran, & Cox, 1998). The method was named *Hinshitsu Kino Tenkai*. The English translation means: *Hinshitsu* (product attributes, quality or qualities) *Kino* (functions, mechanisms, opportunity) *Tenkai* (deployment, development). Successively, QFD became also a key procedure for Toyota (Maritan, 2015).

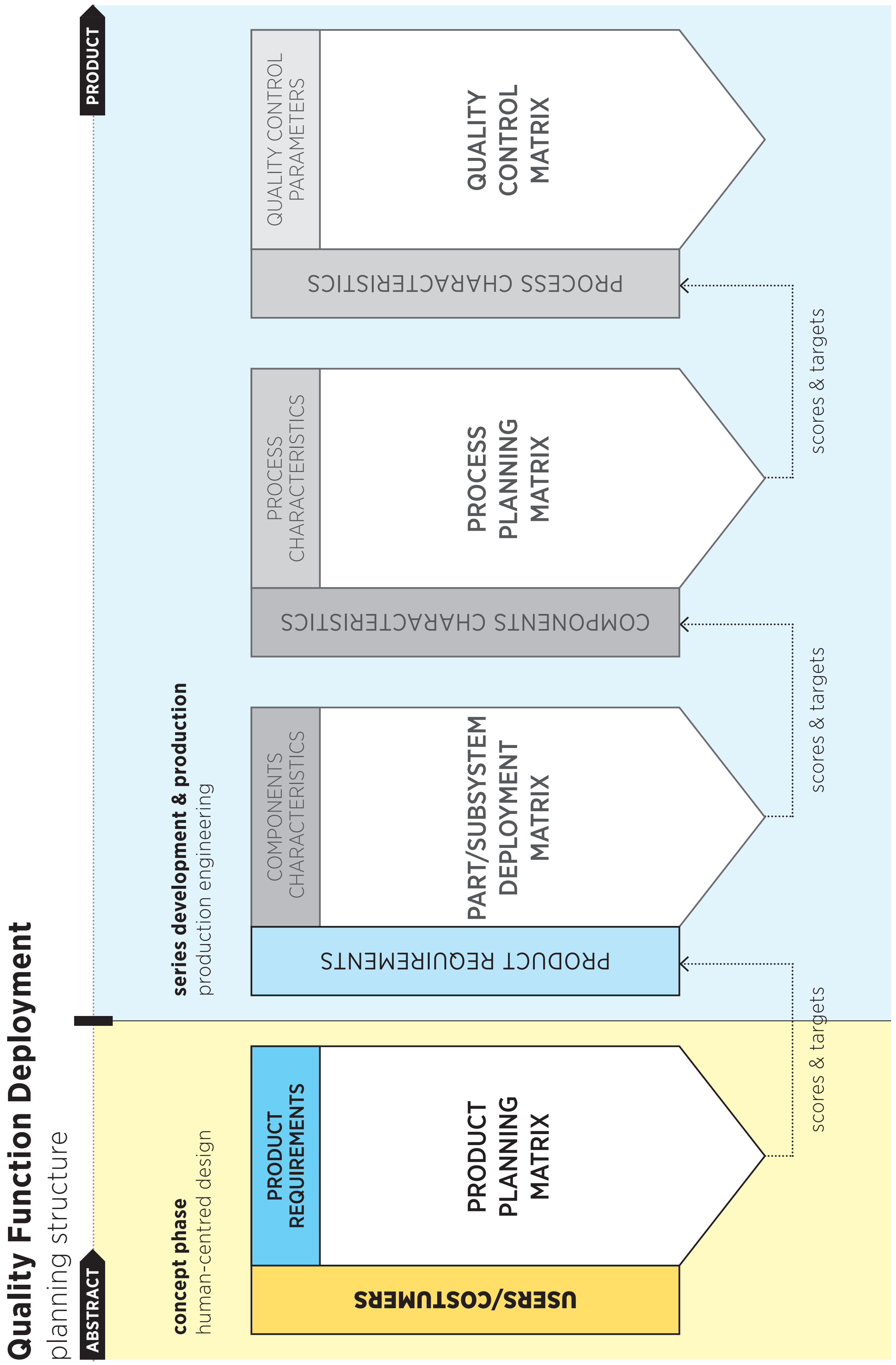
The diffusion of QFD in the western world, especially in the United States, began no earlier than 1986 – almost 15 years after the experiment at the Kobe shipyards – thanks to Don Clausing, a professor at Massachusetts Institute of Technology (MIT), who was working on various ways of developing new products. He introduced the methodology both in academia and industry, especially in Ford (Al-Mashari et al., 2005). The first complete book was published in 1990 by Akao, and successively translated into English by Glenn Mazur (Akao, 1990), who has been continuously spreading QFD to the present days. From the mid-nineties to the early years of the 2000 some authors reported that more than 1,000 case studies were published all over the world (Akao & Mazur, 2003) with a special focus on high technology and transportation (Maritan, 2015). Nowadays America and Asia have the highest percentage of companies that use QFD, whilst in Europe, many applications are presented in some states such as Italy – which seems to be the first country where QFD is being implemented – The Netherlands, United Kingdom, Sweden, Austria, Spain and most of all in Turkey and Germany (Akao & Mazur, 2003; Govers, 1996)

3.3.2 QFD structure

The QFD process begins when the user wants and needs – which are usually expressed in terms of qualitative data – are identified and during the development process they are successively converted in internal company requisites, called design specifications. These properties are generally the global characteristics of a given product (usually measurable parameters) which, if they correctly selected, are capable of satisfying user expectations. The American Supplier Institute (ASI 1987) defines QFD as a system for translating user requirements into appropriate company requirements at every stage of the development process, from research (through product strategy and design) to manufacture, distribution, installation and marketing, sales and service (Xie, Goh, & Tan, 2003).

QFD planning process is a step-by-step path, which is constituted by four main quality tables that enable the research to represent the variables that concur to define a given project **Img. 11 •**. The charts show the various relationships existing among them, supplying useful indications of the levels at which they interact and of the way they interact. The tables of the QFD process are:

- Table 1 (product planning matrix): it compares user needs with the



technical requisites that are needed to render the product specifications coherent with customers' expectations. The matrix defines the relationships occurring between the two elements and their reciprocal priorities. It produces also a competitive benchmarking between the product characteristics and the best available competitor performances that are discovered on the market.

- Table 2 (part deployment matrix): it compares product characteristics with the requirements of the most important components (subsystems) into which the product can be broken down (critical part characteristics).
- Table 3 (process planning matrix): it relates the characteristics of the single subsystems with their respective production processes (critical process steps).
- Table 4 (process and quality control matrix): it defines inspection and quality control parameters and methods to be used in the production process of each process step (quality control process steps). In this form, in particular, each single critical process step is set down, as well as the relative process control parameters, control points, control methods, sample size, frequencies, and check methods.

3.3.3 The House of Quality

The core of QFD is the House of Quality (HoQ), the mathematical bi-dimensional matrix that compares analytically the needs of users with the product characteristics of the expected artefact, in order to identify their reciprocal relationships. In this case, qualitative information about user needs is translated in measurable and detailed engineering specifications to design and produce a product that fulfils the requirements assumed at the beginning of the process. The final assessment shows what the

Img. 11 • The main sequence of QFD planning structure. The first two modules (house of quality and part characteristics) refer to product planning; the second two refer to manufacturing process planning and quality control (Imbesi & Giacobone, 2018).

most important design specifications are necessary to achieve the desired quality of end-users. The outputs are utilized as a design guidelines to take various decisions among different design solutions and develop the expected product. HoQ processed data through many different areas **Img. 12 •**. The final outcomes are represented through a synoptic view that proffers an optimal way of unravelling the complex network of relationships elaborated by QFD matrix.

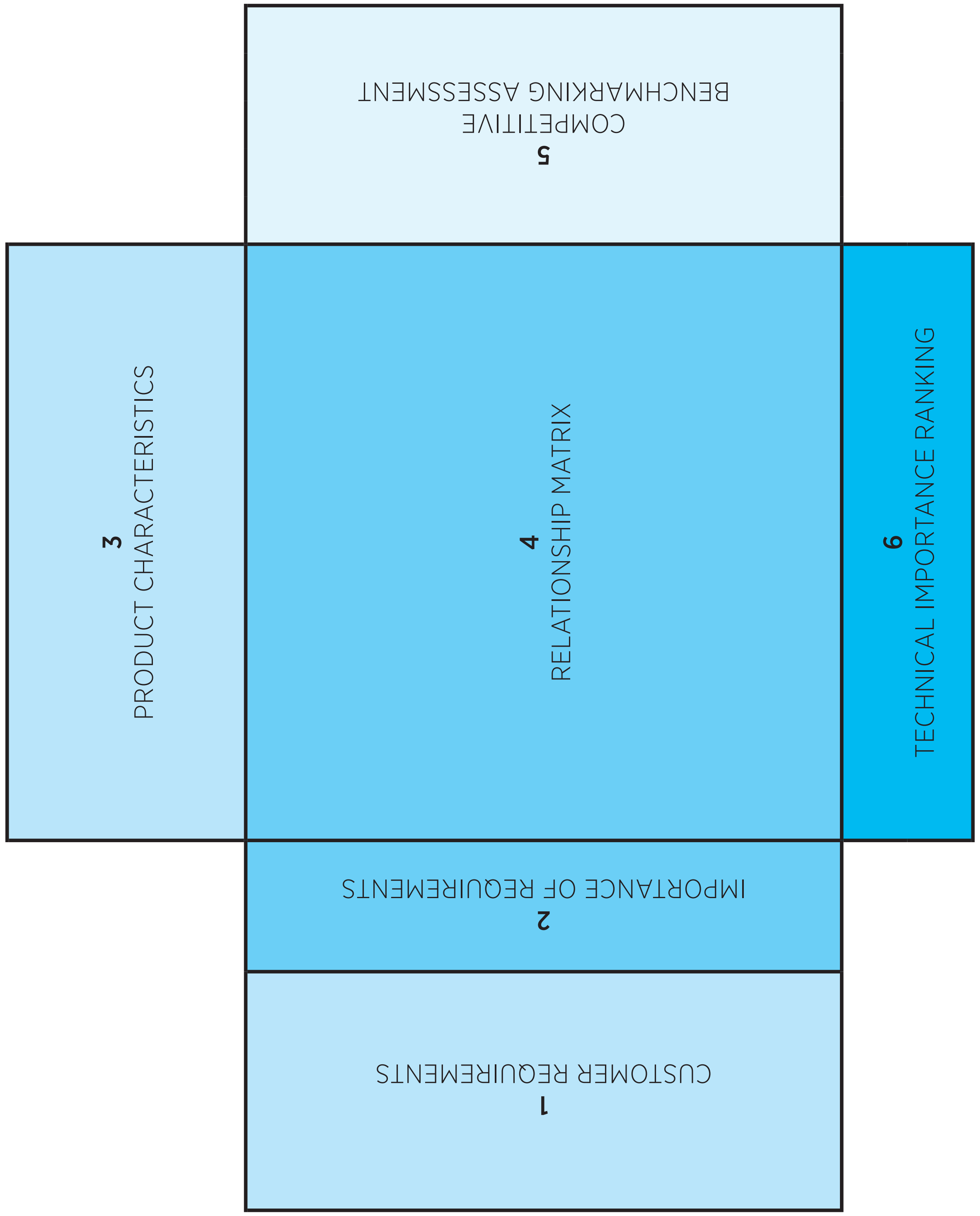
3.3.3.1 Voice of customers or costumer requirements

The first area defines the voice of the customer (VoC) because it represents the qualitative requirements of the end-users (needs, desires, wishes, wants, etc.). The wants are reported in form of descriptive short phrases and they are rationally clustered into similar categories according to hierarchical criteria. The costumer attributes are set down in three main level of detail. In order to better manage the decision-making process, usually VoC recommends to process about 20 or 30 needs for each single matrix. The final table of every selected need is called demanded quality chart (DQ).

3.3.3.2 Relevance of requirements

Once the demanded quality is defined, the second section assigns to each need a rank that indicate its level of importance. Since user expectations and preferences are not equally important for the research, each want must be prioritized in order to understand how much it affects the degree of final product's satisfaction.

Selecting the right weight of each requirement is a delicate operation. To facilitate the decision-making process, the traditional grading system indicates a scale from 1 (for a requisite of negligible importance) to 5 (for an indispensable requisite) (Akao, 1990; Franceschini, 2001; Mincolelli, 2008). The ranking process is obtained from: (a) the decision makers of



Img. 12 • The overall structure of the House of Quality. The 1st and 2nd areas shows the voice of costumer, the 3rd the voice of engineer, in the 4th the correlation matrix, the 5th the competitive benchmarking and finally the 6th the technical importance ranking ranking.

the project; (b) team members' experience about users; (c) survey or questionnaires; (d) interviews; (e) direct observation in the main contexts; (f) marketing researches with statistical techniques.

3.3.3.3 Product/engineering design requirements

The third section represents the voice of the engineer (VoE) because it refers to the product/engineering characteristics provided by the teamwork that are indispensable to reach desired quality of the final product. At least one technical characteristic should be identifiable for each customer request. The engineering requirements proffer a description of the product or service in measurable terms and they directly affect customers' perception concerning quality (Franceschini, 2001). As with the voice of costumers, to obtain as precise as possible description, the design characteristics are also grouped in three levels of details.

3.3.3.4 Relationship matrix

The fourth area is the body of the matrix and it indicates the relationship matrix between the voice of costumers (VoC) and the voice of engineers (VoE). It describes how the technical decisions affect the satisfaction of each customer requirement. The relationship matrix is the most important part of HoQ because the relations obtained in this area determine the final outcomes of QFD process. The relationship is expressed in a qualitative manner, by using a numerical scale that determines the intensity of correlations. The values are: 9 = strong relation; 3 = medium relation; 1 = weak relation; 0 = no relation.

3.3.3.5 Competitive benchmarking

This fifth section tests technical competitiveness of the expected project by using quantitative benchmarking. The user needs are related with the main potential competitors in order to assess the current level of competitiveness. The correspondence between wants and competitors' existing products is evaluated with the same scaling system of the user requirements. The results obtained from benchmarking provide a significant assessment on what needs are more meaningful to improve the quality of the current state of art.

3.3.3.6 Technical importance ranking

The sixth section is placed on the bottom of the matrix. It indicates the technical importance ranking and it shows the outcomes of the entire process. This area assigns to the selected product characteristics specific levels of importance by processing data contained in the relationship matrix. The importance of each product specification is evaluated through a mathematical calculation and it is displayed in form of absolute or relative weight. The final results became technical guidelines to design the expected product.

3.3.3.7 Process steps

According to the main areas of the House of Quality, the traditional process follows specific sequential steps that are necessary to transform user needs into design specifications for defining the aspect of the final artefact. The steps are:

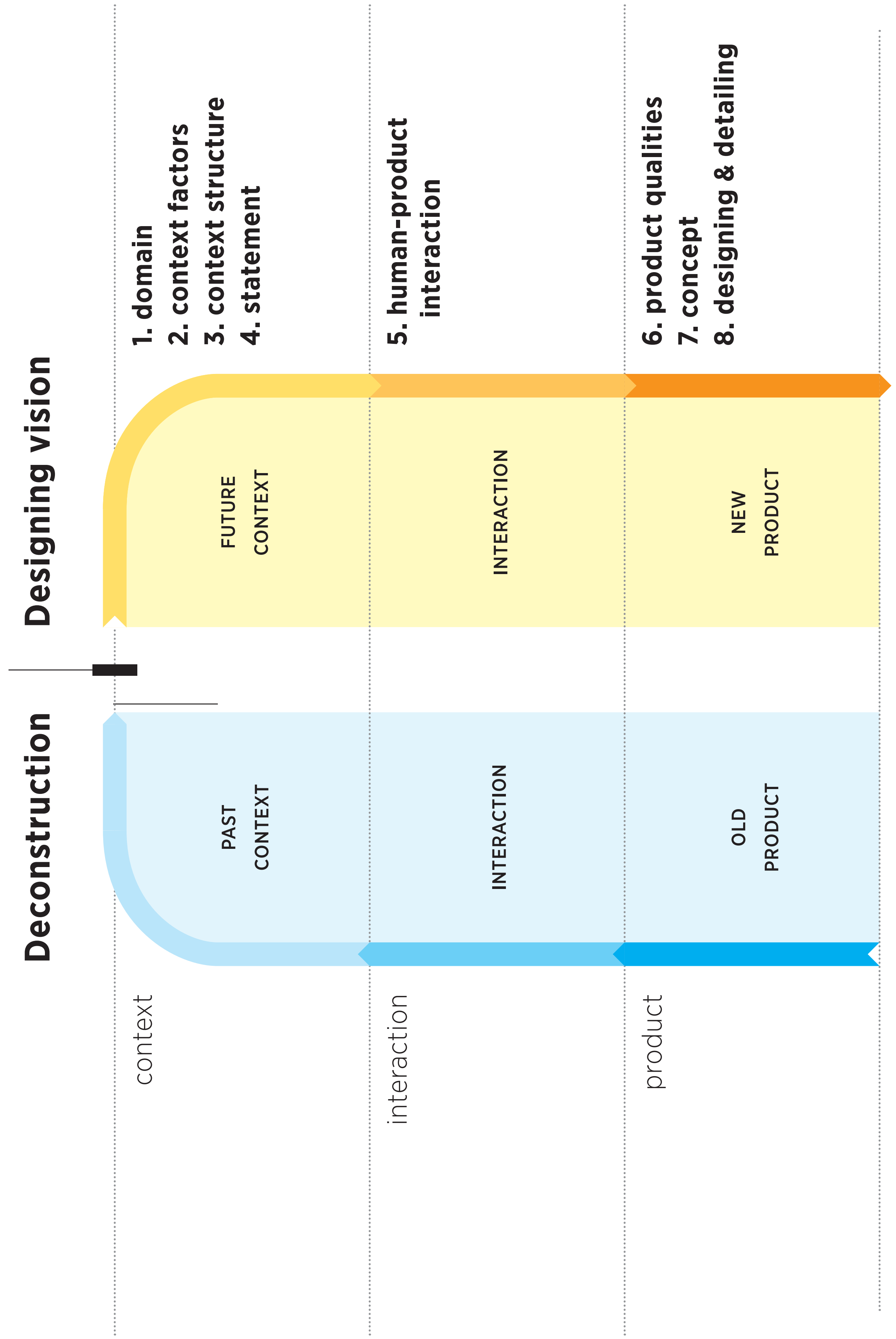
- Identifying user requirements
- Identifying technical/engineering requirements
- Deploying the relationship matrix
- Deploying expected quality by listing user requirements in order of importance and benchmarking competitive products
- Comparing technical characteristics
- Analysing the correlations existing between the various parameters

3.4 Vision in Product Design

Vision in Product Design (ViP) is a human-centred and strategic methodology that enables innovation through envisioning new ideas for the future (Van Boeijen, Daalhuizen, Zijlstra, & Van Der Schoor, 2014). Such as QFD, it tries to produce strategic design decisions for a project starting from the analysis of people in their related context. Though, instead of simply solve present-day problems – which people every day require to be satisfied by functional solutions – ViP tries to discover new design opportunities (for life of people) that can be ideated and developed in the future ahead.

The process defines a vision, not only for creating something in response to a current demand, but also for understanding the possible tomorrow by establishing the *raison d'êtré* of the final design, namely the intrinsic and anthropologic meaning of the artefact, which justify its existence on the world (Hekkert & Van Dijk, 2011). It does not mean that everything could be designed with own creativity, but the design process starts from carefully understanding both the current context, according to the specific purposes, beliefs and dreams of people but also with the current evolution of socio-cultural models (Verganti, 2008). ViP model helps the decision-making process to transform an idea into its best possible manifestation, whatever its final shape is (tangible or intangible).

The main goal of ViP is to define what to design and why, in accordance with the expected context in which the artefact will be putted in the world. The approach is very useful to shape the future through innovation and come up with new ideas in a structured and defined design pro-



Img. 13 • The ViP model. It shows eight essential steps that are necessary to design the vision through three levels of investigation. The left side refers to the "deconstruction" of the current context, while the right side concerns the process of "designing", in which the vision is realized.

cess without having any type of limitations derived from short-term problems of the existing present.

For the success of design process, ViP must incorporate perspective of end-users, because they are the only ones who can justify the existence of a specific artefact (Hax & Wilde, 1999). In this case, ViP helps research in giving new meaning to a particular idea, which in turn, it is capable in providing new values to the current market, trying to getting easily acceptable by people without any type of resistance. In view of this, ViP must consider MAYA principle (Most Advanced Yet Acceptable), a principle coined by the American designer Raymond Loewy (Loewy, 1950) to explain that every project has to find a strong balance between novelty and typically. In other words, ViP process must introduce appropriateness to its artefacts. This because it increases the degree of fitting between the product and the context in which it is consumed, creating at the same time high innovation impact without striving with its socio-cultural environment.

3.4.1 ViP History

ViP method was invented by Paul Hekkert and Matthijs Van Dijk, two designers and professors of Delft University of Technology in The Netherlands. The development of this method was started in 1995 and it took ten years of experimentation and implementation to be refined and transformed into a structured method (Hekkert & Van Dijk, 2011). The two experts used that period to test the model with their clients and their students at TU Delft. Officially, the first handbook was published in the 2011 and from then it has been spreading internationally in different design environments. ViP is a part of the strategic models that have been inserted in Delft Design Guide (Van Boeijen et al., 2014) and currently it is one of the common methodologies that are utilized in the Industrial Design Engineering department of TU Delft.

3.4.2 ViP Structure

ViP model is also context-driven and interaction-centred. Analysing the world of today or tomorrow is necessary to determines behaviours or experiences that people create interacting with specific artefacts. In particular, ViP focuses on those interactions to understand the meaning that people give to their products and what kind of user experience they produce. After that, ViP is able to come up with new opportunities for possible futures in which the vision about the expected product will be placed.

Three levels of investigation – based on context, interaction and product analysis – are investigated throughout a structured step-by-step design process **Img. 13 •**. ViP is composed by two main areas that divide ViP in two different design activities: the left side represent the process of "deconstruction" and it refers to the analysis of the current state of art; the right side is connected to the process of "designing", in which the vision is realized.

Nine crucial stages leads the design process, where the first one investigates the existing context (left side), whilst the other eight parts are completely dedicated to design the vision (right side): from the second to the fifth refer to the context domain, the sixth to the interaction level and the last three steps to the product area.

3.4.2.1 Preparation phase (deconstructing)

The first stage is considered as the "zero" step and it properly prepares the research for the design process. This step consists of analysing carefully the current context and "deconstructing" the traditional and existing design solutions. Starting from the product level, this phase investigates the intrinsic and functional qualities of certain artefacts, because they largely determine how end-users experience and interact with them. Successively, the investigation goes throw the interaction level, where behaviours and relationships that people produce with the products are observed. At the end, the introductory phase jump in the context level to understand the properties of the existing environment in which the two previous levels live in. All characteristics of the three levels must be documented.

At the context level, it is very useful to gather several data from different points of view such as life, culture, technology and society because it helps the process to understand how people live and behave with the existing products. It also contains a number of assumptions that currently are obsolete and need to be reframed (Hekkert & Van Dijk, 2011). From this point, new considerations about the future vision can be explored and compared with the past.

When the "deconstructing" stage is fully described, ViP is ready to move itself on the right side of the model. This stage forms the launch-base for coming up with a new design vision that is capable of redefining the problem domain. In that case, there is no univocal criteria to assess when a step has been completed, but it can be evaluated taking into account the relationship among the different stages.

3.4.2.2 Domain

This stage is the starting point of "designing" process because it fits the strategic goals of research that it wants to achieve through the vision. The domain determines the primary topic area in which the expected vision will be manifested. When the domain is stated, it is necessary also define how far into the future the design vision is projected because it is important to understand what potential typologies of societal, technological and cultural aspects may influence the future context over the years. Often the domain is declared and described through a statement that explains the field of research.

3.4.2.3 Context factors

The future context development is the crucial part of ViP because it gives precise direction to the decision-making process. For this reason, several "building blocks" needs to be discovered and selected to structure the future context. These elements are called context factors, i.e. value-free descriptions of the world phenomena as they appear, which describe and characterize the way of interacting with that specific social and cultural environment. Factors can be observations, theories, laws, considerations, beliefs or opinions and they must be appropriate for the selected domain and interesting for the goal of the future vision. All factors must be value-free descriptions of world phenomena as they appear. Collecting factors must be an objective research activity and the factors must not include moral judgements or personal standpoints as to how people believe the world should be. For this reason, the process is intensive and it requires time to collect only the most important sources that can be scientific and highly reliable.

Basically, context factors are divided in four main typologies, which extensively explain what elements affect the way people perceive, use, experience, respond and relate to products, or more precisely they describe the nature of the human-product interaction (Hekkert & Van Dijk, 2011). They are: states, principles developments and trends. Distinctions between these factors are mainly based on a dimension of stability in observed societal/behavioural fluctuations. States and principles are more stable in the time, while developments and trends can be in flux during the moment of observation.

Each type of the four factors is also divided in different fields and levels. A field is a specific area of interest in which a determinate factor belongs to. They are biology, economics, politics, sociology, technology, psychology, etc. Instead, the second element refers to the level of relationship with the domain. Each level can be directly related to the problem domain (micro level) or very abstract and further away from the main context (macro level). Every factor must be measurable. The fixed time in the future helps the research to predict what kind of factors will represent the expected context.

Making a careful analysis of these factors supports the research in generating an inspiring and original process because they drive the concept development and affect the final solution through their characteristics. The variety among factors – including also elements that at first glance seem to have nothing to do with the selected domain – is the correct strategy to reinforce the context properties and to contribute to the originality of the final solution (Snoek, Christiaans, & Hekkert, 1999). The context range can contain from one to tens or even hundreds of factors, depending on how much time and resources are available for the design process.

3.4.2.4 Context structure

Once the context factors are listed, the set of "building block" must be turned into a unified and coherent structure that explains how the separate elements are connected. To do this, the various factors can be grouped in two common types of cluster: common-quality cluster (the factors that point to the same direction and together form a "meta factor"); emergent-quality cluster (the elements that together elaborate a new unexpected factor). Subsequently, the clusters can be combined together to find new relationships between them. The most common groups are mainly two: pattern or storyline (the cluster may appear as a narrative story); dimension (the cluster seams to conflict or refer to opposing forces that together they create a matrix with different future contexts). If the process is conducted properly, the model produces a clear and consistent

picture of the future world in which the vision can be designed.

3.4.2.5 Statement

This stage concludes the "designing" phase at the context level. It helps the project to take a position among different directions. The choice leads the vision development. In this case, the research decides explicitly what are the most important factors that can be used for designing the future vision. The statement is the form in which the decision is expressed. It must be in line with the strategy of the research's mission. The position should neither be too generic to specific and it should be realistic.

3.4.2.6 Human-product interaction

This stage is the core of ViP model because human-product interactions enable the research to define what the product must express, should do and must look like. Interactions are the inner proprerties of an artefact that act as interface of the relationship between the context of use and the end-users (Simon, 1996). For this reason, the step consists of understanding what kind of relationship or interaction fits in the selected future context, but also those ones that help the process to accomplish what the research want to bring to people in the future.

Interactions describe the way the design relates to the end-users and this relatedness emphasizes the value the product has for them. Word expressions, images or drawings are the principal expressions to describe the correct interactions. Analogies and metaphors help the process to represent an interaction in an existing point of view. Each interaction must be not affected by any kind of bias. Appropriateness, indeed, is the key criterion to choose the correct relationship according to the specific context. In the end, likely the statement that indicates what the vision will offer (the same with the mission), the interactions must describe how the user experience will be performed. During the vision, analogies and appropriateness define together the real meaning of the final product, which also indirectly defines its audience.

3.4.2.7 Product qualities

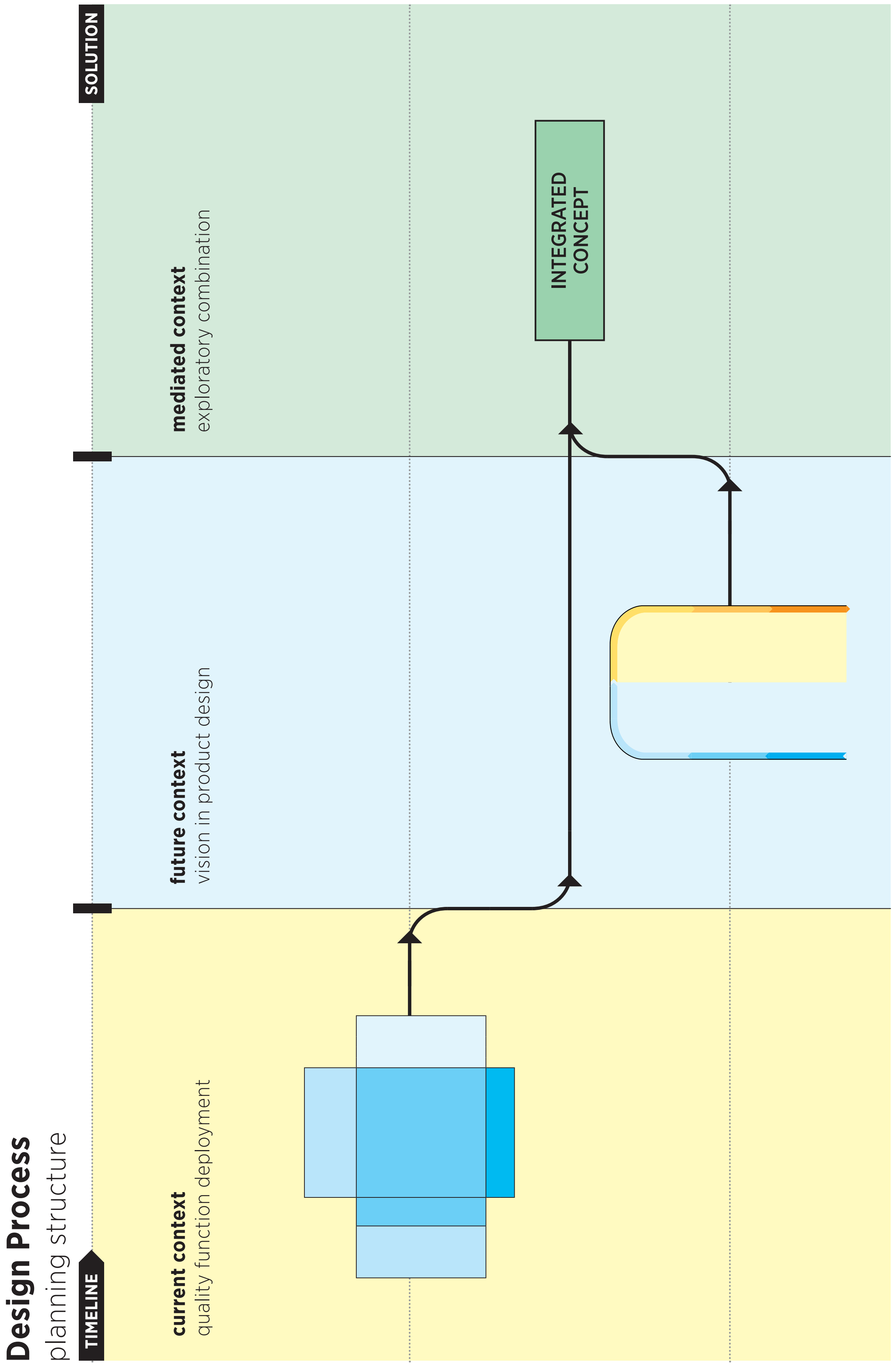
Only when the human-product interactions are defined, the process is able to select the qualitative characteristics of the final product. Those elements must be identified in accordance with the preselected context factors and the human-product interactions and they must be physical features. There are two types of product quality: the first one expresses a product's character; the second one describes how the product could be used or operated. The list of product qualities describes the personality and the properties of the final artefact. As with the human-product interactions, the product qualities can be expressed through words and metaphors. In order to obtain originality, product qualities must also differ from those ones that belong to the present context.

3.4.2.8 Concept

In this step the qualitative characteristics of the vision are transformed into tangible product features. The conceptualization of the vision (statement, interaction and product qualities) is translated in a final combination of features that can literally perceived, used and experienced (Hekkert & Van Dijk, 2011). The shape of the final project (a product, a service or any kind of solution that is deemed appropriate) is defined and designed only in this stage.

The process starts with idea generation that must match the initial de-

Img. 14 • The proposal of the methodological design approach that lays on the exploratory combination between QFD and ViP. The image describes the design process over a linear timeline to develop the concept vehicle.



sign vision but, instead of creating several design solutions, the process elaborates one or few ideas that must be appropriate to the predetermined vision. Again, thinking in terms of analogies helps the process to elaborate the final solution. The concept can be represented through sketches, drawings or quick-and-dirt prototypes of 3D models.

The concept stage is not yet the final manifestation of the expected product but it represents a useful starting point of the last step, visualizing some aspects in a rudimentary way. In other words, this stage creates a synthesis between the features of the personal vision and the constrains of the real world, in order to elaborate a coherent and realistic artefact. In the end, the concept must become the most appropriate response to the expected vision. It is the connection between the statement and what it is possible in the physical world.

3.4.2.9 Design and detailing

The last stage transforms the product concept into its final and tangible manifestation. All constraints or technical restrictions must be entirely taken into account. In this step, the product officially enters into the product development process, in which every technological aspect will be analysed and produced, while the final solution will be both engineered and physically realized.

3.5 Integrated Concept

The peculiarity of this research lays on the exploratory combination between Quality Function Deployment and Vision in Product design for elaborating a new methodological design approach **Img. 14 •**. In this case, this experimental model uses this research as a case study to examine its value during the development of the concept vehicle.

The contribution puts in relation QFD and ViP to explore their strategical potentialities together, in order to fill up their weaknesses by bringing their shared strengthens out. This because, although the approaches are both human-centred oriented, they tackle the same challenge with two different perspectives of problem-solving. Therefore, such aspect can really enrich the quality of the overall automotive development process because the correlation can add to the research some extra information from both point of views. In fact, since QFD is more analytic and engineering-oriented, it is able to provide qualitative and measurable results about costumer demands. Whilst, ViP is largely considered as a conceptual design model, which is able to offer more freedom to the design process to generate novel solutions for the future.

In addition, both approaches work on two different timelines: QFD is tightly related to user needs in the present context or more precisely in a kind of next present; while ViP projects the idea-generating directly into the future, in which such model tries to foresee and predict new solutions that can satisfy the behaviours of tomorrow. Therefore, the time factor allows the research to conduct the overall design process over a linear timeline, from a current situation to a future scenario. Given the substantial differences that characterize the two models, it is possible to note that they produce also two distinguish outputs. For this reason, if they combine their individual outcomes together, at the end of the process, they can produce a novel result. In the next chapters, the research will report this integrated process as a methodological strategy to develop the final concept vehicle.

Initially, the design process will explain the activities of both methodological models, while the last step will describe the integrated process, in which the two human-centred design approaches will be combined together in a unique methodology.

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◆ End of
Chapter 3

CHAPTER 4

Defining the context

4.1 Introduction

The utilization of the car segmentation is important to define the context in which the concept vehicle needs to be inserted. The vehicle segment helps the research also to trace technical and aesthetic characteristics of the expected car by comparing it among its main competitors. This chapter reports the characteristics of the main research context by describing the selected car segment and the current state-of-the-art in order to identify the main end-users, their behaviours, their necessities and lastly, the vehicle attributes that will characterise the entire concept in terms of driving experience, performance, proportions and design forms.

4.2 Vehicle segmentation

Automotive industry is one of the most important and largest economic sectors of the world. It is considered a wide system composed by a wide range of worldwide companies and organizations – called automakers – that are involved in the research, design, development, manufacturing, marketing, and selling of motor vehicles (Bell Rae & K. Binder, 2018). The principal products are wheeled and motorized vehicles, usually moved by an internal combustion engine or an electric motor, or a combination of the two (hybrid cars), dedicated to passengers or commodities carriage and transportation. For national or international legal purposes – based on safety and emission regulations, taxes and market jurisdictions – a classification of several categories identify different types of vehicle. Despite globalization, the legal frameworks are not entirely uniform across different countries, because of a persistence of localism in car markets and industries that continue to shape the automotive industry, through different regulatory regimes, taxation systems, and cultural and historical factors (Nieuwenhuis & Wells, 2015).

In Europe, the European Commission created a general distinction among vehicles (under EU regulation 2007/46/EC based on the ISO 3833) by classifying them in different typologies according to certain design and technical characteristics: (a) category M: vehicles carrying passengers and their luggage; (b) category N: vehicles carrying goods; (c) category L: 2- and 3-wheel vehicles and quadricycles; (d) category T: agricultural and forestry tractors and their trailers (European Commission, 2007; International Organization for Standardization, 1977).

The largest typology and primary source of transportation is the category M, namely the group of vehicles addressed to carrying passengers and their luggage, which in 2017 provided 86.6% of the total motor vehicle production in Europe and 24% of the entire of the worldwide production (European Automobile Manufacturers' Association, 2018).

Within group M, the broad sub-category is M1, which takes into account the smallest class related to passenger and the light-duty vehicles. Although the category is based on ISO 3833 standard the European car segmentation has not a real formal characterization: it defines few and restricted categories to better understand and simplify vehicle classification. The latter considers weight and the shape of the coachwork as parameters for categorising the vehicles. The European classification systems **Img. 15** • is: A-segment: mini car; B-segment: small car; C-segment: medium car; D-segment: large car; E-segment: executive car; F-segment: luxury car; S-segment: sports car; J-segment: sport utility vehicle / off-

Euro Car Classification	Euro NCAP Classification	US EPA Size Classification	American Classification	British Classification	Australian Classification
A-segment: mini car	Passenger car	Minicompact	Microcar	Microcar or Bubble car	Microcar
			Subcompact car Economy car	City car	
B-segment: small car		Subcompact		Supermini car	Light car
C-segment: medium car		Compact	Compact car	Small family car	Small car
D-segment: large car		Mid-size	Mid-size car	Large family car	Medium car
			Entry-level luxury car	Compact executive car	Medium car above $60,000
E-segment: executive car		Large	Full-size car	Executive car	Large car
			Mid-size luxury car		Large car above $70,000
F-segment: luxury car			Full-size luxury car	Luxury car	Upper large car above $100,000
S-segment: sports car			Sport car	Sport car	Sport car
			Gran tourer	Grand tourer	
			Supercar	Supercar	
			Convertible	Convertible	
		Two-seater	Roadster	Roadster	
J-segment: sport utility vehicle/off-road vehicle	Off-road	Small SUV	Mini SUV	Mini 4x4	Small SUV
			Compact SUV	Compact 4x4	Medium SUV
		Standard SUV	Mid-size SUV	Large 4x4	Large SUV
			Full-size SUV		Upper large SUV
	Pickup	Small Pickup truck	Mini pickup truck	Pickup	Utility vehicle
			Mid-size pickup truck		
		Standard Pickup truck	Full-size pickup truck		Pickup
			Heavy duty pickup truck		
M-segment: multipurpose car	MPV	Minivan		Mini MPV	People mover
			Compact minivan	Compact MPV	
			Minivan	Large MPV	
		Cargo van	Cargo van	Van	Van
		Passenger van	Passenger van	Minibus	

Img. 15 • The main worldwide vehicle classifications associated with passenger vehicles that are intended mainly for carrying persons and their luggage and/or goods, with a maximum of nine seating places, including the driving seat. The first column refers to the European classification and this research is primarily addressed to the S-segment dedicated to the sports car models.

road vehicle; M-segment: multipurpose car.

4.2.1 S-segment: sport car

The utilization of the car segmentation is important to define the context in which the concept vehicle needs to be inserted because, as previously stated, it is subjected to technical and administrative regulations that authorize the type-approval and placing on the market. Moreover, the vehicle classification system is used for determining a tax amount. Often the main parameters are the type of engine, fuel, emissions, size, weight, as well as the purpose for which it is used. Car segments are also useful for marketing because helps carmakers to determine vehicle performance and aesthetics of the expected vehicle in comparison to the main competitors' vehicles. Car segmentation defines also specific vehicle attributes that characterise the entire automobile in terms of driving experience, performance, proportions and design forms.

For these reasons, comparing the numerous segment of the cars with the final goal of the overall research, the expected concept refers to the S-segment. A sports car is generally a two-seater vehicle characterized by high performance and nimble handling, which focuses on delivering a pure and full-on driving experience to whom interacts with it **Img. 16** •. The vehicle attributes concern in light weight, capable powertrain, fast acceleration and easy manoeuvrability. This sportive character is dictated also by homogeneous weight distribution, low centre of gravity, and precise dynamic geometry, which together provide great control and reactivity at high speeds or during cornering. Sports cars are aerodynamic shaped as well to increase performance in terms of driving stability and low drag resistance against airflow, which provide more efficiency in propulsion and faster acceleration.

S-Segment is populated by a wide array of automobiles that deliver different types of essential, streamlined or luxurious bodyworks and diverse driving experiences and sensations based on variable typologies of user segmentations. The main models are predominantly: (a) coupés, (b) roadsters, (c) convertibles or spyders, (d) muscle cars, (e) supercars, (f) hyper cars, (g) GT or grand tourers, (h) high-performance cars.

Img. 16 • Mazda MX-5, one of the best selling sports car in the world. Source: Madza.

Taking in consideration only the architecture and styling of a sports car, differences among the models are essentially characterized by: (1) the design of the car pillars, which changes the bodywork silhouette and subsequently the presence of a roof or not; (2) the engine and the wheel-drive layouts, which influence vehicle handling, dynamic setting and geometry; (3) the number of seats between the two-seat, two+two-seat and four-seat configurations.

Most of sports cars, indeed, are essentially two-seat with a rear-wheel drive

Img. 17 • Ferrari 166MM, the sports car on which the *barchetta* style was coined. Source: SWNS.

layout, in which the position of the engine may be either front-engine (especially for grand tourers and muscle cars) or rear-engine (the most privileged for supercars, hyper cars and high-performance cars). Only grand tourers and muscle cars are denoted by the present of either two+two-seat or four-seat configurations. Regarding car pillars, coupé style is denoted by the presence of a hard top as well as most of grand tourers, muscle cars and some supercars and hyper cars. Sometimes these models may have a folding roof that is typical of convertible vehicles, which are the evolution of roadsters, namely open two-seat cars with no weather protection. However, today the meaning of roadster is very blurred and most of these models are identified under convertible denomination, because they are often equipped with a removable hardtop (called *targa* from Targa Florio's Italian road race) or with a traditional folding roof. The two-seater roofless configuration is adopted mainly by high-performance cars that are made without any door as well, which in turn, remembers the traditional open configuration of the old Italian *barchetta* style **Img. 17** •.

4.2.2 High-performance car

Once the vehicle segment is selected, understanding the specific typology of the concept – in which it expects to be designed for – detects the real context of use, how the concept may be configured, who are the end-users and what are the main competitors that compose the current state-of-the-art. Considering this, the aim of the project is to develop a concept sports vehicle that is denoted by a two-seat roofless configuration. Therefore, examining the various models of the S-segment, the expected vehicle lays on the category of high-performance vehicles.

The high-performance vehicles are particular road legal cars in which the racing configuration is predominant, as engineering and technical aspects of the vehicle are maximized to provide extreme performance. All of the models are lightweight vehicles equipped with the rear-wheel drive configuration and most of them present the rear mid-engine layout. While the powertrain has not any type of electronic control, so that the vehicle is able to deliver a thrilling and fun driving experience. The high-performance car is also characterized by a peculiar driving set-up that is capable of simulating a pure experience similar to the Formula racing. In fact, these cars are denoted by a simple and rudimental cockpit (equipped only with one or two seats) and few essential driving controls that eliminates any kind of distraction in order to focus the attention purely on driving. The high-performance vehicles are distinguished also by their extreme styling, where the Formula racing sensation is guaranteed by the absence of both the doors and the rooftop. While sharp lines and acute angles of the coachwork provide an aggressive bodyline. Besides, most of the vehicles are open-wheeled, which contributes to eliciting racing styling.

4.2.3 Track-day car

Analyzing the characteristics of the high-performance cars, the models can be considered specifically as a track-day car. A track-day is an organ-

Img. 18 • Many models of Caterham Seven during the Caterham Academy, a track-day series organised by the same company and exclusively open to novices to introduce new drivers to motorsport. Source: Caterham.

ised event in which people with different driving abilities – novice, intermediated or advanced pilots – are allowed to drive or ride around established motor racing circuits. Most race tracks around the world provide this type of facility, in which a road-legal or track prepared car can be used without speed restriction. Criteria for being eligible to participate is often the holding of a regular driving licence or the appropriate racing license for specific track-day events that require high driving abilities. A track-day event can be a single event or can be a part of a sponsored racing series organized among different circuits of the same region, state or located in different countries. Considering this, the track-day events present many race formats based on either the characteristics of the sports vehicles or the participants' individual level of driving experience **Img. 18 •**. Drivers usually participate in these events with their own vehicles, however, a growing number of tracks and organizers are starting to provide hire vehicles. Moreover, the practice of renting is quite often accompanied by extra facilities such as instructor guidance and a small team of technicians for setting-up and maintaining the vehicle during the event.

4.3 State-of-the-art

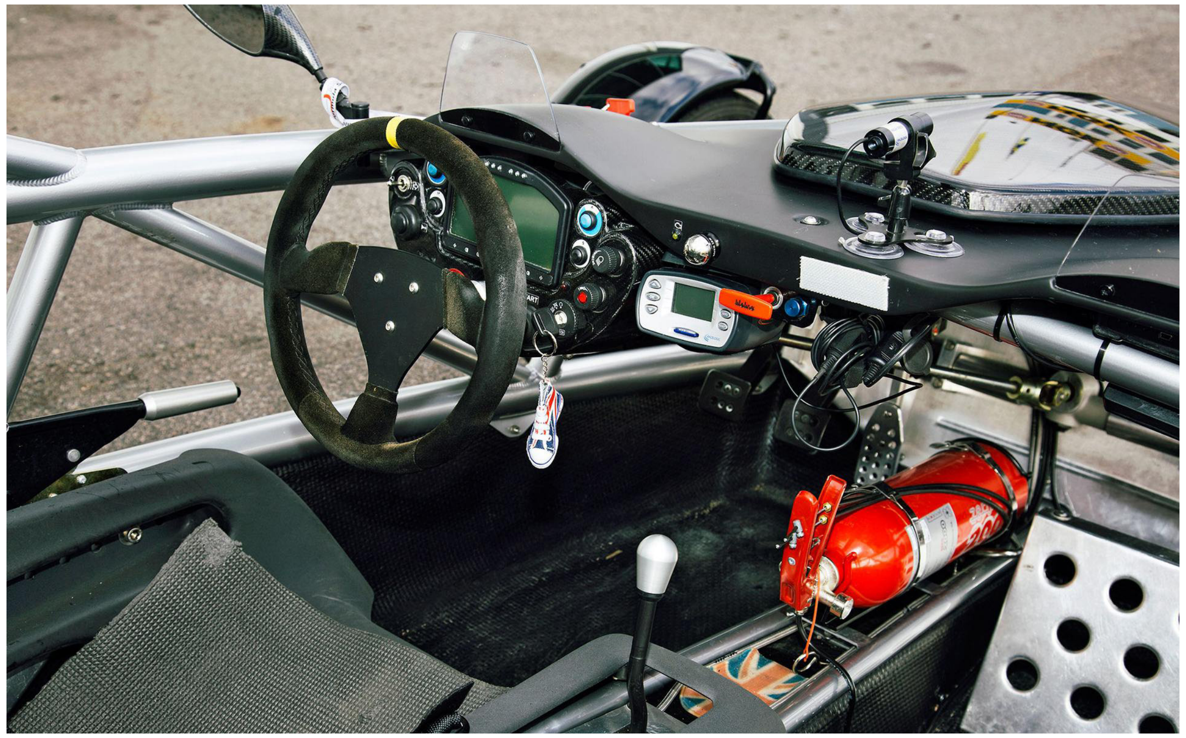
Taking into account the aforementioned considerations, an high-performance car addressed to track-days, it is a roadgoing sports car primarily designed for racing purposes. In this case, the vehicle must be versatile and adaptable to the changing context (urban roads or race tracks) according to the driver's intentions, but also to the many legal frameworks that regulate both driving environments.

The pioneer of this typology among the high-performance cars was the British design engineer Colin Chapman when designed the Lotus Seven, the entry-level car model of its automotive company Lotus cars. It was a small and cheap sports car that could be used into date British low-cost formula racing for open-top roadgoing sports cars. Over time this typology of racing evolved e became highly popular in some countries, especially in the nations of the Commonwealth. At the meantime, other carmakers started to produce new road-legal cars (based on the same category of sports vehicles) to follow the same purpose of the Lotus Seven. The latter became the property of the British car company Caterham, which bought the rights and it sold the vehicles based on the Lotus's original design. Nowadays the track-day events are still present for racing car enthusiasts, while some car companies (for example Briggs Automotive Company, Caterham and KTM) have started to organize their own mono-brand series to incites people to use their vehicles. Over time, those activities have produced a niche market of the S-segment, which currently offers several particular car models for track-days purposes. Regarding this research, some of those cars have been identified and selected to produce a comprehensive analysis of the state-of-the-art. During the research activities, the investigation has been used as a benchmark to develop the concept vehicle. The selected cars are reported hereinafter by briefly describing their vehicle characteristics.

Img. 19 • Ariel Atom. Source: Atom Motor

4.3.1 Ariel Atom

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1828	3410	1195	520	2345	1600	n.d.	50000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.45	ICE	Honda i-VTEC	4 straight	2000	245	8600	240	7200
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,12	233	489,16	2,78	tube frame	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
195 / 50	15	195 / 50	15	240	240	2	pushrod double wishbones	



Img. 20 • Ariel Atom interiors. Source: Auto Express

The Ariel Atom is a road-legal high-performance sports car made by the British Ariel Motor Company. The vehicle is a two-seater open-wheeled and roofless car with no doors. The Ariel Atom styling is characterised by a peculiar steel tube chassis, which provides to the entire structure a naked aesthetics that distinguish the coachwork from other similar sports vehicles. The structure is very narrow and sharp that imprint on the vehicle fastness, a wind splits and robust styling. Few composite panels cover the tube frame to make aerodynamics more efficient and to provide to the coachwork a uniform shape such as a shell. Moreover, many uncovered elements create no distinction between interior and exterior, and they give the Atom the qualitative aspect of a rude and exasperated car showing at the same time a clear and transparent anatomy of the vehicle. A rigid seating and the essential interface delivers to the drivers pure and thrilling driving experience.

Img. 21 • Bac Mono. Source: Carscoops.

4.3.2 Bac Mono

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1836	3952	1110	580	2565	n.d.	n.d.	150000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.54	ICE	Ford/ Cosworth	4 straight	2500	309	8000	308	6000
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central longitu-dinal	2,8	274	525,73	2,59	carbon fibre monocoque	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
205 / 40	17	245 / 40	17	295	295	1	pushrod double wishbones	

Img. 22 • Bac Mono interface. interface. Source: Briggs Automotive Company.

The Mono is a road-legal high-performance sports car made by the British carmaker named Briggs Automotive Company based in Speke, Liverpool. The vehicle is an open-wheeled and roofless car with no doors as most of the similar models, but the peculiarity of this car is the single-seater configuration that provides an individual driving experience as the Formula racing set-up. The Mono's qualitative aspects denote straight and blitz lines and the character elicited by its styling is brave, daring, resolute and determined. Moreover, each vehicle is custom-built around the body shape of the driver, which makes the involvement of driving more personal and intimate. The driving interface follows the same configuration of the Formula racing, in which all controls are embedded on the steering wheel. The single-seater permits the car to be narrower in order to increase its stability, aerodynamic efficiency, but also delineating a wind splits styling lines. The Mono uses a carbon fibre monocoque over a steel chassis and the weight-distribution is focused on maintaining a low centre of gravity.

Img. 23 • Caparo T1. Source: Sunday Times Driving

4.3.3 Caparo T1

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1924	4066	1076	550	2900	1664	1623	350000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.4	ICE	Caparo V 90°	V8	3500	583	10500	420	9000
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central longitu-dinal	2,5	330	1060	1,28	aluminium monocoque	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
235 / 40	18	295 / 30	19	355	355	2	pushrod double wishbones	

Img. 24 • Caparo T1 passenger package. Source: Stratton Motor Company.

The T1 is a road-legal racing car built by Caparo Vehicle Technologies, a British automotive founded by three engineers of the McLaren F1 in Basingstoke, Hampshire. The styling of the T1 is inspired by the design of the Formula One racing car because it is open-wheeled and it closely resembles that of a racing prototype. The aesthetic qualities of the vehicle present streamed, fluid and wind splits lines, whilst the character elicited by the T1's front side is comfortable and confident but the overall shape and stance of the coachwork is also focused and energetic. The car features a carbon fibre aerodynamic low drag body design, composed of individual sections, with an adjustable twin element front wing, single element rear wing, adjustable flaps, and a ground-effect diffuser. The interior is a rough two-seat configuration, in which the passenger's seat is set back from the driver's seat slightly, allowing the seats to be placed closer together, thereby reducing the overall width of the car.

Img. 25 • Caterham Seven 620R. Source: Motorbox.

4.3.4 Caterham Seven 620R

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1575	3100	1090	572	2225	1335	1355	70000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.39	ICE	Ford Duratech	4 straight	2000	315	7700	297	7350
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	front longitu-dinal	2,8	250	550	n.d.	tube frame	6 - manual	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
185 / 55	13	215 / 55	13	254	254	2	pushrod double wishbones	

Img. 26 • Caterham Seven 620R passenger package. Source: Evo.

Caterham is a road-legal high-performance sports car produced by the British company Caterham Cars in Crawley, Sussex. The Seven is a super-lightweight open-wheeled car based on the design of the Series 3 Lotus Seven. The car presents no roof, no windshield and no doors, but it is a singular front-engine layout, which denotes a different dynamic configuration compared to other models that are rear mid-engine cars. The visible tube frame, the floating lightings and the thin and long nose of the coachwork (made by aluminium panels) equip the aesthetic qualities of the car with classic and old-fashioned lines. The character is stable but also playful and euphoric. Caterham provides different models of the same car based on the level of driver's abilities. The 620R is the most powerful variant. The interior is very essential while the interface presents only the basic driving controls. The speedometer confers to the car an old-style because of it is analogue. Instead, the narrowed shape sometimes creates difficulties during the ingress and the egress.

Img. 27 • Dallara Stradale. Source: Autocar.

4.3.5 Dallara Stradale

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1875	4185	1041	855	2475	n.d.	n.d.	190000	ITA
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.69	ICE	Ford/ Cosworth	4 straight	2300	400	6200	500	4000
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,25	280	468,41	2,9	carbon fibre monocoque	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
205 / 40	18	255 / 30	19	305	280	2	pushrod double wishbones	

Img. 28 • Dallara Stradale passenger package. Source: Dallara.

The Stradale is a road-legal high-performance sports car produced in Varano de' Melegari, Parma by the Italian chassis manufacturer Dallara Automobili. The Stradale embodies the Lotus Seven's philosophy of lightweight minimalist sports car. The vehicle is a *barchetta* in its basic form, with no windshield and no doors, but its overall vehicle styling is denoted by a uniform and continuous shape that is typical of the standard supercars. The qualitative aspects of the styling are characterised by fluid smoothed and carved lines. The overall character is elegant and focused, but also confident and assured. The peculiarity of this car relies on its aerodynamic shape that is capable of creating a great amount of downforce at high speed, which is quite similar to its same weight. The standard model is the Berlinetta, but after the installation of a removable windshield, the car can be also Roadster or Targa. The interior is made by an essential carbon fibre cockpit while the main controls of the car are integrated directly into the steering wheel.

Img. 29 • Drakan Spyder. Source: Hi Consumption.

Img. 30 • Drakan Spyder interface. Source: CKM.

4.3.6 Drakan Spyder

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
2032	3962	1117	907	2616	n.d.	n.d.	125000	USA
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.52	ICE	GM LS3 / Corvette	V8	6200	430	5900	575	6600
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central longitu-dinal	3,2	265	478	n.d.	tube frame	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
235 / 40	17	315 / 30	18	327	327	2	pushrod double wishbones	

The Drakan Spyder is an American high-performance and lightweight sports vehicle manufactured by Sector111 based on the Palatov Motorsport, a coach builder and automotive design studio located in Portland, Oregon. The Drakan Spyder is a road-legal two-seater roofless car with no doors but it is equipped with a small and thin windshield. The structure is made up by a steel tube frame and the shape is very sharp which give the vehicle aggressiveness. The qualitative aspects of the vehicle denote an old-fashioned and classic styling similar to the hot-rod cars. The aesthetic is masculine and its character is bold. Lightweight composite panels cover the structure eliciting a shiny aspect. The car is also open-wheeled and it presents floating lightings as the Caterham Seven. Indeed, the styling was influenced by that model but also by the Ariel Atom and the KTM X-Bow. The powertrain is powered by a V8 engine, which provides higher power compared to other similar models. The interior is very essential while the interface presents only the basic driving controls.

Img. 31 • Elemental RP1. Source:Evo.

4.3.7 Elemental RP1

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1775	3740	1070	580	2525	1544	n.d.	98000	UK
length / wheelb.	Motor				Power		Torque	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.48	ICE	Ford Ecoboost	4 straight	2000	320	n.d.	450	2000
Drive wheel		Accelera-tion	Top Speed	Power to weight ratio		Chassis	Gear	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central longitu-dinal	2,8	265	550	n.d.	carbon fibre monocoque	6 - manual sequential	
Wheels f/r				Brakes f/r		Seats	Suspension	
mm	inch	mm	inch	mm	mm	numbers	type	
215 / 45	17	245 / 40	18	280	280	2	pushrod double wishbones	

Img. 32 • Elemental RP1 passenger package. Source: Evo.

The RP1 is a road-legal and high-performance track-day car designed and manufactured by the Elemental Automotive Group, a British company based in Hambledon, Hampshire. The Rp1 is a roofless two-seater open-wheeled car with no doors and no windshield. The vehicle structure is made up by a carbon fibre cockpit and rear tube frames, which suspend the powertrain. Compared to the transversal layout of other similar cars, the peculiarity of the Rp1 lays on the longitudinal layout of the engine, which permits to set it lower in the chassis. Some body panels cover the body structure giving it a uniform and solid styling. The qualitative aspects of the styling confer to the car straight and defined lines. The character is stable, truthful but also energetic and resolute. In addition, a long diffuser at the front of the car and another one at the rear provide a high amount of downforce. The interior and its driving interface are simple and clean while the carbon fibre denotes all elements of the cabin. The latter presents also a racing-oriented seating configuration.

Img. 33 • KTM X-Bow. Source: KTM

4.3.8 KTM X-Bow

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1915	3738	1202	790	2430	1644	1624	70000	A
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.54	ICE	Audi	4 straight	2000	300	6400	420	3200
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,9	232	379,25	3,59	carbon fibre monocoque	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
205 / 40	17	255 / 35	18	305	262	2	pushrod double wishbones	

Img. 34 • KTM X-Bow GT interface. Source: KTM

The X-Bow is an Austrian road-legal track-day vehicle. It is the first light-weight car manufactured by Europe's largest motorbike company KTM, in Graz, Austria. The X-Bow is a two-seater open-wheeled roofless car with no doors and no windshield. The styling of the car is characterized by strong, straight, jittery and extreme lines, which confers to the vehicle an exasperated and aggressive character. The peculiarity lays on the cockpit, which is capable of creating no separation or between exterior and interior, creating at the same time a clean and monolithic volume of carbon fibre. Other few panels of the same materials cover the safety cell recreating the same sheer styling of the off-road bikes. The carbon fibre is dominant inside the cabin as well, whilst the driving interface is simple and essential. The X-Bow exists in three variants: the roofless Rookie; the GT, which is equipped with a windshield; the GT4, which is characterized by a rigid rooftop and it is designed specifically for the FIA GT4 Championship.

Img. 35 • Kyburz eRod. Source: Koray's car.

4.3.9 Kyburz eRod

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1600	3000	1250	650	2520	n.d.	n.d.	50000	CH
length / wheelb.	**Motor**						**Power**	**Torque**
ratio	type	maker	volt	ampere	duration		HP	Nm
1.20	EV	Brus	324	120	39kWh		201	305
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	rear trans-verse	4,5	140	335	n.d.	tube frame	1 - automatic	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
195 /50	15	195 / 50	15	195 / 50	15	2	pushrod double wishbones	

Img. 36 • Kyburz eRod passenger package. Source: Kyburz.

The eRod is a lightweight and high-performance sports car designed and manufactured in Freienstein-Teufen, Bülach, Swizterland by the innovative company Kyburz. The eRod is the first commercial road-legal full-electric car of its vehicle category, which is specifically designed for track-day. It is a two-seater, open-wheeled roofless car with no doors and no windshield. The vehicle structure features a steel tube frame chassis, which is partially covered with some composite body panels with straight and decisive lines. An electric motor located right behind the seats spins the rear wheels, while the battery is in the centre of the car. The rough and spartan styling takes inspiration from the Ariel Atom. The character is reliable and vigorous but it is also clear and playful. The eRod is available in three variants: eRod Basic, eRod Fun, and eRod Race. The last one is specifically designed for racing purposes. The interior is very rudimental while the interface presents only basic driving controls and a small screen to control the battery.

Img. 37 • Lotus 3-Eleven. Source: Caricos.

4.3.10 Lotus 3-Eleven

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1858	4120	1201	925	2370	1460	1500	50000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.74	ICE	Rover / Lotus	V6	3500	430	7000	440	4500
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,1	290	467	n.d.	aluminium monocoque	6 - manual manual	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
225 / 40	18	275 / 30	19	370	350	2	pushrod double wishbones	

Img. 38 • Lotus 3-Eleven interiors. The sequential gearbox refers to a race model. Source: Caricos.

The 3-Eleven is a high-performance sports car made by the British famous automotive company Lotus Cars based in Hethel, Norfolk. The vehicle is a two-seater roofless car with no doors no windshield. The vehicle structure is made up by extruded and bonded aluminium sections and by a rear tube frame chassis, which connects the powertrain to the cockpit. The qualitative aspects of the car are characterized by an aggressive stance and styling, which present a solid shape characterized by straight lines and strong and sharp edges. The character is aggressive, brave, uplifted and determined. The coachwork is composed of lightweight body panels, made by the resin infusion composite technology. The 3-Eleven is available in two configurations: road-legal and race versions. The aluminium frame characterises the overall cockpit, while the driving interface is equipped by simple but well-detailed driving controls. Compared to the road-legal version, the race variant is single-seater and it presents a sequential gearbox.

Img. 39 • Radical SR3. Source: Financial times.

4.3.11 Radical SR3

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1785	4190	1070	550	2370	1760	n.d.	80000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.77	ICE	Suzuki W701	4 straight	1500	256	9500	214	7000
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central longitu-dinal	3,8	237	549,47	2,47	tube frame	6 - manual sequential	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
205 / 60	16	205 / 60	16	260	260	2	pushrod double wishbones	

Img. 40 • Radical SR3 interiors. Source: Wheelsage.

The SR3 is a road-legal high-performance and lightweight vehicle specifically designed for track-days by the British manufacturer Radical Sportcars in Peterborough, United Kingdom. The SR3 is a two-seater roofless vehicle with no doors and no windshield. The vehicle structure is made up by an elemental carbon-steel spaceframe chassis while its styling is characterised by a uniform shape equipped of replaceable glass reinforced plastic panels that imprint playfulness to the car. This particular form is inspired by the classic styling of the Le Mans racing series. The qualitative aspects of the care are denoted by smoothed, splined and fluid lines. The character is encouraged, energetic and exhilarated. The Radical provides different variants of the same car for different driving purposes, which include also the participation at international racing events. The SR3 is the medium-level version but it is the most popular model produced to date. The passenger package is very essential while the interface presents only the basic driving controls which provide a pure driving experience.

Img. 41 • Vühl 05. Source: Autocar.

4.3.12 Vühl 05

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1876	3718	1120	725	2300	n.d.	n.d.	67000	MEX
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.62	ICE	Ford/ Cosworth	4 straight	2000	285	n.d.	420	n.d.
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,7	245	398,57	3,41	aluminium monocoque	6 - manual	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
205 / 45	17	245 / 35	18	330	330	2	pushrod double wishbones	

Img. 42 • Vühl 05 passenger package. Source: Car Body Design.

The 05 is a Mexican road-legal high-performance sports car produced by the company Vühl in Querétaro. The lightweight structure of the cockpit is constructed from aluminium extrusions and aluminium honeycomb. The Vühl 05 is a roofless car with no doors and no windshield. Its extreme torsional stiffness allows the suspension to be finely tuned for road and track, as required. The vehicle is also set up by a high-performance aerodynamic configuration that includes a large single-plane rear wing, which produces a high amount of downforce at high speeds. The qualitative aspects of the vehicle denote splined lines and a solid and clean surface. The character of styling is venomous, masculine, aggressive and spirited. Many carbon fibre panels cover the entire aluminium structure and they make the form of the front side attentive and concentrated. The passenger package presents a basic interior with two rigid carbon fibre seats and its corresponding vehicle interface denotes an elemental layout made up by few essential controls.

Img. 43 • Zenos E10 R. Source: Evo.

4.3.13 Zenos E10 R

Width	Length	Height	Weight	Wheelb.	Track f/r		Prize	Nation
mm	mm	mm	kg	mm	mm	mm	€	
1870	3800	1130	700	2300	1560	1600	62000	UK
length / wheelb.	**Motor**				**Power**		**Torque**	
ratio	type	maker	cylinder	cc	HP	rpm	Nm	rpm
1.65	ICE	Ford Ecoboost	4 straight	2300	350	6000	475	4000
Drive wheel		**Accelera-tion**	**Top Speed**	**Power to weight ratio**		**Chassis**	**Gear**	
layout	engine	0-100 s	km/h	HP/ton	kg/KW	type	type	
rear	central trans-verse	3,5	230	500	2,7	carbon fibre monocoque	6 - manual	
Wheels f/r				**Brakes f/r**		**Seats**	**Suspension**	
mm	inch	mm	inch	mm	mm	numbers	type	
195 / 50	16	225 / 45	17	285	285	2	pushrod double wishbones	

Img. 44 • E10 R passenger package. Source: Auto Express.

The E10 R is a road-legal high-performance sports car designed and produced by the British company Zenos Cars based in Wymondham, Norfolk. The car features an aluminium structure to which a composite passenger base and front and rear subframes are attached. The composite tub of the vehicle structure is formed of a sandwich that comprises a thermoset plastic core contained between sheets of carbon fibre. The E10 R is a roofless vehicle with no doors and no windshield. The R model, the exclusive higher-powered variant of Zenos. The qualitative aspects of the car denote splined lines and decisive edges. The styling is characterised by a uniform coachwork equipped of replaceable glass reinforced plastic body panels, which are intended to reduce repair costs in the event of an accident. The character is uplifted, energetic, and focused. The interior is minimal, denotes few essential driving controls but it incorporates an additional central screen that allows the passenger to view information that would normally only be visible to the driver.

4.4 References

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◆ End of
Chapter 4

PART 3:
DESIGNING THE PROJECT

CHAPTER 5

Research activities

5.1 Introduction

This chapter reports all of the activities that were conducted to achieve the initial goal of the research: developing the concept of a hybrid sports vehicle, specifically defining its architecture and styling, through a human-centred design methodology. In particular, the chapter is divided into four main sections, where each of them describes a particular activity of the research. The first part describes the qualitative analysis of the main users and their needs. Next, the second section refers to the QFD process, which was used to transform the user requirements into technical and measurable specifications of the vehicle for satisfying their needs. Successively, the research used the ViP model to envision the concept in the future to delineate its character but also a long-term strategy for the vehicle styling. In the end, the outcomes of both approaches were combined together to produce a novel and integrated design solution, which was conceived as guidelines to define the technical and aesthetic properties of the final expected vehicle.

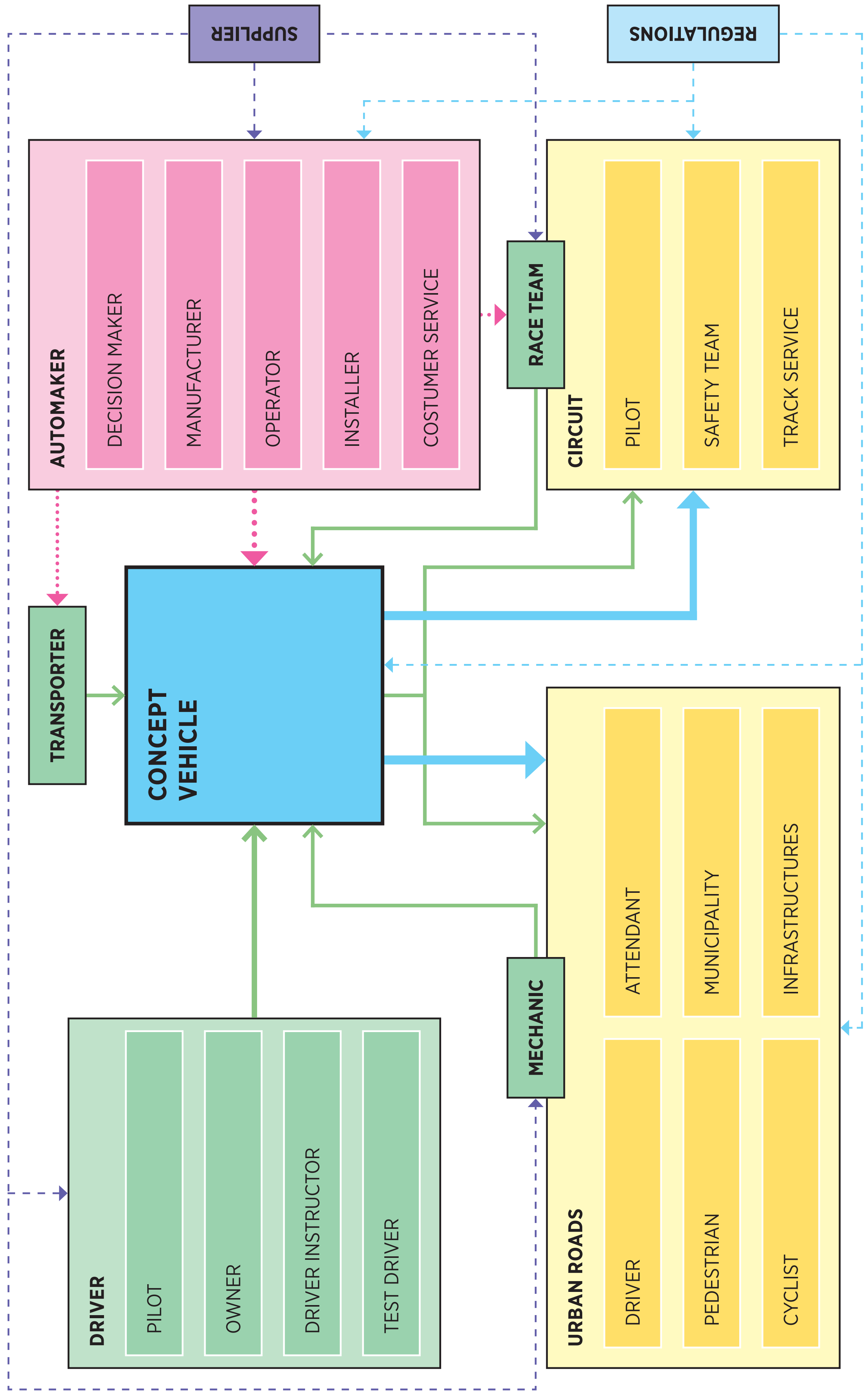
5.2 User analysis

The Human-Centred Design approach ensures that the final design of an artefact matches the needs and capabilities of the people for whom it is intended (Norman, 2014). For this reason, understanding the users and the context of use is a crucial part of the HCD process because it helps the project to understand the main needs that arise from the human activities that the user target creates while interacting with a product directly in its social-technical environment (A. Rizzo, Marti, & Bagnara, 2001).

Applied ethnography is one of the most effective practices of analysing users because it consists of a series of practise that support the research in observing people while they are performing their activities directly in the real context of use (Talamo, Mellini, & Giorgi, 2011). The practice is the branch of anthropology that deals with the scientific description of human cultures (Norman, 1991) and it was introduced in the Design discipline at the beginning of the 90s' by some research of the University of San Diego as a new method of user analysis (Nardi, 1995). It serves to understand the characteristics of people, their behaviours and tasks that they have to accomplish, their routine, the communication flow among them and moreover the criticality inside their activities (Norman, 1999). The applied ethnography can be conducted also involving people in the research by using participative activities, such as contextual interviews, in order to better understand the activities that need to be registered directly from the users (Beyer & Holtzblatt, 1998). In the end, data collection provides to the research quantitative data from a user's point of view that can be used to make design decisions. Nowadays the practise is very common in the field of the Human-Centred Design and it for this reason it was used within the research to identify the target contest and successively to analyse the users and their needs.

The term user is very complex to define because it englobes different user sub-categories that express different behaviours to interact with the product. In this case the user is considered a collection of people that create a relation with the artefact at any stages of its product life cycle (Mincolelli,

Img. 45 • The ERAF systems diagram that displays all elements of the selected system and their interactions with one another (Kumar, 2012). In this case, the system shows the relations between the users and the expected product within the target context.



2008b). For this reason, extending the collection of end-users increases the possibility of satisfying a wider range of user needs making the project more inclusive. Indeed, the user is not only the individual who buys or uses a product, but also the one who is implicated in producing, distributing and selling the artefact or it is related to it through third-party services such as maintenance (Mincolelli, 2008a). Extending the investigation to different user categories gives the chance to include into the analysis also the extreme users, the people who live on the edges of the prefixed area of the leading user target (Brown, 2015).

Taking in consideration the previous assumption, this research identified four different typologies of user who had direct or indirect relations with the expected concept vehicle **Img. 46** •. For doing this, the research investigated the principal context of use previously described in the earlier chapter. Many typologies of user were directly extrapolated from the context and grouped in four macro categories:

- (D) Driver: it is the primary user that interact with the vehicle most than other categories because it drives the vehicle. The interactions with the vehicle occur inside the vehicle, in particular interacting with the vehicle controls during driving. The use of the car happens in two different contexts: urban roads and racing tracks. This category has wide range of users with diverse levels of driving ability who may necessitate different requirements based on the context of use. Often the driver is the owner who drives the vehicle in both contexts, but also it could be an individual who looks only for a racing experience. In this case the user can rely on the practice of renting provided directly by the carmakers or by the track-day organizers. The user can be addressed also to professional drivers such as racing pilots or driving instructors who rides the vehicle with different purposes. Considering this, the sub-categories are:

Img. 46 • The four main typologies of user that were identified in this research

- Owner: it is the most important user because it is the one who buys and individually owns the vehicle under many different purposes: pure and racing driving experience, *status quo*, car collection and so on. It is a very car enthusiast with good economic resources who can be a novice, intermediated or advanced driver. The vehicle is used mainly used on urban roads but it is prepared also for track-day events.
- Novice driver: the user is a car enthusiast and it is not a beginner driver who enjoys the vehicle driving it predominantly on racing tracks. The user usually owns the car, but often it prefers to use the practice of renting because of the high cost of the vehicle. It also prefers to participate in a racing series usually organized by the vehicle companies or track organizers.
- Advanced driver: usually, It is an enthusiast driver who is related to the racing competitions. This category includes also the driving instructor who uses the car for use for teaching driving skills. In any case, the user is a skilled and professional driver and it aims to use the vehicle mostly or exclusively in racing tracks. The user can be either the owner or the holder of the vehicle.
- Racing pilot: it drives the vehicle only in racing tracks and only under extreme conditions. It has a high driving experience and often it is not the owner of the car but rides those ones provided by the vehicle companies or track organizers.

- (T) Technician: it is the secondary user who interacts with the vehicle from an engineering point of view. The user is an expert and skilled person in configuring the technical and engineering characteristics of the car during racing activities. Indeed, the interactions with the vehicle occur mostly in racing tracks and when the vehicle is stationary. The primary user's task is to set up the vehicle, its performance or its dynamic configuration according to the drivers' needs or purposes. The user supports also the drivers during competitions analysing and evaluating their driving performance. It always works in team. This type of user involves different sub-categories:
  - Team manager: it is the leader of the racing team. It is responsible for both managing all member of the team and for making strategical decisions during a track-day or racing event. It interacts with the vehicle though electronic tools to monitor vehicle's and driver's performance.
  - Race engineer: it is an expert highly specialized in mechanical or electronics engineering who is responsible for monitoring the parameters of the vehicle performance during its use. It interacts with the vehicle though mechanical or electronic tools.
  - Mechanical technician: the user is a highly specialized mechanical engineer implicated in setting and maintaining the vehicle during racing use. It interacts with the vehicle though mechanical or electronic tools.
  - Tyre specialist: it is responsible for tyres management. It helps the driver to check the tyres conditions and to improve their performance.
- (O) Operator: it is a minor user who interacts with the vehicle from a technical point of view as the technician but it is not an expert engineer. It has only practical skills to produce, assembly, transport, maintain or repair the vehicle at different stages of its life cycle. Usually, the user belongs to the car company and it is used to work in team. The interactions occur with the mechanical parts of the car, mostly inside the company's factory (before sales), but also during logistics or among the traditional factories located in the urban context. Different sub-categories of this user are:
  - Manufacturer: it is an employer of the company and it is responsible for the vehicle's parts manufacturing.
  - Installer: it is another employer of the company and it is responsible for the vehicle assembly.
  - Truck driver: the user is responsible for the logistics of the vehicle at different stages of its life cycle. It is implicated in transporting the car for sales but also for track-day or racing events.
  - Mechanic/repairer: it is the user who repairs and maintains the vehicle during its use. It interacts with the vehicle in an urban context.
- (S) Stakeholder: it is the user who relates to the vehicle at the early stages of the vehicle because it represents the decision-maker of the vehicle development program. Often, it is a member of the company or it may be an external consultant, but both work together and intervene in the project during the concept phase. It interacts with the vehicle defining its development strategy with other experts and members of the project. The needs of this category are important to find many trade-offs between the marketing and/or legislative requirements and the needs of the other categories. The typology of this user involves different sub-categories:
  - Program manager: it is the head of the vehicle development program. It knows all technical and strategical requirements of the company and it coordinates all the teams involved in the project. It also makes the final decisions for accomplishing the goal of the company.
  - Commercial director: the user is responsible for marketing.
  - Technical director: it is responsible for vehicle engineering.
  - Chief designer: it is responsible for vehicle styling.
  - R&D officer: the user is responsible for the research and develop-

ment area, which helps the project to introduce new technologies in future vehicles.

5.3 Needs analysis

Once the main users were identified, the research activities focused on the analysis of their needs. In psychology, the lack of one or more elements that constitute the personal level of well-being is considered a need. The latter has a different nature in base of people's motivations. The Maslow's hierarchy of needs (Maslow, 1954) is a generalised model for understanding the variety of those needs. The approach identifies a hierarchy of five sets of basic needs: (a) physiological; (b) safety; (c) love/belonging; (d) esteem; (e) self-actualization. Nowadays, most of the needs come directly from people's desires, which are usually backed by the economic system to increase the concept of demand. In this case, the needs can be easily called wants because they refer not essentially to a human necessity but simply to something that a person would like to have (Quester et al., 2007).

5.3.1 Typologies of needs

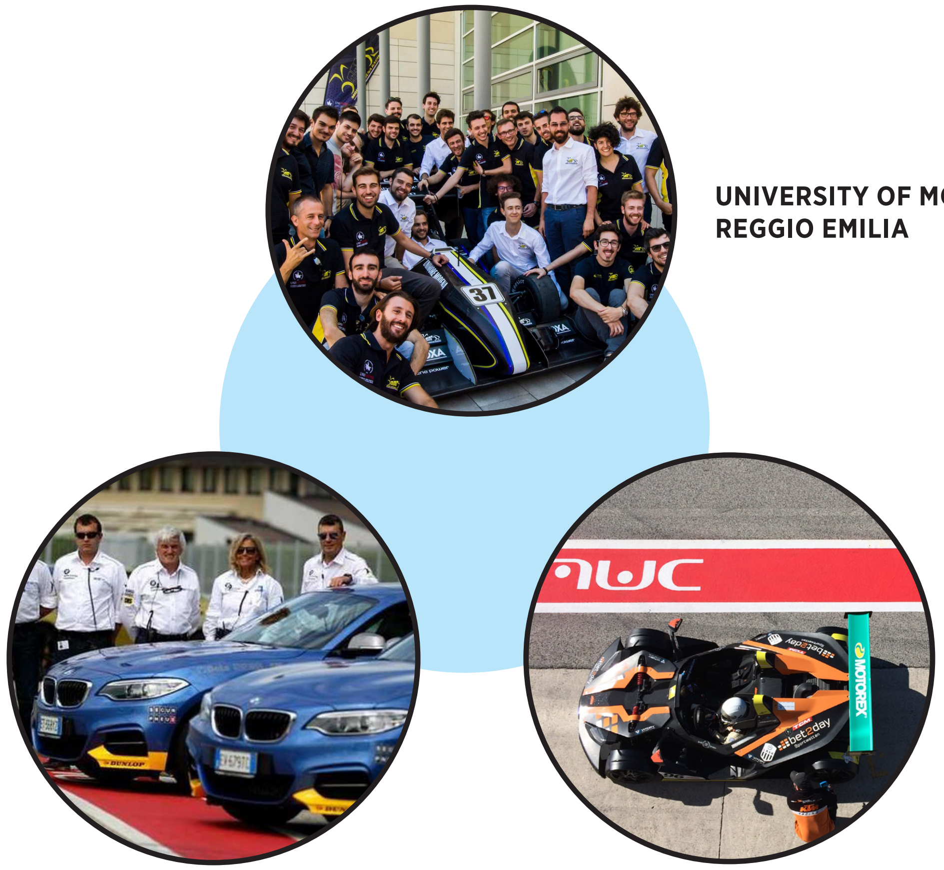
Discovering the right problems is a difficult operation because every user gives the same need or want different importance in relation to its motivation or its priority. Sometimes, the users are completely not aware of most of their problems or they are not able to recognize them. For this reason, HCD supports the research in understanding the right problems that come from the analysis of users' needs. For facilitating this operation, HCD classifies the nature of the needs in three main classes – which derived from the Kano's costumer preferences classification theory (Kano, Seraku, Takahashi, & Tsuji, 1984) – to better understand those are more important to face up during the design process in order to produce a substantial innovation (Gharajedaghi, 2011; Mincolelli, 2008a):

- Implicit needs: users do not care about them because they are taken for granted. Users typically remain indifferent in front of them because they do not increase the quality of the product. Vice versa these needs are fundamental to be included and maintained in every project because without them it may possible to create a decrease of the entire satisfaction of users;
- Explicit needs: users have direct awareness of them because user are able to autonomously list them or recognize them after answering either questions or specific suggestion about their necessities. These needs are the main frame of a product because affect positively or negatively the satisfaction of final users;
- Latent needs: Users have this need but they are not yet aware of their presence. Usually they are perceived more as a frustration than a necessity, because market is not able to satisfies them. These needs are always hidden under critical behaviours or habits that create dissatisfaction inside users. They are difficult to find but they are the most important insights for the final product as they can be a breakthrough both for its evolution and for its perceived quality.

Considering this, geography and time can affect positively or negatively a specific need or want (Franceschini, 2001). In the first case, a need may be perceived differently by changing the cultural context. Whilst, in the second case, a need may vary its importance according to future cultural and sociological changes over time.

5.3.2 Practical methods

The analysis of needs is an important phase of the research because it supports the project in evolving in the right direction as it directly points on satisfying user demands. Identifying needs is a hard task and for this



Img. 47 • The three principal groups that were used to gather user requirements.

reason, many methods, which raised in the field of applied ethnography over the years, have been developed to facilitate this practise. Following the synthesis delineated by Saffer (Saffer, 2009) the most common approaches can be essentially synthesized in three main typologies:

- Observation: It is the easiest of all design research methods and it permits to uncover hidden meaning in the observed behaviours (Kolko, 2011). It is used to simply observe what people are doing in a conscientious manner. This method helps a research to watch or interact with people or tag along with subjects to ask them questions about how and why they are doing what they are doing (Beyer & Holtzblatt, 1998).
- Interviews: Talking to people and hearing their stories is one of the

common practises to gather information about user needs and is a great way to uncover attitudes and experiences of people (Baxter & Courage, 2005). It is important to be careful in determining what people say they do and what they actually do because people sometime are not completely aware of their real needs.
- Activities: it is a recent trend in design research because the activities include not only to observe and talk to users, but also to involve them in making tangible things (Sanders & Stappers, 2008). This process, named Co-Design, allows a research to draw out emotions and understand how people think about a subject with practical actions (F. Rizzo, 2009). Doing activities frees subjects' creativity and allows them to express themselves differently than they would in an interview (Sanders, 2000; Sanders & Dandavate, 1999).

Whatever the method is, each technique is able to gather significant data from people that are useful to satisfy their demands. Moreover, for improving those activities, the human-centred approach must also include empathy, the personating act of socializing with people that helps the research to catch many inspiring ideas through the comprehension of the users' experiences and emotions (Brown, 2015).

5.3.3 Groups of analysis

Regarding this research, the analysis of needs was conducted involving various users by using the first two methods described in the previous section: observation and interviews. In particular, the analysis selected three main groups of people in order to offer wider variety of needs to the entire research **Img. 47** •. Each group corresponds to the categories of users that were previously selected for this project:

- University of Modena-Reggio Emilia: Since the university is the coordinator and one of the partners of this project, the analysis involved many professors and students related to the SAE Formula Student who participated in the same research. The activities gathered several needs from a technical point of view and helped the research to improve the engineering knowledge of the research. The people involve were:

- (a) Professors Francesco Leali and Matteo Giacopini (responsible for the Formula Student research centre) who delivered the brief of the overall project;
- (b) The laboratory of aerodynamics coordinated by Professor Enrico Stalio and the researcher Andrea Fregni, which provided information on aerodynamics applied to the vehicle;
- (c) The laboratory of virtual engine simulation, coordinated by the Professor Matteo Giacopini and the colleague of the second work package Valerio Mangeruga, which offered information on the powertrain system;
- (d) The MilleChili research laboratory, coordinated by Professor Sara Mantovani, which provided many data about the dynamics and safety of the vehicle body;
- (e) The Professors Stefano Carmassi and Franco Cimatti who reported considerations on the vehicle architecture and packaging;
- (d) The three student teams of the SAE Formula Student, which provided information in different aspects of the vehicle, from the technical needs of the technicians to the driving needs of the racing pilots. The three groups are: Combustion team, coordinated by Giacomo Giunchi (team leader) and William Zanin (chief aerodynamicist), which offered their experiences during the SAE's racing events; Hybrid team, coordinated by Elisabetta Pellegrino, which provided information on hybrid and electric system applied on automotive; Driverless team, coordinated by Valerio Aquilani, which delivered information on the Advanced Driver Assistance Systems;

- Guidare Pilotare: it is an advanced driving school coordinated by the ex-racing pilot Siegfried Stohr and sponsored by the BMW Driving Experience's driving programmes. The analysis gathered several data directly from the many experiences of the driving instructors. The investigation concerned in conducting direct interviews with the drivers and performing many observations during their driving activities in the real context. Most of the activities were performed thanks to the availability of the director Siegfried Stohr, the driver instructors Luca and Mattero Drudi, and moreover of the precious support of the responsible for the mechanic team Nicholas Manzaroli.
- KTM X-Bow-Battle: it is the most important group of users the research because refers to a racing series organized annually by KTM company, one of the selected companies that have been used to delineate the current state-of-the-art of the presented thesis. The investigation permitted to gather significant data specifically to the user target and directly in the right track-day context. The activities were conducted through direct interviews with both drivers and technicians but also through the observation of the users during their tasks.

5.3.4 Case study: KTM X-Bow-Battle

The X-Bow-Battle is an annual and mono-brand track-day series completely based on the X-Bow model and entirely organized by the KTM company. The KTM offers this facility to its own clients and to all of the people who are interested in this particular events to promote and extend the use of its sports vehicles in racing contexts. The series is international and it involves several racing tracks scattered in Europe. The series is open to different typologies of drives (novice, intermediated and advanced) but it is essentially divided in three categories according to the variants of the X-Bow model:

- (a) Rockie: it is the entry-level category that uses the standard X-Bow and it refers to private clients (owners and holders) who have no racing teams;

- (b) Elite: the category involves private teams that use a higher powerful variant of the X-Bow specifically prepared for track-day. This typology presents private teams or others offered by KTM through the practice of renting;
- (c) GT4: it is the most extreme category that refers to the X-Bow GT4, a high-performance model exclusively designed for racing purposes, especially for the international FIA GT4 championship. The category is populated both by private teams and others offered by KTM through the practice of renting. The series is mostly addressed to advanced drivers or racing pilots who use this event for training.

Considering this, the activity of data gathering was performed within one of the KTM's events, in particular during the Italian stage. The event lasted three days from the 27th to 29th of September 2018 and it was held at the MWC (Misano World Circuit), Misano (Province of Rimini), Italy. The investigation was allowed by the availability of the main organizers Georg Silbermayr (the coordinator), Birgit Kampl (event management director) and Manfred Wolf (international media manager) who freely opened the access to the entire pit-lane, in order to facilitate the interaction with the primary users in a real context of use. Observation and direct interviews were the main approaches for gathering data from people's activities. Conducting the analysis consecutively for three days permitted also to understand the typical user experience journey of each user, which consequently unveiled both their criticalities and satisfaction in every phase of the racing event. Observation, especially photo reporting, was the most fruitful practices of the overall research phase. Those approaches permitted also to produce a parallel visual analysis of the needs **Img. 48** •, as they were significant for capturing the ways of interacting

Img. 48 • Photo reporting of the primary users during the X-Bow-Battle event at the Misano World Circuit, Misano (Rimini), Italy (27-28-29th of September 2018). The activities were utilized to capture numerous users' behaviours, which in turn were translated in the form of needs.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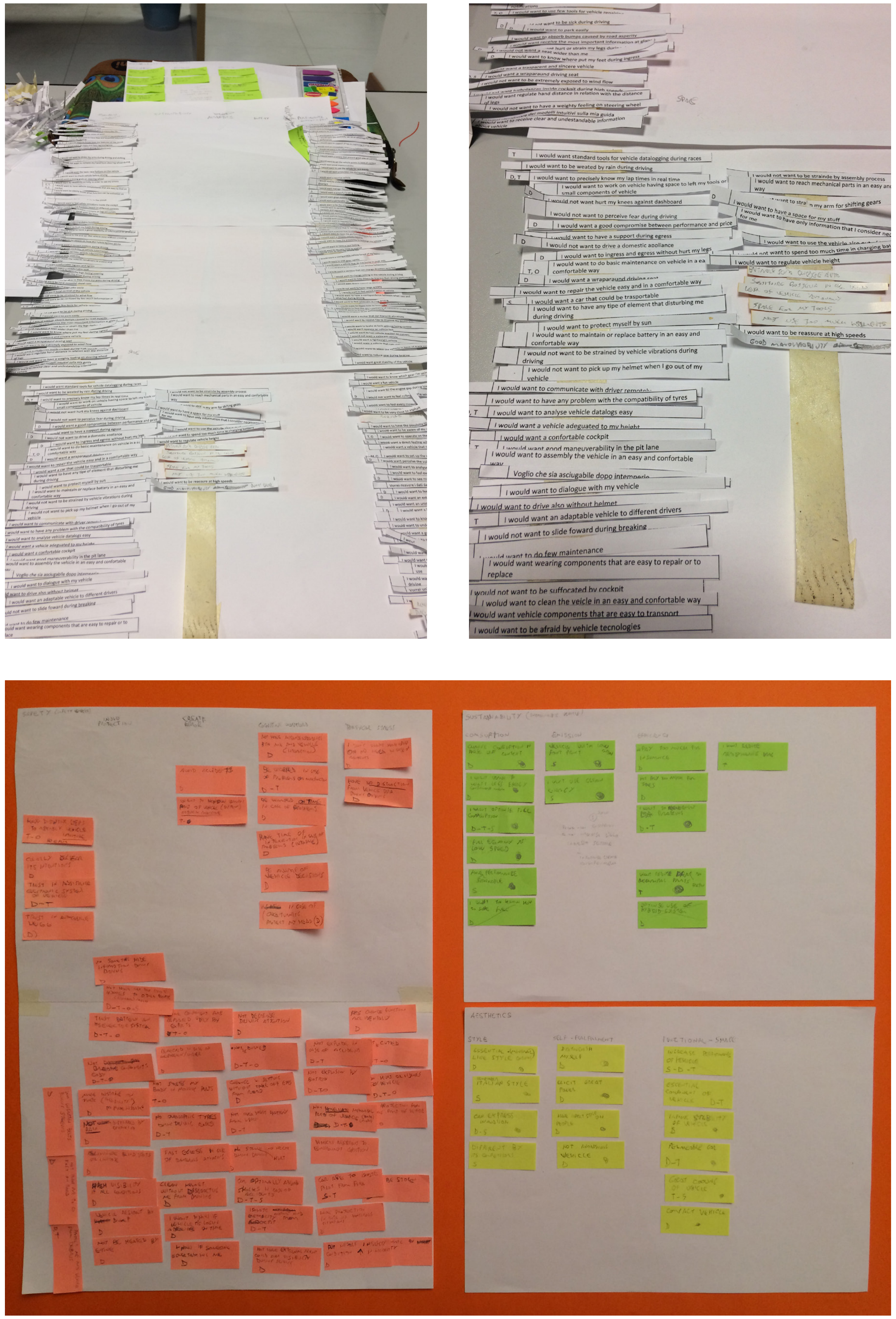


Img. 49 • Representation of the data analysis that was utilized to interpreter the raw, which derived from insights of the main users and their behaviours, into verbal expressions. Data were undergone to an abstraction process to eliminate any early indication on the expected product.

whit the vehicle that would have been difficult to represent in the form of speaking (Brown, 2015; Sanders & Dandavate, 1999).

5.3.5 List of needs

After the activities of data gathering, every raw information derived from the insights of each user group was interpreted and transformed into verbal expressions. Each of them represented a specific user need in the form of a short sentence. This operation was significant to clarify what needs were more important for the development of the research, especially for Quality Function Deployment. In order to facilitate this practice, each needs or want to avoid the anticipation of any potential design solutions because they can affect or compromise the overall decision-making process (Mincolelli, 2008a). Indeed, anticipating design solutions can produce preconceptions already in the early stages of the design process. For this reason, the verbal expressions were undergone to an abstraction process, namely to a technique capable of expressing only moods, wishes and feelings of users in few words, eliminating at the same time any indication about technical characteristics of the expected artefact (Maritan, 2015).

During data processing, about 200 needs were identified and listed based on the four examined user categories **Img. 49** •. Some expressions that reported a similar requirement were merged in a single sentence. The classification was useful to understand the most representative category but also to know whether the distribution of the needs covered all of the typologies of users. Some needs or wants were assigned to multiple categories because were indicated by more than one typology of the user. At the end of the process the needs were:

000	D	I do not want to be strained by vehicle vibrations
001	D	I want to have nimble handling
002	D	I want to have great reactivity in changing direction
003	D	I want to have immediate response to my commands
004	D	I do not want continuously contrasting the vehicle behaviours
005	D	I do not would to hurt my legs against leg room during turning
006	D	I want to have a strong grab on steering wheel
007	D	I do not want to remove my hands on steering wheel
008	D	I do not want to perform weighty driving operations
009	D	I want to have total control on driving actions
010	D	I want to be direct connected to the wheels
011	D	I want to rapidly realign the vehicle in case of adherence loss
012	D	I want to make driving mistakes
013	D	I do not want to accidentally unfasten belts
014	D	I do not want to strain my arms caused by driving
015	D	I want to feel the sensation of shifting gear
016	D	I want to shift gear also on curves
017	D	I want to shift gear rapidly
018	D	I want to feel every behaviour of vehicle
019	D	I want to feel adrenalin during driving
020	D	I want to have a race driving experience
021	D	I want to perceive a safety sensation during driving
022	D	I want to be sick by vehicle motion
023	D	I do not want to have a feeling of suffocation
024	D	I want to protect myself by sun
025	D	I do not want to be extremely wet by rain
026	D	I want to have a comfortable seating position
027	D	I want to customize my driving seat
028	D	I want to have an interior space easy to clean
029	D	I want to be wrapped by driving seat
030	D	I want to have a adequate to my height

031	D	I want to have a restraining cockpit
032	D	I do not want to obstruct my arms
033	D	I do not want to hurt my knees because of driving
034	D	I do not want to hurt my legs caused by pressure of steering
035	D	I do not want to scratch my heels because of driving
036	D	I do not want to be heated by engine
037	D	I want to be protected from debris
038	D	I want to protect my head in case of overturning
039	D	I want to protect myself in case of accident
040	D	I want to strain my neck in case of great deceleration
041	D	I want to rapidly exit from vehicle in case of dangerous situations
042	D	I do not want to hurt myself caused by ingress or egress
043	D	I want to enter or exit on my own
044	D	I want to clearly know how to enter or exit
045	D	I want to have a comfortable ingress or egress
046	D	I want to see at long distance
047	D	I want to have wide-range visibility
048	D	I do not want to have dirty visibility
049	D	I want to drive without helmet
050	D	I do not want to be stressed by wind turbulences
051	D	I want to perceive the volume of the vehicle
052	D	I want to high visibility in all environmental conditions
053	D	I want to eliminate blind spots
054	D	I want to keep me eyes on the road
055	D	I want to have total control of the vehicle on my hands
056	D	I do not want to decrease my driving attention
057	D	I want to recognise every function very fast
058	D	I want to adjust parameters during driving
059	D	I want to reach fast the driving commands
060	D	I want to change functions in base of my preferences
061	D	I want to have different driving styles based on context

062	D	I want to manage braking force
063	D	I want to set up traction control in base of context
064	D	I do not want to change driving functions accidentally
065	D	I do not want to be distracted during the interaction with vehicle functions
066	D	I want to have sincere and transparent vehicle
067	D	I want to be entertained during my trips
068	D	I want to know when the race finish
069	D	I do not want to obstruct the visibility of information
070	D	I do not want have misunderstanding with vehicle system
071	D	I want to be aware of vehicle decisions
072	D	I want to understand information very fast
073	D	I want to have information visible at glance
074	D	I would always want to know the state of vehicle system
075	D	I want to know which gear I'm using
076	D	I want to be aware about the state of vehicle autonomy
077	D	I want to see only the essential vehicle information
078	D	I want to intuitive forms of communication
079	D	I want to have great readability in all environmental conditions
080	D	I want to have essential visual cues
081	D	I do not want to be stressed by information workload
082	D	I want to be warned in time in case of malfunctions
083	D	I want to learn from my driving mistakes
084	D	I want to know every characteristic of the circuit
085	D	I want to analyse my driving behaviours in real-time
086	D	I want to know if I'm losing time laps
087	D	I want to understand if I have proper driving trajectories
088	D	I want to have a progressive thrust during throttle
089	D	I want a vehicle that transmits a powerful sensation
090	D	I want to feel the engine on my body
091	D	I want to hear the vehicle breathing like a lung
092	D	I want to be involved in driving

093	D	I do not want to drive a domestic appliance
094	D	I want to have power also on curves
095	D	I do not want to lose control during throttle
096	D	I do not want to have a nervous vehicle
097	D	I want to trust in battery efficiency
098	D	I do not want to be pushed to drive at high speed on the road
099	D	I want to isolate the vehicle in case of accident
100	D	I do not want to be worried by vehicle autonomy
101	D	I do not want to have range-anxiety
102	D	I do not want to be worried in finding charging places
103	D	I want to enjoy driving during small trips
104	D	I want to adapt energy consumption in base of context
105	D	I want to have a vehicle with predictable behaviours
106	D	I want to have a compact vehicle
107	D	I do not want to be brusque pushed in changing direction
108	D	I do not want to lose traction during turning wheels
109	D	I want reduce under steering and over steering
110	D	I want to brake at limit without losing control
111	D	I do not want to slide toward during braking
112	D	I want to brake powerfully at high speeds
113	D	I want to know how to save energy
114	D	I want to perceive the line of wind flow
115	D	I want to have balanced breaking forces
116	D	I do not want a vehicle that appears awkward
117	D	I want to be very close to asphalt
118	D	I want to have a vehicle that elicits great power
119	D	I want to have good compromise between price and performance
120	D	I do not want to pay too much for insurance
121	D	I want to have space for put my stuff
122	D	I do not want to pick up my helmet when I exit from vehicle
123	D	I do not want to have a vehicle that could be stolen

124	D	I want to have a vehicle with an essential style
125	D	I want to distinguish myself on the road
126	D	I want to shift gear at the right moment
127	D, T	I want to have power also at low RPM
128	D, T	I do not want to lose power during shifting gear
129	D, T	I want to feel a good thrust also at high speed
130	D, T	I want to feel fast acceleration
131	D, T	I do not to spend too much time in charging battery
132	D, T	I want to recover dissipate energy of the car
133	D, T	I want to park easy in the pit lane
134	D, T	I want to check the vehicle parameters before a driving section
135	D, T	I want to speak with my team on-board
136	D, T	I want to track the vehicle on circuit
137	D, T	I want to monitor driving behaviours for improving performance
138	D, T	I want to configure the vehicle according to track regulations
139	D, T, S	I want to maximise traction control
140	D, T, S	I do not want to overheat mechanical parts
141	D, T, S	I do not want to have dangerous situations caused by mechanics
142	D, T, S	I want to optimise energy utilization
143	D, T, S	I want to reduce pitching during breaking
144	D, T, S	I want a balanced vehicle
145	D, T, S	I want to perceive great stability on curved roads
146	D, T, S	I want to reduce rolling during cornering
147	D, T, S	I want to feel great adherence on road
148	D, T, S	I want to perceive lightness
149	D, T, S	I want to have great manoeuvrability on curved roads
150	D, T, S	I want to protect working parts from debris
151	T	I want to reduce unsprung masses
152	T	I want to refill the vehicle very fast
153	T	I want to have a great cooling efficiency
154	T	I want to improve the vehicle traction

155	T	I do not want to lose braking efficiency during driving
156	T	I want to change pilot fast
157	T	I want to monitor vehicle parameters remotely
158	T	I want to set up the vehicle tools for race
159	T	I want to analyse driving data easily
160	T	I want to regulate vehicle height
161	T	I want to adapt the vehicle based on track characteristics
162	T	I want to adapt the vehicle to different drivers
163	T	I want to set up the vehicle with few tools
164	T	I want to easily reach the parts to be configured
165	T	I do not want to create situations of tyres overlapping
166	T	I want to integrate race instruments on vehicle
167	T, O	I want to maintain tyres in optimal conditions
168	T, O	I want to move and assembly components without strain my body
169	T, O	I want to have adequate space to work
170	T, O	I want to easily reach mechanical parts
171	T, O	I do not want to lose small components of vehicle
172	T, O	I want to easy access to wearing elements for basic maintenance
173	T, O	I want to repair the vehicle without problems
174	T, O	I want to reduce wiring
175	T, O	I want to lift or set the vehicle without creating damages
176	T, O	I want to tow the vehicle fast in case of accident
177	T, O	I want to easily transport the vehicle
178	T, O	I want to optimise the space of transport
179	T, O	I do not want to be fulgurate by electricity
180	T, O	I do not want to be burned
181	T, O	I do not want to have injuries during working
182	T, O	I want to reduce costs of tyre compatibility
183	T, O, S	I want to have a vehicle made up of few components
184	T, O, S	I want to have spare components that are easy to find on market
185	T, S	I want to have a permeable vehicle

186	T, S	I want to support the boost lack of ICE at low RPM
187	T, S	I want to have every element as lower as possible
188	T, S	I want to reduce frictions
189	T, S	I want to avoid yawing during braking
190	T, S	I do not want to have great load on the vehicle overhangs
191	T, S	I want to absorb bumps caused by road asperity
192	T, S	I want to isolate the vehicle in case of dangerous conditions
193	T, S	I want to have a vehicle with great stiffness
194	T, S	I want to optimally absorb shocks in case of accident
195	O	I want to have few components to assembly
196	O	I want to have distinctive steps to assembly the vehicle
197	S	I want to have vehicle components that are hard to brake
198	S	I do not want to have a vehicle that creates injuries
199	S	I want to reduce the vehicle carbon footprint
200	S	I want to use clean energy
201	S	I want to have a vehicle resistant to environmental agents
202	S	I want to hide dangerous parts from people
203	S	I want to have a vehicle that expresses its innovation
204	S	I want to be different from my competitors
205	S	I want to have a vehicle related to the territory
206	S	I do not want to have an anonymous vehicle
207	S	I want to reduce vehicle taxes
208	S	I want to have a reliable vehicle

5.4 QFD process

Once the analysis of the users and their requirements was concluded, the list of every need was processed through the Quality Function Deployment. The human-centred approach transformed the qualitative data of the users' verbal expressions into design specifications in order to better

Img. 50 • The four selected vehicle systems that were elaborated with the QFD.

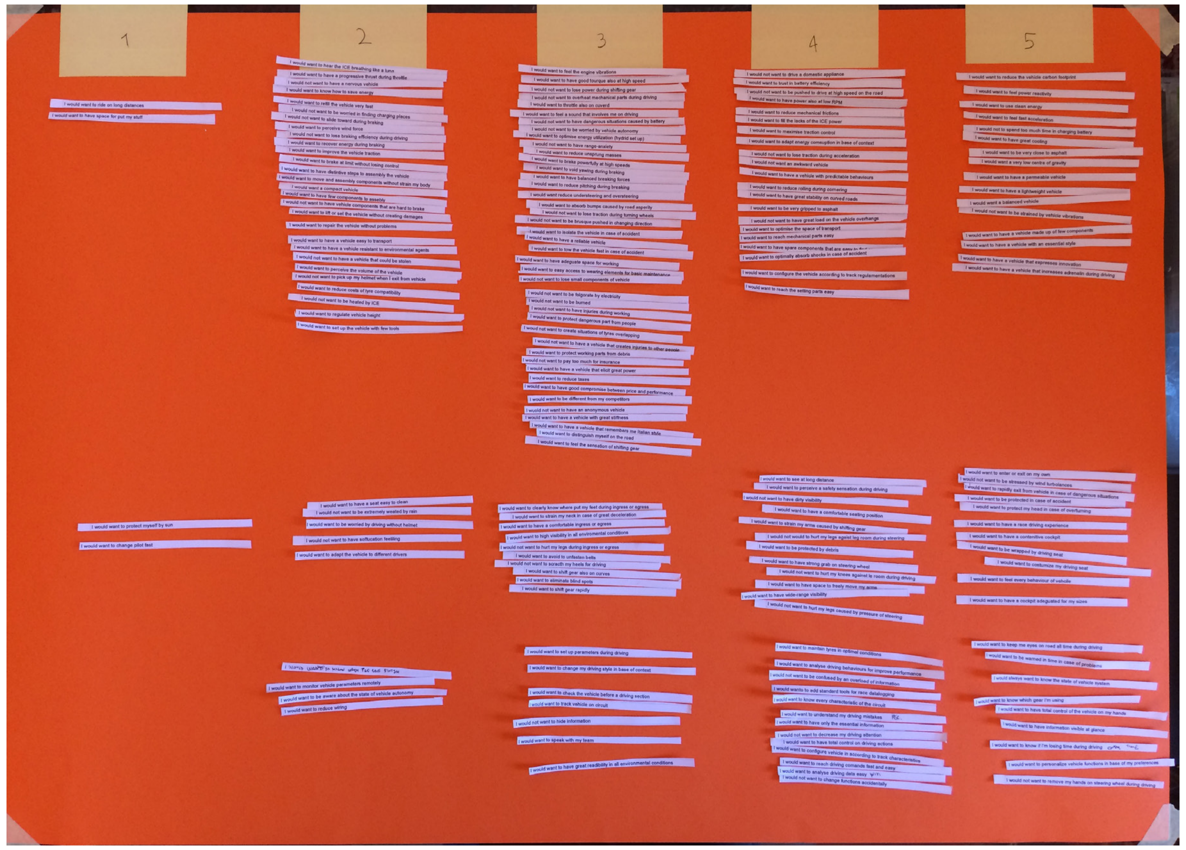
support the design process in developing the expected concept car through numerable variants.

Given the complexity of managing automotive design process but also given the divergence among some requirements of the users, the research grouped the needs in four main QFD matrices, which corresponded to four specific systems of the vehicle that was considered significant for satisfying the costumer demands. This choice is because reducing the quantity of the elements presented in a single relationship matrix allowed QFD to produce a easier management of its process and at the same time to elaborate a better quality of the expected results. The four selected vehicle systems **Img. 50 •** were: (a) vehicle structure; (b) powertrain system; (c) passenger package; (d) vehicle interface.

The first reason about this selection is because interactions between car and end-users occur more often within these areas. Secondly, the four systems can guarantee the success of the vehicle, because they are able to cover every aspect of product experience required by end-users in terms of styling, sustainability, safety, performance, comfort and usability. In the end, the use of the first two groups has expected to strategically support the engineering development of second (propulsion and powertrain) and third (vehicle body and dynamics) work packages of the research network, in order to offer to the overall project a human-centred point of view.

Since boundaries between each vehicle system are blurred, all considerations about the concept vehicle, which emerged during QFD, were interrelated to each other even though qualitative data of costumer demands were divided in the four matrices. In this way, the QFD method could solve many issues with few and efficient design solutions and, at the same time, could develop the concept car as a whole instead of thinking it only through every single system. In view of this, the list of user needs was divided and distributed in the four designated groups, one for each selected system of the vehicle. Each group selected the most important needs. Subsequently, the technical requirements of each QFD matrix were selected based on those specific needs that were related to a particular area of the car.

About 20-24 user needs for each vehicle system were selected to be processed within the QFD. Next, about 20-28 technical requirements related to the vehicle were chosen for each House of Quality, according to the level of correspondence with the desires expressed by end-users. The ranges



Img. 51 • Representation of the data analysis that was utilized to assign to every need its corresponding level of importance according to customer demands. Next, the needs were grouped in the four selected areas of the vehicle in order to be successively processed with QFD.

of both elements (user needs and product specifications) were deliberately restricted in order to better manage complexity of the four QFD matrices but also to improve quality of the outputs. Data of each QFD matrix were correlated together revealing the most important design specifications which they were taken into account to design the concept vehicle.

According to the QFD process, every sentence received quantitative value that corresponds to its level of importance according to costumer demands **Img. 51 •**. For this research the rating was: 5 = indispensable; 4 = very important; 3 = important; 2 = preferable; 1 = negligible. Successively, corresponding design specifications were chosen based on people requests and every relation received a value based on its strength. The rating scale was: 9 = strong relation; 3 = medium relation; 1 = weak relation; 0 = no relation. The relationships were weighted according to the considerations expressed by end-users.

5.4.1 Design invariants

Design invariants are the technical or legislative aspects that must be included during the development process for the successful final project (Mincolelli, 2008a). Usually, design invariants are linked to external regulations, standards or laws or they are associated with internal specifications (Bhise, 2013). The omission of those aspects may reject the market's acceptance of the expected project. Whilst, every oversight may cause delays or limits in production, loss of time or internal resources, or the failure of the company objectives (Bhise, 2017). Therefore, it is important to consider the design invariants during the early stages of the project because they facilitate the decision-making process for designing an adequate solution that corresponds to those requirements.

Regarding this research, an automotive product requires a high number of design invariants. Many regulations are mostly related to road safety, but other restrictions are linked to environmental pollution in terms of fuel consumption and carbon emissions footprint. Particular attention is also focused on both ergonomics of the passenger package and on Human-Machine Interaction to improve the driver's comfort and prevents potential errors or distractions while the driver is interacting with the in-vehicle system during driving (Gkikas, 2013; Ho & Spence, 2008). Besides, some variant constraints may come from the company's brief, product strategy, expected goals, limited number of intern resources, technologies or other external factors such as the status both of world economy or the reference of its suppliers or its competitors (Bhise, 2017).

Since the vehicle is a complex system, the argument about the design invariants is very huge and complex to being covered in this thesis, but it is

important to consider during the design process in order to simplify the development of the final concept vehicle. Hereinafter, the research presents an overview of the main design invariants that are important for this research. Those considerations are related to the four selected vehicle areas elaborated through the QFD process.

Many constraints are linked to the objectives of this research. As described in the previous chapters, this research aims to develop a road-legal track-day car, which must be equipped with a hybrid layout system. The primary contexts are urban roads and racing tracks. The vehicle must be characterized both by high performance and efficient and sustainable solutions in terms of fuel consumption and carbon emissions. The concept must also provide to the drivers a playful experience, which in turn must be accessible to a wide range of users' driving capabilities.

Instead, other external constraints address to the uniform system of regulations, which has been designed for facilitating international trade. These requirements are regulated by the working party called World Forum for Harmonization of Vehicle Regulations provided by the Stainable Transport Division of the United Nations Economic Commission for Europe (UNECE)[1]. In North America those requirements are regulated by the Federal Motor Vehicle Safety Standards (FMVSS) of the National Highway Traffic Safety Administration (NHTSA)[2] and the Canada Motor Vehicle Safety Standards (Mastinu & Ploechl, 2013).

Safety and crashworthiness test the minimum safety performance requirements for vehicles. It is important that the vehicle must be able to pass several crash tests protecting the passengers against risks of death

[1] UNECE reports its regulations in https://www.unece.org/trans/main/welcwp29.html
[2] The safety standards of NHTSA are in https://icsw.nhtsa.gov/cars/rules/import/FMVSS/

or injury in case of accident. Safety performance of the vehicle is verified through: frontal test, rear test, side impact, pole test and pedestrian test (Mastinu & Ploechl, 2013). Environmental compatibly is more related to the reduction of CO2 emission and the improvement of the fuel economy. For increasing these standards to protect the environment, the requirements are manly controlled in Europe by European emission standards and in North America by the Canadian Environmental Protection Act (CEPA) and the Environmental Protection Agency (EPA) (Bhise, 2017).

The regulations related to the ergonomics of the vehicle package and the human factors of the in-vehicle systems are mainly supported by several standards provided both by the Society of Automotive Engineers (SAE)[3] and by the International Organization for Standardization (ISO)[4]. The main aspects, which are considered by SAE and ISO standards, are related to: vehicle dimension, occupant packaging, passenger seating, field of view, driver vision model, ergonomics on human-systems interaction, lighting and ingress/egress of the car (Bhise, 2016; Harvey & Stanton, 2013).

Since the vehicle is addressed to track-day, the research can also consider other guidelines that derive from FIA GT4. Those regulations, indeed,

[3] Some of the most important regulations are: J222: front position lamps; J287: driver hand control reach; J578: colour specification for electric signal lighting devices; J585: tail lamps; J587: license plate illumination devices; J588: stop lamps; J826: devices for use in defining and measuring vehicle seating accommodation; J941: motor vehicle driver's eye locations (eyellipse); J1050: describing and measuring the driver's field of view; J1052: motor vehicle driver and passenger head position; J1100: motor vehicle dimensions; J1517: driver selected seat position for class B vehicles - seat track length and SgRP; J2364: navigation and route guidance function accessibility while driving; J2365: calculation of the time to complete in-vehicle navigation and route guidance tasks;J2650: performance requirements for light emitting diode (led) road illumination devices; J4004: positioning the h-point design tool - seating reference point and seat track length. The SAE standards are reported in https://www.sae.org/standards/

[4] Some ISO standards are correlated to SAE regulations and they are described in https://www.iso.org/standards.html

can extend the use-range of the vehicle for official racing series as well, consequently expanding its viability to a wider customer demand linked to the same specific market. In this case, FIA GT4 regulations[5] refer to the technical properties of the vehicle to guarantee the sporting homologation. Those invariants take into account also the minimum level of sales to prove that the car is designed not only for racing purposes, but it is intended also for public roads as long as the government regulations are met.

5.4.2 Vehicle structure

The first QFD matrix referred to the vehicle structure. The matrix was important to recognize the most important characteristics of the car's body style and dynamics to guarantee an adequate size of the overall vehicle, an efficient aerodynamic shape, good handling and the correct level of craftsmanship that will be perceived by end-users during the interaction with the vehicle.

5.4.2.1 Vehicle structure: user needs

The selected needs of the first QFD matrix are:

N01	**001**	**D**	**Driving**	**I want to have nimble handling**
Drivers want a high level of driveability and handling to guarantee an easier and faster manoeuvrability. Drivers want also direct control on the vehicle and an immediate correlation between the driving actions and the vehicle response.				
N02	**002**	**D**	**Driving**	**I want to be direct connected to the wheels**
Drivers require great sensibility on driving controls to feel every movement of the car and to have adequate time to respond to that behaviour.				
N03	**004**	**D**	**Driving**	**I do not want continuously contrasting the vehicle behaviours**

[5] Information about the FIA GT4 technical regulations are described in https://european.gt4series.com/gb_en/regulations

The users want a predictable vehicle, which can be easy to control and fun to drive so that they are not stressed or strained by its dynamic behaviours.				
N04	008	D	Driving	I do not want to perform weighty driving operations
The drivers want light handling, which must not require high effort from them while they are performing driving operations for long periods of time.				
N05	092	D	Driving	I want to be involved in driving
Drivers want to be directly involved by the vehicle into a racing driving experience in terms of aesthetic, emotional, sensory sensations.				
N06	103	D	Driving	I want to enjoy driving during small trips
Since the expected vehicle must be road-legal, the drivers want a car that provides a comfortable and pleasant experience of travelling for long distances.				
N07	117	D	Driving	I want to be very close to asphalt
Drivers want to experience the racing driving configuration by sitting in a very low driving position in order to perceive also the dynamics and the adherence of the vehicle.				
N08	145	D, T, S	Driving	I want to perceive great stability on curved roads
The users want a balanced and nimble vehicle, which is able to provide great adherence on the road.				
N09	110	D	Performance	I want to brake at limit without losing control
The drivers require a balanced and powerful braking system that must not compromise the vehicle dynamics during its use.				
N10	153	T	Performance	I want to have a great cooling efficiency
The users want to maintain the temperature of the powertrain system in an efficient condition in order to always deliver high performance.				
N11	155	T	Performance	I do not want to lose braking efficiency during driving
The users want to maintain the temperature of the braking system in the optimal efficiency range.				
N12	185	T, S	Performance	I want to have a permeable vehicle
The users require great aerodynamic efficiency in terms of downforce and drag reduction				

N13	089	D	Styling	I want a vehicle that transmits power sensation
Drivers want a powerful and racing oriented vehicle styling.				
N14	114	D	Styling	I want to perceive the line of wind flow
Drivers want to benefit the open roof configuration of the vehicle to perceive the wind force, which in turn must deliver a pure driving experience. Aerodynamics must be also perceived through vehicle styling.				
N15	116	D	Styling	I do not want a vehicle that appears awkward
Drivers want a proportional vehicle, which can be perceived as a nimble vehicle. Moreover, they want a shape that must not affect the dynamic performance of the car.				
N16	124	D	Styling	I want to have a vehicle with an essential style
Since users focus their attention purely on driving, they require an essential vehicle styling, especially for the interior, which features a simple and clean configuration devoted to having fun.				
N17	125	D	Styling	I want to distinguish myself on the road
Drivers want an original vehicle styling, which can be easily recognizable on the road and can be distinguished from the other competitors.				
N18	148	D, T, S	Styling	I want to perceive lightness
Users want to perceive the lightweight through a combination of aesthetic line that compose the bodywork (for example aerodynamics), materials of components and technical performance provided by dynamics.				
N19	203	S	Styling	I want to have a vehicle that expresses its innovation
Users want to perceive the innovation elicited by the hybrid system through its form.				
N20	205	S	Styling	I want to have a vehicle related to the territory
The users want to have a particular a tight relation with the surrounding territory (Emilia Romagna) in terms of vehicle styling.				
N21	169	T, O	Optimization	I want to have adequate space to work
Technicians and operators want to easily reach and access to the mechanical parts of the vehicle so that they can operate on those components without stress.				
N22	178	T, O	Optimization	I want to optimise the space of transport

Since the type of car is often used for racing purposes, the users want a compact vehicle that can be easily packed and transported with a truck.

5.4.2.2 Vehicle structure: relevance of needs

The list of the relevance assigned to the selected needs is:

5	N01	001	D	I want to have nimble handling
5	N12	185	T, S	I want to have a permeable vehicle
5	N13	089	D	I want a vehicle that transmits power sensation
5	N19	203	S	I want to have a vehicle that expresses its innovation
4	N02	002	D	I want to be direct connected to the wheels
4	N05	092	D	I want to be involved in driving
4	N07	117	D	I want to be very close to asphalt
4	N10	153	T	I want to have a great cooling efficiency
4	N14	114	D	I want to perceive the line of wind flow
4	N18	148	D, T, S	I want to perceive lightness
4	N20	205	S	I want to have a vehicle related to the territory
3	N03	004	D	I do not want continuously contrasting the vehicle behaviours
3	N04	008	D	I do not want to perform weighty driving operations
3	N06	103	D	I want to enjoy driving during small trips
3	N08	145	D, T, S	I want to perceive great stability on curved roads
3	N11	155	T	I do not want to lose braking efficiency during driving
3	N15	116	D	I do not want a vehicle that appears awkward
3	N16	124	D	I want to have a vehicle with an essential style
3	N21	169	T, O	I want to have adequate space to work
3	N22	178	T, O	I want to optimise the space of transport
2	N09	110	D	I want to brake at limit without losing control
2	N17	125	D	I want to distinguish myself on the road

5.4.2.3 Vehicle structure: technical design requirements

The corresponding technical design requirements, which were chosen for

the first relationship matrix, are:

T01	**Wheelbase**	**cm**
It is the longitudinal distance between front wheel axle and rear wheel axle.		
T02	**Track**	**cm**
It is the distance between two the centreline of two wheels on the same axle.		
T03	**Height**	**cm**
It is the height of the entire vehicle. It affects the centre of gravity of the car.		
T04	**Ground clearance**	**cm**
It is the space between road and the base of the vehicle.		
T05	**Wheel diameter**	**Diameter**
It is the diameter of the wheel.		
T06	**Energy storage volume**	**LxWxH**
It is the space dedicated to storing the energy to supply the engine or the motor.		
T07	**Propulsion package**	**LxWxH**
It is the area dedicated both to the engine and the motor system.		
T08	**Passenger package**	**LxWxH**
It is the volume dedicated to the cockpit.		
T09	**Cargo package**	**LxWxH**
It is the usable space dedicated to cargo space.		
T10	**Weight**	**Kg**
It is the weight of the entire vehicle.		
T11	**Weight balance**	**%**
It is the weight distribution on the longitudinal axis. It affects the centre of the mass.		
T12	**Thrust force**	**N/m**
It is the acceleration or reaction force that the vehicle use to move itself on the road.		
T13	**Braking force**	**N**
It is the braking power necessary for stopping the vehicle.		
T14	**Lateral force**	**G**
It is the acceleration or deceleration force that the vehicle produces during cornering.		
T15	**Turning radius**	**Angle**

It is the angle that the steering wheel that is used to steer the wheels in relation to the smallest circular turn that the vehicle is capable of making.		
T16	**Suspension stiffness**	**N/m**
It is the force of the suspension to keep the wheels in contact with the road.		
T17	**Aerodynamic drag**	**Cx**
It is the resistance of the vehicle to overpass the surrounding air flow.		
T18	**Downforce**	**Cz**
It is the downwards thrust created by the aerodynamic characteristics of the vehicle.		
T19	**Surface acuteness**	**Angle**
It is the level of acuteness impressed on the edges of the vehicle bodywork.		
T20	**Border radius**	**Angle**
It is the calculation of smoothness related to both the sides and the angles of the vehicle bodywork.		
T21	**Tangent continuity**	**Degree**
It is the continuity between two curves that have the same radius of curvature at specific point of the vehicle shape.		
T22	**Colour**	**THz**
It is the electromagnetic radiation that is visible to the human eye.		
T23	**Material reflection**	**RΩ,v & RΩ,λ**
It is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated.		
T24	**Surface roughness**	**µm**
It is the touch feel provided by the surface of the bodywork.		
T25	**Material stiffness**	**N/m**
It is the resistance force to deformation in response to an applied force.		

5.4.2.4 Vehicle structure: outcomes and design guidelines

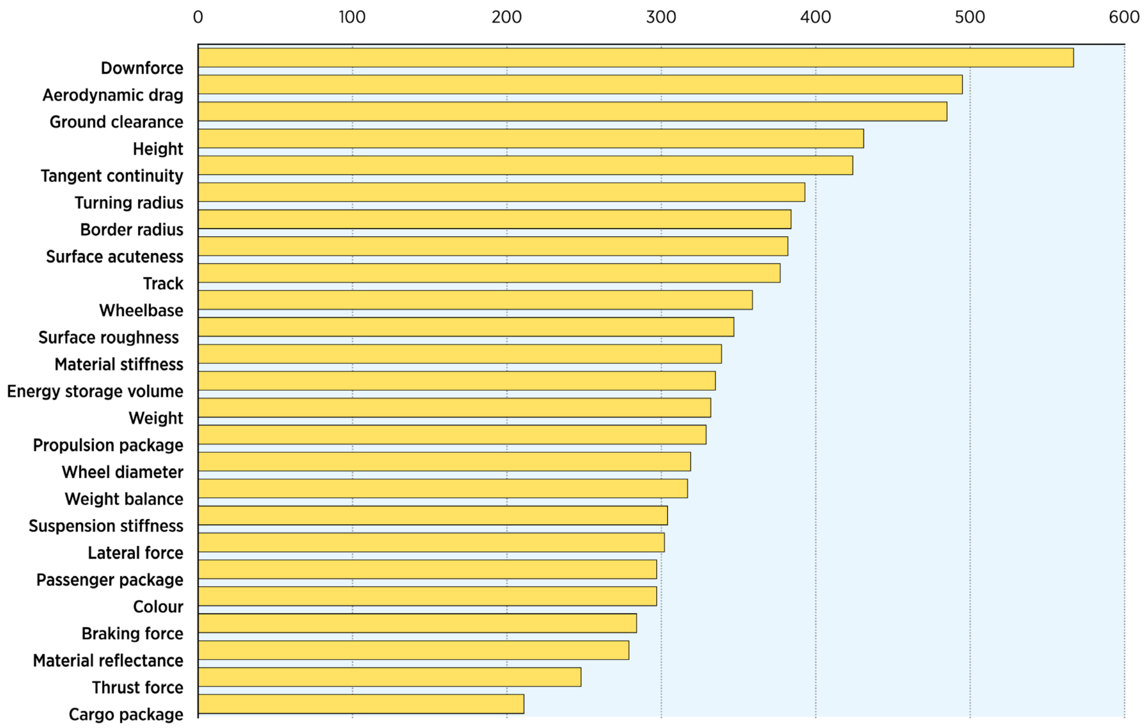
The first QFD assessment **Img. 52** • shows that the most important design specifications – associated with the vehicle structure – are linked to aer-

Img. 52 • QFD matrices and technical benchmarking of the vehicle structure.

			Weight of needs	% Weight of needs	Wheelbase	Track	Height	Ground clearance	Wheel diameter	Energy storage vol.	Propulsion package	Passenger package	Cargo package	Weight	Weight balance	Thrust force	Braking force
D	001	I want to have nimble handling	5	6%	9	9	9	9	9	3	3	3	3	9	9	3	3
D	002	I want to be direct connected to the wheels	4	5%	3	3	9	9	9	1	1	3	1	3	9	9	9
D	004	I do not want continuously contrasting the vehicle behaviours	3	4%	9	3	9	9	3	1	1	3	1	9	9	9	9
D	008	I do not want to perform weighty driving operations	3	4%	3	3	9	9	9	3	3	3	3	9	9	3	3
D	092	I want to be involved in driving	4	5%	1	1	3	9	3	1	1	3	1	3	3	9	9
D	103	I want to enjoy driving during small trips	3	4%	3	1	3	9	3	9	3	3	9	1	1	3	3
D	117	I want to be very close to asphalt	4	5%	1	1	9	9	3	3	9	3	3	0	0	0	0
D, T, S	145	I want to perceive great stability on curved roads	3	4%	3	3	3	9	9	1	1	1	1	3	9	1	3
D	110	I want to brake at limit without losing control	2	3%	9	3	9	9	9	1	1	1	1	3	9	3	9
T	153	I want to have a great cooling efficiency	4	5%	3	9	3	9	1	3	9	3	0	0	0	0	3
T	155	I do not want to lose braking efficiency during driving	3	4%	1	3	1	3	9	1	1	1	1	1	1	3	9
T, S	185	I want to have a permeable vehicle	5	6%	3	9	9	9	1	9	9	9	9	0	0	0	0
D	089	I want a vehicle that transmits power sensation	5	6%	3	3	1	1	3	3	3	3	1	3	1	9	9
D	114	I want to perceive the line of wind flow	4	5%	9	3	9	9	3	3	3	3	3	3	3	1	1
D	116	I do not want a vehicle that appears awkward	3	4%	3	9	3	3	3	9	3	3	3	9	9	3	3
D	124	I want to have a vehicle with an essential style	3	4%	9	9	9	3	3	3	3	3	3	3	3	3	3
D	125	I want to distinguish myself on the road	2	3%	3	3	3	3	3	9	3	9	3	1	1	9	3
D, T, S	148	I want to perceive lightness	4	5%	9	9	3	3	3	3	9	9	1	9	9	1	1
S	203	I want to have a vehicle that expresses its innovation	5	6%	3	3	3	3	3	9	3	3	1	9	3	1	1
S	205	I want to have a vehicle related to the territory	4	5%	3	3	3	3	1	1	1	1	1	3	1	1	1
T, O	169	I want to have adequate space to work	3	4%	3	3	1	1	1	9	9	3	1	1	0	0	0
T, O	178	I want to optimise the space of transport	3	4%	9	9	9	3	1	9	9	9	9	9	3	0	0
		TOTAL	79	100%	359	377	431	485	319	335	329	297	211	332	317	248	284
		Importance of every technical parameter of the final product		➡	4%	4%	5%	5%	4%	4%	4%	3%	2%	4%	4%	3%	3%

			Weight of needs	% Weight of needs	Lateral force	Turning radius	Suspension stiffness	Aerodynamic drag	Downforce	Surface acuteness	Border radius	Tangent continuity	Colour	Material reflectance	Surface roughness	Material stiffness
D	001	I want to have nimble handling	5	6%	9	9	9	9	9	3	1	3	1	1	1	3
D	002	I want to be direct connected to the wheels	4	5%	9	9	9	3	9	1	1	1	1	1	3	3
D	004	I do not want continuously contrasting the vehicle behaviours	3	4%	3	9	9	3	9	1	1	1	1	1	1	3
D	008	I do not want to perform weighty driving operations	3	4%	9	9	9	9	9	1	1	1	1	1	1	3
D	092	I want to be involved in driving	4	5%	9	9	9	9	9	9	9	9	9	9	9	9
D	103	I want to enjoy driving during small trips	3	4%	3	9	3	3	3	3	3	1	1	1	1	3
D	117	I want to be very close to asphalt	4	5%	0	1	3	3	9	0	0	0	0	0	0	0
D, T, S	145	I want to perceive great stability on curved roads	3	4%	9	9	9	3	9	0	0	0	0	0	1	3
D	110	I want to brake at limit without losing control	2	3%	3	3	9	3	9	0	0	0	0	0	0	1
T	153	I want to have a great cooling efficiency	4	5%	0	0	0	9	3	3	3	9	1	1	3	1
T	155	I do not want to lose braking efficiency during driving	3	4%	3	1	1	9	3	3	1	3	0	0	9	3
T, S	185	I want to have a permeable vehicle	5	6%	0	3	1	9	9	9	3	9	1	1	3	3
D	089	I want a vehicle that transmits power sensation	5	6%	9	9	3	9	9	9	9	9	9	9	9	9
D	114	I want to perceive the line of wind flow	4	5%	1	1	1	9	9	9	9	9	3	3	3	3
D	116	I do not want a vehicle that appears awkward	3	4%	3	9	3	3	9	9	9	9	3	3	9	3
D	124	I want to have a vehicle with an essential style	3	4%	3	3	3	9	9	9	9	9	9	3	9	3
D	125	I want to distinguish myself on the road	2	3%	9	3	3	3	3	3	3	3	9	9	3	3
D, T, S	148	I want to perceive lightness	4	5%	1	1	1	9	9	9	9	9	9	9	9	9
S	203	I want to have a vehicle that expresses its innovation	5	6%	1	1	1	9	9	9	9	9	9	9	9	9
S	205	I want to have a vehicle related to the territory	4	5%	1	1	1	3	3	3	9	9	9	9	3	3
T, O	169	I want to have adequate space to work	3	4%	0	3	0	1	1	3	9	3	1	1	3	3
T, O	178	I want to optimise the space of transport	3	4%	0	9	1	1	1	1	3	1	1	1	3	9
		TOTAL	79	100%	302	393	304	495	567	382	384	424	297	279	347	339
		Importance of every technical parameter of the final product		➡	3%	4%	3%	6%	6%	4%	4%	5%	3%	3%	4%	4%

			Weight of needs	% Weight of needs	Ariel Atom	Bac Mono	Caparo T1	Caterham Seven 620R	Dallara Stradale	Drakan Spyder	Elemental RP1	KTM X-Bow	Kyburz eRod	Lotus 3-Eleven	Radical RS3	Vuhl 05	Zenos E10 R	
D	001	I want to have nimble handling	5	6%	5	5	4	4	5	4	5	5	4	5	5	4	4	
D	002	I want to be direct connected to the wheels	4	5%	4	5	5	3	5	3	4	5	3	4	5	4	4	
D	004	I do not want continuously contrasting the vehicle behaviours	3	4%	3	4	3	3	4	4	4	4	4	4	3	3	4	
D	008	I do not want to perform weighty driving operations	3	4%	3	4	3	3	4	3	3	3	4	3	3	3	3	
D	092	I want to be involved in driving	4	5%	4	5	5	3	4	3	4	4	3	4	5	4	3	
D	103	I want to enjoy driving during small trips	3	4%	3	3	2	3	4	3	4	4	4	3	2	4	3	
D	117	I want to be very close to asphalt	4	5%	3	4	4	2	4	3	4	4	2	3	4	3	3	
D, T, S	145	I want to perceive great stability on curved roads	3	4%	4	5	4	3	4	4	4	4	3	4	5	4	3	
D	110	I want to brake at limit without losing control	2	3%	4	5	4	3	5	3	4	4	4	4	4	3	4	
T	153	I want to have a great cooling efficiency	4	5%	4	4	2	2	5	3	4	4	3	3	3	3	3	
T	155	I do not want to lose braking efficiency during driving	3	4%	4	4	3	3	4	3	4	4	4	4	3	3	3	
T, S	185	I want to have a permeable vehicle	5	6%	3	5	4	2	5	3	4	3	2	4	5	3	3	
D	089	I want a vehicle that transmits power sensation	5	6%	2	2	1	1	3	1	1	2	5	2	1	1	1	
D	114	I want to perceive the line of wind flow	4	5%	2	4	3	2	5	2	4	3	3	3	3	3	3	
D	116	I do not want a vehicle that appears awkward	3	4%	4	4	3	3	4	3	4	3	4	4	4	4	3	
D	124	I want to have a vehicle with an essential style	3	4%	3	4	3	3	4	3	3	3	3	4	4	3	3	
D	125	I want to distinguish myself on the road	2	3%	5	5	4	3	4	3	3	4	3	4	5	3	3	
D, T, S	148	I want to perceive lightness	4	5%	3	5	4	3	4	3	3	3	4	3	4	3	3	
S	203	I want to have a vehicle that expresses its innovation	5	6%	4	5	3	2	4	2	3	5	5	3	3	3	3	
S	205	I want to have a vehicle related to the territory	4	5%	4	3	3	4	5	2	2	4	2	4	3	2	2	
T, O	169	I want to have adequate space to work	3	4%	4	4	3	4	3	3	4	3	4	3	4	4	3	
T, O	178	I want to optimise the space of transport	3	4%	4	3	3	4	3	3	3	3	4	3	4	4	4	
		TOTAL	79	100%	79	92	73	63	92	64	78	81	77	78	82	71	68	998
		Importance of every technical parameter of the final product		➡	8%	9%	7%	6%	9%	6%	8%	8%	8%	8%	8%	7%	7%	100%



Img. 53 • Technical importance ranking of the vehicle structure.

odynamics. It puts together styling and functional aspects of the bodywork, which are necessary to ensure both high dynamic performance and a qualitative aesthetic form. Moreover, some important parameters address specifically to the vehicle appearance, which needs to be characterized by a distinguishing and innovative styling related to the territory of Emilia Romagna.

Other technical requirements refer to the vehicle size, in particular on its height because it is an essential element that regulates the stability of the car dynamics. For this reason, the research suggested creating a compact and nimble sports vehicle, according to the exigences of every car package. In particular, the energy storage and the propulsion layout need more attention to not compromise vehicle weight or extra space at the expense of other packages. In the end, although weight received a medium relevance, it remains a crucial datum because it always regulates the overall performance of the car. The design considerations about the final outputs are:

6%	567	T18	Downforce	Cz
This parameter is directly related to aerodynamic drag and it is important to improve stability and adherence of the vehicle. It must produce high downwards thrust to allow the vehicle to produce higher cornering speeds, without affecting its aerodynamic drag. In this case, the use of the ground effect can increase downforce because it is able to create a great downwards thrust without producing drag. In addition, actives wings may also improve the aerodynamics of the vehicle by dynamically adjusting the performance while the vehicle is in operation.				
6%	495	T17	Aerodynamic drag	Cx
This element is important to improve the efficiency of the energy consumption, carbon footprint, propulsion power, vehicle dynamics, braking, top speed and air cooling. It affects also vehicle styling because the body style's shape can be designed on its physical parameters. In this case, this factor must configure the frontal cross-section of the car to guarantee the maximum permeability of its shape, but it must cover the wheels to reduce turbulences. In addition, the element can improve the driving experience by exposing the drivers to the wind flow.				
5%	485	T04	Ground clearance	cm
This requirement must confer the lowest centre of gravity to the vehicle in order to increase its dynamics. It must be regulated in accordance with both different driving contexts the road regulations. It also must guarantee high ground effect to the vehicle, in order to increase downforce As with the vehicle height, ground clearance can be affected by the diameter of wheels and the suspension geometry.				
5%	431	T03	Height	cm
The parameter must guarantee high stability and adherence to the vehicle. Indeed, this element is essential to decrease the vehicle's centre of gravity, which is necessary to regulate the vehicle stability in all of the three dynamic axes. The factor regulates also the overall height of the car, which is able to increase aerodynamic efficiency by reducing its frontal-section area. This technical requirement is influenced by the sitting position and the powertrain configuration. The diameter of wheels, suspension geometry and ground clearance may affect this parameter.				
5%	424	T21	Tangent continuity	Degree
This technical requirement regulates the vehicle styling by giving it a particular character. Moreover, this parameter directly affects both aerodynamics and downforce, as the two elements are in relation.				
4%	393	T15	Turning radius	Angle

<table>
<tr><td colspan="5">The parameter must ensure high manoeuvrability of the steering wheel according to different human capabilities. It must be flexible also to different contexts of use, in order to provide more comfort in urban roads. Moreover, direct correspondence between steering angle and wheel rotation helps drivers to have more sensibility and direct manipulation on the vehicle.</td></tr>
<tr><td>4%</td><td>384</td><td>T20</td><td>Border radius</td><td>Angle</td></tr>
<tr><td colspan="5">This elements connected to the vehicle aesthetics and it can influence its appearance through the level of its parameters. This element imprints on the vehicle a particular styling language, together with the other aesthetic parameters, especially with the surface acuteness. It affects mostly the angles and the sides of the bodywork, that can modify vehicle aggressiveness.</td></tr>
<tr><td>4%</td><td>382</td><td>T19</td><td>Surface acuteness</td><td>Angle</td></tr>
<tr><td colspan="5">Since the vehicle must have a particular styling profile, this technical requirement must be considered as an element that can imprint on the vehicle specific aesthetic shape. It depends by the selecting materials that are used to made the car and it can influence the sensations of drivers through its aesthetic appearance.</td></tr>
<tr><td>4%</td><td>377</td><td>T02</td><td>Track</td><td>cm</td></tr>
<tr><td colspan="5">In accordance with wheelbase, the track must be appropriate to guarantee the minimum space for occupant package and a good stability to the vehicle dynamics, without affecting its agility on curved roads. This technical requirement must allow to the vehicle to be compact for both providing nimble handling and reducing rotation in the roll axis, but also it needs to present narrow width of the frontal cross-section, in order to decrease its aerodynamic drag.</td></tr>
<tr><td>4%</td><td>359</td><td>T01</td><td>Wheelbase</td><td>cm</td></tr>
<tr><td colspan="5">This parameter has to guarantee balanced length of the vehicle in order to get adequate longitudinal space for arranging the occupant package together with the powertrain but without influencing its dynamics. It must not affect the proportion and the weight balance of the vehicle, in order to better control any rotation mainly in the pitch and yaw axes. Powertrain layout and the space for fuel or batteries can be influence its distance.</td></tr>
<tr><td>4%</td><td>347</td><td>T24</td><td>Surface roughness</td><td>μm</td></tr>
<tr><td colspan="5">This technical parameter must improve the overall quality of the costumer experience in terms of tactile feel, as it is an important element that can improve the vehicle craftsmanship. It provides tactile sensations to drivers when the vehicle is used, improving their pleasure and comfort in driving and it is regulated by the choosing materials that compose the bodywork.</td></tr>
<tr><td>4%</td><td>339</td><td>T25</td><td>Material stiffness</td><td>N/m</td></tr>
</table>

<table>
<tr><td colspan="5">The vehicle must be resistant against hurts in order to be at the same time safe for drivers and reliable. This parameter has to guarantee rigidity to the vehicle structure in order to be more stable on the roads but also capable to better transmit vibrations to the driver. In addition, this requirement is also linked to the choice of the external materials of the vehicle, which in turn, can influence the final aesthetic of the bodywork.</td></tr>
<tr><td>4%</td><td>335</td><td>T06</td><td>Energy storage volume</td><td>LxWxH</td></tr>
<tr><td colspan="5">The vehicle has to guarantee sufficient space both for batteries and for fuel tank, without stealing enough space to the other more important packages (as occupant package and powertrain package). This product element must be regulated in base of vehicle power, in order to not elicit range anxiety to drivers. It directly affects the overall vehicle weight and its position must be allocated in a safety place in order to reduce dangerous risks in case of accidents. In particular, for battery it is also necessary to have a strategic collocation in order to guarantee an efficient cooling system.</td></tr>
<tr><td>4%</td><td>332</td><td>T10</td><td>Weight</td><td>Kg</td></tr>
<tr><td colspan="5">Weight is an essential element of the car because it is one of the most important parameters that contributes to improve power efficiency and lightness of the vehicle. It is also one of the most elements that is affected by all the other components. For this reason, its value it has to be lighter as much as possible in order to increase power-to-weight ratio of the vehicle and subsequently its high performance.</td></tr>
<tr><td>4%</td><td>329</td><td>T07</td><td>Propulsion package</td><td>LxWxH</td></tr>
<tr><td colspan="5">This technical requirement has to provide to the vehicle an accessible space to the propulsion system that must be set up to guarantee both weight balance and a comfortable configuration that it is easy to reach for technicians or operators. The propulsion system bust be compact as much as possible to improve lightweight and compactness of the entire vehicle body. Its orientation and layout can directly affect the proportions of the overall vehicle shape.</td></tr>
<tr><td>4%</td><td>319</td><td>T05</td><td>Wheel diameter</td><td>Diameter</td></tr>
<tr><td colspan="5">Wheel diameter is very important because affects the transmission ratio of powertrain, ground clearance and the overall height of the car. It is important that the technical requirement provides the correct size of the wheels in order to guarantee adherence in relation to the vehicle propulsion power and great stability according to its height. The diameter has to guarantee more acceleration that high speed. It also influences the overall aesthetic of the vehicle in relation to its bodywork proportions.</td></tr>
<tr><td>4%</td><td>317</td><td>T11</td><td>Weight balance</td><td>%</td></tr>
</table>

This technical requirement has to guarantee a balanced vehicle that can be easily driven without any particular efforts or high driving skills. In this case, the distribution of the several packages must be precisely organized to assurance both the correct weight distribution and load transfer, in order to provide stability and reduce any rotation in the three main axes. It can be affected by the powertrain layout. In addition, the more the weight is organized the less suspensions suffered load transfer.				
3%	304	T16	Suspension stiffness	N/m
This parameter must support the car to be reactive against the road asperity, in order to provide stability and adherence to the vehicle at high speed, in particular on curved roads. Stiffness must be high in order to better maintain weight balance and reduce either load transfer or any rotation in the three main axes that may cause adherence loss. This parameter can increase rapidity to the vehicle and gives more dynamic response to the driver commands. It also has the task to support the transmission of both harness and vibration inside the cockpit in order to increase the quality of the driving experience. In addition, the vehicle may present active suspensions in order to adapt itself to various uses without losing its performance or its comfort in base of different contexts.				
3%	302	T14	Lateral force	G
Another element that positively influences driving experience is the acceleration or deceleration force that the vehicle is able to produce during cornering. This technical requirement is affected by several parameters like the position of the centre of gravity, vehicle size, load transfer wheel size, suspension and chassis stiffness. The more stability the vehicle provides to its dynamic, the more the lateral acceleration increases.				
3%	297	T08	Passenger package	LxWxH
This product parameter is the most important system of the vehicle as it is dedicated to the driving cockpit. It must guarantee the minimum necessary space for the occupants according to the norms that regulate the top percentile of drivers. It also has to be comfortable and accessible to drivers with different capabilities. It mostly affects the overall size of the car – as it is the starting point to design the vehicle shape – especially its wheelbase and height according to the orientation of the sitting position.				
3%	297	T22	Colour	THz
This technical parameter is one of the elements that can support the overall aesthetic of the vehicle, including its craftsmanship. The requirement can be use as expression of a particular design styling or elicit several sensations related to race contexts. It can be chosen according to the tight relation to the colours used by other different and famous car makers that are distributed on the main territory of Emilia Romagna, in which the concept vehicle expects to be designed. The parameter is tight related to the type of material reflectance.				

3%	284	T13	Braking force	N
As with the acceleration, this parameter increase the perception of thevehicle to drivers during its deceleration. The more braking system is powerful, the more the driving experience can be improved. Brakes must be sized in accordance with the vehicle weight and power, in order to provide efficient and powerful braking but also they must be light as much as possible to do not affect its dynamics or do not produce strong and unpredictable load transfers. In addition, it necessary a good aerodynamic in order to provide an efficacy braking performance and safety. Also, braking system can be designed to capture from it, the necessary kinetic energy that subsequently can be used to charge the batteries.				
3%	279	T23	Material reflection	RΩ,v & RΩ,λ
This character, is linked to the colour and together they support the vehicle structure in creating its own styling. In this case, it must be regulated to elicit aesthetic sensations that refers to a racing context.				
3%	248	T12	Thrust force	N/m
The vehicle must ensure fast acceleration to increase the involvement of the users and increase their adrenaline during driving. Configurating an optimal power-to weight ratio can guarantee high performance.				
2%	211	T09	Cargo package	LxWxH
Since the vehicle is road-legal, it must guarantee a minimum cargo space to arrange the essential equipment for small trips. However, cargo space must affect neither the configuration of the other car packages nor the weight of the car.				

5.4.3 Powertrain system

The second QFD referred to the powertrain. The system was significant to identify the most important technical specifications of the hybrid propulsion system, which were useful to guarantee efficiency in terms of high performance consumption and sustainability.

5.4.3.1 Powertrain system: user needs

The selected needs of the second QFD matrix are:

N01	019	D	Sensation	I want to feel adrenalin during driving

Driver wants a powerful vehicle, which is capable of stimulating driving excitement through its high performance.				
N02	090	D	Sensation	I want to feel the engine on my body
Through the cockpit and when the vehicle is in motion, the users want a direct connection to the vibrations of propulsion system.				
N03	091	D	Sensation	I want to hear the vehicle breathing like a lung
Since people usually confer particular human aspects to their objects, users want to perceive the vehicle as a living entity.				
N04	093	D	Sensation	I do not want to drive a domestic appliance
Since the car is equipped with an electric motor, drivers do not want lose the traditional feeling of the ICE cars.				
N05	101	D	Sensation	I do not want to have range-anxiety
Since the vehicle features an electric motor, drivers want to be reassured that the vehicle provides a reliable autonomy.				
N06	118	D	Sensation	I want to have a vehicle that elicits great power
Drivers want to feel the power of the vehicle through a multisensory perception. This stimulus is also related to the vehicle shape, which helps the powertrain to increase this sensation.				
N07	003	D	Performance	I want to have immediate response to my commands
Users want direct manipulation on the propulsion system when they are driving.				
N08	094	D	Performance	I want to have power also on curves
Driver wants to adjust the vehicle thrust also during steering by sliding on curves without losing the control of the vehicle.				
N09	095	D	Performance	I do not want to lose control during throttle
Users prefer to control the slip of the vehicle wheels during acceleration.				
N10	096	D	Performance	I do not want to have a nervous vehicle
Drivers want a linear acceleration or deceleration in order to avoid rough vehicle behaviours.				
N11	128	D, T	Performance	I do not want to lose power during shifting gear
Users want to avoid loss of power during the particular moment of shifting, which usually it is related to the ICE engine.				
N12	129	D, T	Performance	I want to feel a good thrust also at high speed
Drivers prefer a reactive vehicle even when the engine RPM are high to have always fast response and high acceleration of the propulsion system.				
N13	186	T, S	Performance	I want to support the boost lack of ICE at low RPM
As for the shifting time, users want high thrust even when the engine is at low RPM. In this case, users want a good technical compromise that support the ICE engine to have more thrust during acceleration.				
N14	104	D	Efficiency	I want to adapt energy consumption in base of context
Drivers want to adapt the vehicle efficiency according to the context of use.				
N15	142	D, T, S	Efficiency	I want to optimise energy utilization
Users want to be able to change the performance of the propulsion setting in base of context.				
N16	188	T, S	Efficiency	I want to reduce frictions
Engineers want to find suitable and innovative solutions to reduce frictions within the propulsion system, by improving its mechanical efficiency.				
N17	199	S	Efficiency	I want to reduce the vehicle carbon footprint
Since the vehicle is designed to be hybrid, the user wants to take benefit from the electric motor, in order to use green energy as much as possible, consequently reducing the vehicle carbon foot print.				
N18	163	T	Operation	I want to set up the vehicle with few tools
Users want to have an accessible propulsion system, in order that the maintenance become more easy and fast to make on the vehicle.				
N19	036	D	Safety	I do not want to be heated by engine
Users wants to have a motor propulsion that is isolated to the occupant package and correctly cooled, in order to not be invested by engine heat, that consequently can create discomfort to the driver.				

N20	**098**	**D**	**Safety**	**I do not want to be pushed to drive at high speed on the road**
When the vehicle is used on urban and city roads, drivers want to be encouraged to drive carefully without overpass road limits and becoming a dangerous entity for other drivers.				
N21	**140**	**D, T, S**	**Safety**	**I do not want to overheat mechanical parts**
Users want a vehicle that has an efficient cooling system, in such a way that the colder are the overcharged engine, electric motor and batteries and the more performance the propulsion system has.				
N22	**141**	**D, T, S**	**Safety**	**I do not want to have dangerous situations caused by mechanics**
Users, especially technicians, want to have reliable vehicle, in which the propulsion system is designed to have few maintenances. Also the mechanic and electronic elements, in particular the electric system, must guarantee safety to their users.				
N23	**164**	**S**	**Regulation**	**I want to reduce vehicle taxes**
The user wants to take the challenge in creating a vehicle that have less ecological impact on the environment, in order to receive more economical benefits about selling or principally using the car.				

5.4.3.2 Powertrain system: relevance of needs

The list of the relevance assigned to the selected needs is:

5	N01	019	D	I want to feel adrenalin during driving
5	N04	093	D	I do not want to drive a domestic appliance
5	N07	003	D	I want to have immediate response to my commands
5	N13	186	T, S	I want to support the boost lack of ICE at low RPM
5	N14	104	D	I want to adapt energy consumption in base of context
4	N02	090	D	I want to feel the engine on my body
4	N05	101	D	I do not want to have range-anxiety
4	N06	118	D	I want to have a vehicle that elicits great power
4	N11	128	D, T	I do not want to lose power during shifting gear
4	N12	129	D, T	I want to feel a good thrust also at high speed
4	N17	199	S	I want to reduce the vehicle carbon footprint
4	N20	098	D	I do not want to be pushed to drive at high speed on the road
4	N21	140	D, T, S	I do not want to overheat mechanical parts
3	N03	091	D	I want to hear the vehicle breathing like a lung
3	N08	094	D	I want to have power also on curves
3	N09	095	D	I do not want to lose control during throttle
3	N10	096	D	I do not want to have a nervous vehicle
3	N15	142	D, T, S	I want to optimise energy utilization
3	N16	188	T, S	I want to reduce frictions
3	N18	163	T	I want to set up the vehicle with few tools
3	N22	141	D, T, S	I do not want to have dangerous situations caused by mechanics
2	N19	036	D	I do not want to be heated by engine
2	N23	164	S	I want to reduce vehicle taxes

5.4.3.3 Powertrain system: technical design requirements

The corresponding technical design requirements, which were chosen for the first relationship matrix, are:

T01	**Volume**	**LxWxH (cm3)**
It is the size of entire propulsion system.		
T02	**Weight**	**Kg**
It is the weight of the entire propulsion system.		
T03	**Power-to-weight ratio**	**Kg/kW**
It is the proportion between power of the propulsion system and weight of vehicle.		
T04	**Power boost**	**Kw**
It is the power provided by horsepower of the vehicle.		
T05	**Voltage**	**Volt**
It is the electric tension of the propulsion system, in particular of the electric motor.		
T06	**Charging time**	**Watt**
It is the velocity of the battery used to charge its power.		

T07	**Propulsion response**	**ms**
It is the time that the powertrain uses to respond to the driver controls		
T08	**Torque**	**N/m**
It is the moment of force provided by the propulsion system.		
T09	**Max speed**	**Km/h**
It is the top velocity that can be reached by the vehicle.		
T10	**Autonomy**	**Kw/h**
It is the quantity of energy consumed in relation to a specific distance during time.		
T11	**Emission**	**CO2 g/km**
It is the carbon footprint created by the engine.		
T12	**N. of mappings**	**Number**
It is the number of different power settings that control the propulsion system.		
T13	**Gear ratio**	**Equation**
It is the relation between engine or motor rotation and vehicle transmission.		
T14	**Time to shift**	**ms**
It is the time required to shift the gear.		
T15	**Differential control**	**%**
It is the level of electronic support used to manage traction control.		
T16	**Heat balance**	**Q**
It is the capacity to exchange heat between the cooling system and the engine.		
T17	**Sound**	**Hz**
It is the quality of sound provided by the propulsion system.		
T18	**Vibration**	**dB**
It is the level of vibration and resonance created by the propulsion system on vehicle frame.		
T19	**Noise**	**dB**
It is the level of noise or loudness produced by the propulsion system.		

5.4.3.4 Powertrain system: outcomes and design guidelines

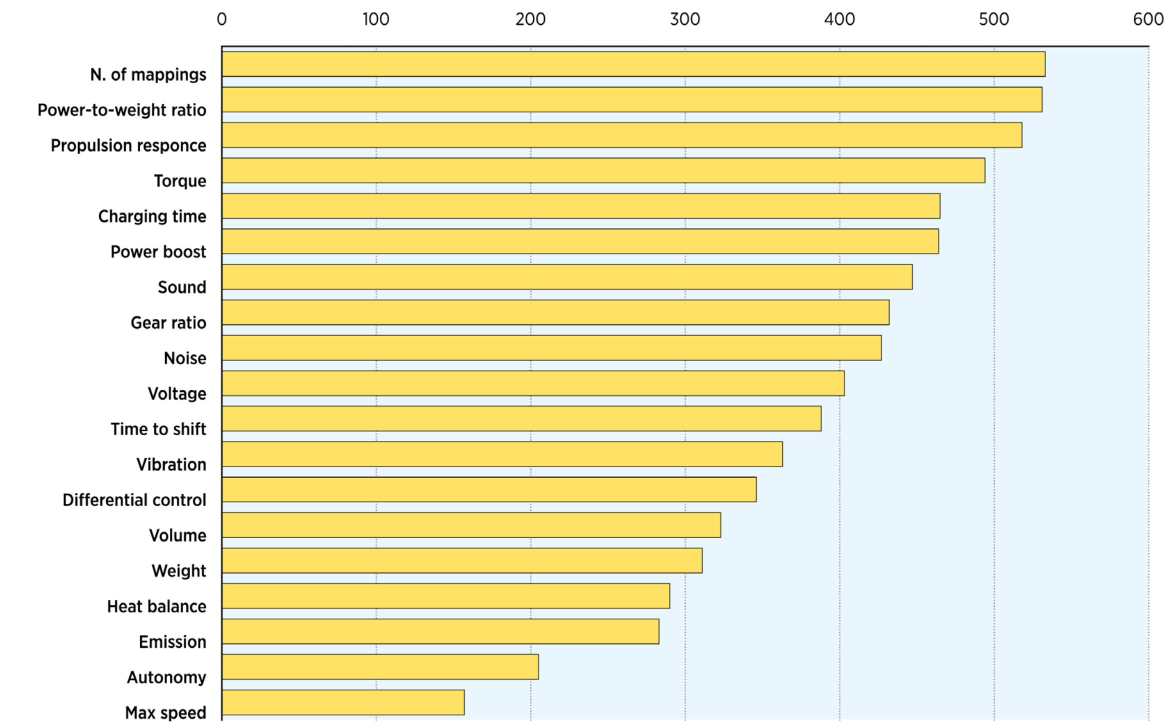
The second QFD assessment **Img. 54** • shows that the most important de-

			Weight of needs	% Weight of needs	Volume	Weight	Power-to-weight ratio	Power boost	Voltage	Charging time	Propulsion response	Torque	Max speed	Autonomy
D	019	I want to feel adrenalin during driving	5	6%	3	1	9	9	9	3	9	9	3	1
D	090	I want to feel the engine on my body	4	5%	3	1	3	3	1	1	9	3	1	1
D	091	I want to hear the vehicle breathing like a lung	3	4%	9	1	0	1	1	1	3	3	1	1
D	093	I do not want to drive a domestic appliance	5	6%	1	1	9	3	3	3	3	3	3	3
D	101	I do not want to have range-anxiety	4	5%	9	9	9	3	9	9	3	3	3	9
D	118	I want to have a vehicle that elicits great power	4	5%	3	3	9	9	3	9	9	9	3	1
D	003	I want to have immediate response to my commands	5	6%	9	9	9	9	3	9	9	9	1	1
D	094	I want to have power also on curves	3	4%	3	3	3	3	3	3	9	9	1	1
D	095	I do not want to lose control during throttle	3	4%	3	9	9	9	3	3	9	9	1	1
D	096	I do not want to have a nervous vehicle	3	4%	3	3	9	9	3	3	9	9	1	1
D, T	128	I do not want to lose power during shifting gear	4	5%	3	3	3	3	3	3	9	9	1	1
D, T	129	I want to feel a good thrust also at high speed	4	5%	3	3	9	3	3	9	9	9	3	1
T, S	186	I want to support the boost lack of ICE at low RPM	5	6%	3	3	9	9	9	9	9	9	1	3
D	104	I want to adapt energy consumption in base of context	5	6%	3	9	9	9	3	9	9	9	3	9
D, T, S	142	I want to optimise energy utilization	3	4%	9	9	9	9	3	9	3	3	3	9
T, S	188	I want to reduce frictions	3	4%	1	1	3	3	1	3	3	3	3	3
S	199	I want to reduce the vehicle carbon footprint	4	5%	3	3	3	3	9	3	3	3	3	3
T	163	I want to set up the vehicle with few tools	3	4%	3	1	0	0	1	1	0	0	0	0
D	036	I do not want to be heated by engine	2	2%	3	1	1	1	9	9	1	1	1	1
D	098	I do not want to be pushed to drive at high speed on the road	4	5%	3	3	9	9	3	9	9	9	3	1
D, T, S	140	I do not want to overheat mechanical parts	4	5%	3	1	1	3	9	3	1	1	0	0
D, T, S	141	I do not want to have dangerous situations caused by mechanics	3	4%	1	1	1	1	9	9	1	1	0	0
S	164	I want to reduce vehicle taxes	2	2%	3	3	9	9	9	1	1	1	1	1
		TOTAL	85	100%	323	311	531	464	403	465	518	494	157	205
		Importance of every technical parameter of the final product		➡	4%	4%	7%	6%	5%	6%	7%	7%	2%	3%

Img. 54 • QFD matrices and technical benchmarking of the powertrain system.

			Weight of needs	% Weight of needs	Emission	N. of mappings	Gear ratio	Time to shift	Differential control	Heat balance	Sound	Vibration	Noise
D	019	I want to feel adrenalin during driving	5	6%	1	3	9	9	3	9	9	9	9
D	090	I want to feel the engine on my body	4	5%	1	3	3	3	1	3	9	9	9
D	091	I want to hear the vehicle breathing like a lung	3	4%	3	3	0	0	0	1	9	9	9
D	093	I do not want to drive a domestic appliance	5	6%	1	3	3	3	1	3	9	9	9
D	101	I do not want to have range-anxiety	4	5%	1	9	3	1	1	1	1	1	1
D	118	I want to have a vehicle that elicits great power	4	5%	1	9	9	9	3	3	9	9	9
D	003	I want to have immediate response to my commands	5	6%	3	3	9	9	3	3	3	1	3
D	094	I want to have power also on curves	3	4%	1	3	3	1	9	1	3	1	3
D	095	I do not want to lose control during throttle	3	4%	1	3	9	1	9	1	3	3	3
D	096	I do not want to have a nervous vehicle	3	4%	3	9	3	9	9	1	3	3	3
D, T	128	I do not want to lose power during shifting gear	4	5%	3	9	9	9	3	1	3	1	3
D, T	129	I want to feel a good thrust also at high speed	4	5%	3	9	9	3	3	3	9	1	9
T, S	186	I want to support the boost lack of ICE at low RPM	5	6%	9	9	9	9	9	3	3	1	3
D	104	I want to adapt energy consumption in base of context	5	6%	9	9	3	3	3	3	3	1	3
D, T, S	142	I want to optimise energy utilization	3	4%	9	9	3	3	3	3	3	3	3
T, S	188	I want to reduce frictions	3	4%	3	3	9	3	9	3	9	9	9
S	199	I want to reduce the vehicle carbon footprint	4	5%	9	9	3	3	3	9	9	1	9
T	163	I want to set up the vehicle with few tools	3	4%	0	9	1	1	9	0	1	1	1
D	036	I do not want to be heated by engine	2	2%	1	3	3	3	9	9	3	3	3
D	098	I do not want to be pushed to drive at high speed on the road	4	5%	3	9	3	9	3	3	9	9	3
D, T, S	140	I do not want to overheat mechanical parts	4	5%	1	9	3	3	3	9	3	3	3
D, T, S	141	I do not want to have dangerous situations caused by mechanics	3	4%	0	3	3	1	3	3	1	9	1
S	164	I want to reduce vehicle taxes	2	2%	9	1	0	0	0	0	1	1	3
		TOTAL	85	100%	283	533	432	388	346	290	447	363	427
		Importance of every technical parameter of the final product		➡	4%	4%	7%	6%	5%	6%	7%	7%	2%

			Weight of needs	% Weight of needs	Ariel Atom	Bac Mono	Caparo T1	Caterham Seven 620R	Dallara Stradale	Drakan Spyder	Elemental RP1	KTM X-Bow	Kyburz eRod	Lotus 3-Eleven	Radical RS3	Vuhl 05	Zenos E10 R	
D	019	I want to feel adrenalin during driving	5	6%	4	5	4	3	5	4	4	4	3	4	5	4	3	
D	090	I want to feel the engine on my body	4	5%	4	4	5	4	4	4	4	4	1	4	5	4	4	
D	091	I want to hear the vehicle breathing like a lung	3	4%	5	4	5	5	4	5	4	5	1	5	5	4	4	
D	093	I do not want to drive a domestic appliance	5	6%	4	5	5	4	4	4	4	4	1	4	5	4	3	
D	101	I do not want to have range-anxiety	4	5%	4	4	3	3	4	4	4	4	2	4	3	4	4	
D	118	I want to have a vehicle that elicits great power	4	5%	5	5	5	3	5	4	5	4	2	4	5	3	3	
D	003	I want to have immediate response to my commands	5	6%	5	5	5	4	5	4	5	4	5	5	5	4	5	
D	094	I want to have power also on curves	3	4%	5	5	5	4	5	4	4	4	4	4	5	5	4	
D	095	I do not want to lose control during throttle	3	4%	3	5	2	3	5	4	5	5	4	5	3	3	3	
D	096	I do not want to have a nervous vehicle	3	4%	3	4	1	2	4	3	4	4	3	4	3	4	4	
D, T	128	I do not want to lose power during shifting gear	4	5%	4	5	5	4	5	4	5	5	5	5	5	5	5	
D, T	129	I want to feel a good thrust also at high speed	4	5%	5	5	5	4	4	4	5	4	5	4	5	4	4	
T, S	186	I want to support the boost lack of ICE at low RPM	5	6%	3	4	3	3	4	3	4	4	4	4	4	4	4	
D	104	I want to adapt energy consumption in base of context	5	6%	2	2	1	1	2	1	2	1	5	2	1	1	1	
D, T, S	142	I want to optimise energy utilization	3	4%	2	3	2	1	2	1	2	2	2	2	2	2	2	
T, S	188	I want to reduce frictions	3	4%	4	4	3	3	4	4	4	4	5	4	4	4	3	
S	199	I want to reduce the vehicle carbon footprint	4	5%	0	0	0	0	0	0	0	0	5	0	0	0	0	
T	163	I want to set up the vehicle with few tools	3	4%	4	4	4	4	4	4	4	4	4	4	4	4	4	
D	036	I do not want to be heated by engine	2	2%	4	4	1	2	4	4	4	3	5	4	3	3	4	
D	098	I do not want to be pushed to drive at high speed on the road	4	5%	2	1	2	3	3	3	3	3	4	3	1	3	3	
D, T, S	140	I do not want to overheat mechanical parts	4	5%	4	4	2	3	5	3	4	3	5	4	4	3	4	
D, T, S	141	I do not want to have dangerous situations caused by mechanics	3	4%	4	4	1	2	4	3	4	3	4	4	3	4	4	
S	164	I want to reduce vehicle taxes	2	2%	2	2	1	1	2	1	2	2	5	2	2	2	2	
		TOTAL	85	100%	82	88	70	66	88	75	86	80	84	85	82	78	77	1041
		Importance of every technical parameter of the final product		➡	8%	8%	7%	6%	8%	7%	8%	8%	8%	8%	8%	7%	7%	100%



Img. 55 • Technical importance ranking of the powertrain system.

sign specifications – associated with the powertrain system – must provide to the vehicle adequate adaptability to be used in many contexts by different users' driving abilities or preferences. Considering this, the vehicle must be configurable according to the characteristics of the external context by adjusting its performance and efficiency based on drivers' purposes.

The direct manipulation of the powertrain system and its fast response to the drivers' commands are some of the parameters that must be considered to ensure a thrilling driving experience. Powerful propulsion and lightness must guarantee also a fast but driveable vehicle. In the end, sound and noise must complete the sensory sensation of the overall racing experience. Instead, the carbon footprint is one of the technical parameters that has not received adequate consideration by end-users in this specific vehicle category. In this case, the element may be a good starting

point to give users more awareness about sustainability. The design considerations about the final outputs are:

7%	533	T12	N. of mappings	Number

Since the vehicle needs to be adaptable to different context and user preferences, the propulsion system must be configurable in different power settings. This parameter supports the car be more sustainable in urban context but more powerful in race context. Also mapping configuration helps the vehicle to be more accessible to users with different capabilities.

7%	531	T03	Power-to-weight ratio	Kg/kW

The vehicle has to have a great correlation and balance between weight and power. In this case, lightness helps the vehicle to have an engine downsizing, because the overall structure can be carried out with minor but efficient power. Subsequently, a smaller ICE provides at the same time less carbon footprint and less vehicle taxes. Moreover, since the weakness of batteries is weigh, lightness can help battery to have more capacity in term of power provided to the propulsion system.

7%	518	T07	Propulsion response	ms

When the vehicle is moving, the propulsion system has to provide direct manipulation to its drivers through its driving controls. The more rapid is the user control, the more driver's emotions are increased and the driving experience (and fun) is qualitatively improved, especially for high performance cars.

7%	494	T08	Torque	N/m

For increasing fun and the driving experience, both ICE and battery have to provide a fast acceleration. In this case, the vehicle may prefer to lose the threshold of max speed to increase vehicle thrust also at low speed. To provide more acceleration and rapidity, this technical specification is direct linked to the gear ratio.

6%	465	T06	Charging time	Watt

This technical parameter is very important to give to batteries the adequate usefulness when the vehicle is moving. The faster is the charging time, the more the batteries can be used to support the ICE when it is working. Besides, longer use of the battery can decrease the carbon foot print of the ICE and reduce fuel consumption.

6%	464	T04	Power boost	Kw
The combination between ICE and electric motor has to guarantee a great power that can be compared to its competitors that are using only a traditional propulsion system. It is preferable to give more attention on the electric motor, in order to downsize the volume of ICE.				
6%	447	T17	Sound	Hz
One of the most important elements that helps the vehicle to have a good driving experience is sound. For this reason, it is useful to guarantee a good quality of sound, in order to improve driver's fun and emotions, maintaining at the same time the traditional characteristics of a race car. The sound helps the vehicle to have great personality and identity and it avoids to not show a soulless vehicle, which is a feature typically assigned to the electric cars.				
6%	432	T13	Gear ratio	Equation
The vehicle has to guarantee a good relation between power and speed, in order to give more importance to acceleration and improve direct manipulation to at different velocities. The more the car is devoted to be rapid the more fun and adrenaline are increased. This product parameter can affect torque and rapidity of the overall propulsion system.				
6%	427	T19	Noise	dB
Since drivers do not want to drive a silent and dumb car, the propulsion system has to provide a good resonance that increase driver's sensations and emotions during driving. On the contrary, noise must not be too much elevate in order to not create stress or discomfort to the driver. This parameter tight is related both to vibration and the characteristics of the ICE.				
5%	403	T05	Voltage	Volt
Since the vehicle is hybrid, the battery has to guarantee sufficient autonomy to support some inefficiencies of ICE with adequate power, in such a way that its utilization results sustainable and efficient. The quantity of this parameter affects the weight the batteries and the hybrid configuration of the entire propulsion system.				
5%	388	T14	Time to shift	ms
One of the elements that can affect direct manipulation and fun is shifting gears. In this case, the vehicle needs to have a good time response of the gear box, when the driver is shifting, as this parameter increases the quality of driving experience and shows a vehicle more devoted to fastness. This parameter is related to the noise and sound of vehicle and it may affect time response of the propulsion system.				

5%	363	T18	Vibration	dB
Together with sound, the propulsion system has to provide sufficient vibrations to the drivers during driving, in order to improve the quality of driving experience. Motor vibrations are the direct haptic feedback to the engine response and for this reason they always provide the status of its system to end-users with their stimuli, which are subsequently used to increase fun and adrenaline. This parameter is linked to sound and noise and it is related to the characteristics of ICE, stiffness of both vehicle structure and suspension.				
5%	346	T15	Differential control	%
In order to guarantee fun a drivability to different driver's capabilities, the vehicle must be accessible managing the electronic configuration of the propulsion system. In this case, the vehicle can be personalized according to different ability levels of drivers. The higher is the level of driver, the less support the vehicle may provide. Also, this element can support driver in different environmental conditions. This technical requirement is tight related to the number of configurations that the vehicle provide.				
4%	323	T01	Volume	LxWxH (cm3)
The propulsion system must be not intrusive and compact as much as possible, in order to provide lightness and dynamic shape. These two factors are able to present an agile and compact vehicle, because the empty spaces created by the engine can be used to provide more aerodynamic efficiency. Also, the volume must be easy to reach for mechanics and technicians and it must not use the space guaranteed to the occupant package.				
4%	311	T02	Weight	Kg
This technical parameter is very important to improve performance and sustainability of the vehicle. he vehicle must to be lighter as much as possible, in order to decrease the force of				
4%	290	T16	Heat balance	Q
The propulsion system must have a good cooling system configuration, especially for batteries that need great cooling for not being dangerous for users. Overcharged engine and batteries need a great amount of cooled air. The more cooling system is well configured the more performance the vehicle receives. This product specification is affected by the layout of the propulsion system and by aerodynamics.				
4%	283	T11	Emission	CO_2 g/km

The vehicle must guarantee the low emission as much as possible. For this reason, the propulsion system has to optimise the utilization of the electric motor, in order to not take power form ICE. This technical specification can be helped using different mapping configurations, through lightness, aerodynamic and downsizing. For this specific parameter, it is important increase awareness and consciousness about the tremendous impact derived from the carbon foot print produced everyday by ICE.				
3%	205	T10	Autonomy	Kw/h
According to different context, in particular those related to urban roads, the vehicle must guarantee an adequate autonomy, in such a way that the driver is able to use and drive the vehicle also for long distance. This parameter can directly affect the lightness of the entire vehicle, through fuel tank and batteries.				
2%	157	T09	Max speed	Km/h
Compared to its competitors, the vehicle must have sufficient speed to elicit great power and fastness to drivers. This product parameter is tight related to torque, power boost and it is affected by the gear ratio.				

5.4.4 Passenger package

The third QFD matrix referred to the passenger package. This area identified the most important properties of the vehicle interior and its ergonomics, especially for ensuring a comfortable seated posture, adequate visibility and correct operability inside the vehicle during driving activities.

5.4.4.1 Passenger package: user needs

The selected needs of the first QFD matrix are:

N01	**18**	**D**	**Performance**	**I want to feel every behaviour of vehicle**
The user wants to be directly connected to the vehicle through his/her sitting position and his/her driving controls, in order to feel on his/her body the behaviour of the car.				
N02	**32**	**D**	**Performance**	**I do not want to obstruct my arms**
The user wants to have adequate interior space to move his/her arms to operate on the vehicle without any difficulty.				

N03	**47**	**D**	**Performance**	**I want to have wide-range visibility**
The driver wants to have a good relation between the occupant package and the sitting position, in order to have both clear visibility and around the vehicle and a long-distance view during driving.				
N04	**50**	**D**	**Performance**	**I do not want to be stressed by wind turbulences**
Due to the absence of windshield, users want to have an occupant package that avoids the driver's head to be extremely exposed to wind force, with its shape and aerodynamics. Turbulences create stress on the driver's head and discomfort during high speed.				
N05	**53**	**D**	**Performance**	**I want to eliminate blind spots**
The user wants to have an occupant package that permits to maintain clear visibility around the car and see the road without any type of view obstruction, especially on the two lateral sides and on the back, as they are the more critical points of view for the driver.				
N06	**59**	**D**	**Performance**	**I want to reach fast the driving commands**
Drivers want to have a comfortable cockpit that has accessible and adequate reach envelope to use driver controls in a easy and fast way.				
N07	**14**	**D**	**Comfort**	**I do not want to strain my arms caused by driving**
Users want to have comfortable and ergonomic driving controls that allow to drive the vehicle in an accessible way, without causing too much fatigue to them. The users also want to drive for long distances without being affected by the vehicle harshness, which can affect their driving performance.				
N08	**21**	**D**	**Comfort**	**I want to perceive a safety sensation during driving**
Drivers want to have an interior space that can elicit great safety sensation through its shape and the hardness of its materials, used to protect them in case of accident.				
N09	**23**	**D**	**Comfort**	**I do not want to have a feeling of suffocation**
Users want to have a suitable and shaped cockpit but not enough narrow that could create claustrophobic sensations.				
N10	**25**	**D**	**Comfort**	**I do not want to be extremely wet by rain**

During bad environmental conditions, drivers want to have a vehicle that avoids water infiltration or they want to have a cockpit that protects them to the direct water flow caused by lack of windshield.				
N11	**29**	**D**	**Comfort**	**I want to be wrapped by driving seat**
For every driver it is important to be entirely shaped inside the driving seat, in such a way that the human body can be directly connected to the vehicle structure in order to feel its behaviours on the road. Also, the body shaped seat permits to the driver to do not be affected by any type of dynamic force during driver, allowing him/her to have more comfort and less effort during driving.				
N12	**30**	**D**	**Comfort**	**I want to have a seat adequate to my height**
Users want to have a sitting position that allows to have a race sitting position according to their different height, in order to maintain the correct visibility on the road. In addition, taller drivers want not to be extremely exposed to wind, because it can elicit less safety and can produce discomfort during driving.				
N13	**34**	**D**	**Comfort**	**I do not want to hurt my legs caused by pressure of steering**
Drivers want to have a comfortable and shaped leg room that avoids legs to hurt against hard surfaces, caused by lateral force. Moreover, drivers do not want to hurt their legs against the steering wheel due to inadequate knee clearance.				
N14	**35**	**D**	**Comfort**	**I do not want to scratch my heels because of driving**
Typically, high performance cars are designed to have high performance, renouncing to comfort. For this reason, the driver wants to have a comfortable and smooth vehicle floor, which allows to create discomfort to the driver's feet.				
N15	**42**	**D**	**Comfort**	**I do not want to hurt myself caused by ingress or egress**
The user wants to have enough space to enter or exit to the vehicle in a fast and safe way, without having any type of obstruction or dangerous surface.				
N16	**49**	**D**	**Comfort**	**I want to drive without helmet**
Inside vehicles that have no windshield, the drivers prefers to have the possibility to drive also without an helmet when it is possible this type of setting, such us urban contexts or low speed.				

N17	**27**	**D**	**Operation**	**I want to customize my driving seat**
In order to have more comfort, a body shaping and suitable seat, the driver wants the ability to modify his/her seat, also creating customizable seat for his/her human body.				
N18	**28**	**D**	**Operation**	**I want to have an interior space easy to clean**
Since high performance cars are roofless, users prefer to have a cockpit that is enough comfortable to clean every time is needed due to pollution, external agents or critical environmental conditions.				
N19	**43**	**D**	**Operation**	**I want to enter or exit on my own**
Users want to have a inclusive and accessible cockpit, which allows people with different human capacities to enter or exit with their abilities.				
N20	**44**	**D**	**Operation**	**I want to clearly know how to enter or exit**
High performance vehicles usually have not doors and for this reason, drivers want to have an easy and understanding ingress or egress, which it facilitates access.				
N21	**37**	**D**	**Safety**	**I want to be protected from debris**
The driver wants to have a driving position that at the same time maintains low centre of gravity and does not allow to other external agent to enter inside the cockpit with the shape or aerodynamics of the vehicle.				
N22	**38**	**D**	**Safety**	**I want to protect my head in case of overturning**
Drivers want to have a safe cockpit that permits to the vehicle to protect themselves during an overturning even the car does not present any type of hard top.				
N23	**39**	**D**	**Safety**	**I want to protect myself in case of accident**
The driver wants to have a resistant capsule of surviving, which protects him/her against injuries, in case of accident.				
N24	**40**	**D**	**Safety**	**I want to strain my neck in case of great deceleration**
Drivers want to have an ergonomic headroom that can avoid great pressure on their head, especially in their neck, during breaking or cornering.				
N25	**41**	**D**	**Safety**	**I want to rapidly exit from vehicle in case of dangerous situations**

The driver wants to have a safe cockpit that permits to him/her to rapidly exit from the cockpit in few seconds without encountering any type of obstruction during the operation.

5.4.4.2 Passenger package: relevance of needs

The list of the relevance assigned to the selected needs is:

5	N01	018	D	I want to feel every behaviour of vehicle
5	N04	050	D	I do not want to be stressed by wind turbulences
5	N06	059	D	I want to reach fast the driving commands
5	N11	029	D	I want to be wrapped by driving seat
5	N17	027	D	I want to customize my driving seat
4	N02	032	D	I do not want to obstruct my arms
4	N03	047	D	I want to have wide-range visibility
4	N05	053	D	I want to eliminate blind spots
4	N08	021	D	I want to perceive a safety sensation during driving
4	N12	030	D	I want to have a seat adequate to my height
4	N13	034	D	I do not want to hurt my legs caused by pressure of steering
4	N23	039	D	I want to protect myself in case of accident
3	N07	014	D	I do not want to strain my arms caused by driving
3	N09	023	D	I do not want to have a feeling of suffocation
3	N14	035	D	I do not want to scratch my heels because of driving
3	N15	042	D	I do not want to hurt myself caused by ingress or egress
3	N19	043	D	I want to enter or exit on my own
3	N21	037	D	I want to be protected from debris
3	N22	038	D	I want to protect my head in case of overturning
3	N24	040	D	I want to strain my neck in case of great deceleration
3	N25	041	D	I want to rapidly exit from vehicle in case of dangerous situations
2	N10	025	D	I do not want to be extremely wet by rain
2	N16	049	D	I want to drive without helmet
2	N18	028	D	I want to have an interior space easy to clean
2	N20	044	D	I want to clearly know how to enter or exit

5.4.4.3 Passenger package: technical design requirements

The corresponding technical design requirements, which were chosen for the first relationship matrix, are:

T01	**Min. seat volume**	**LxWxH**
It is the minimum space of the occupant package.		
T02	**Max. seat volume**	**LxWxH**
It is the maximum space of the occupant package.		
T03	**Hip height**	**cm**
It is the H point, namely the height of the SgRP - seating reference point.		
T04	**Elbow room distance**	**cm**
It is the width of the occupant package.		
T05	**Minimum reach envelope**	**AxD**
It is the area in which the driver can reach the controls of vehicle.		
T06	**Entrance height**	**cm**
It is the height of the lateral trim panel.		
T07	**Door thickness**	**cm**
It is the thickness of the lateral trim panel.		
T08	**Belt height**	**cm**
It is the height where the belt is connected to the seat.		
T09	**Headroom height**	**cm**
It is the the height of the vehicle that protect head in case of overturning.		
T10	**Leg room space**	**LxWxH**
It is the space for legs in which there are the pedal box.		
T11	**Leg horizontal space**	**cm**
It is the distance between H point and accelerator heel point.		
T12	**Pedal plane angle**	**Degree**
It is the angle of the pedal box.		
T13	**Knee clearance**	**cm**

It is the distance between knee of driver and steering wheel.		
T14	**Eyellipse envelope**	**AxD**
It is the space of the eye location of driver.		
T15	**Steering wheel volume**	**LxWxH**
It is the area where the dashboard and the steering wheel are positioned in front of the driver.		
T16	**Angle of steering wheel**	**Degree**
It is the longitudinal angle of the steering wheel plane.		
T17	**Stiffness**	**N/m**
It is the resistance force to deformation in response to an applied force.		
T18	**Hardness**	**Number**
It is the inner resistance of a specific material to localized plastic deformation.		
T19	**Roughness**	**µm**
It is the touch feel provided by specific material.		
T20	**Personalization**	**%**
It is the level of customization of the driving seat.		

5.4.4.4 Passenger package: outcomes and design guidelines

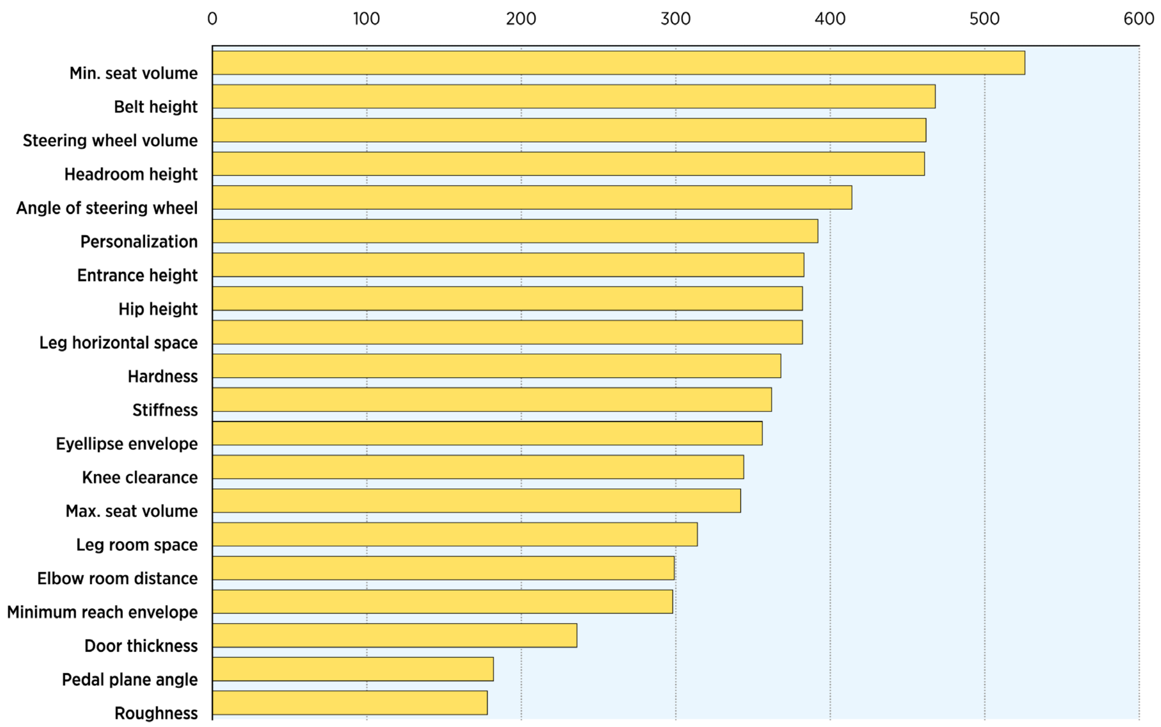
The third QFD assessment **Img. 56** • shows that the most important design specifications – associated with the passenger package – refers to the volume of the overall cockpit and the steering hub, which must guarantee a comfortable and accessible driver's seating position. The cockpit must provide also a safety sensation, by raising the lateral sides of the coachwork and covering the driver's shoulders, but also by better protecting the driver's head. The cockpit must also ensure to the driver a wide-range visibility of the surrounding environment. Personalization is another important element that is necessary to make the vehicle suitable to numerous users with different requirements, especially to those who are tall and run the risk of stressing their necks due to a high exposition of their

			Weight of needs	% Weight of needs	Min. seat volume	Max. seat volume	Hip height	Elbow room distance	Minimum reach enve-	Entrance height	Door thick-ness	Belt height	Headroom height	Leg room space
D	018	I want to feel every behaviour of vehicle	5	6%	9	3	3	1	1	1	1	3	1	3
D	032	I do not want to obstruct my arms	4	5%	3	3	3	9	9	3	1	3	3	0
D	047	I want to have wide-range visibility	4	5%	1	1	9	3	3	9	1	9	9	3
D	050	I do not want to be stressed by wind turbulences	5	6%	1	1	9	1	0	3	1	9	9	0
D	053	I want to eliminate blind spots	4	5%	1	3	9	1	1	3	1	9	9	1
D	059	I want to reach fast the driving commands	5	6%	3	3	3	3	9	3	1	3	3	3
D	014	I do not want to strain my arms caused by driving	3	3%	9	3	3	9	9	3	1	3	1	0
D	021	I want to perceive a safety sensation during driving	4	5%	9	3	3	3	3	3	3	3	9	9
D	023	I do not want to have a feeling of suffocation	3	3%	9	9	1	9	9	3	1	9	9	9
D	025	I do not want to be extremely wet by rain	2	2%	3	9	3	3	1	9	1	9	9	3
D	029	I want to be wrapped by driving seat	5	6%	9	9	3	9	9	3	3	3	3	3
D	030	I want to have a seat adequate to my height	4	5%	9	3	9	3	3	3	1	9	9	9
D	034	I do not want to hurt my legs caused by pressure of steering	4	5%	9	3	3	0	3	1	1	1	1	3
D	035	I do not want to scratch my heels because of driving	3	3%	1	1	1	0	0	0	0	1	0	3
D	042	I do not want to hurt myself caused by ingress or egress	3	3%	9	3	3	9	1	9	9	9	3	3
D	049	I want to drive without helmet	2	2%	3	3	3	1	1	3	3	9	9	1
D	027	I want to customize my driving seat	5	6%	9	9	3	3	3	1	1	3	3	1
D	028	I want to have an interior space easy to clean	2	2%	3	3	1	1	3	3	1	1	1	3
D	043	I want to enter or exit on my own	3	3%	9	3	9	3	3	9	3	3	1	3
D	044	I want to clearly know how to enter or exit	2	2%	3	3	1	1	1	9	9	3	3	3
D	037	I want to be protected from debris	3	3%	3	3	9	1	1	9	9	9	9	3
D	038	I want to protect my head in case of overturning	3	3%	9	9	3	3	3	9	3	9	9	3
D	039	I want to protect myself in case of accident	4	5%	9	3	3	3	1	9	9	9	3	9
D	040	I want to strain my neck in case of great deceleration	3	3%	3	1	3	1	1	1	0	3	9	3
D	041	I want to rapidly exit from vehicle in case of dangerous situations	3	3%	9	3	3	3	1	9	9	3	9	9
		TOTAL	88	100%	526	342	382	299	298	383	236	468	461	314
		Importance of every technical parameter of the final product		➡	7%	5%	5%	4%	4%	5%	3%	7%	6%	4%

Img. 56 • QFD matrices and technical benchmarking of the passenger package.

			Weight of needs	% Weight of needs	Leg horizontal space	Pedal plane angle	Knee clearance	Eyellipse envelope	Steering wheel vol.	Angle of steering	Stiffness	Hardness	Roughness	Personalization
D	018	I want to feel every behaviour of vehicle	5	6%	3	3	1	1	1	1	9	9	3	3
D	032	I do not want to obstruct my arms	4	5%	1	0	3	1	9	9	0	0	0	3
D	047	I want to have wide-range visibility	4	5%	3	1	3	9	3	9	0	0	0	3
D	050	I do not want to be stressed by wind turbulences	5	6%	1	0	1	9	3	9	0	0	0	9
D	053	I want to eliminate blind spots	4	5%	1	0	3	9	3	3	0	0	0	3
D	059	I want to reach fast the driving commands	5	6%	9	1	3	9	9	3	0	0	1	9
D	014	I do not want to strain my arms caused by driving	3	3%	1	0	3	0	9	9	9	9	1	1
D	021	I want to perceive a safety sensation during driving	4	5%	3	3	9	9	3	9	9	9	3	3
D	023	I do not want to have a feeling of suffocation	3	3%	3	3	3	3	3	3	1	1	1	9
D	025	I do not want to be extremely wet by rain	2	2%	3	1	1	9	9	3	1	1	1	9
D	029	I want to be wrapped by driving seat	5	6%	9	3	3	1	9	3	9	9	3	9
D	030	I want to have a seat adequate to my height	4	5%	9	3	3	9	3	3	1	1	1	9
D	034	I do not want to hurt my legs caused by pressure of steering	4	5%	9	3	9	1	9	9	3	3	3	3
D	035	I do not want to scratch my heels because of driving	3	3%	9	9	3	0	3	1	3	9	9	3
D	042	I do not want to hurt myself caused by ingress or egress	3	3%	3	3	9	1	3	3	3	3	3	3
D	049	I want to drive without helmet	2	2%	1	1	1	9	9	3	3	3	1	3
D	027	I want to customize my driving seat	5	6%	3	1	1	1	1	1	9	9	3	9
D	028	I want to have an interior space easy to clean	2	2%	1	0	1	0	1	1	3	3	9	1
D	043	I want to enter or exit on my own	3	3%	3	1	9	1	9	3	3	3	3	3
D	044	I want to clearly know how to enter or exit	2	2%	1	1	1	1	3	3	1	1	1	1
D	037	I want to be protected from debris	3	3%	3	1	3	9	9	9	3	3	1	1
D	038	I want to protect my head in case of overturning	3	3%	1	1	3	3	3	3	9	9	3	1
D	039	I want to protect myself in case of accident	4	5%	9	3	9	1	9	3	9	9	1	1
D	040	I want to strain my neck in case of great deceleration	3	3%	9	9	3	1	1	3	9	3	3	1
D	041	I want to rapidly exit from vehicle in case of dangerous situations	3	3%	3	1	9	1	9	9	1	3	0	1
		TOTAL	88	100%	382	182	344	356	462	414	362	368	178	392
		Importance of every technical parameter of the final product		➡	5%	3%	5%	5%	6%	6%	5%	5%	2%	5%

			Weight of needs	% Weight of needs	Ariel Atom	Bac Mono	Caparo T1	Caterham Seven 620R	Dallara Stradale	Drakan Spyder	Elemental RP1	KTM X-Bow	Kyburz eRod	Lotus 3-Eleven	Radical RS3	Vuhl 05	Zenos E10 R	
D	018	I want to feel every behaviour of vehicle	5	6%	3	5	4	2	5	2	4	4	3	4	4	3	3	
D	032	I do not want to obstruct my arms	4	5%	3	3	3	2	4	3	3	3	3	3	3	4	3	
D	047	I want to have wide-range visibility	4	5%	5	5	4	4	3	3	4	3	5	3	4	3	3	
D	050	I do not want to be stressed by wind turbulences	5	6%	2	3	2	2	4	5	4	3	2	4	3	3	3	
D	053	I want to eliminate blind spots	4	5%	4	3	4	4	3	3	3	2	5	3	4	3	3	
D	059	I want to reach fast the driving commands	5	6%	3	5	3	3	5	3	4	5	4	4	4	4	3	
D	014	I do not want to strain my arms caused by driving	3	3%	3	5	3	2	5	3	5	5	3	4	3	2	4	
D	021	I want to perceive a safety sensation during driving	4	5%	2	4	2	2	4	3	4	4	3	4	3	4	3	
D	023	I do not want to have a feeling of suffocation	3	3%	5	3	4	5	4	3	4	4	5	4	4	4	4	
D	025	I do not want to be extremely wet by rain	2	2%	2	4	3	2	3	4	3	2	2	3	3	3	3	
D	029	I want to be wrapped by driving seat	5	6%	3	4	4	2	4	2	4	3	2	3	3	3	2	
D	030	I want to have a seat adequate to my height	4	5%	3	4	4	2	4	4	4	4	3	4	3	3	3	
D	034	I do not want to hurt my legs caused by pressure of steering	4	5%	3	3	4	3	4	3	4	4	3	3	3	3	3	
D	035	I do not want to scratch my heels because of driving	3	3%	3	4	4	2	4	3	3	3	2	4	4	3	4	
D	042	I do not want to hurt myself caused by ingress or egress	3	3%	3	4	4	2	4	3	4	3	4	4	3	4	3	
D	049	I want to drive without helmet	2	2%	2	2	2	3	3	5	3	3	2	3	2	3	3	
D	027	I want to customize my driving seat	5	6%	3	3	3	2	4	2	4	4	2	3	4	3	2	
D	028	I want to have an interior space easy to clean	2	2%	4	3	2	4	4	2	4	4	4	3	3	3	2	
D	043	I want to enter or exit on my own	3	3%	4	3	3	5	4	3	5	3	4	3	2	3	3	
D	044	I want to clearly know how to enter or exit	2	2%	4	3	3	4	3	3	4	4	4	3	4	3	3	
D	037	I want to be protected from debris	3	3%	2	4	3	3	4	4	4	3	2	4	3	4	3	
D	038	I want to protect my head in case of overturning	3	3%	2	4	3	2	4	3	4	4	2	4	3	2	3	
D	039	I want to protect myself in case of accident	4	5%	2	4	3	2	4	4	4	4	2	4	4	3	3	
D	040	I want to strain my neck in case of great deceleration	3	3%	3	4	3	2	4	3	4	4	2	3	4	3	3	
D	041	I want to rapidly exit from vehicle in case of dangerous situations	3	3%	4	3	3	3	4	3	4	4	4	3	3	4	4	
		TOTAL	88	100%	77	92	80	69	98	79	97	89	77	87	83	80	76	1084
		Importance of every technical parameter of the final product		➡	7%	8%	7%	6%	9%	7%	9%	8%	7%	8%	8%	7%	7%	100%



Img. 57 • Technical importance ranking of the passenger package.

bodies to the wind. The design considerations about the final outputs are:

7%	526	T01	Min. seat volume	LxWxH

According to the ergonomics regulations, the vehicle must provide the minimum adequate volume for the driver, in order to guarantee adequate comfort but also to maximize – with less aerodynamic drag and weight – both the entire shape and volume of the vehicle.

7%	468	T08	Belt height	cm

This product specification is related to height of the lateral sides of the cockpit and it ensures lateral viewing. A correct belt height allows the driver to be strongly connected to the driving seating and it protects him/her to eventual lateral impacts. On the contrary, it provides the adequate wind force that improve the quality of driving experience, but at the same time avoid the driver to be subjected to strong turbulences. Moreover, the adequate height ensures an accessible ingress or egress for all users.

6%	462	T15	Steering wheel volume	LxWxH

The volume of the steering wheel hub must ensure sufficient space to the vehicle interface, without taking space dedicated to the driving seat. This parameter must allow driver both to easy reach driving controls and to have an ergonomic configuration. Moreover, it must have a determinate shape that can protect driver's head to the direct wind flow and it must be low as much as possible in order to ensure to the drivers a long-distance view. The technical requirement influences the volume of leg room, he space of the seat and the frontal area of viewing.

6%	461	T09	Headroom height	cm

The cockpit must have a specific upper element that protect the driver in case of overturning, but also this space must guarantee an accommodation for the driver's head, without impeding his/her field of view. This specific requirement affects the overall height of the vehicle.

6%	414	T16	Angle of steering wheel	Degree

This technical requirement permits to have the correct inclination of the vehicle interface, which is directly inside the field of view of the driver, but also of the steering wheel, which ensures to the driver the correct ergonomic position of his/her arms. The angle must be adaptable according to different human capabilities and characteristics, as this parameters directly influences the space dedicated to the driver and his/her sitting position.

5%	392	T20	Personalization	%

The configuration of the cockpit, especially driving seat, must be suitable to users who have different anthropometric characteristics and preferences.

5%	383	T06	Entrance height	cm

The vehicle has to ensure an accessible ingress and egress to users with different abilities, favouring people who have more difficulties to enter or exit from the cockpit. Also, a correct height guarantees better visibility to driver and provide to him/her more safety in case of accident.

5%	382	T03	Hip height	cm

The driving seat must be low as much as possible to guarantee a low centre of gravity of the entire vehicle. Hence the H point have to ensure a short height in order to provide a race sitting position. This specific specification is directly related to the length of the leg horizontal space.

5%	382	T11	Leg horizontal space	cm

Driving seat must have a comfortable position that can permit to drivers to take a race sitting configuration. Space for legs must be adaptable to different anthropometric measures and preferences, in such a way that the pedal box become easy to reach. This technical requirement is directly related to the length of wheelbase and affect the vehicle height.				
5%	368	T18	Hardness	Number
The occupant package must be made by hard materials and it must have hard interior components that can improve the sensation of the direct connection between user and vehicle behaviours and are able to produce vibrations or moderate harshness to driver, which are essential to provide a race experience.				
5%	362	T17	Stiffness	N/m
The occupant package must have good stiffness in order to provide to user great race sensation through vibrations. Stiffness has to guarantee also good resistance and safety against any type of external impact, because the cockpit is an important structural element of the car and it must absorb a great part of kinetic force.				
5%	356	T14	Eyellipse envelope	AxD
Sitting position and vehicle interface have to guarantee to drivers the correct field of view over the hood in order to perceive the position of the car on the road. When he/she is driving, visibility must be addressed on the road and on the instrument panel, without any type of obstructions. The open space has to guarantee also the lateral and rear view.				
5%	344	T13	Knee clearance	cm
The relation between driving seat and the steering hub must guarantee to the driver sufficient space in order to have an accessible ingress and egress and good sitting position. This technical parameter must permit to the driver a comfortable driving condition without creating accidental hurts or obstructions on his/her legs.				
5%	342	T02	Max. seat volume	LxWxH
It is important that the volume of the occupant package must be sufficient to accommodate the ninety-five percentile of the target user in a comfortable way, without compromising the overall vehicle space dedicated to the other vehicle packages and consequently the dynamic performance of the car. (sae international handbook)				
4%	314	T10	Leg room space	LxWxH
The space has to guarantee adequate space to driver's legs in order to not create obstacles during driving. At the same time the space must ensure a shaped volume that contains legs and prevents them against hurts, inside the leg room, caused by lateral force.				
4%	299	T04	Elbow room distance	cm
The occupant package has to have the correct width to guarantee a comfortable accommodation to the users. The space must allow to the driver to move his/her arms inside the cockpit without hurt himself/herself against lateral surfaces or controls during driving.				
4%	298	T05	Minimum reach envelope	AxD
The cockpit has to have adequate volume that guarantees to the driver accessibility in reaching the driver controls without any difficulties.				
3%	236	T07	Door thickness	cm
The two lateral sides of the vehicle must be enough thick in order to be very resistant against impacts and they must avoid intrusions caused by external agents. Moreover, thickness has to be adequate to allow an easy and accessible ingress or egress to driver with different capacities.				
3%	182	T12	Pedal plane angle	Degree
According to the length of driving seat, the pedal box has to be adaptable to different anthropometric characteristics of every user, in order to provide the correct pedal plane angle. It needs to produce less effort and stress on driver's ankles or heels and it serves to provide more direct feeling with the vehicle controls (throttle, brake and clutch).				
2%	178	T19	Roughness	μm
Craftsmanship of the entire occupant package has to be not harsh in order to create discomfort to drivers, but different types of roughness could be used to distinguish different areas of the vehicle and create different sensations to the pilots.				

5.4.5 Vehicle interface

The fourth and last QFD matrix referred to the vehicle driving interface. The matrix was important to identify the most important characteristics of the driving controls. They were useful to maximize physical-cognitive resources of driver, but also provide a high level of usability, which was necessary to guarantee the execution of different tasks while continuously monitoring the driving scene (Wierwille, 1993).

5.4.5.1 Vehicle interface: user needs

The selected needs of the fourth QFD matrix are:

N01	**054**	**D**	**Visibility**	**I want to keep me eyes on the road**
The user wants to have a wide-range visibility during driving. He/she wants to perceive information at glance and he/she does not want to move his/her head or lose time to find the requested functions provided by car interface.				
N02	**069**	**D**	**Visibility**	**I do not want to obstruct the visibility of information**
Every information or command should be clearly visible and present inside the driver's field of view.				
N03	**077**	**D**	**Visibility**	**I want to see only the essential vehicle information**
The user does not want to be confused with too much information when he/she is driving. He/she does not be distracted to any type of superfluous data.				
N04	**079**	**D**	**Visibility**	**I want to have great readability in all environmental conditions**
Every data provided by interface must be always visible in different conditions of weather or daylight.				
N05	**068**	**D**	**Monitor**	**I want to know when the race finish**
During a motorsports event, the user wants to receive every and useful real-time information about the status of his/her race.				
N06	**074**	**D**	**Monitor**	**I would always want to know the state of vehicle system**
The user needs to know in real-time if his/her vehicle and its components are in good conditions and he/she wants to be warned in case of critical issues.				
N07	**086**	**D**	**Monitor**	**I want to know if I'm losing time laps**
The driver wants to understand his/her performance in terms of lap timing.				
N08	**126**	**D**	**Monitor**	**I want to shift gear at the right moment**
The user wants to be aware and usually warned when it is the good moment to shift gear without losing engine power or time on the lap.				
N09	**134**	**D, T**	**Monitor**	**I want to check the vehicle parameters before a driving section**
Before a driving section, users want to control if the conditions of the vehicle are enough correct to use it either on track or on the road.				
N10	**136**	**D, T**	**Monitor**	**I want to track the vehicle on circuit**
Within a track day, it is useful to monitor the vehicle around the circuit, in order to store some additional information about driver's performance or the behaviour of the car during its utilization.				
N11	**157**	**T**	**Monitor**	**I want to monitor vehicle parameters remotely**
For a technician it is important to monitor the vehicle when the driver is driving, because he/she can supports him in analysing both status and behaviour of the car in real-time.				
N12	**159**	**T**	**Monitor**	**I want to analyse driving data easily**
Every time that a vehicle finish a driving section, the users wants to download data of acquired by the vehicle in order to control the driver's performance and help him/her to improve the pilot's driving abilities.				
N13	**007**	**D**	**Control**	**I do not want to remove my hands on steering wheel**
The user prefers to have total control on the vehicle and for this reason wants to have a handy instrument panel.				
N14	**060**	**D**	**Control**	**I want to change functions in base of my preferences**
Every user has his/her habits or modes to display information or drive a sport vehicle.				
N15	**135**	**D, T**	**Control**	**I want to speak with my team on-board**
To support the driver during a driving section, the technician wants to cut the speaking distance between them.				

N16	**056**	**D**	**Safety**	**I do not want to decrease my driving attention**
The user does not want to be distracted or confused by unnecessary feedbacks or useless information provided by the vehicle interface.				
N17	**064**	**D**	**Safety**	**I do not want to change driving functions accidentally**
The possibility to create an error on the system configuration must be reduced.				
N18	**081**	**D**	**Safety**	**I do not want to be stressed by information workload**
Every information or feedback has to be simple, understandable and it must be delivered to the driver only when is necessary. They must be showed through an hierarchy and they must not be overlapped on each other.				
N19	**082**	**D**	**Safety**	**I want to be warned in time in case of malfunctions**
Dashboard must clearly warn – through appropriate feedbacks – the driver in time when the vehicle has any type of malfunction.				
N20	**058**	**D**	**Configure**	**I want to adjust parameters during driving**
During a driving section, it is useful to give to the users the possibility to change the vehicle setup also on the road.				
N21	**061**	**D**	**Configure**	**I want to have a specific driving style based on context**
According to different contexts, such as city roads or race tracks, it is useful to have different modalities on how the vehicle delivers its power.				
N22	**067**	**D**	**Configure**	**I want to be entertained during my trips**
For long distances on the road, users prefer to be entertained by infotainment that may make the trip comfortable as much as possible.				
N23	**158**	**T**	**Configure**	**I want to set up the vehicle tools for race**
When the vehicle is used for a race, the users want to set up the car according to the race regulations. In this case, specific data, like lap timing, or particular vehicle configurations, such as high performance, are required.				
N24	**083**	**D**	**Learn**	**I want to learn from my driving mistakes**
The driver prefers to analyse driving data to understand what type of improvement can be use to increase his/her timing performance on the circuit. Often the analysis happens together with his/her team.				
N25	**084**	**D**	**Learn**	**I want to know every characteristic of the circuit**
The driver wants to know how to approach with a specific circuit in terms of driving behaviours.				

5.4.5.2 Vehicle interface: relevance of needs

The list of the relevance assigned to the selected needs is:

5	N01	054	D	I want to keep me eyes on the road
5	N06	074	D	I would always want to know the state of vehicle system
5	N13	007	D	I do not want to remove my hands on steering wheel
5	N14	060	D	I want to change functions in base of my preferences
5	N19	082	D	I want to be warned in time in case of malfunctions
4	N03	077	D	I want to see only the essential vehicle information
4	N07	086	D	I want to know if I'm losing time laps
4	N08	126	D	I want to shift gear at the right moment
4	N18	081	D	I do not want to be stressed by information workload
4	N23	158	T	I want to set up the vehicle tools for race
4	N24	083	D	I want to learn from my driving mistakes
4	N25	084	D	I want to know every characteristic of the circuit
3	N02	069	D	I do not want to obstruct the visibility of information
3	N04	079	D	I want to have great readability in all environmental conditions
3	N09	134	D, T	I want to check the vehicle parameters before a driving section
3	N10	136	D, T	I want to track the vehicle on circuit
3	N12	159	T	I want to analyse driving data easily
3	N16	056	D	I do not want to decrease my driving attention
3	N17	064	D	I do not want to change driving functions accidentally
3	N20	058	D	I want to adjust parameters during driving

3	N21	061	D	I want to have a specific driving style based on context
2	N05	068	D	I want to know when the race finish
2	N11	157	T	I want to monitor vehicle parameters remotely
2	N15	135	D, T	I want to speak with my team on-board
2	N22	067	D	I want to be entertained during my trips

5.4.5.3 Vehicle interface: technical design requirements

The corresponding technical design requirements, which were chosen for the first relationship matrix, are:

T01	**Viewing distance**	**LxAngle**
It is the field of viewing of the driver.		
T02	**Dashboard form factor**	**L max : L min**
It is the morphological proportion of the dashboard area in relation with its length.		
T03	**Dashboard area**	**LxW**
It is the area of the entire physical instrument panel.		
T04	**Screen resolution**	**LxW**
It is the size of the virtual display.		
T05	**Brightness**	**Lux**
It is the quantity light necessary to display information on the screen.		
T06	**Contrast**	**Colour ratio**
It is the luminosity ratio that compare the brightest and the darkest colour to improve the quality of reading.		
T07	**Menu depth**	**Number**
It is the level of depth of the information architecture		
T08	**Font/Icon size**	**Height**
It is the size of text on the screen.		
T09	**Space of intersection**	**mm**
It is the space between to values or commands.		
T10	**Number of information**	**Number**
It is the information quantity that is represent in a single screen.		

T11	**Number of options**	**Number**
It is the number of potential options that the interface offers on a particular situation.		
T12	**Error rate**	**%**
It is the probability of a human error occurring during a specific task.		
T13	**Colours**	**RGB**
It is the electromagnetic radiation that is visible to the human eye.		
T14	**Border radius ratio**	**%**
It is the smoothness related to a specific shape of an input or output operation.		
T15	**Frequency of use**	**%**
It is the time of utilization of a particular vehicle function.		
T16	**Operation distance**	**cm**
It is the distance between human and the vehicle functions.		
T17	**Operation time**	**ms**
It is the time utilized to complete a specific task.		
T18	**Operation steps**	**Number**
It is the number of steps that are necessary to complete a specific task.		
T19	**Input area**	**LxW**
It is the area necessary to perceive a specific function and then to activate it.		
T20	**Contour depth difference**	**mm**
It is the contrast space that divide two functions to each other.		
T21	**Roughness**	**Ωm**
It is the touch feel provided by specific material.		
T22	**Fingertip force**	**Newton**
It is the force to contrast the resistance of the physical controls.		
T23	**Feedback response**	**ms**
It is the velocity of a determined feedback.		
T24	**Feedback intensity**	**%**
It is the level of loudness of a specific feedback that the human sensory system perceives and interpreters.		
T25	**Personalization**	**%**
It is the level of customization of the vehicle interface.		

T26	Memory	Byte
It is the storage quantity provided by the electronic system.		
T27	Number of input	Number
It is the quantity of sensors linked to the dashboard to gather external data.		
T28	Number of output	Number
It is the quantity of output channels of the interface to communicate with it.		

5.4.5.4 Vehicle interface: outcomes and design guidelines

The fourth QFD assessment **Img. 58** • shows that the most important design specifications – associated with the vehicle interface – are concentrated mostly on the quality of the driving operations and their task flows (both provided by the system or performed by the driver) rather than on the usability or readability of driving information (Giacobone & Mincolelli, 2020). Moreover, the information architecture and the system personalization are two significant elements that must be considered to provide a customizable and inclusive interface to users with different capabilities or preferences.

The interface must divide the primary operations – which are more frequently utilized and more required by drivers – from the secondary tasks that are associated only to specific moments (for instance when the vehicle is stationary. Besides, every driving operation must be fast actionable and it must reduce as much as possible at the minimum step required to complete a determined task. The most important controls must be always visible and constantly present on the vehicle dashboard, while the secondary commands can be organized in the system setup.

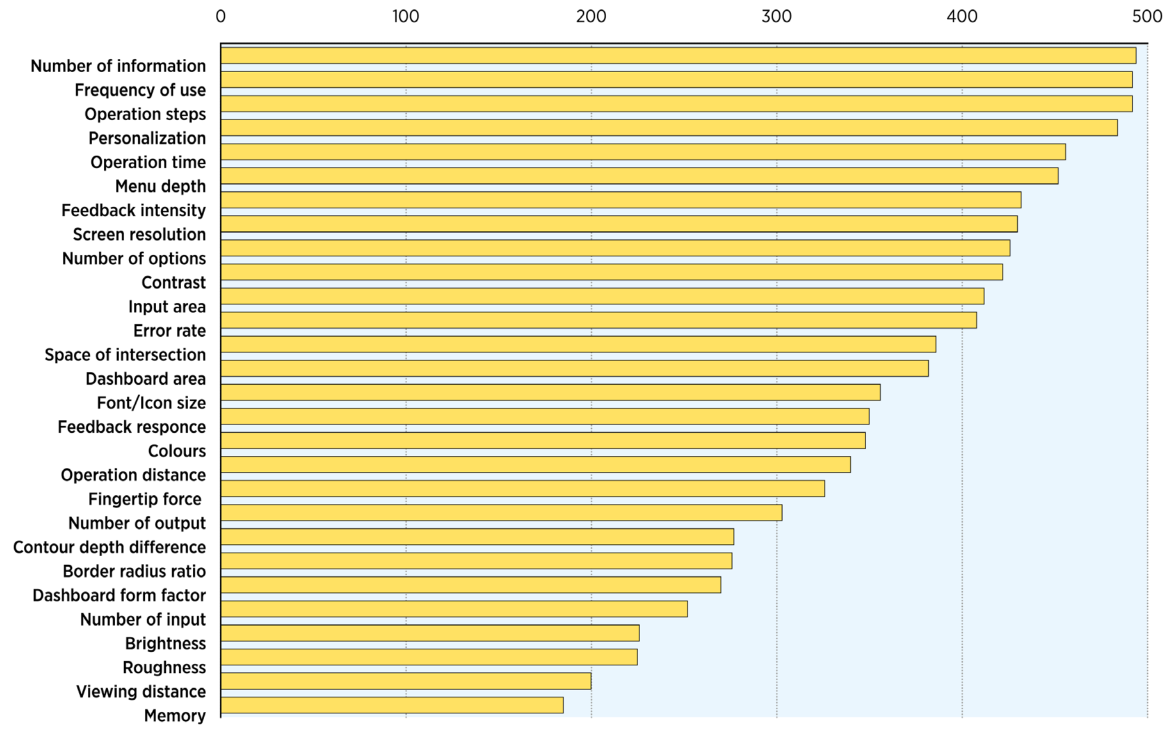
The number of information and its organization must have an essential and linear hierarchy, in order to reduce the error rate and not create any

Img. 58 • QFD matrices and technical benchmarking of the vehicle interface.

			Weight of needs	% Weight of needs	Viewing distance	Dashboard form factor	Dashboard area	Screen resolution	Brightness	Contrast	Menu depth	Font/Icon size	Space of Intersection	Number of information	Number of options	Error rate	Colours	Border radius
D	054	I want to keep me eyes on the road	5	6%	3	9	9	9	3	9	9	3	3	9	3	3	3	3
D	069	I do not want to obstruct the visibility of information	3	3%	9	3	3	9	3	3	1	1	9	1	1	3	3	1
D	077	I want to see only the essential vehicle information	4	5%	3	3	9	9	3	3	9	3	9	9	9	9	9	3
D	079	I want to have great readability in all environmental conditions	3	3%	3	3	9	9	9	9	3	9	9	3	3	3	3	3
D	068	I want to know when the race finish	2	2%	3	1	3	3	3	3	9	9	3	9	1	3	3	1
D	074	I always want to know the state of vehicle system	5	6%	3	1	3	9	3	3	3	3	3	3	3	9	3	3
D	086	I want to know if I'm losing time laps	4	5%	3	1	3	3	3	3	1	9	3	3	3	3	3	3
D	126	I want to shift gear at the right moment	4	5%	3	1	3	3	3	9	1	9	9	9	3	9	3	1
D, T	134	I want to check the vehicle parameters before a driving section	3	3%	1	1	3	3	3	3	9	3	3	9	9	3	3	3
D, T	136	I want to track the vehicle on circuit	3	3%	1	1	1	3	1	1	3	3	3	3	3	1	1	1
T	157	I want to monitor vehicle parameters remotely	2	2%	0	0	0	0	0	0	3	0	0	0	0	0	0	0
T	159	I want to analyse driving data easily	3	3%	1	1	1	3	3	3	9	3	9	9	3	1	1	1
D	007	I do not want to remove my hands on steering wheel	5	6%	3	9	3	3	3	9	3	3	3	3	9	3	3	9
D	060	I want to change functions in base of my preferences	5	6%	3	1	9	9	1	3	9	3	3	9	9	3	9	9
D, T	135	I want to speak with my team on-board	2	2%	1	1	1	1	1	3	3	1	1	3	3	3	1	1
D	056	I want to decrease my driving attention	3	3%	1	3	3	9	3	9	1	3	3	3	3	3	3	1
D	064	I want to change driving functions accidentally	3	3%	1	9	3	3	3	9	3	3	3	9	9	9	9	9
D	081	I do not want to be stressed by information workload	4	5%	1	3	9	3	1	9	3	3	3	9	9	9	9	3
D	082	I want to be warned in time in case of malfunctions	5	6%	3	3	3	9	3	9	9	9	9	3	3	9	9	3
D	058	I want to adjust parameters during driving	3	3%	3	9	3	3	3	3	3	3	3	9	9	3	3	3
D	061	I want to have a specific driving style based on context	3	3%	1	1	1	1	1	1	9	3	3	3	3	3	3	3
D	067	I want to be entertained during my trips	2	2%	1	3	9	3	3	3	9	3	3	3	3	9	1	1
T	158	I want to set up the vehicle tools for race	4	5%	1	3	9	3	3	3	9	3	3	9	9	3	3	3
D	083	I want to learn from my driving mistakes	4	5%	1	1	1	1	1	1	3	3	3	3	1	3	1	1
D	084	I want to know every characteristic of the circuit	4	5%	1	1	1	1	1	1	3	3	3	3	3	3	1	1
		TOTAL	91	100%	200	270	382	430	226	422	452	356	386	492	426	408	348	276
		Importance of every technical parameter of the final product		⬆	2%	3%	4%	4%	2%	4%	4%	4%	4%	5%	4%	4%	3%	3%

			Weight of needs	% Weight of needs	Frequency of use	Operation distance	Operation time	Operation steps	Input area	Contour depth	Roughness	Fingertip force	Feedback response	Feedback intensity	Personalization	Memory	Number of input	Number of output
D	054	I want to keep me eyes on the road	5	6%	9	3	9	3	9	3	3	9	1	9	1	0	1	1
D	069	I do not want to obstruct the visibility of information	3	3%	3	3	3	3	9	0	0	1	1	1	1	0	0	0
D	077	I want to see only the essential vehicle information	4	5%	9	3	9	3	3	3	3	3	3	3	9	0	1	1
D	079	I want to have great readability in all environmental conditions	3	3%	1	1	1	1	9	3	3	3	3	9	3	0	1	1
D	068	I want to know when the race finish	2	2%	9	1	3	3	1	1	1	1	3	3	9	1	3	3
D	074	I always want to know the state of vehicle system	5	6%	9	3	3	3	3	1	1	3	9	9	3	3	3	3
D	086	I want to know if I'm losing time laps	4	5%	3	3	3	3	3	1	1	1	3	3	9	3	3	3
D	126	I want to shift gear at the right moment	4	5%	9	9	9	9	9	9	9	9	9	9	3	0	0	0
D, T	134	I want to check the vehicle parameters before a driving section	3	3%	3	3	3	9	3	3	1	3	3	3	9	3	3	3
D, T	136	I want to track the vehicle on circuit	3	3%	9	3	3	3	3	3	3	3	3	3	9	3	9	3
T	157	I want to monitor vehicle parameters remotely	2	2%	3	9	3	3	1	0	0	0	1	1	9	3	3	3
T	159	I want to analyse driving data easily	3	3%	3	3	9	9	1	1	1	3	1	1	3	9	3	9
D	007	I do not want to remove my hands on steering wheel	5	6%	9	9	9	9	9	9	3	9	3	3	9	0	0	3
D	060	I want to change functions in base of my preferences	5	6%	3	3	3	9	9	3	1	3	3	3	9	1	3	9
D, T	135	I want to speak with my team on-board	2	2%	9	3	3	3	3	3	3	3	3	3	9	0	9	9
D	056	I want to decrease my driving attention	3	3%	1	3	9	9	3	3	1	3	9	9	1	0	1	1
D	064	I want to change driving functions accidentally	3	3%	3	3	3	9	9	9	9	9	3	3	1	0	3	1
D	081	I do not want to be stressed by information workload	4	5%	9	1	9	9	3	3	3	3	3	9	3	0	1	1
D	082	I want to be warned in time in case of malfunctions	5	6%	3	9	3	3	3	1	1	1	9	9	1	0	3	9
D	058	I want to adjust parameters during driving	3	3%	9	9	9	9	9	9	9	9	9	9	3	1	1	3
D	061	I want to have a specific driving style based on context	3	3%	9	3	3	3	3	3	3	3	3	3	9	1	1	1
D	067	I want to be entertained during my trips	2	2%	3	1	9	9	3	3	3	3	3	3	9	9	1	1
T	158	I want to set up the vehicle tools for race	4	5%	3	3	3	9	3	3	3	3	3	3	9	1	9	3
D	083	I want to learn from my driving mistakes	4	5%	3	1	3	3	0	0	0	0	3	3	3	9	3	3
D	084	I want to know every characteristic of the circuit	4	5%	3	1	3	3	0	0	0	0	1	1	9	9	9	9
		TOTAL	91	100%	492	340	456	492	412	277	225	326	350	432	484	185	252	303
		Importance of every technical parameter of the final product		➡	5%	3%	5%	5%	4%	3%	2%	3%	3%	4%	5%	2%	2%	3%

			Weight of needs	% Weight of needs	Ariel Atom	Bac Mono	Caparo T1	Caterham Seven 620R	Dallara Stradale	Drakan Spyder	Elemental RP1	KTM X-Bow	Kyburz eRod	Lotus 3-Eleven	Radical RS3	Vuhl 05	Zenos E10 R	
D	054	I want to keep me eyes on the road	5	6%	4	5	4	4	5	4	4	4	4	4	4	4	4	
D	069	I do not want to obstruct the visibility of information	3	3%	3	5	3	3	5	3	4	5	3	5	4	4	2	
D	077	I want to see only the essential vehicle information	4	5%	3	4	3	3	5	3	4	3	3	5	3	4	3	
D	079	I want to have great readability in all environmental conditions	3	3%	3	4	3	3	4	3	4	3	3	4	3	3	3	
D	068	I want to know when the race finish	2	2%	2	3	2	1	3	3	2	2	1	3	3	2	3	
D	074	I always want to know the state of vehicle system	5	6%	5	5	3	3	5	4	5	4	4	5	4	4	3	
D	086	I want to know if I'm losing time laps	4	5%	3	4	3	1	5	4	4	3	1	5	3	3	3	
D	126	I want to shift gear at the right moment	4	5%	4	5	4	3	5	3	5	3	4	5	5	4	3	
D, T	134	I want to check the vehicle parameters before a driving section	3	3%	4	4	4	3	5	4	4	4	4	4	4	4	4	
D, T	136	I want to track the vehicle on circuit	3	3%	4	4	4	3	4	4	4	4	3	4	4	4	3	
T	157	I want to monitor vehicle parameters remotely	2	2%	2	2	1	1	2	2	2	2	1	2	2	2	2	
T	159	I want to analyse driving data easily	3	3%	3	3	3	1	3	4	3	3	3	3	4	4	3	
D	007	I do not want to remove my hands on steering wheel	5	6%	4	5	4	3	5	3	4	5	4	4	3	3	3	
D	060	I want to change functions in base of my preferences	5	6%	5	5	4	3	5	4	4	4	4	4	4	4	3	
D, T	135	I want to speak with my team on-board	2	2%	2	1	1	1	2	1	1	3	1	2	2	2	1	
D	056	I want to decrease my driving attention	3	3%	4	4	3	3	4	3	4	4	4	4	4	4	3	
D	064	I want to change driving functions accidentally	3	3%	3	3	3	3	4	3	4	3	3	4	3	4	3	
D	081	I do not want to be stressed by information workload	4	5%	4	4	4	4	4	3	4	3	3	4	3	4	2	
D	082	I want to be warned in time in case of malfunctions	5	6%	3	5	3	3	4	3	4	3	3	4	3	3	3	
D	058	I want to adjust parameters during driving	3	3%	4	5	4	3	4	4	4	3	3	3	3	3	3	
D	061	I want to have a specific driving style based on context	3	3%	3	3	3	2	4	3	4	3	4	3	3	3	3	
D	067	I want to be entertained during my trips	2	2%	1	1	1	1	2	1	1	3	1	2	1	1	1	
T	158	I want to set up the vehicle tools for race	4	5%	4	4	4	4	4	3	4	4	3	4	4	4	3	
D	083	I want to learn from my driving mistakes	4	5%	3	4	4	2	4	4	4	4	4	3	3	3	3	
D	084	I want to know every characteristic of the circuit	4	5%	3	3	3	1	4	4	3	2	1	4	4	4	2	
		TOTAL	91	100%	83	95	78	62	101	80	90	84	72	94	83	84	69	1075
		Importance of every technical parameter of the final product		➡	8%	9%	7%	6%	9%	7%	8%	8%	7%	9%	8%	8%	6%	100%



Img. 59 • Technical importance ranking of the vehicle interface.

type of distraction or confusion to drivers. In addition, it is important to provide to drivers a multisensory perception of the feedbacks in such a way that the system notifications are always recognized by human senses even if one of those sensory channels is disturbed either by the surrounding context or by other external agents. The design considerations about the final outputs are:

5%	494	T10	Number of information	Number

The vehicle must provide adequate data according to the driving context (road or track). On the tracks, the system must allow driver to operate in a fast and safe way. Information must be intelligible and clearly organized through a hierarchy to create a good comprehension of the system and to allow the driver to operate with few glances. This technical specification is directly linked to the frequency of the driver's actions on the system and it is tight associated to the time and modality necessary to make specific tasks.

5%	492	T15	Frequency of use	%

Vehicle data and controls must be organized according to their priority of use to facilitate accessibility The most requested functions or controls must be more visible and accessible, whilst the others can be organized under different levels of use. The frequency of use of the controls must not affect the primary task of driving.

5%	492	T18	Operation steps	Number

To facilitate driving, it is essential that each operation is carried out rapidly (preferably in a single step) or in a specific time that must be adequate to the complexity of a specific task. In this case, the operations that require multiple steps must not compromise driver's performance nor create errors. Complex and long operations can be executable when the vehicle is stopped.

5%	484	T25	Personalization	%

Interface must be used in different contexts and it must be utilized by users with different capabilities. In this case, it is important to provide a flexible and adaptable interface for every need or preference of every single user, facilitating at the same time comfort, accessibility and high driving performance.

5%	456	T17	Operation time	ms

Driving operations must be intuitive and fast to activate, whilst graphic information must be clearly visible at glance. In this case, both elements must be accessible and easy to reach. The system has to create adequate distinction between the operations that are necessary for driving and the controls that can be manipulated also when the vehicle is stopped or high attention is not requested.

4%	452	T07	Menu depth	Number

Information must need a clear and short information architecture. Most data must be at the first level of depth in relation to frequency of use and time of use (which must be very fast) and only the operations that required more time or can be performed when the vehicle is stopped, can have deeper levels.

4%	432	T24	Feedback intensity	%

Since driving is a complex task, multimodal feedback helps the cognitive workload to be distributed on several different pools of resources to guarantee more efficiency to drivers when a specific action on the system is required. This because if one of these stimuli is obscured by the environment or its corresponding receptor shows some disadvantages (for example, sunlight hides a visual warning signal or driver does not see the feedback because of driving), it can be represented by other remaining sensory channels (for example an haptic signal supports the visual one).

4%	430	T04	Screen resolution	LxW
The vehicle interface has to have sufficient resolution that is able to contain the minimum number of information to display during driving. Its size must be proportional to the viewing area of the driver.				
4%	426	T11	Number of options	Number
The interface has to provide an adequate and essential number of driving functions or controls according to the driving context (urban roads or track circuits). It is important that those controls can be modified based on the context of use. In particular, in a race environment the driver's operations on the vehicle system must be intuitive and they must not produce neither errors nor create high cognitive workload, because they can reduce driver's reaction time and performance.				
4%	422	T06	Contrast	Colour ratio
The interface has to clearly show information with a good readability, at glance and in different environmental conditions. Although the contrast of the vehicle interface is often high, in order to be accessible for all, this technical parameter must be always guaranteed to people who have low acuity.				
4%	412	T19	Input area	LxW
Input size must permit users to recognize and subsequently use driving controls at glance, avoiding any type of error during driving. Different areas can distinguish the functions in base of their importance or frequency of use.				
4%	408	T12	Error rate	%
The interface must not be much complex in order to avoid errors during the process of an intention or an action that are elaborated to manipulate the system. Also, the interface must allow to annul wrong operations. The system must guarantee a high level of situation awareness.				
4%	386	T09	Space of intersection	mm
Every information or driving control must be clearly distinguished to each other, in order to allow the to operate on the system in driver a fast and understandable way. This technical requirement is tight related to the interface layout, because it permits clear distinction between data through black spaces.				
4%	382	T03	Dashboard area	LxW

The area must contain all vehicle controls and all data that are useful both to control and monitor the vehicle. The organization of the elements must take into account the reaching envelope of the driver and its viewing area.				
4%	356	T08	Font/Icon size	Height
Font and icon sizes must be adequate to the driver's viewing distance. Sizes have to allow reading information at glance to different viewing capabilities in different environmental conditions. Different sizes can be used to create a visual hierarchy between vehicle controls and data of the interface.				
3%	350	T23	Feedback response	ms
Feedbacks must be immediately sent to users as soon as an action is make on the vehicle system. In order to have faster delivery of the feedbacks, the system can use multiple sensory channels at once.				
3%	348	T13	Colours	RGB
Colour must allow to distinguish vehicle controls and data of the interface to each other (in particular between different warning signals) and they must guarantee high contrast on the screen, in order to provide more readability to drivers.				
3%	340	T16	Operation distance	cm
Users must be able to reach vehicle controls in an easy and comfortable way, without compromising driving performance. In order to guarantee more efficiency, some functions that are used more frequently can be allocated and grouped around the driver's hands (close to the steering wheel).				
3%	326	T22	Fingertip force	Newton
Driving controls must be enough resistant to pressure, in order to deliver to users a direct feedback of his/her action and to avoid any type of wrong activation or deactivation of a specific function.				
3%	303	T28	Number of output	Number
Interface must allow both to drivers and technicians to visualize every output of the vehicle system. In particular, the most important data must be clearly displayed on screen and they must be accompanied by efficient and multimodal feedbacks.				
3%	277	T20	Contour depth difference	mm

<table>
<tr><td colspan="5">Vehicle controls can have different heights of thickness to each other, so as the driver can perceive every function without moving his/her eyes on the interface but he/she can recognize it only by touching its physical contour.</td></tr>
<tr><td>3%</td><td>276</td><td>T14</td><td>Border radius ratio</td><td>%</td></tr>
<tr><td colspan="5">In order to distinguish vehicle functions, it is possible to use different bi-dimensional shapes that are able to organize vehicle controls and vehicle data to each other, through a clear visual hierarchy.</td></tr>
<tr><td>3%</td><td>270</td><td>T02</td><td>Dashboard form factor</td><td>L max : L min</td></tr>
<tr><td colspan="5">Interface must have adequate proportion in relation to the width of the instrument panel, without obstructing ingress or egress to the driver but maintaining wide-range visibility.</td></tr>
<tr><td>2%</td><td>252</td><td>T27</td><td>Number of input</td><td>Number</td></tr>
<tr><td colspan="5">Interface must be equipped by several sensors that are able to track the vehicle on circuit. Moreover, the system must have particular plugs, in order to connect mobile devices that are useful to mechanics for monitoring both driver and vehicle parameters during a race or a track day.</td></tr>
<tr><td>2%</td><td>226</td><td>T05</td><td>Brightness</td><td>Lux</td></tr>
<tr><td colspan="5">Brightness must make information visible to every user with particular capabilities and it must be dimmable according to specific external environmental conditions.</td></tr>
<tr><td>2%</td><td>225</td><td>T21</td><td>Roughness</td><td>µm</td></tr>
<tr><td colspan="5">The physical interface can utilize roughness as particular element to divide and better recognize many controls. Roughness can also improve grip on physical instruments.</td></tr>
<tr><td>2%</td><td>200</td><td>T01</td><td>Viewing distance</td><td>LxAngle</td></tr>
<tr><td colspan="5">Interface must have the correct distance and angle to allow drivers to concentrate themselves exclusively on driving. Information must be visible at glance and the inclination must avoid eventual light reflection on the screen, caused by environment.</td></tr>
<tr><td>2%</td><td>185</td><td>T26</td><td>Memory</td><td>Byte</td></tr>
<tr><td colspan="5">Memory has to permit data recording of every data related both to the vehicle status and to the behaviours of driver during a driving section. Also, the system must allow to save every preference of very user that are associated to the setting of either vehicle or interface.</td></tr>
</table>

As described in the previous section, at the end of the QFD process, each selected area of the vehicle gathered many technical considerations that delineated the first design guidelines to design the expected vehicle according to the user requirements. However, data collected during this phase were temporarily "frozen" and the research passed on the following methodological phase to delineate the styling strategy of the expected vehicle. In this case, the project decided to use the information in the last part of the design process to produce a unique result by integrating the technical aspects of the QFD with the functional and morphological that would derive from the ViP's outcomes.

5.5 ViP process

As described in the previous section, the research continued the design process by elaborating a styling strategy for the expected concept car. Since the outputs of the QFD produced several design guidelines from a technical point of view, this phase was necessary to support the project in delineating the morphological aspect of the overall vehicle as well.

Considering this, the research used the ViP approach because the model is able to develop a strategical design process that focuses on the qualitative level of the total product experience, in terms of appearance, functions, and operations (Hekkert & Schifferstein, 2008). For this reason, ViP was utilized to envision the concept vehicle in a future context, in order to not create something in response to the current demand, but also to understand the possible tomorrow by establishing the *raison d'être* of the final design (Hekkert & Van Dijk, 2011).

This step was conducted in collaboration with the Industrial Design Engineering (IDE) at TU Delft in the Netherlands, which contains an important research section dedicated to the automotive design. The partnership provided a solid background about the ViP process that was successively used to conduct the research. The design process followed every step of the ViP model to create the vision of the expected car, namely the advanced concept.

5.5.1 Deconstructing phase

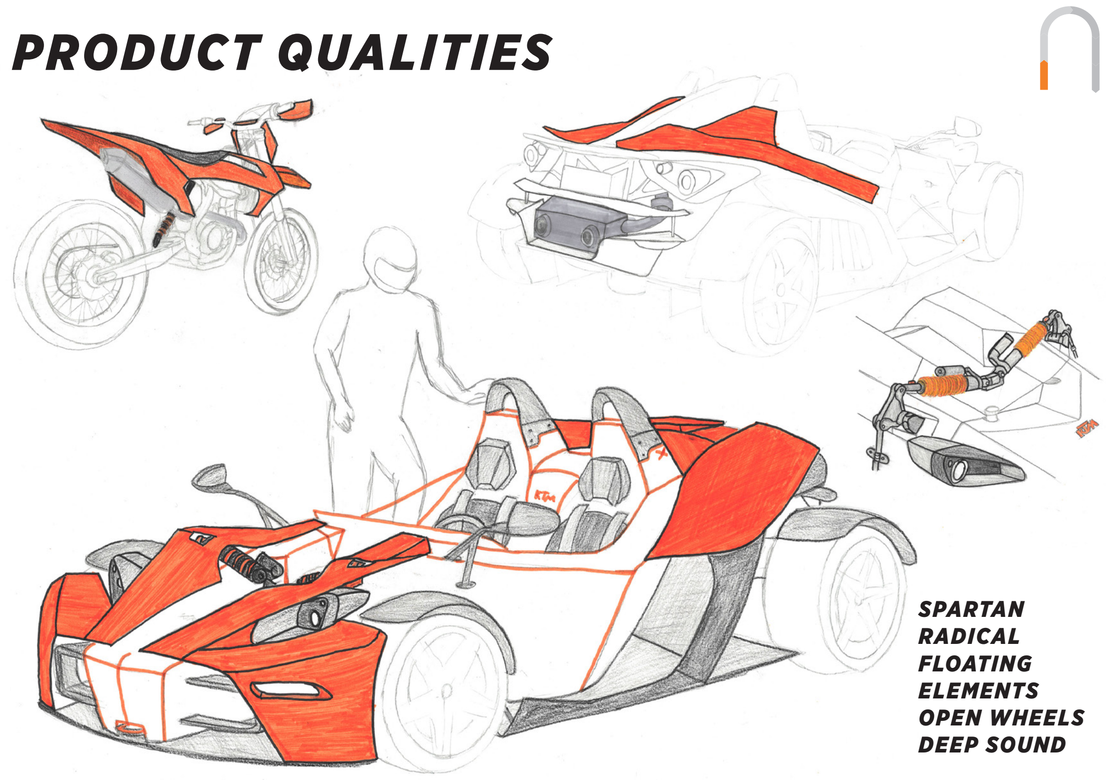
In the ViP's first step, the research investigated the deconstructing phase, the left side of the model, to analyse the present context.

5.5.1.1 Deconstructing phase: product qualities

For facilitating the process, all of the activities were based on an existing car model, which was selected as case study to develop the vision: the KTM X-Bow. This specific vehicle of KTM was selected because its particular styling configuration and its technical properties perfectly coincided both to the objectives of the project and to the selected car segment delineated at the early stages of the process. The X-Bow was chosen also because the user analysis was conducted principally through a specific event promoted directly by the same carmaker, and hence, it was the main automotive product, which people interacted with. Therefore, X-Bow was used as an existing product reference, on which it was possible to develop the vision of the expected car.

In the first step of ViP, KTM X-Bow was analysed in depth to obtain information about the configuration of the selected car model. X-Bow's features were utilized as starting point to project the existing model into the world of tomorrow. The research investigated both technical and styling characteristics of the X-Bow.

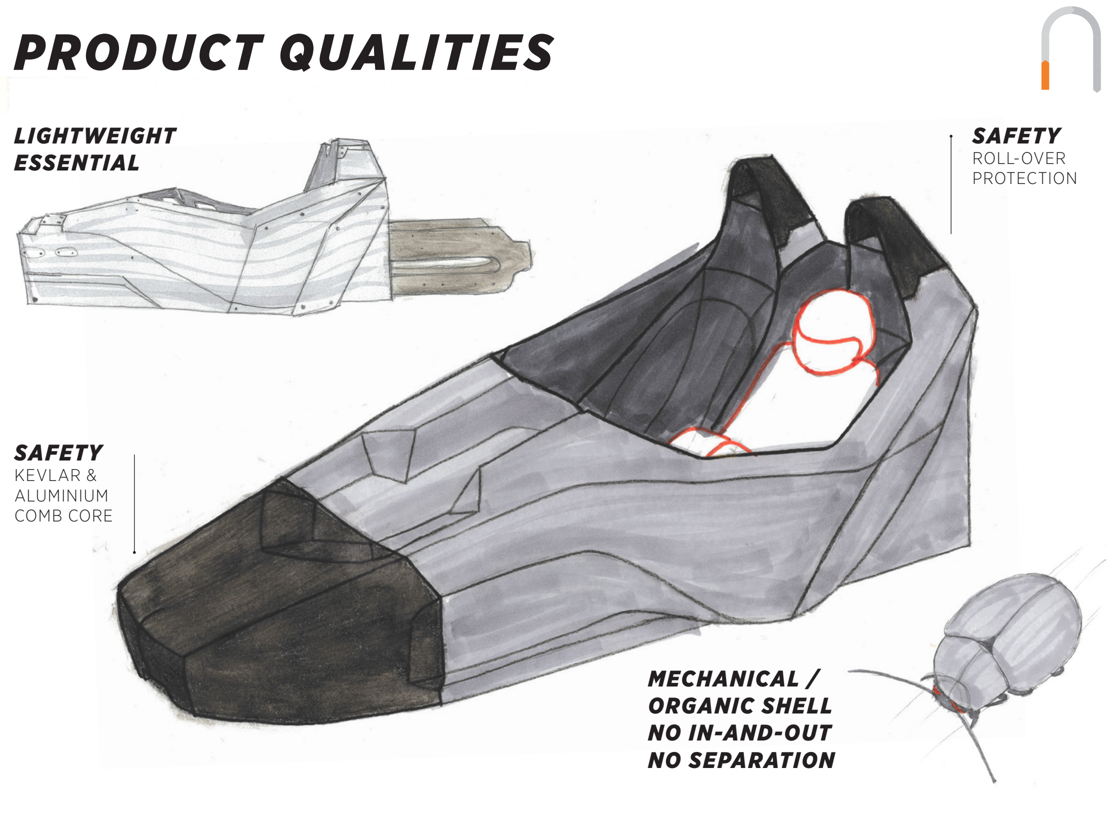
From technical point of view, X-Bow **Img. 60 •** is a two-seater lightweight car (820 Kg), equipped with rear-wheel drive configuration and rear



Img. 60 • Morphological qualities of the KTM X-Bow.

mid-engine layout, which typically denote a sports car. The vehicle dimensions are 3738 x 1915 x 1202 mm. In comparison with other car segments, X-Bow size is tightly similar to subcompact models (B-segment) but slightly shorter and relatively wider and lower (ground clearance is 10 cm) to determine superior quality of dynamics in terms of handling, adherence and agility. The 4-straight transverse engine, an Audi's 2.0-liter turbo (300 HP), allows X-Bow to have shorter body style compared to the opposite longitudinal layout of similar sports cars.

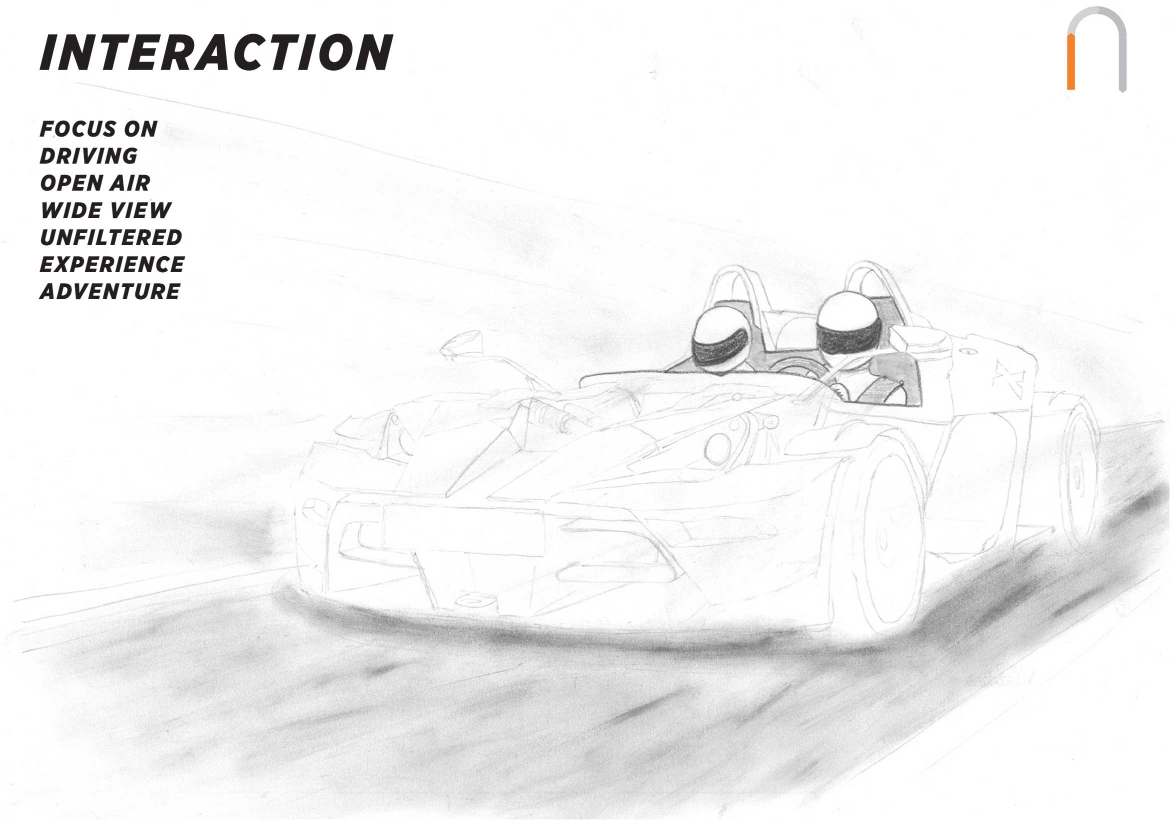
X-Bow's peculiarity is the absence of both rooftop and doors, which are replaced by a lightweight carbon fibre monocoque. This allows the car to reduce weight and provide high power-to-weight ratio (3,6 HP/Kg), which in turn, enables X-Bow to provide high performance without forcing powertrain over-sizing. The interior is clean essential while the driving inter-



Img. 61 • The product qualities of the X-Bow monocoque.

face presents only a steering wheel with few driving controls on it and a small LCD screen that displays basic information.

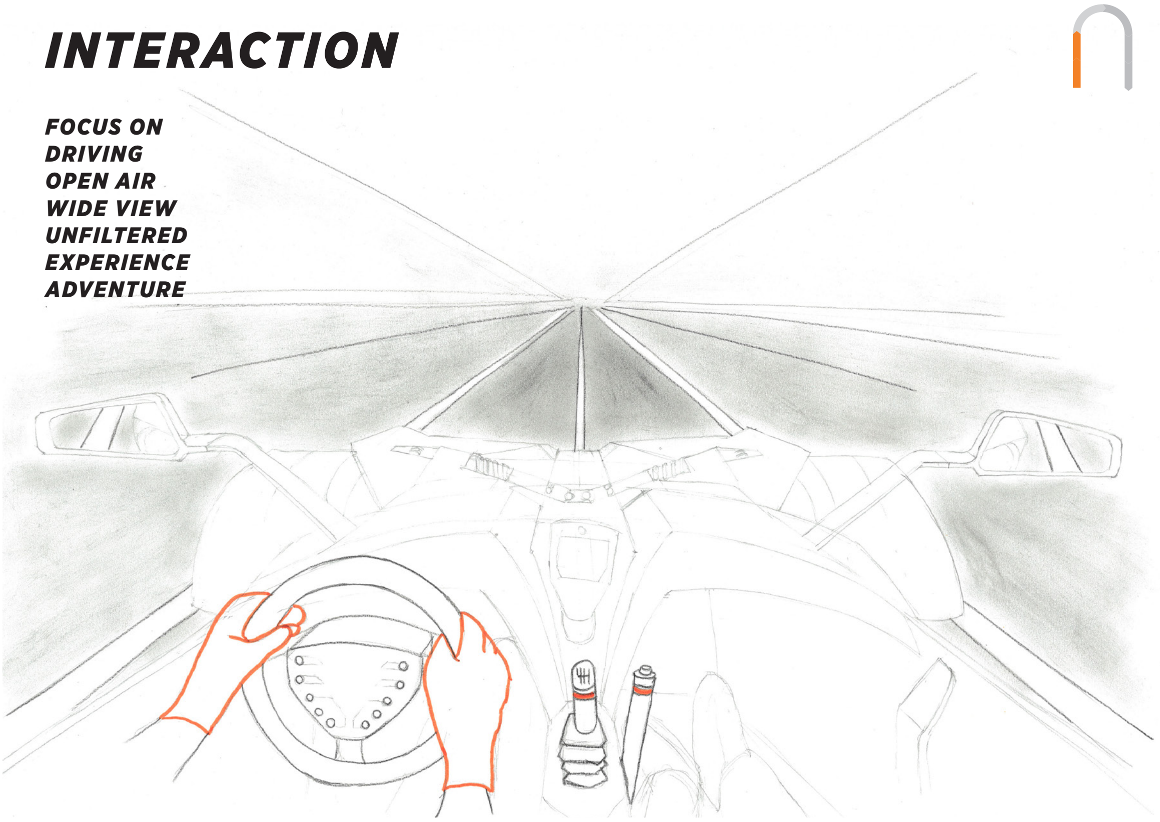
From styling point of view, KTM's monocoque characterizes appearance of the entire bodywork **Img. 61** •. The vehicle styling is defined by straight lines and sharp trailing edges that express aggressiveness. The cockpit creates no separation or distinction between exterior and interior, merging the two parts in a unique monolithic volume of carbon fibre. Indeed, the two seats are englobed inside the cockpit in a unique form. The open-wheeled configuration and the floating carbon fibre panels that cover the monocoque structure are the only elements that protrude from the monolithic cockpit. All elements of the bodywork are able to imprint into the car raw and spartan style, which perfectly coincides with the sportive brand strategy of KTM.



Img. 62 • Representation of the unfiltered and pure driving experience produced by the X-Bow.

5.5.1.2 Deconstructing phase: human-product interactions

Then, personality of X-Bow – elicited during the interaction with its end-user – was identified. It was fundamental for understanding the essential character of the vehicle, which suggests a new but coherent vehicle styling for the advanced concept. Given the essential aspects of the vehicle, X-Bow evokes an extreme character entirely addressed to adventure. Deep sound of engine supports the vehicle to elicit a powerful character. Due to the absence of doors, users need to jump in or jump off from the cockpit creating enthusiasm, dynamism and determination on drivers. The absence of windshield eliminates A-pillars, and thus, it allows the car to have wider driving view. In addition, this sight configuration is able to guarantee pure and unfiltered driving experience **Img. 62** •, because the driver remains directly and constantly connected with external environment. The sport configuration of the occupant seats and the essenti-



Img. 63 • The human-product interaction of the KTM X-Bow during the act of driving.

ality of the vehicle interface offer to drivers an immersive user experience only focused on driving **Img. 63** •. Other extra infotainments would result unnecessary.

5.5.1.3 Deconstructing phase: current context

All of the elements permitted to better understand the world of today that motivated the raison of being of the X-Bow. The analysis of the present context corresponds to the one that was already defined in the previous chapter. Considering this, the context refers to a small market niche that focuses on car enthusiasts who have appropriate economic resources to own or rent one a sports vehicle. In particular, the car provides to the drivers special sing-values because of its particular styling and configuration, which in turn confer to them not only a specific *status quo*, but also a peculiar personal driving experience. However the car is relegated

to a limited use because it corresponds mostly to racing tracks and hence it results uncomfortable or inaccessible to a standard usage in a urban context, especially for long driving periods. Indeed, since the vehicle is race-oriented, several emerging restrictions regarding traffic limitations may have an huge impact on its standard use, especially on urban roads. All of these considerations were successively discussed to elaborate the world of tomorrow.

5.5.2 Defining the vision

Once the deconstructing phase was concluded, the research investigated the right side of ViP to envision future mobility, namely the domain in which the advanced concept would be designed. Since the automotive product development implies investing high amount of resources in advance towards a shorter time-to-market process (Brunner, Hirz, & Wurzer, 2017), the selected time span for envisioning the advanced concept was ten years ahead in order to anticipate new emerging automotive trends.

5.5.2.1 Structuring the context

Following the structure of ViP (Hekkert & Van Dijk, 2011) described during the explanation of the referred methodology, the research collected several context factors to generate the scaffold for structuring the future vision. The factors were divided under the four primary typologies that are recommended in the ViP model: developments, trends, states and principles. Distinctions between the four types of factor are based on a dimension of stability in observed societal/behavioural fluctuations. States and principles are factors that can be stable and constant over longer periods of time. Whilst, developments and trends are factors that are currently changing or are expected to change in the near future. All the factors together provided a picture of the future context in which the relationship between the project and the human is going to be designed. They permitted to better understand the potential direction of our society in the near future, in order to select the elements that have a higher impact on the selected domain.

Moreover, to increase the variety of the research, these typologies of factors were also distributed in several fields. For this project eight areas: cultural, demographic, sociological, technological, economic, psychological, biological, political. In order to be more related to the project, all the fields were associated with the domain of mobility. In this case, the strategy enriched the chance to produce originality during the development of the future vision. Every context factor that was discovered and selected for this research is listed hereinafter:

	Developments	Trends	States	Principles
Cultural	People trust in technology	People prefer to personalize their objects	People want to be more independent	
		People care about their well-being	Cars are a symbol of personal freedom	
		People are becoming more sensible about environmental problems	Perception risk is decreasing	
		People are becoming more nomad		
		Women associated to races or sport environments are increasing		
		People seek learning or creating experiences rather than distraction		
Demographic	Ageing is increasing			
	68% of the world population lives in urban areas			
Technological	Hydrogen fuel cells technology is increasing	People create strategies for finding the best choice before achieving their tasks	Telemetry and data logging are two key factors for producing high performance in motorsports	Steering wheel is the interface between cars and drivers
	Battery efficiency is growing	New generations are more addicted to technology	AI's experience needs to be trained	AI technology creates automation biases
	15% of cars are fully autonomous		Most of the jobs produce sedentary lifestyle	AI cannot be reliable at 100%
	AI systems are becoming more utilized in the everyday life		Wi-Fi is an essential tool for everyone	Autonomous driving creates moral dilemmas
	Electrification is increasing in automotive industry			
	People have more leisure time			
	Digitalization of driving controls is prevailing on vehicles			
	Vehicle automation is increasing			
Social	Gender equality is increasing	People are looking for adventure to disconnect themselves from the urban life	People want to distinguish themselves from the others	People love entertainment

	Women's empowerment is increasing	New generations delay and reduce time in taking driving license	Sport cars are an hobby	
			The identity of a car produces a devotion in car enthusiasts	
			Owing a car creates a *status quo*	
Economical	Car sharing is increasing	People prefer to be more travellers rather than tourists	Car are parked 95% or their life span	
	On-demand services are becoming a standard	New generations are not interested in owning a car	Petrol cars are banned in the market	
	Analysing data is a competitive advantage	Accessibility is more common that owing a product	Owing a car needs a huge amount of time and resources	
	Car sales are decreasing their percentage		Drivers waste at least 100 hours per year in traffic	
	Fuel price is increasing		Tracks are expensive to maintain	
			Race vehicles require more technical maintenance that utility cars	
Psychological			Angry & anxiety are the most common driving styles	The act of driving needs regular practise

			In tree hours of trip, people are looking away from the road about 33%	Negative emotions increase the risk of car accidents
			Driving produces an unique personal experience	A critical task between two entities create the issue of split responsibility
				Humans have inherently attentional limitations
				Driving is a stressful and complex task
Biological				Driving abilities are reduced at old age
				Muscle strength and mass decrease with ageing about 5-10%
				Typically women have 65-70% of the men's strength
				Optimal viewing zone is between +5° and -30°
Political	Policy makers think cars more like a public transportation		Vehicles are heavily taxed	
			Cars must be zero emission	
			Vehicles are banned in the city centres	

The factors, which were considered important to generate the future context, were correlated to each other and successively clustered together based on their affinities **Img. 64** •. All the factors were turned into a unified and coherent structure that explained the relationship among those separate elements. This process structured the context of tomorrow. The research generated the future context, which was summarised and described hereinafter:

"In 2030, cities are going to be more crowded and densely populated. In terms of society, ageing will be increasing and there will be more gender equality. Mobility will be chaotic, frenetic and stressful where traffic and congestion will be more presents in big cities. Sustainability is going to be the most important factor for the successful development of urban society.

Peripheries will be important elements to connect city centres with the countryside, as most people will live them. On the contrary, cities are going to be the centres of working life for the most of the intellectual works, in which most of the people will still have a sedentary position (office work), but with more independence and flexibility to schedule their work time. This division between centre and periphery will be also an element that generates differences between different mid and high social classes. In their free time, people seek to disconnect themselves from their urban life and they look for learning experiences or adventures that can enrich their personal life and well-being.

The way of automobile transportation is provided and experienced, will be reduced, restricted and changed for several issues: policies and new regulations are going to eliminate fossil fuels and to ban vehicles in the city centres giving space to bike transportation; cars are 90% parked and the costs about their taxes, their

Img. 64 • Images of the visual process that was conducted to construct the vision. The context factors were distributed in their corresponding fields and successively were clustered in many groups in order to find their relations with one another to define the future context.

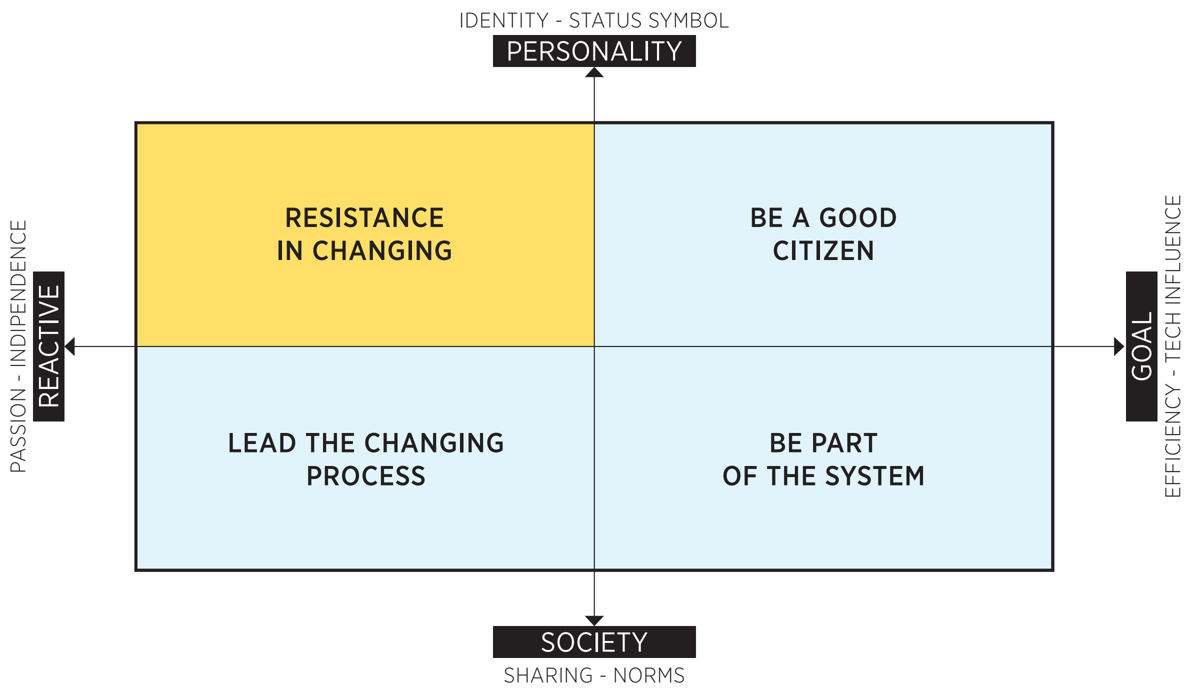
insurances or their maintenance are high; new generations are less interested in taking a driving licence or owing a private vehicle but rent a service; citizens are more sensible about environmental issues and they take care more about their well-being, so are more addressed to physical or sustainable mobility.

Public and shared transportations are going to be key tenets of urban mobility. They embrace diversity and provide independence of moving to people who not have driving capabilities, have temporary or permanent diseases or are not interested in driving. Technology and especially automation will be more predominant in the development of transportation because it expects to increase transport efficiency – in terms of safety (driving is a stressful task that needs skills, practise, experience and high attention and it is very dangerous for drivers and vulnerable road users), energy and time safe (utilizing mainly data analysis and A.I.) – but also to reduce its carbon footprint on the urban environment (using alternative sources of energy unlike fossil fuel)"

5.5.2.2 Statement definition

Considering the previous description, the context analysis generated four different parallel scenarios, which indicated four potential opportunities for designing the project. The contexts were transformed into a four-square matrix, where each square indicated a statement, namely a potential way in which the advanced concept would be designed **Img. 65 •**. The two main axes served to represent the opposing forces among those scenarios.

The vertical axis consisted of divergence between promoting individuality and sharing mobility. In the bottom side, the vision proposes a sharing context, in which the vehicle would be merely designed for the community as a public transport. In this case, the vehicle would lose its identity and its character to become a functional object serving the needs of the society. On the contrary, the top side still considers the vehicle as a form



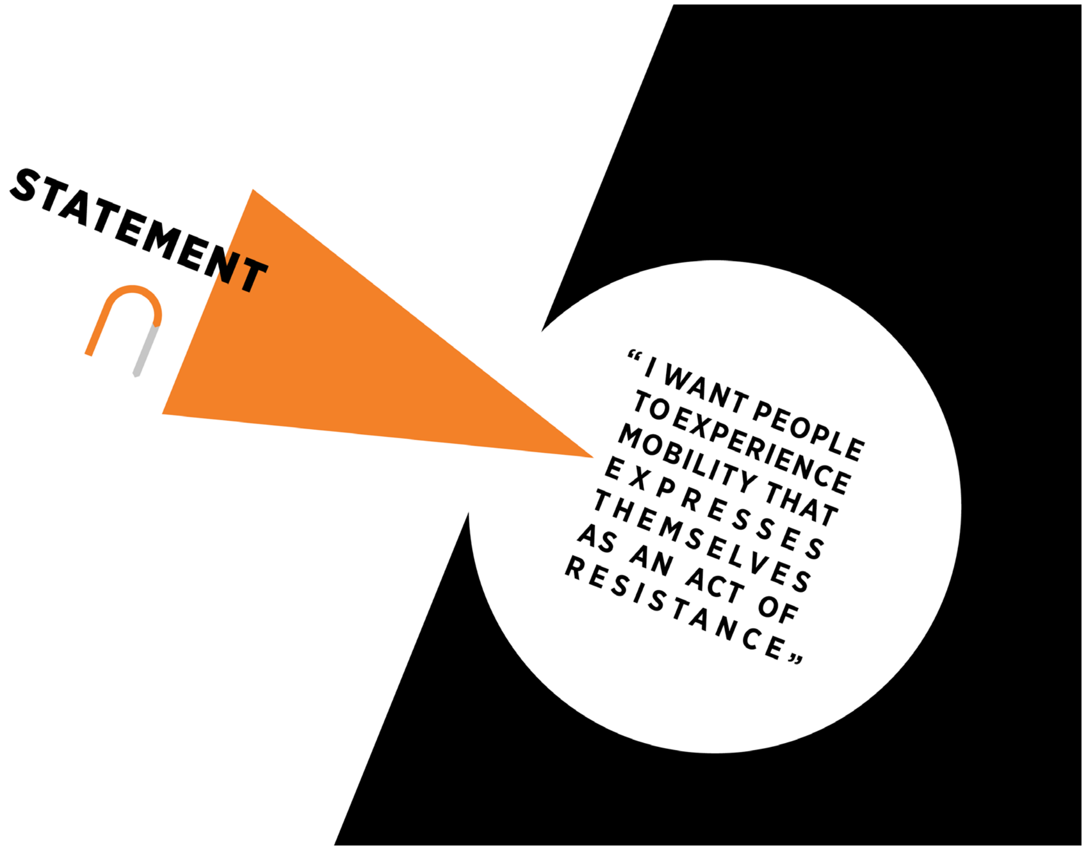
Img. 65 • The four-square matrix that was used to generate for structuring the future context.

of self-expression and for this reason, its character must be present because it is necessary to express distinct sing-values.

Instead, the horizontal axis concerned in the divergence between the efficiency declared by the technology changing and the sense of driving passion. On the right, the vision promotes all the trends that nowadays are been developing in the field of automotive, which are aspiring to generate an efficient mobility. They consist of electrification, on-demand services and autonomous driving. In this case, people would be overwhelmed by technology because they think that it can simplify the people's everyday life and for this reason, they would lose their ability to drive and their independence provided by the traditional car. Hence, people would lose also their relationship with the vehicle itself in terms of emotional and sensory sensations. On the left, the vision suggests a resistant and old-fashioned context, in which the humans are car enthusiasts and they still keep control over those technologies. Considering this, the relation with the driver would still present and it would be intimate during the driving experience, in which the car would remain a symbol of independence and passion.

The two axes served to produce the four statement:

- (a) Top-left: "Resistance in changing", which indicates a context in which people resist against the technological innovation because they want to maintain their independence while driving and they prefer to have an individual relation whit their vehicles;
- (b) Top-right: "Be a good citizen", which denotes a context where people what to preserve the *status quo* by passively accepting the emerging technology;
- (c) Bottom-left: "Lead the changing process", which expresses a context in which people actively change the traditional transportation model of the cars in more shared and convivial mobility;



Img. 66 • Visual representation of the selected statement.

- (d) Bottom-right: "Be part of the system", which represents a context where people passively follow social changes and technological innovation, losing at the same time their enthusiasm and independence.

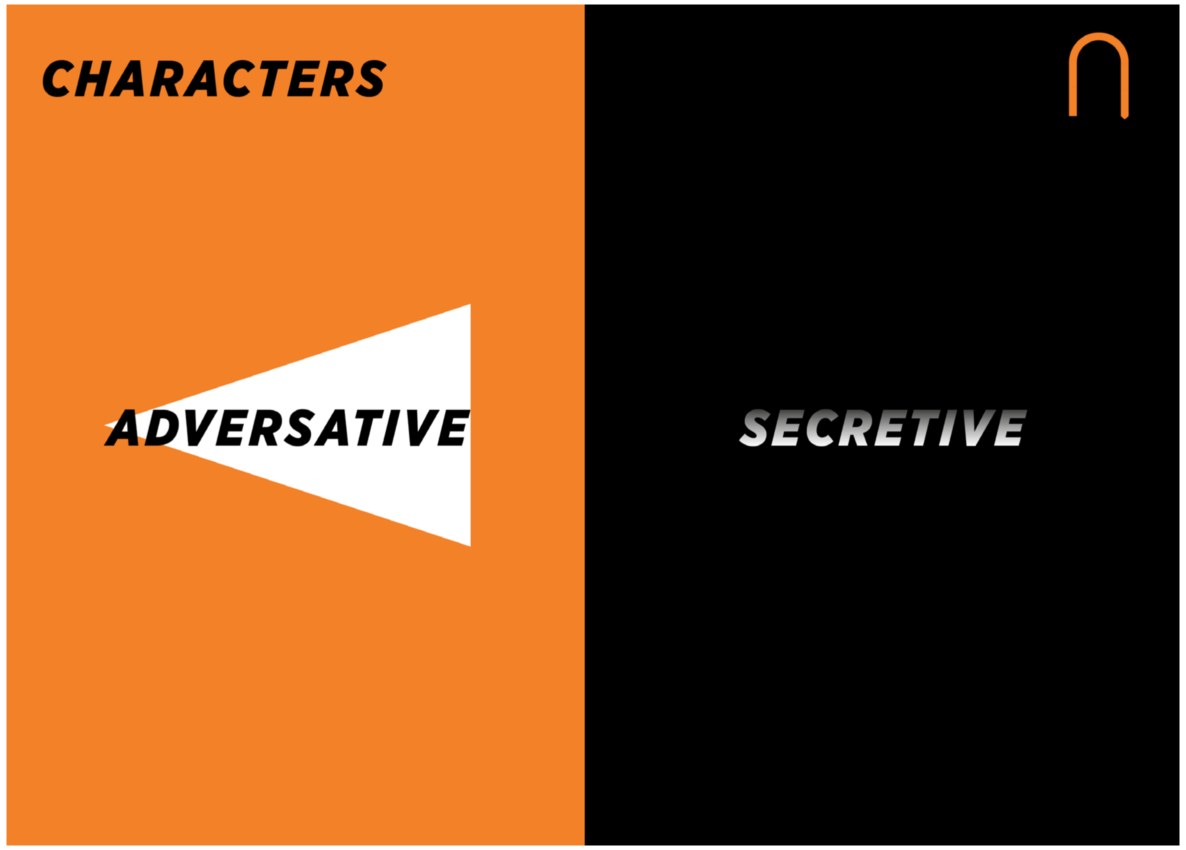
According to the goal of the project, the research decided to develop the advanced concept in the top-left square, "Resistance in changing". The ideology of the selected square was translated in the statement for the vision. The statement definition **Img. 66** • was:

> *"I want people to experience mobility that expresses themselves as an act of resistance"*

5.5.2.3 Establishing human-product interaction

The statement was the first point to discover the main human-product

Img. 67 • The analogy that was used to express the human-product interaction of the vision.



Img. 68 • The two meanings that characterised the properties of the advanced concept.

interactions that the concept vehicle would expect to produce. Through the use of the analogies, the character and the properties of the expected car were discovered. Storytelling facilitated the process of envisioning the advanced concept because it helped to identify those interactions. The process produced the correct analogy that fully matched the selected statement Img. 67 •. It was:

W

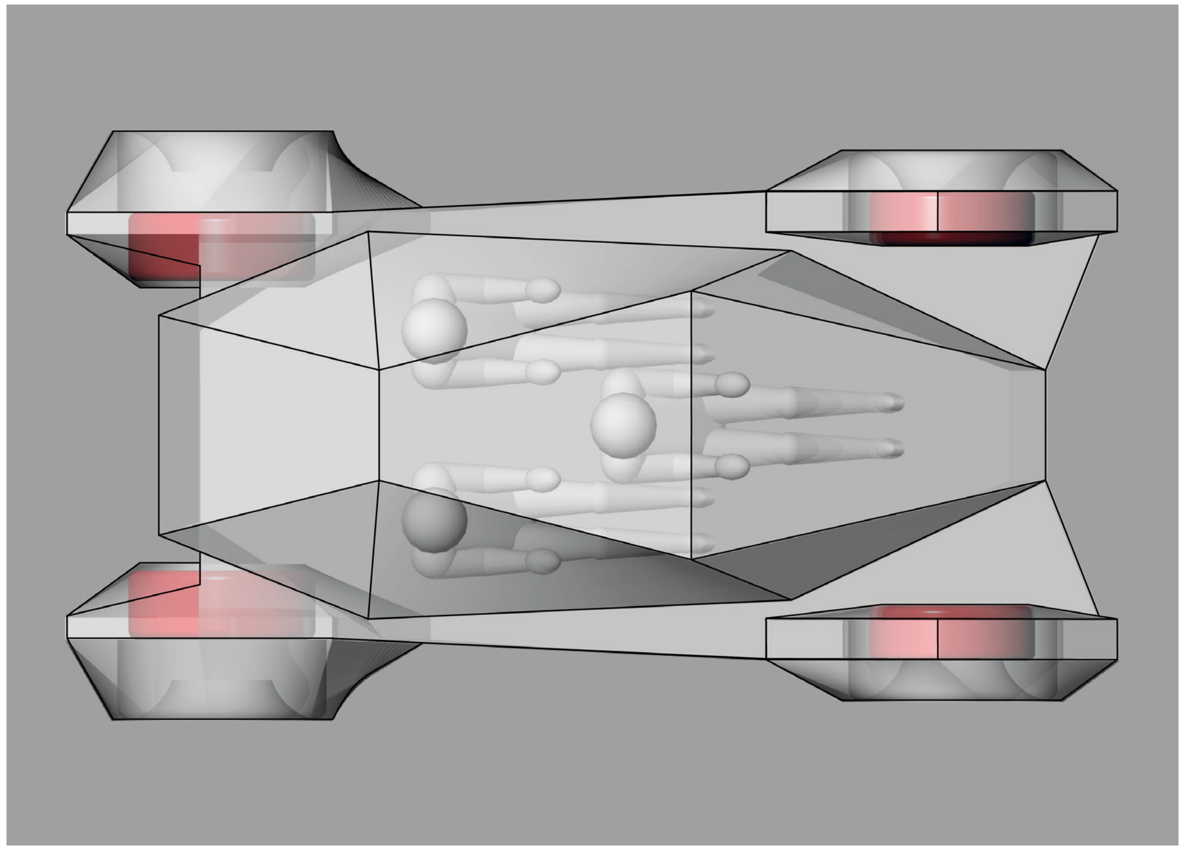
"It feels like making graffiti on the wall"

This because the sensation of producing graffiti on the wall is recognized as a rebel act against a particular ideology or system. Considering the four-square matrix, the system is represented by the opposite area of the square that was selected for the vision: "Be part of the system". This particular area, indeed, represented the context in which technological innovation prevails on the automotive industry by producing radical social changes – for instance, autonomous driving, electrification and shared mobility – that are able to affect the traditional idea of the car that people are used to having. Therefore, the selected area, "Resistance in changing", represents the resistance against the upcoming technological development. For this reason, the analogy translates the car itself in a rebel expression, which is capable of escaping from the prevailing technology – which transforms the car into a functional and anonymous object – to manifest its dissension by providing s specific status to its owner and by maintaining its subjective experience of driving.

5.5.2.4 Defining the product qualities

The intrinsic meaning of the analogy delineated two main product characters that were used throughout the vision to define technical and styling properties of the advanced concept encompassing technologies, operations and forms. The aim was examining the feeling and the sensation that this kind of behaviour produces to understand the main interactions that occur while that action is performed in relation to the corresponding context. The two primary product qualities were secretive and adversative Img. 68 • because the two elements perfectly expressed the intrinsic meaning of the analogy.

In fact, making graffiti on the wall is a dissenting act, which means that the behaviour is intrinsically adversative because it acts as an opposing force against the prevailing system. In this case, the world of adversative creates somehow an act of resistance, which perfectly reflects the statement of the vision. On another point of view, making graffiti is also an individual action that produces a visual expression in a public context, but nobody is able to recognize the author (except by the details of the drawing). For this reason, the graffiti produce secretiveness, because they cover the identity of its producer even the drawing is visible to all.

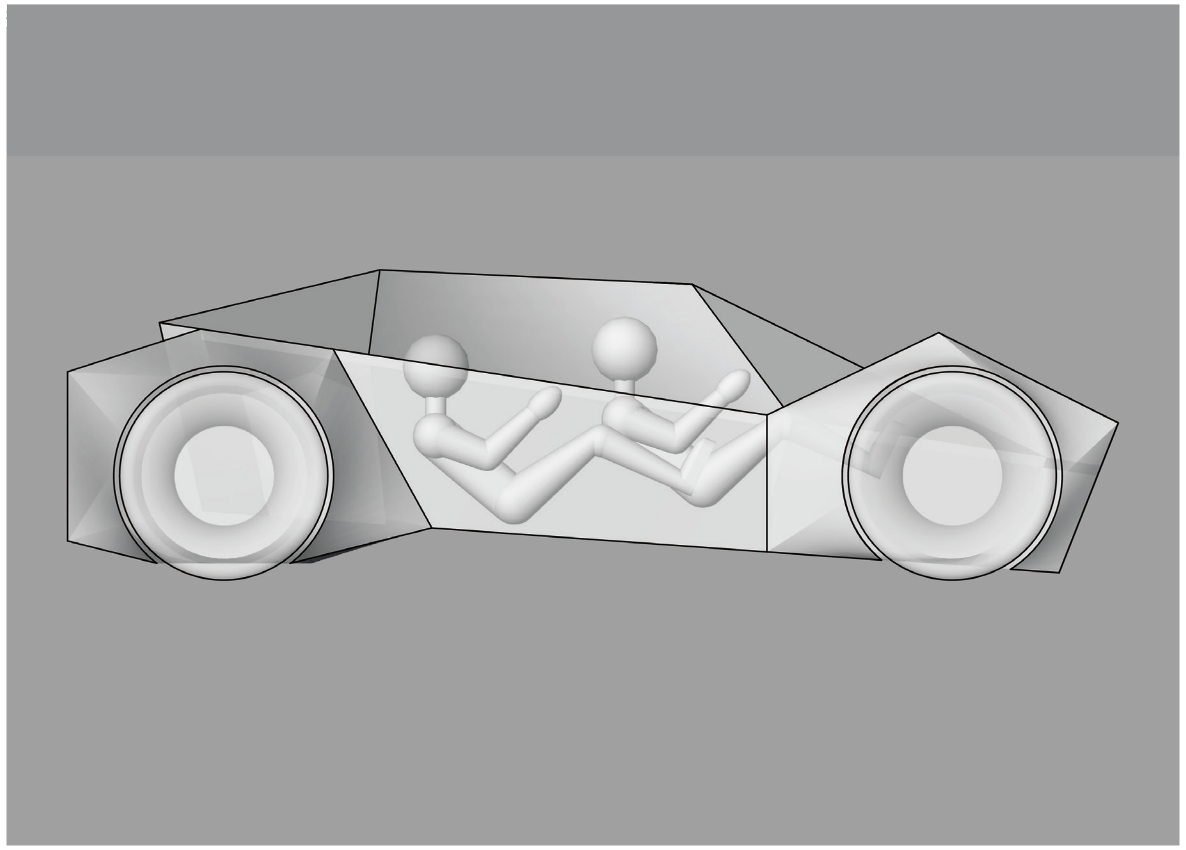


Img. 69 • Top view of the advanced concept. In red the in-wheel layout of the electric powertrain.

To encourage the vision in diverging itself from the current context, neither constraints nor restrictions were included during the process. At the end of the vision, the investigation produced the expected advanced concept. To facilitate the vision process, all the considerations emerged during the design activities were conducted through the four vehicle systems that had been already defined in the QFD phase.

5.5.2.5 The advanced concept

The two characters of the vehicle stressed the process to create a visionary vehicle. According to those elements, the scenario envisioned a hidden and silent car. It can be driven only in the night or darkness as a symbol of resistance or rebelliousness against the daylight routine of efficient and technological mobility. For this reason, the selected powertrain is fully electric because it produces fast acceleration without generating any kind



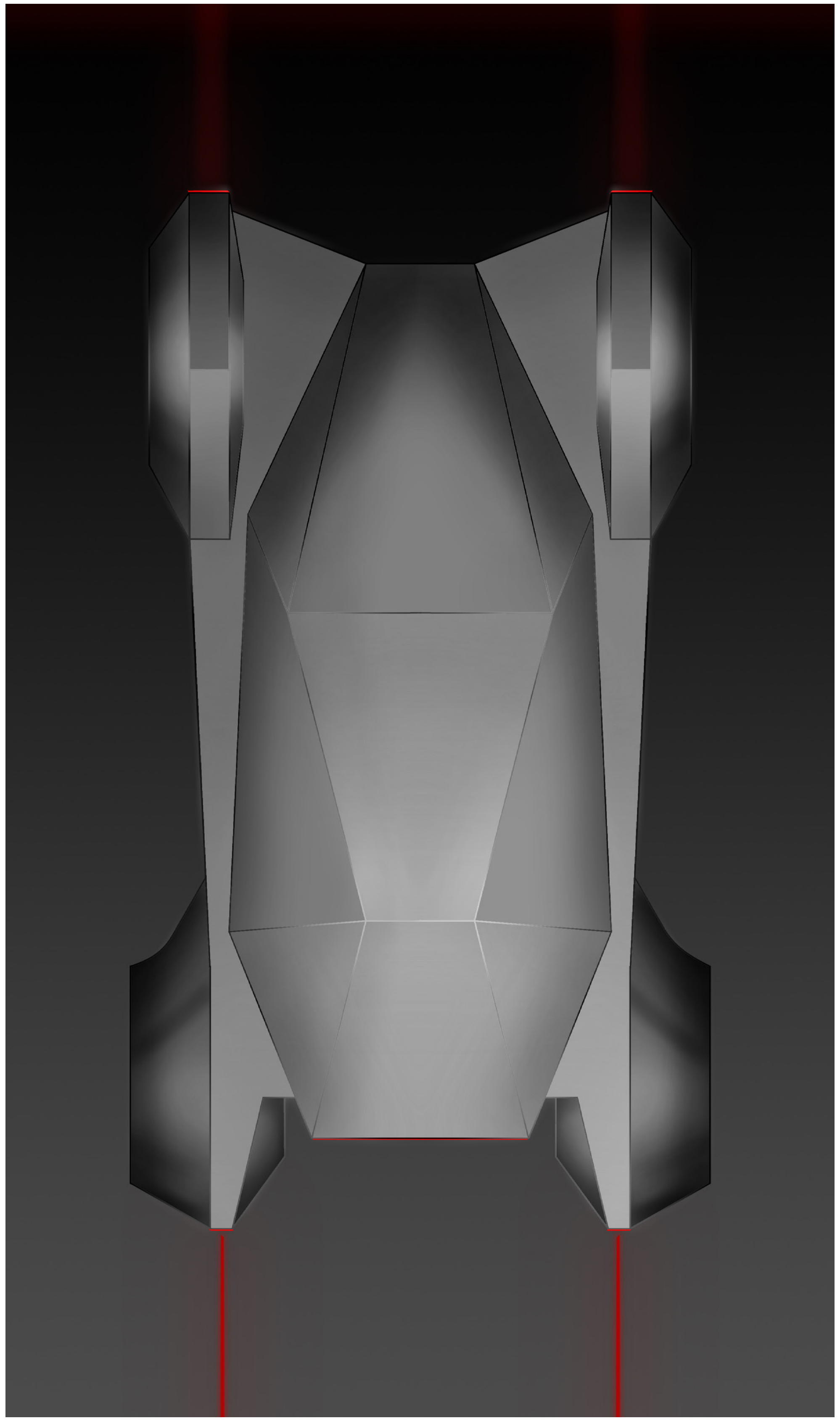
Img. 70 • Side view of the advanced concept. It shows the passenger seating configuration.

of sound. The drivetrain is equipped with four independent motors Img. 69 •, which are able to express an adverse sensation of driving through the four-wheel drive layout. All the four electric motors feature an in-wheel configuration. The two motors in the back are mounted on the extremities of the rear mid axis because the ingress/egress is located in that specific location Img. 72 •, and hence, the rear mid-axis itself is removed in favour of the space for the passengers. The occupant package is also hidden by an obscure coachwork because its configuration eliminates the traditional outlines of the doors from the vehicle. Therefore, it obscures both the occupant package and the vehicle's driving orientation, providing at the same time a unique secretive styling.

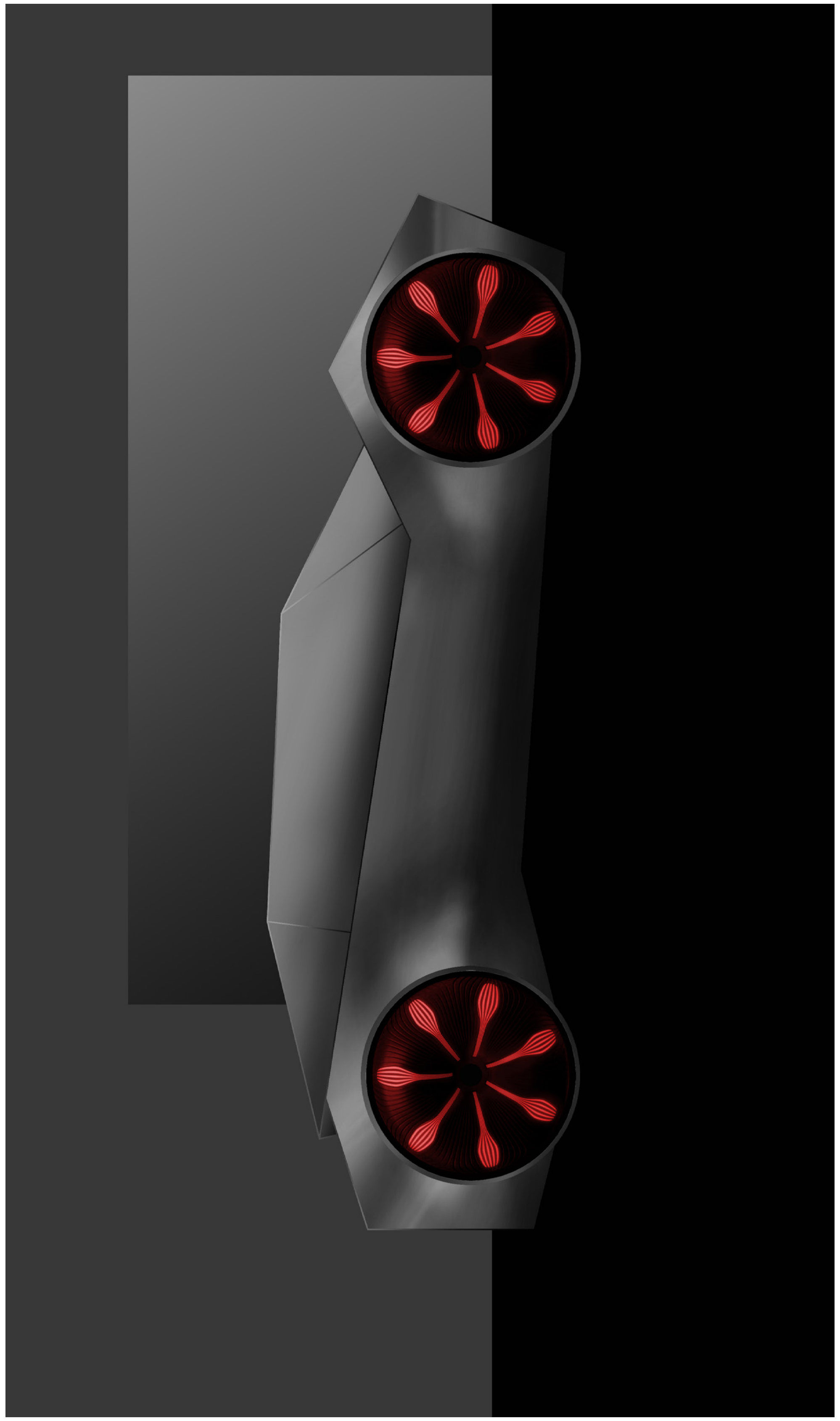
The cockpit covers the driver's identity as well by eliminating windshield and every lateral or rear window from the car Img. 73 •. Consequently,

Img. 71 • Visual representation of the advanced concept. Front view.

Img. 72 • Visual representation of the advanced concept. Rear view.



Img. 73 • Top view of the advanced concept.



Img. 74 • Lateral view of the advanced concept.

the interface proposes to drive the vehicle only through digital screens, improving driver's perception through the night vision system (radar, infrared light and thermo-graphic camera) **Img. 71** •. The car features a three-seater configuration to balance the power of rebelliousness among the occupants **Img. 70** •. However, the driver's position is in the middle while the other ones are slightly positioned behind it in such a way that the adversative character can imprint to the primary driver more activism by giving it the leadership of the rebel act of driving. This experience is also accentuated by maintaining a traditional steering hub. Such the aeroplane joy-pad, an anatomic steering wheel transfers every vehicle's behaviour directly to the driver's hands.

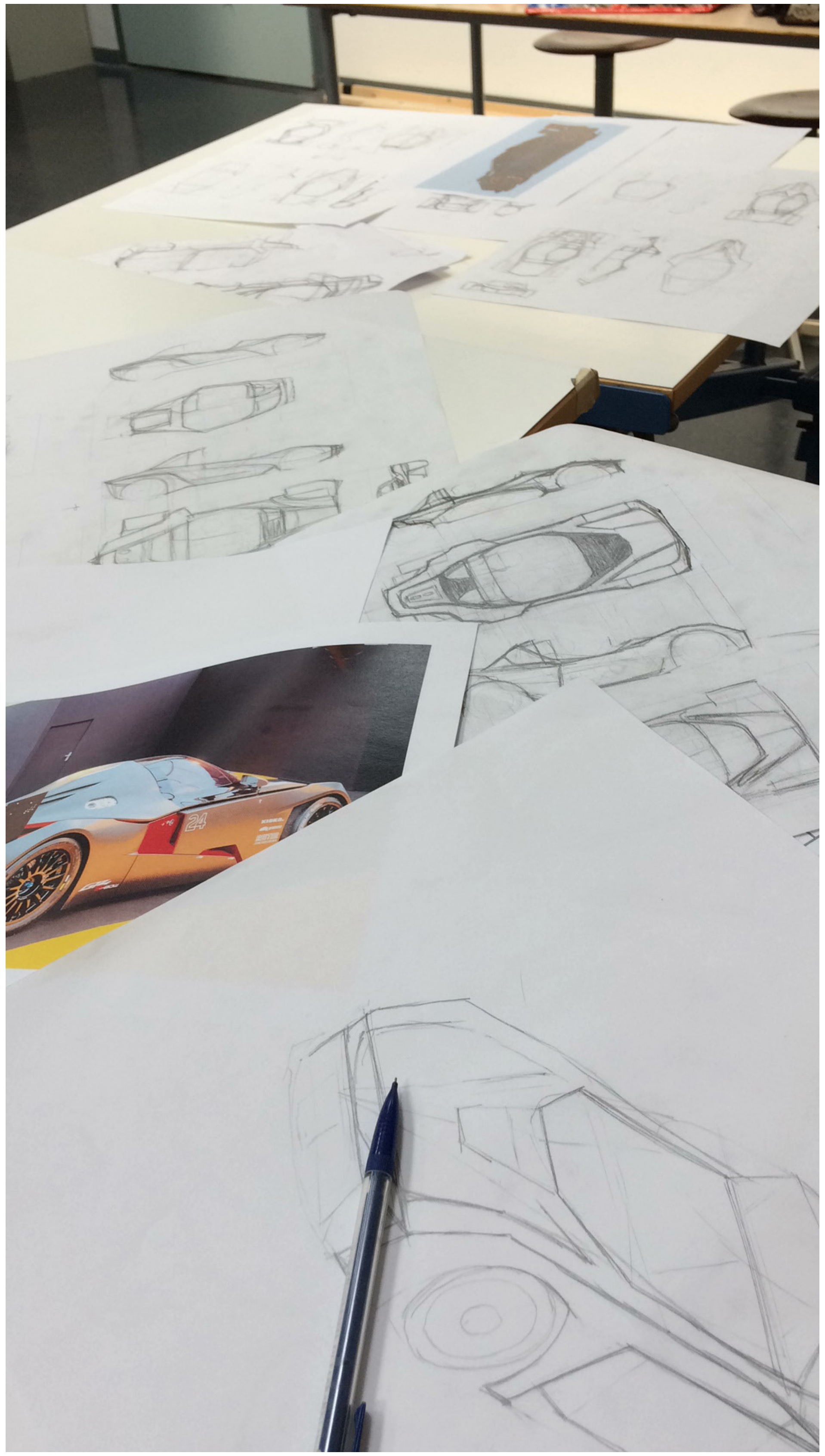
When the ViP process was concluded, since the outcomes of the vision were visionary, the advanced concept could not be considered the final model of the research because resulted too advanced to be accepted in the present context. On the contrary, the vision became a source of inspiration for developing the expect concept vehicle, which would develop in the next integrated phase. In particular, the functional and morphological features of the advanced concept were utilized in the third last research phase as framework to characterize the entire design of the mediated concept. Those aspects were implemented according to the user requirements. Indeed, in order to match user satisfaction, the vision was interpreted again by shifting the advanced concept backwards in a near and intermediated context – closer to the present – in which the properties of the conceptual vehicle was combined with the QFD outcomes to develop an integrated final solution.

5.6 Integrated process

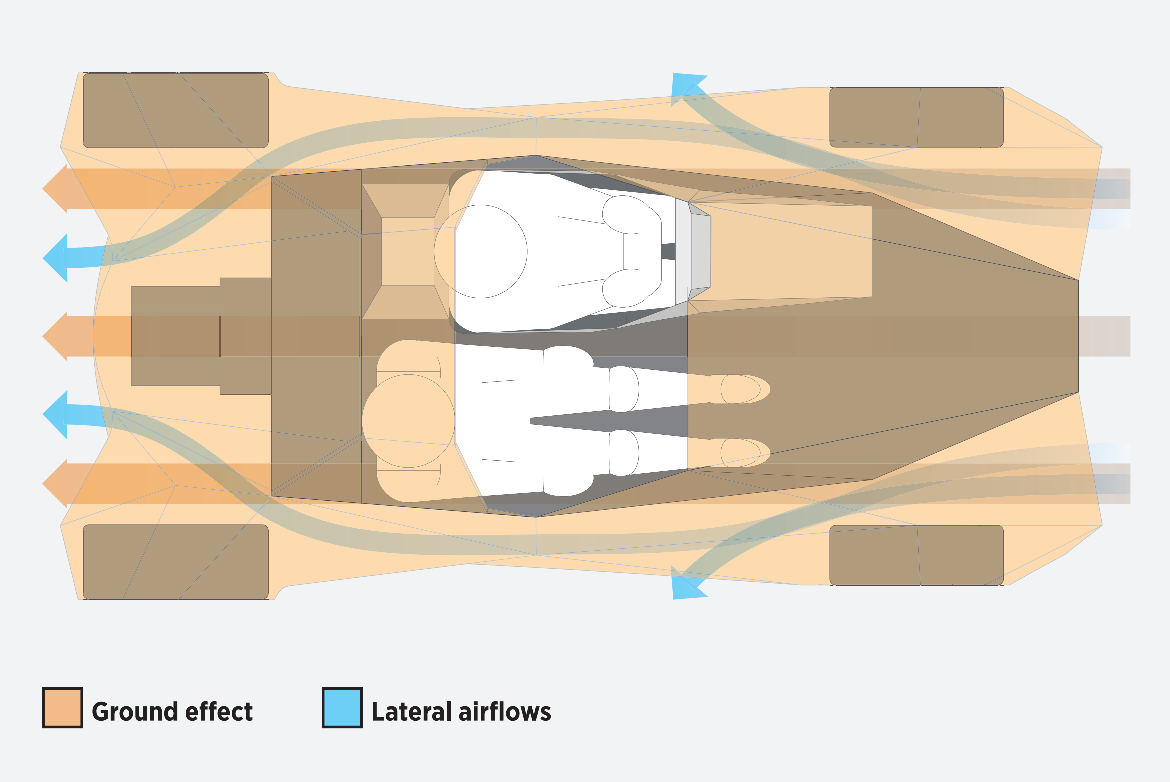
Once the many outcomes of QFD and ViP were established, the third and last design process was conducted to accomplish the goal of the research. The peculiarity of this step relied on the exploratory combination of both methods, which was used to delineate a new methodological integrated solution. All data of both processes were correlated and interpreted together, and hence, they come up with a novel concept vehicle **Img. 75** •. The ViP vision created an initial framework on which the integrated model was developed, while the outputs of QFD provided technical specifications that would made the car more feasible and related to user expectations.

Img. 75 • Visual representation of the mediated concept.

Since the KTM X-Bow became an existing product reference to develop the vision during the ViP process, the same car model was utilized with the same purpose to support last design phase in relating the integrated concept to the target car segment (high-performance sports vehicles) and to the corresponding context (track-day cars). The X-Bow, indeed, offered a basic starting layout on which the final solution was realized, such as vehicle size, powertrain layout, driving configuration.



Img. 76 • Sketching activities during the development of the integrated concept in Delft.

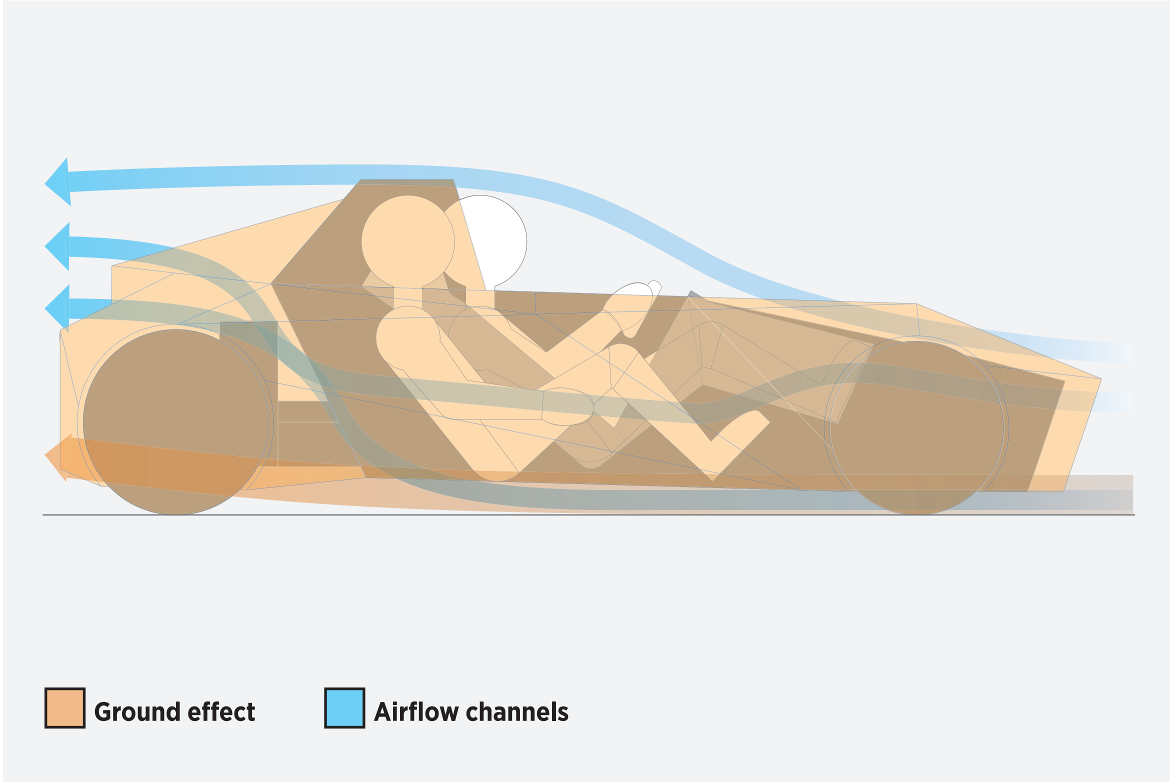


Img. 77 • Top view of the aerodynamic set-up. It shows the hidden flow of the side intakes.

Besides, the integrated solution was designed within a context that merged the two time lines of both approaches in a single and mediated context. This because the research aimed to design an innovative concept that expected to become most advanced for the present context but completely acceptable from the main users (Loewy, 1950). For this reason, the mediated context guaranteed the same designing freedom of ViP while maintaining the real expectations of people and the technical constraints that were analysed and identified with the QFD process.

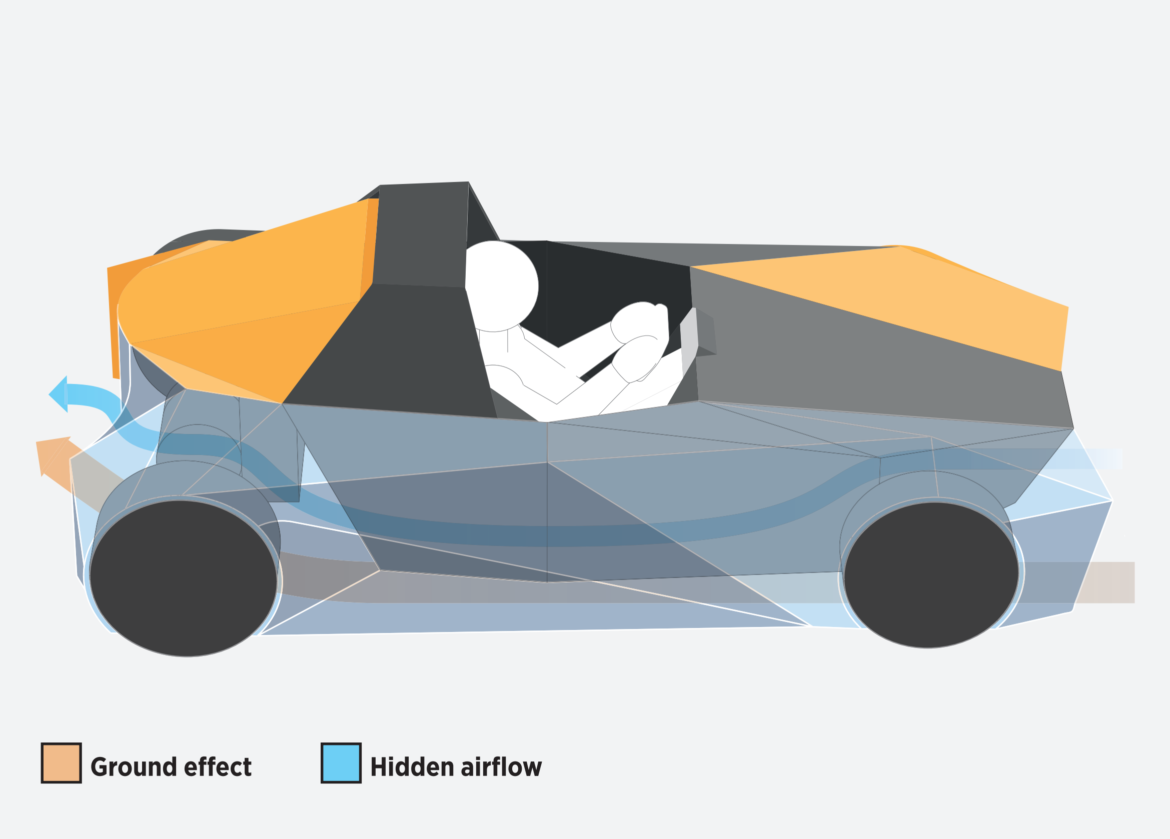
5.6.2.1 The integrated concept: bodywork

ViP conferred specific styling to the car. The "adversative" character produced the strong and sharpened style lines of the coachwork, whilst the aspect of "secretive" characterized some elements associated to the aesthetic aerodynamics of the car **Img. 77 • Img. 78 •**, more specifically the



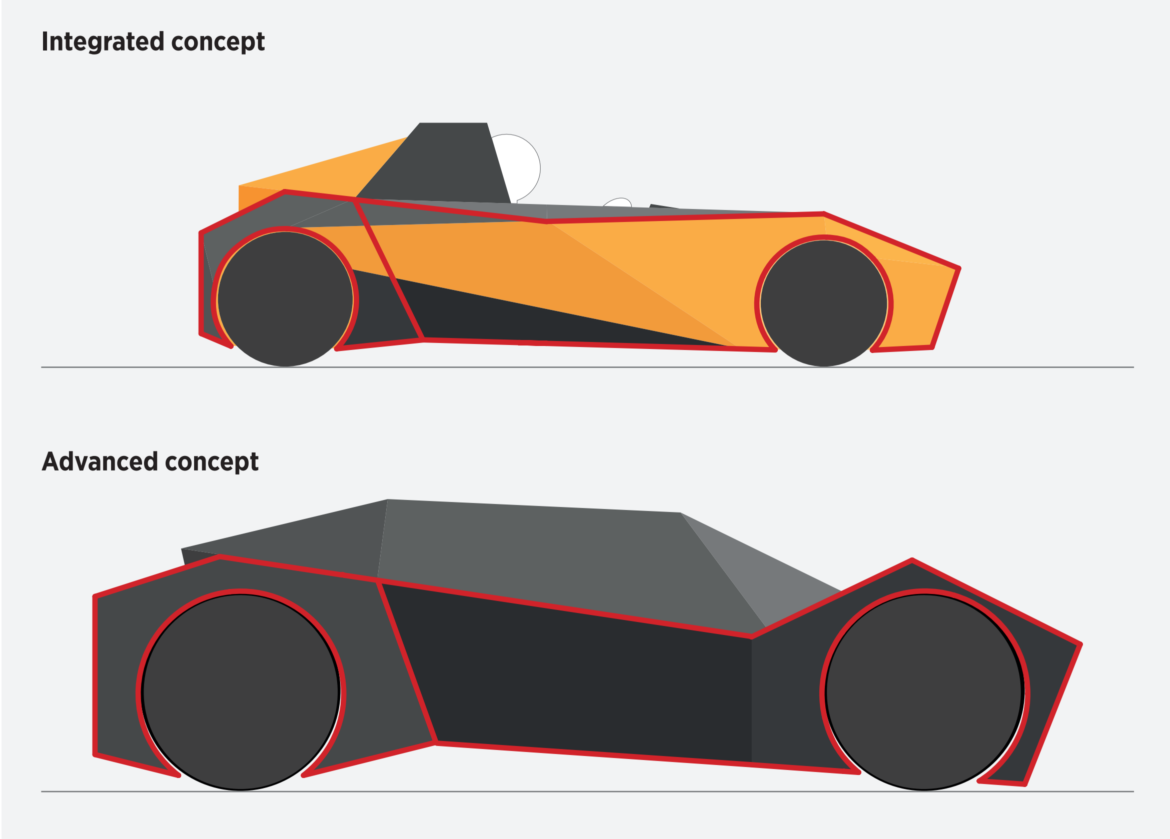
Img. 78 • Lateral view of the aerodynamic set-up.

Img. 79 • The Stradale inspired the aerodynamic of the integrated concept. Source: Dallara.

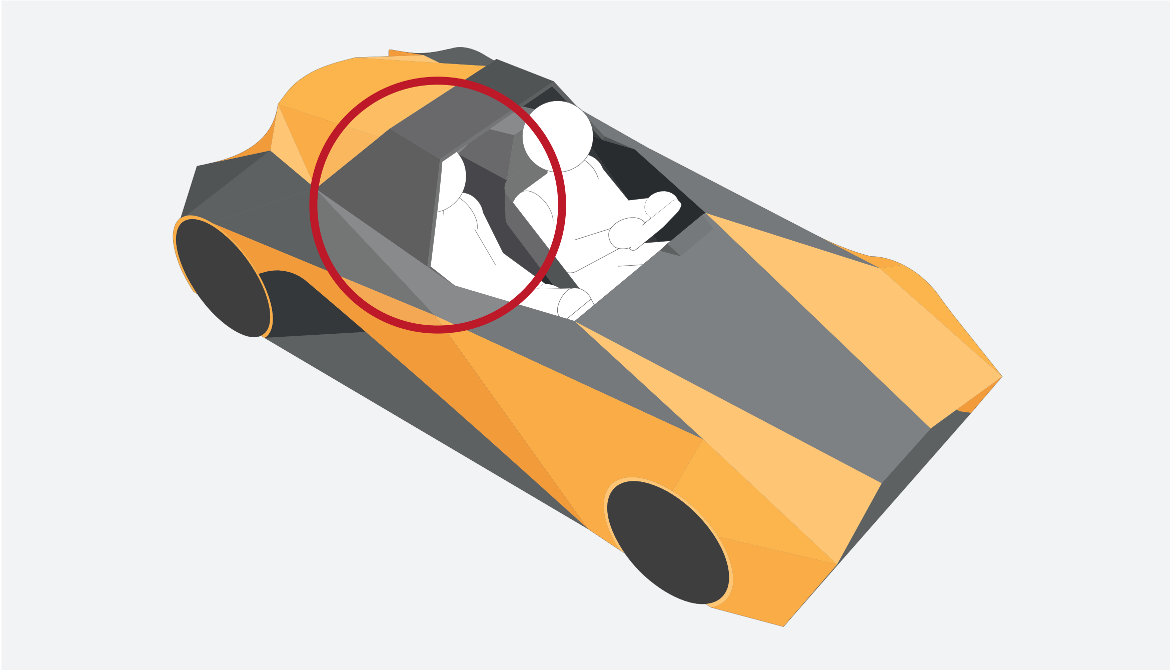


Img. 80 • Tridimentional representation of the "secretive" air channel.

air channels located under the structure of the vehicle. Some of aerodynamic aspects were inspired by the Dallara Stradale because it resulted the best competitor in the QFD's competitive benchmarking in terms of aerodynamic qualities. In particular, the peculiarity of the Stradale is to conduct the airflow directly to the engine along the two sides of the car through two hidden channels **Img. 79** •. For this reason, the same solution was adopted also in the integrated concept. Two air intakes in the front deviate airflow along the lateral sides of the vehicle – necessary to cool powertrain on the rear – both hiding the two air channels under the coachwork and obscuring their morphological outlines **Img. 80** •. Another "secret" intake is positioned under the chassis to cool the battery pack through underbody airflow. The flat underbody helps the car to increase the ground effect in order to improve high downforce. The same action is provided by two open front air intakes, which were designed to cre-

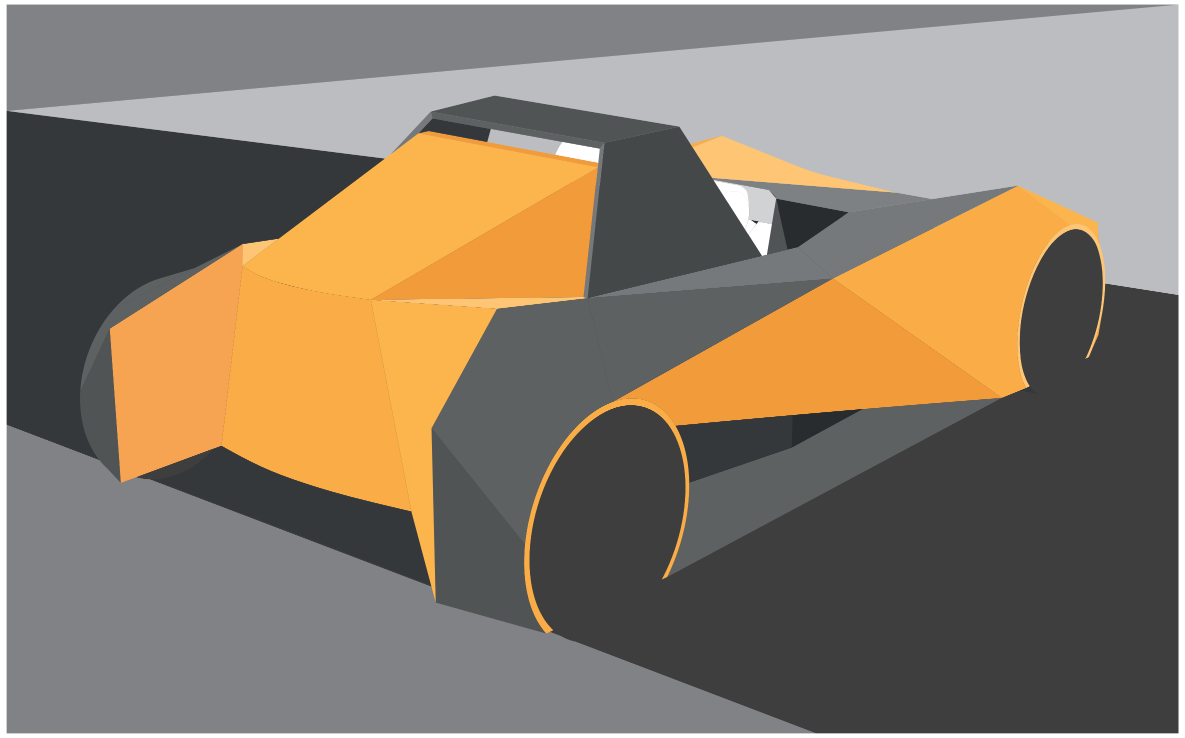


Img. 81 • The thick red line shows a common styling outline between the two concepts.

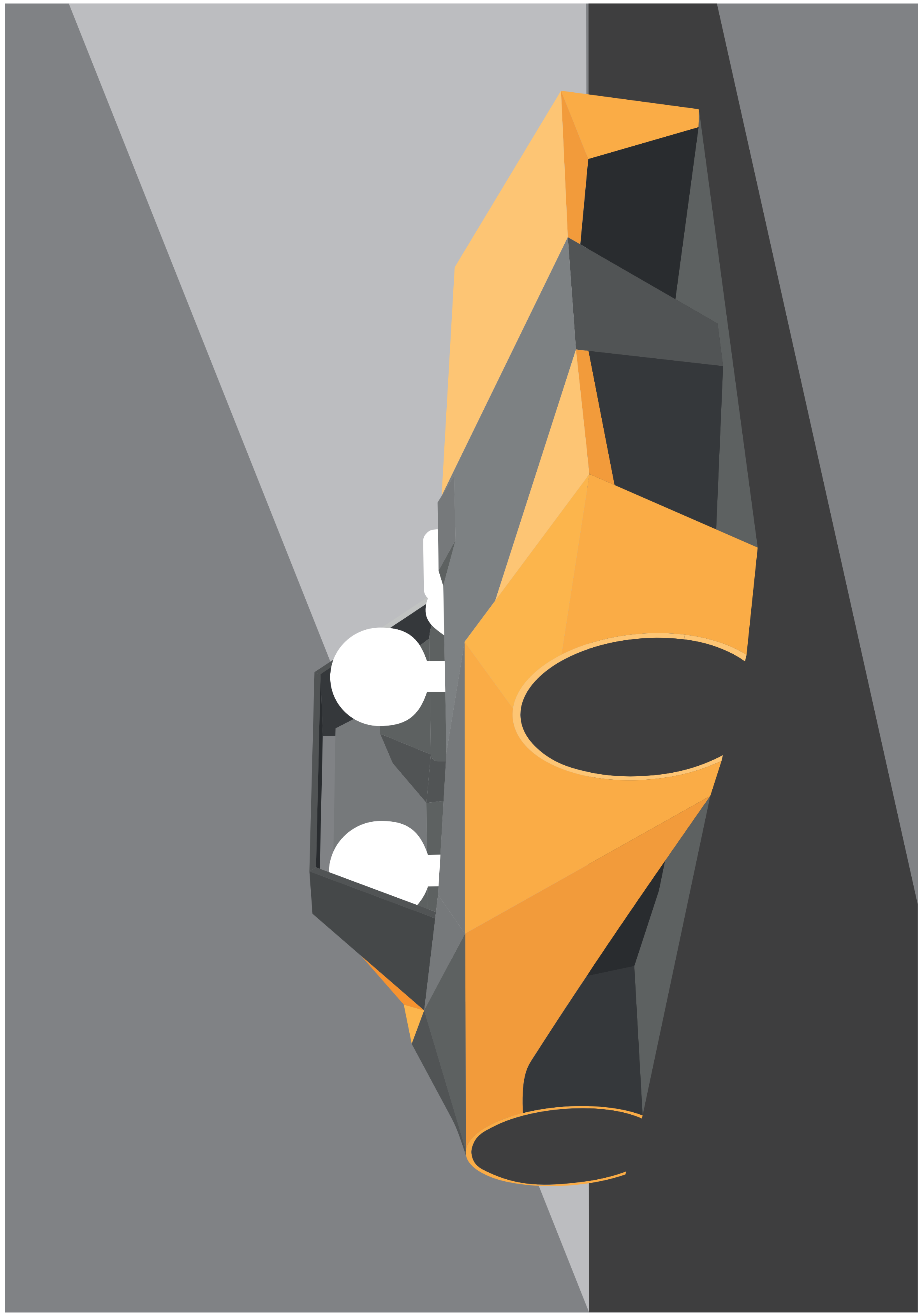


Img. 82 • The "sectretive" character hides the visibility of the second passenger.

Img. 84 • Side view of the integrated concept.



Img. 83 • Rear view of the integrated concept.



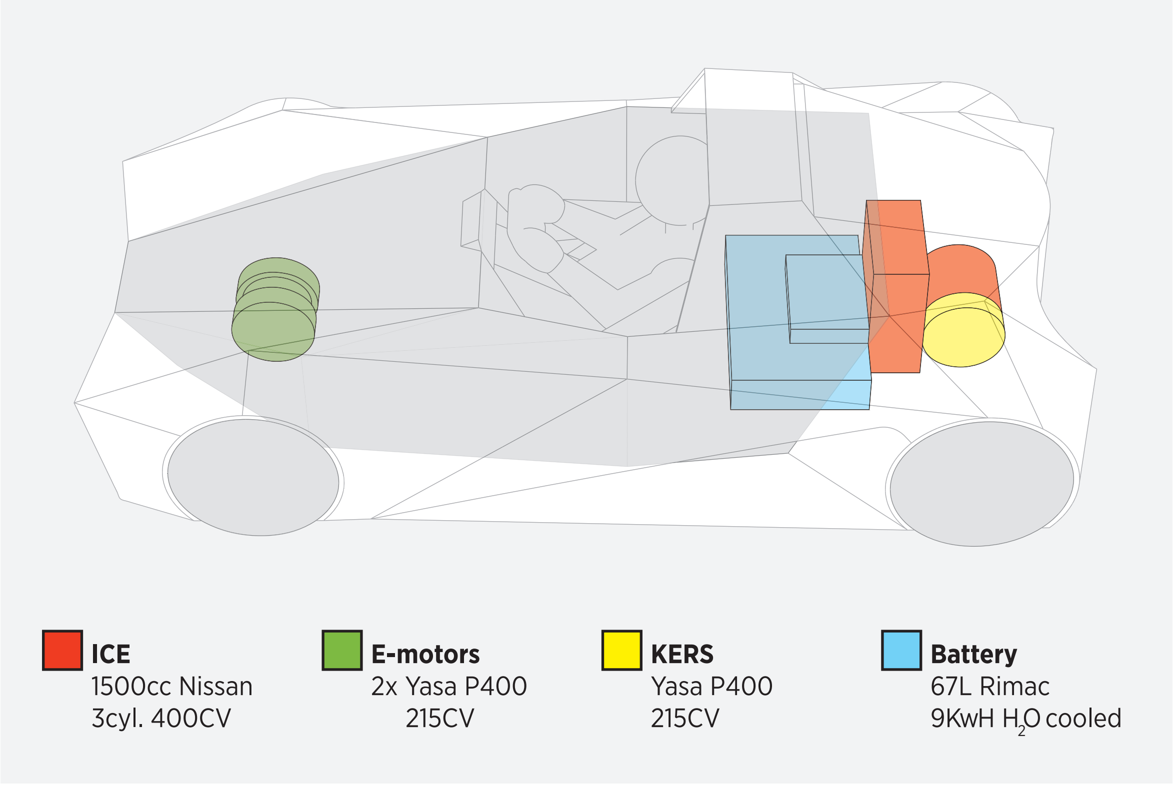
Img. 85 • Front view of the integrated concept.

ate low pressure under the body in order to generate more aerodynamic lift. Instead, the results of the QFD process made the frontal-section area of the car narrower and more permeable in order to reduce aerodynamic drag (Katz, 1995). The latter increased ground effect as well by maintaining ground clearance very low as much as the X-Bow. The styling of the integrated concept emerged from the characters of the advanced concept. In particular, the outline of the final car derived mostly from the "adversative" outline of the vision **Img. 81** •. Instead, the character of "secretive" was utilized also to design the roll-over structure for protecting the passengers. In fact, the structure was positioned above the second passenger seat to hide as much as possible the second passenger **Img. 82** •. In this case, the solution embodies not only the identity of the vision but also improves the safety sensation required by the user during the QFD process.

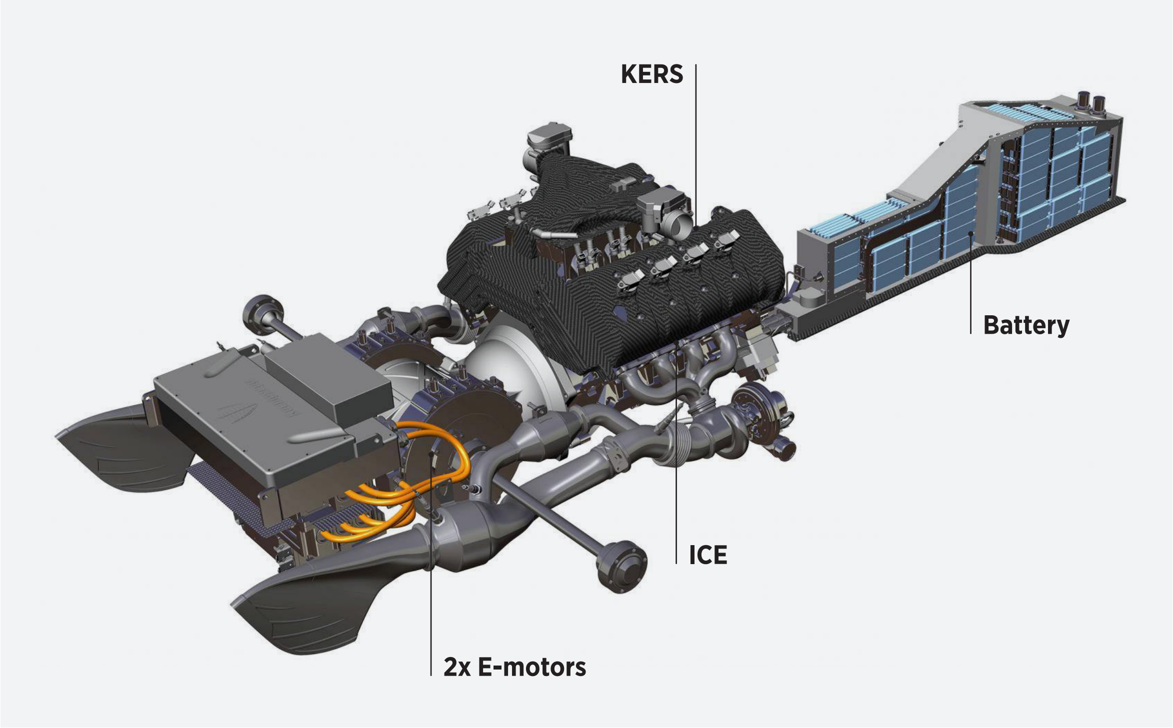
5.6.2.2 The integrated concept: powertrain system

Taking into account the outputs of both methods, the integrated solution's powertrain **Img. 86** • adopted the parallel hybrid system[6]. Compared to other hybrid drivetrains (Denton, 2016), this specific configuration uses the internal combustion engine (ICE) and electric motor in tandem to drive the vehicle (Hodkinson & Fenton, 2001). Therefore, the car is able to preserve the rear mid-engine layout of X-Bow, which is the more common configuration adopted by the sports car segment. According to the guidelines of QFD, the ICE maintains the role of dominant power source, whilst the mechanical gearbox and the sound of engine can be preserved to provide the traditional driving experience. An electric motor, KERS (Kinetic Energy Recovery System), is directly integrated in the drivetrain to

[6] The powertrain of the project was inspired by the hybrid powertrains of Koenigsegg **Img. 87** • and Porsche 918. Both cars are primary equipped with a rear mid-engine layout, which is supported by an integrated KERS in the ICE and an extra electric power source that can be utilized also in full electric mode. In particular, the Porsche 918 arranges the electric motor in the front.



Img. 86 • Image of the integrated solution's parallel hybrid layout.



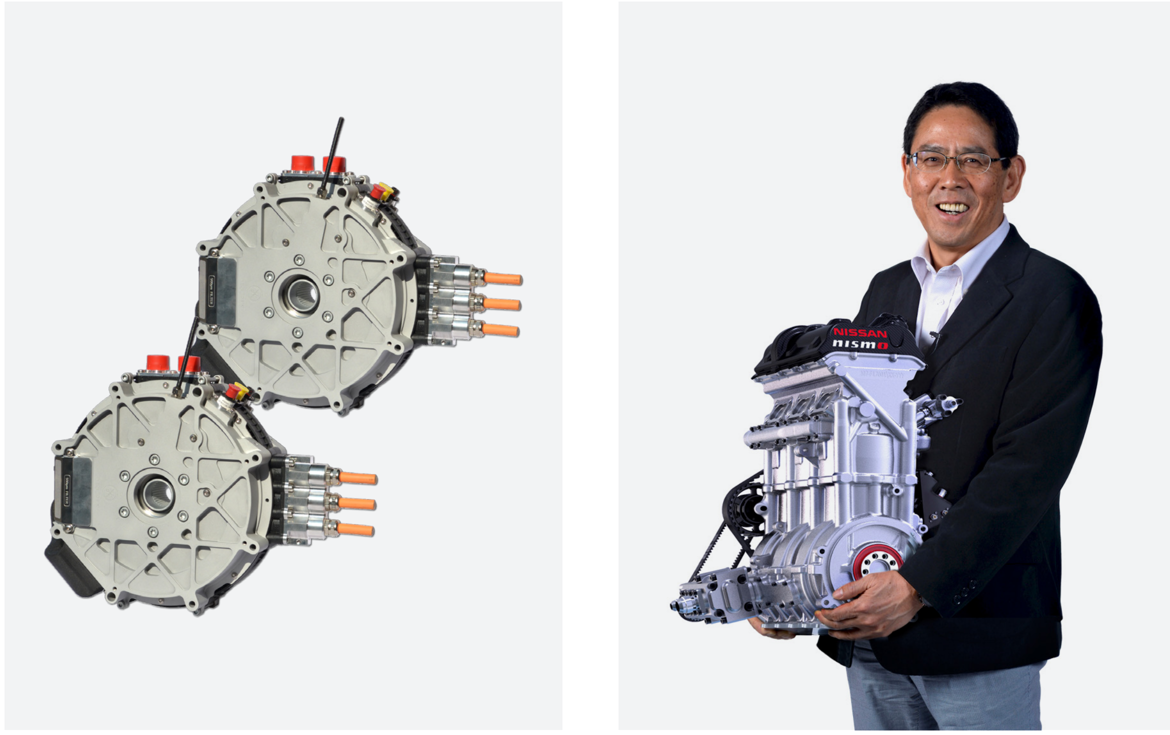
Img. 87 • The hybrid layout of Koenigsegg Regera. Source: Koenigsegg.

increase powertrain performance especially in acceleration. Instead, following the characters of the vision, two extra and independent motors in the front allow the vehicle to be equipped with four-wheel drivetrain. The selected hybrid configuration enables powertrain to offer different power settings according to the context of use. For instance, pure electric drive can be utilized in urban contexts while different hybrid modes can be set up for track-days or racing purposes. Thus, electric power source improves the efficiency of both fuel consumption and carbon emission, because it reduces engine size and optimizes its power source to fulfil the desired power demand (Jain & Kumar, 2018). In this case, two sources of inspiration was utilized to set up the selected hybrid layout: the Yasa electric motors and the Nissan Nismo internal combustion engine **Img. 89** •. The first elements are the same electric sources adopted by the Koenigsegg because they are able to deliver high power to the car through a high compact and lightweight solution. Whilst, the Nismo ICE is a small engine that can guarantee a high power-to-weight ratio ensuring, at the same time, both weight- and space-saving. For this reason, those elements would be useful components to increase sustainability and the efficiency of fuel consumption without renouncing to high performance.

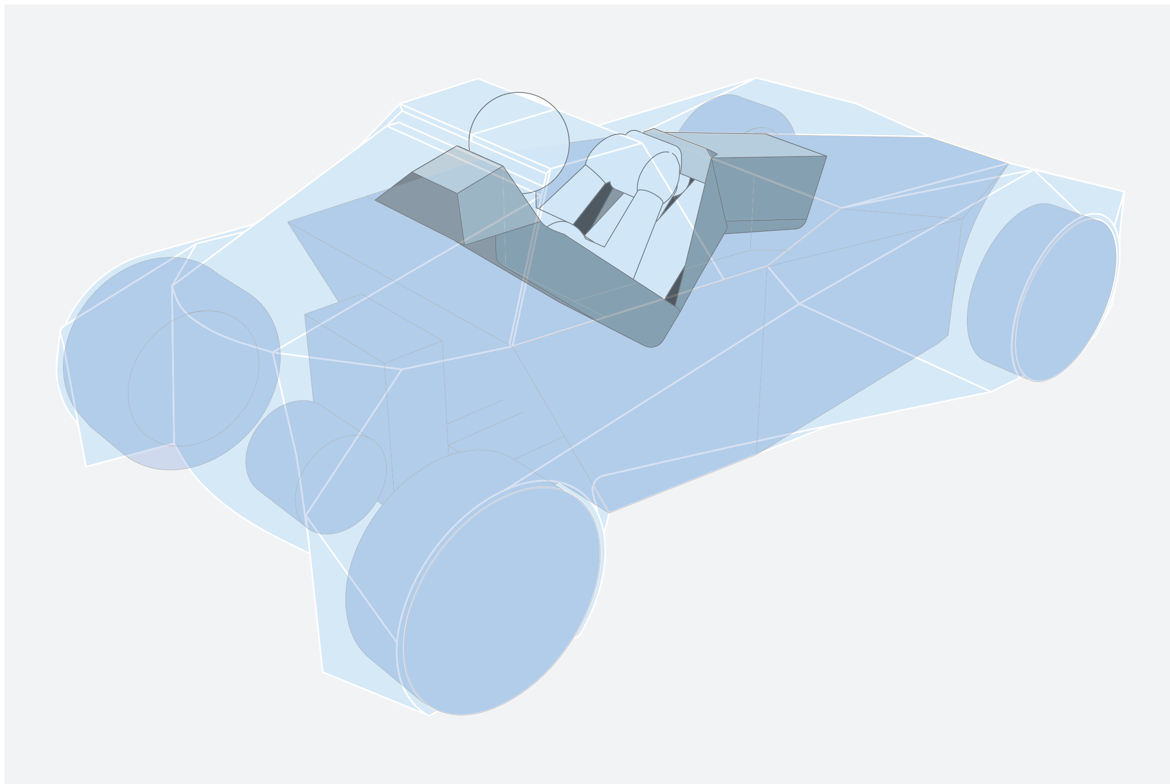
5.6.2.3 The integrated concept: passenger package

The integration of both method leaded the design of the passenger package and its corresponding driving interface as well. Instead of designing a traditional two-seater sports vehicle, the outputs of QFD translated the vision's three-seat layout – provided by the character of "adversative" – into an active driving seat **Img. 88** •. The latter, provides to the car a peculiar driving configuration[7] that is able to float from the traditional lateral

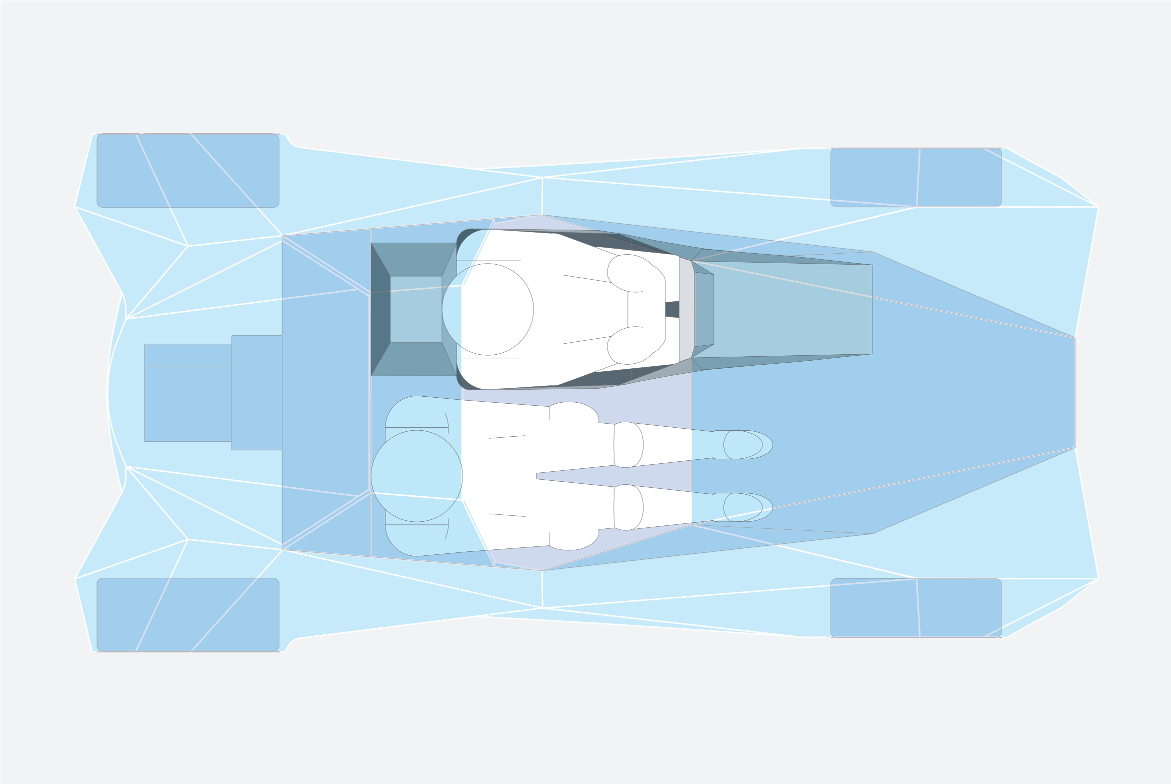
[7] The inspiration of the active driving seat derived from Audi AI:RACE **Img. 93** •, an electric concept car in which the seat can slid inside the cockpit in order to provide different driving experiences.



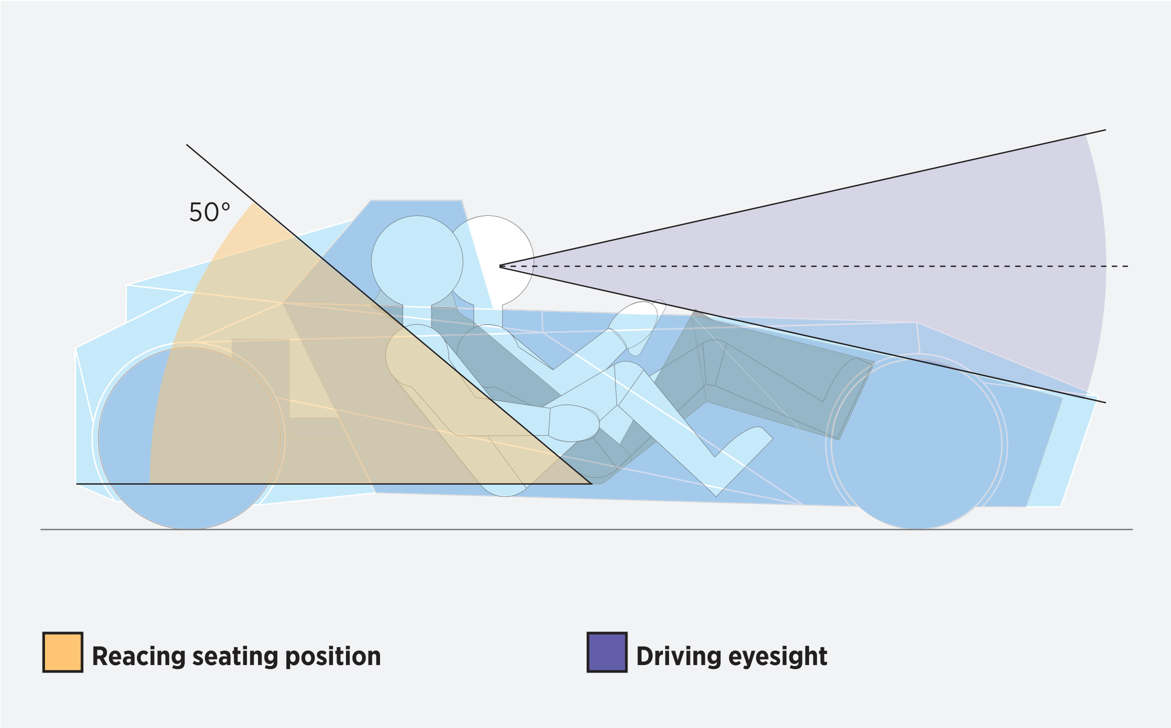
Img. 89 • The Yasa's electric motors and the compact ICE of Nissan. Sources: Yasa & Nissan



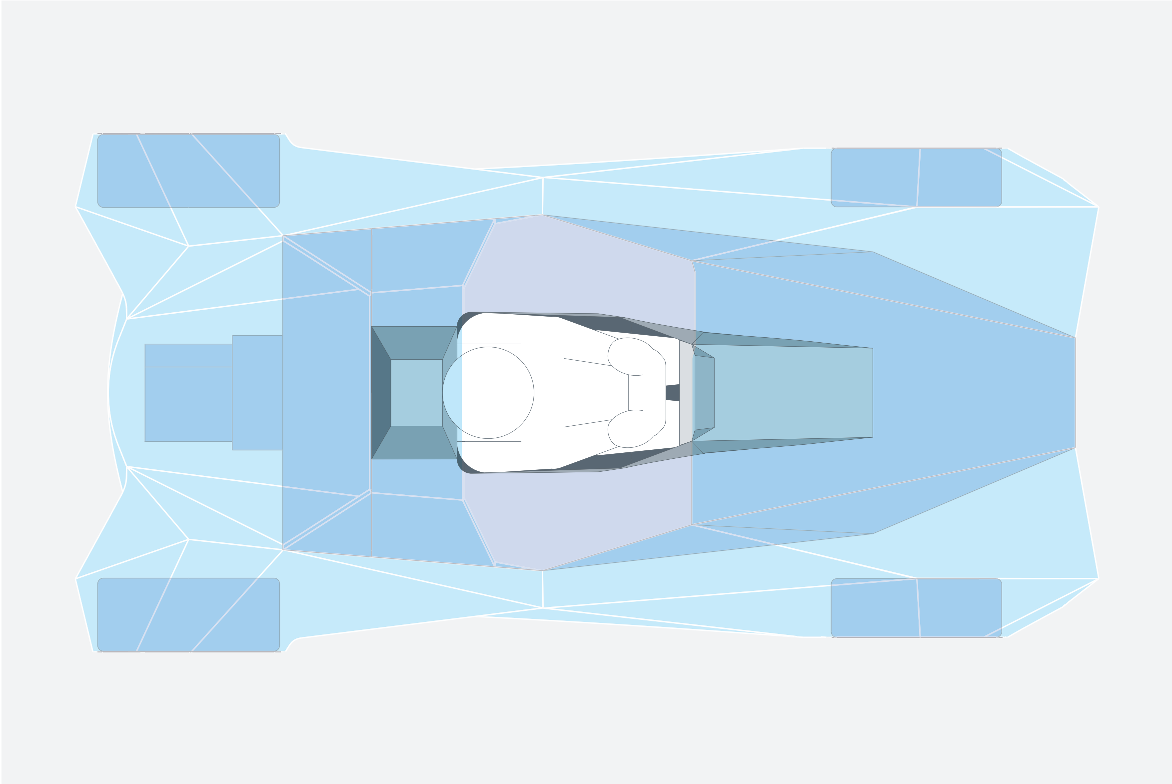
Img. 88 • Representation of the dynamic driving seat of the mediated concept.



Img. 90 • Image of the active seating position during the traditional mode.

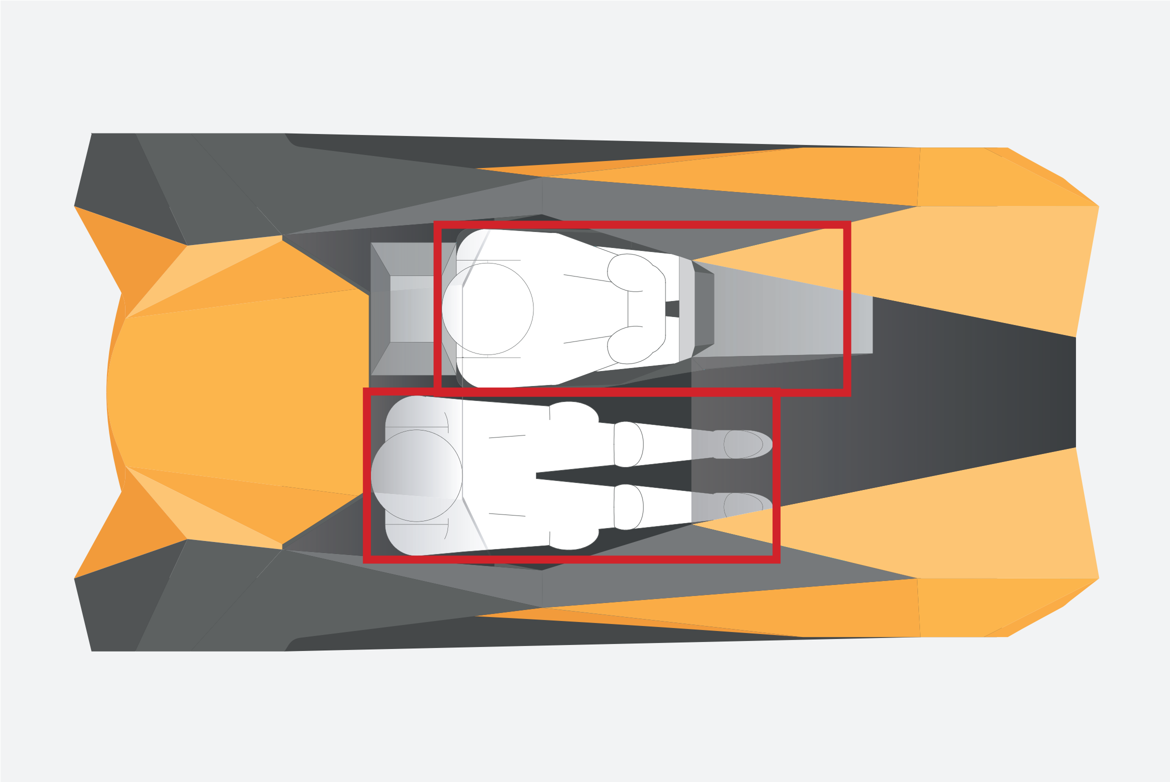


Img. 91 • The lateral view shows the racing setup of the driving position.

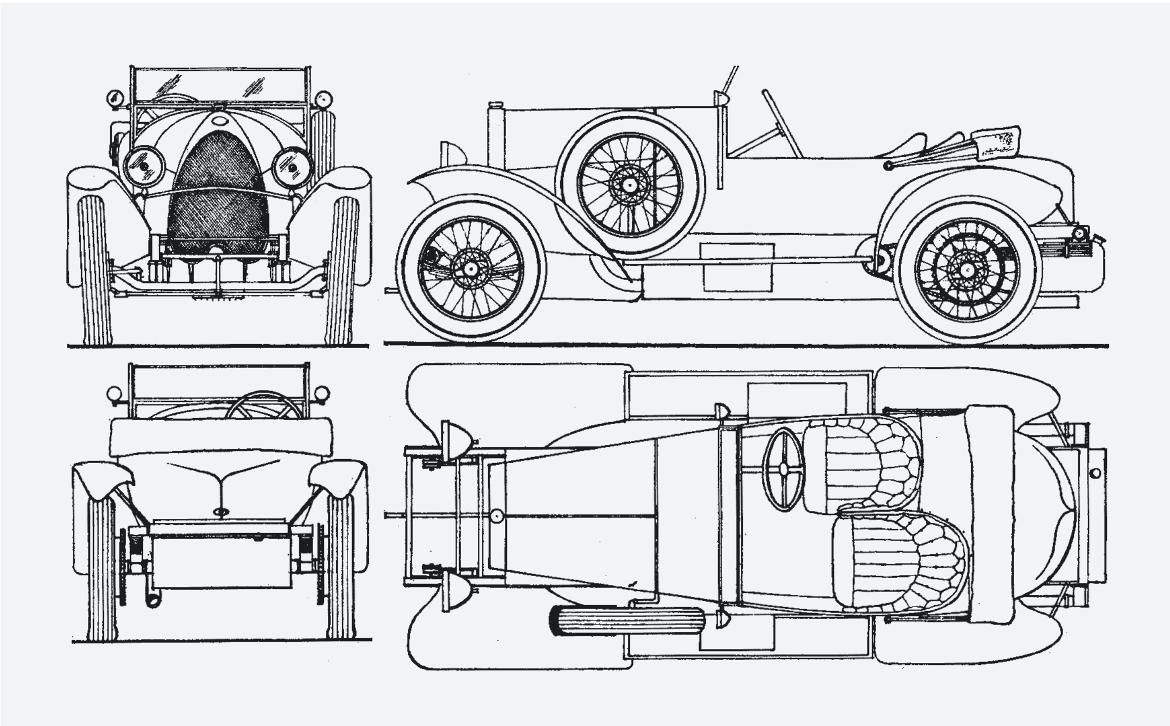


Img. 92 • Image of the active seating position during the racing mode.

Img. 93 • The Audi PB18 driving seat was utilized for inspiring the project. Source: Caricos.



Img. 94 • Top view of the mediated concept's asymmetrical two-seater layout.



Img. 95 • Bugatti Type 18 inspired the asymmetrical seating setup. Source: Outlines.

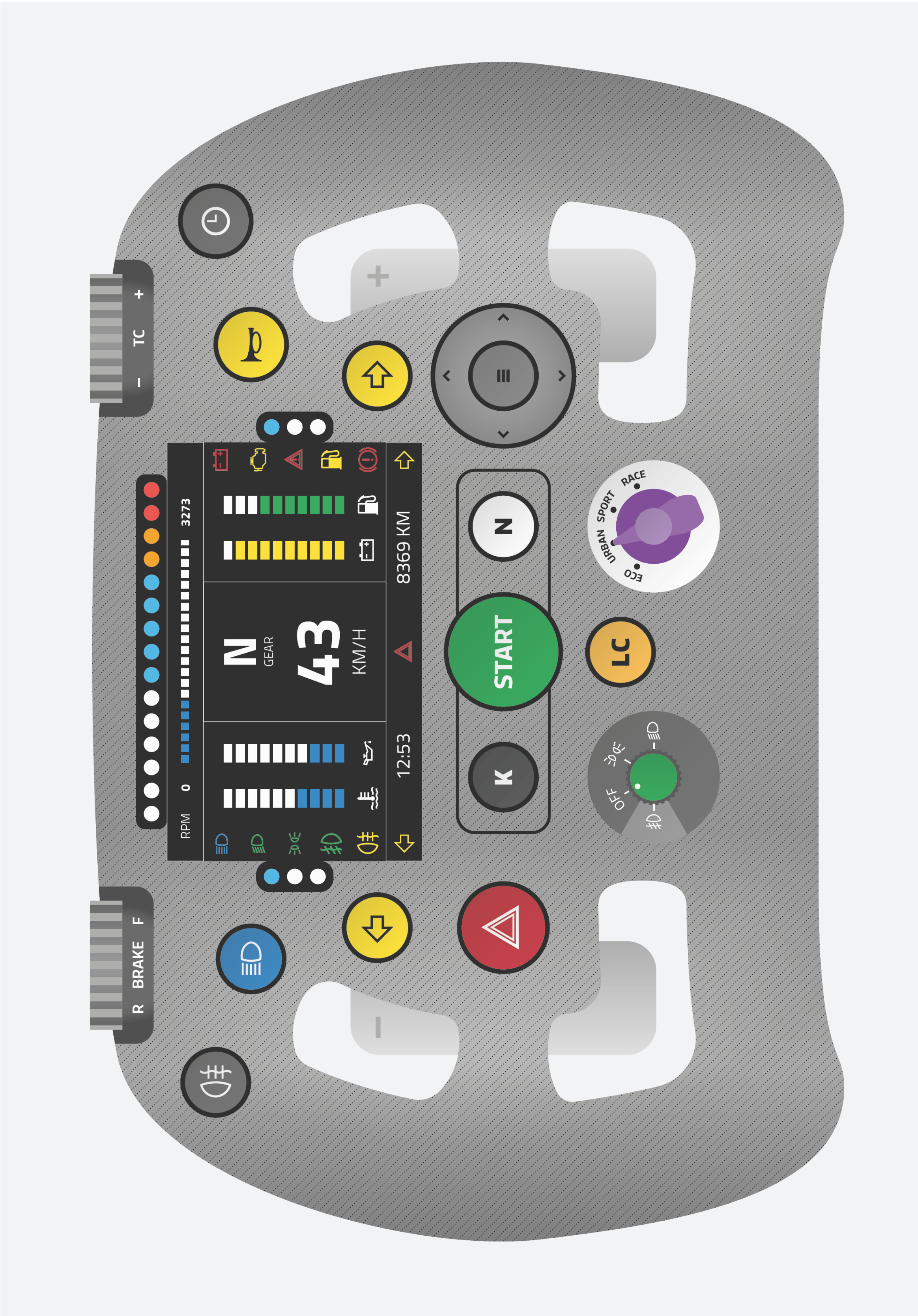
seating position **Img. 90** • to the centre driving system **Img. 92** •. This dynamic configuration guarantees much more involvement in driving and it permits to experience the car in different modalities according to a specific context of use.

The integrated concept's seating configuration **Img. 94** • provides an asymmetrical two-seater layout [8] to decrease the track of the car, which in turn is capable of reducing both aerodynamic drag in the front and rolling effect on curves (Hans, 2006; Katz, 1995). The passenger package features also a racing seating position to reduce aerodynamic drag. This is possible by decreasing the overall height of the car, which in turn, is able to narrow its frontal section area in order to reduce its exposure against the force of the wind. Compared to X-Bow model, the technical specification of the QFD raised also the height of the vehicle's lateral sides – specifically at the belt and head height – not only to increase the safety sensation required by users but also to better protect the driver from lateral collisions and from the force of wind during driving.

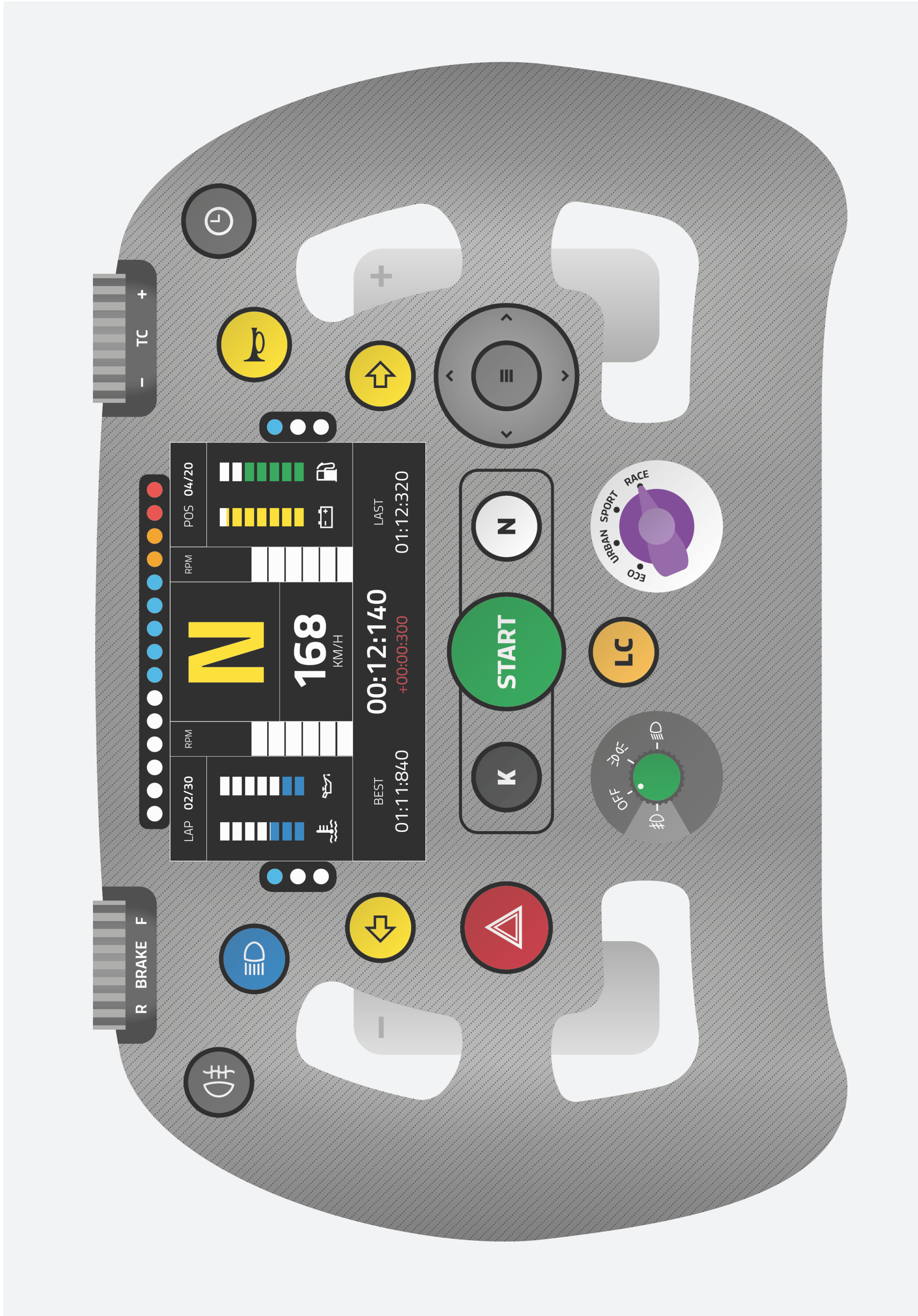
5.6.2.4 The integrated concept: driving interface

The active character of "adversative" configured also the driving interface toward a more racing-oriented experience, conserving some aspects of the pure driving sensation provided by the same competitors. According to user demands, the principal driving controls are located on the steering wheel in order to maintain eyesight focused on the road and at the same time to reach the driving functions more rapidly by hands. In fact, driving is a complex multi-task activity (Regan, Lee, & Young, 2009), consisting of a series of interactions between the driver, the vehicle and

[8] The asymmetrical seating layout was inspired by Bugatti Type 18 **Img. 95** •, an old race vehicle that had the same seating configuration to decrease aerodynamic drag by reducing its frontal-section area.

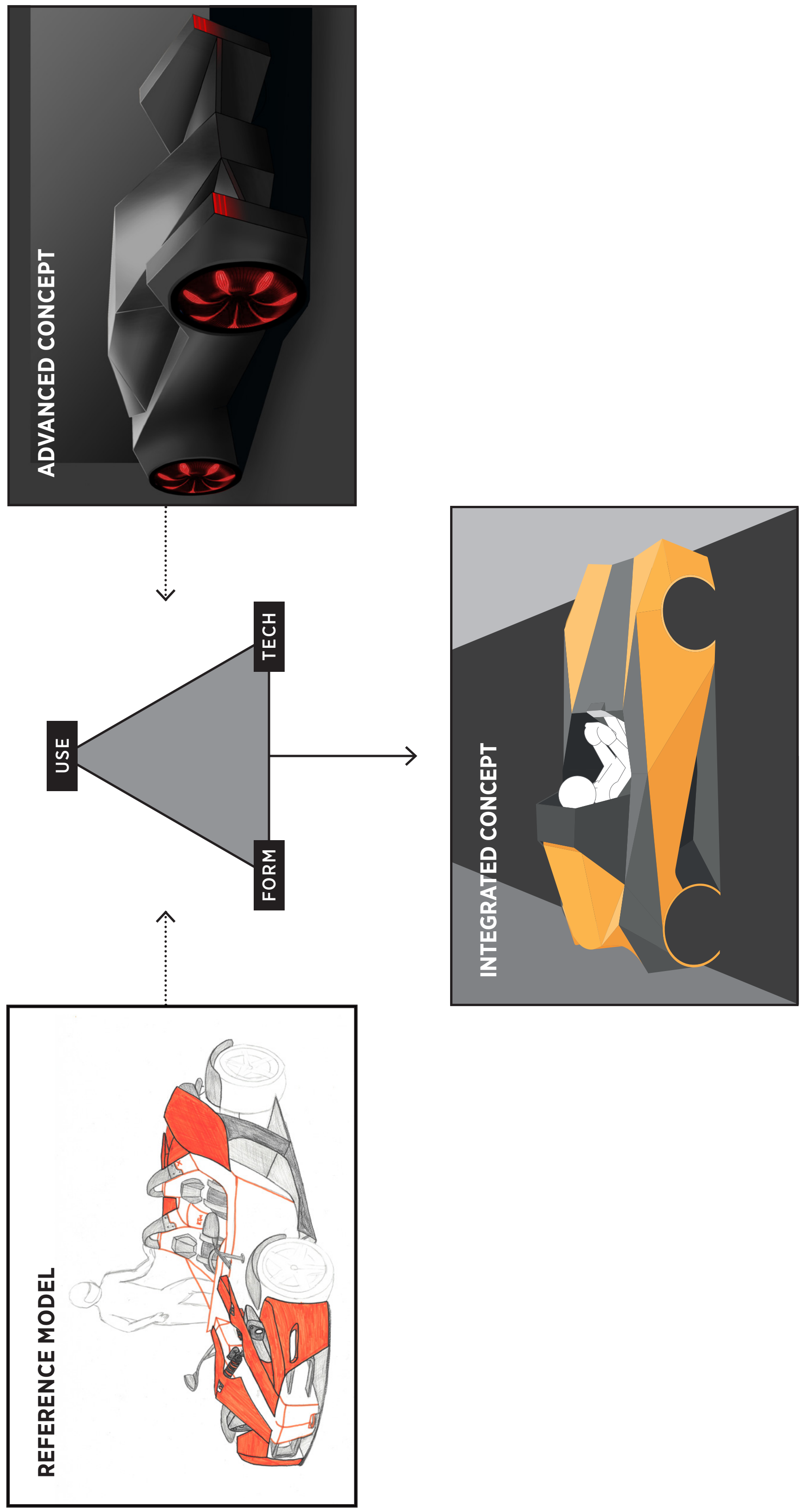


Img. 96 • Image of the driving interface. Urban mode.



Img. 97 • Image of the driving interface. Race mode.

Concept development
design process



Img. 98 • The evolution of the concpet vehicle developed by the exploratory method.

the environment (Rakotonirainy & Tay, 2004). Therefore, the act of driving requires the successful integration and coordination of the driver's cognitive, physical, sensory, and psycho-motor skills (Young & Regan, 2007). For this reason, an essential digital interface **Img. 96** • guarantees the execution of few easy tasks allowing drives to continuously monitor the driving scene (Wierwille, 1993). Considering this, the parameters delineated with the QFD (Giacobone & Mincolelli, 2020) served to maximize the drivers' physical-cognitive resources and consequently to guarantee to them the correct context awareness while they are interacting to the vehicle (Camilli, 2011).

For delivering a versatile vehicle, the interface is capable of configuring itself in four different driving modalities according to either the context of use or the driver's purposes. The driving modes are eco, urban, sport and race. For instance, the eco and the urban modes **Img. 96** • can operate through the electric power source, the lateral seating layout and every control necessary to drive on public roads. For example, driving in the urban context needs conventional sings[9] or the tasks of the drivers are focused on the velocity to respect speed limits or maybe on the fuel gauge to control the consumption. Instead, the sport and race modes **Img. 97** • can be experienced by utilizing the hybrid powertrain, the central seating position and only the information or controls that are important for racing purposes (such as time-lap, engine revolution, number of gear and so on). In addition, the race mode guarantees the driver the full control of the car by removing every electronic support in order to provide an extreme driving experience. Finally, all these settings can provide several personalized driving experiences according to the different exigences or

[9] The icons presented on the interface refers to the ISO standards ISO 2575:2010 which specifies symbols for use on controls, indicators and tell-tales applying to passenger cars, to ensure identification and facilitate use. They are described in https://www.iso.org/standards.html

capabilities of the end-users.

In conclusion, starting from the analysis of the KTM as an existing reference, the research generated a future context in which a new vision the expected concept car was manifested. The qualities of the advanced concept were developed in accordance with the first car model but always detaching the intent of the vision from the current context in order to create the chance of designing innovative solutions. In the end, the character of the advanced concept was reinterpreted into a mediated context, in which its qualities were integrated into many vehicle characteristics taken from the QFD analysis. The result **Img. 97 •** is a combination between the current model and the concept of the vision, which embodies the styling and technical elements of both vehicles.

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◆ End of
Chapter 5

PART 4:
DISCUSSION & EVALUATION

CHAPTER 6

Conclusion

6.1 Introduction

This chapter reports the final evaluation of the methodological process that drove this research. In particular, the chapter presents the discussion about the final outcomes of the project and many considerations on how the QFD and ViP were able to support each during the research activities.

6.2 Final evaluation

As required by the initial goal of this project, the design process produced the concept vision of an hybrid sports car. The entire vehicle was developed by using an exploratory methodology, which integrated together two different Human-Centred Design approaches. The designed activities delineated both the technical characteristics and the morphological aspects of the vehicle by using the users' perspective analysed and investigated throughout the research. At the end of the process, all the engineering and styling properties of the concept car were utilized to give a proper vision and form to the concept under the four main systems selected at the early stages of the design process: bodywork; propulsion system; passenger package; driving interface.

Those vehicle requirements became also a technical framework for the entire multidisciplinary network. Since this particular research is the only work package that acts from a human-centred perspective, it expects to benefit to the overall project by providing to the other partners many design guidelines to develop their engineering researches through a human-centred point of view.

As denoted in the methodological chapter, usually automotive industry is based on a technology-driven orientation. Therefore, the approach tends to follow advanced scientific and engineering practice for innovation. This is translated into products that target highly quantifiable and highly marketable measures of performance.

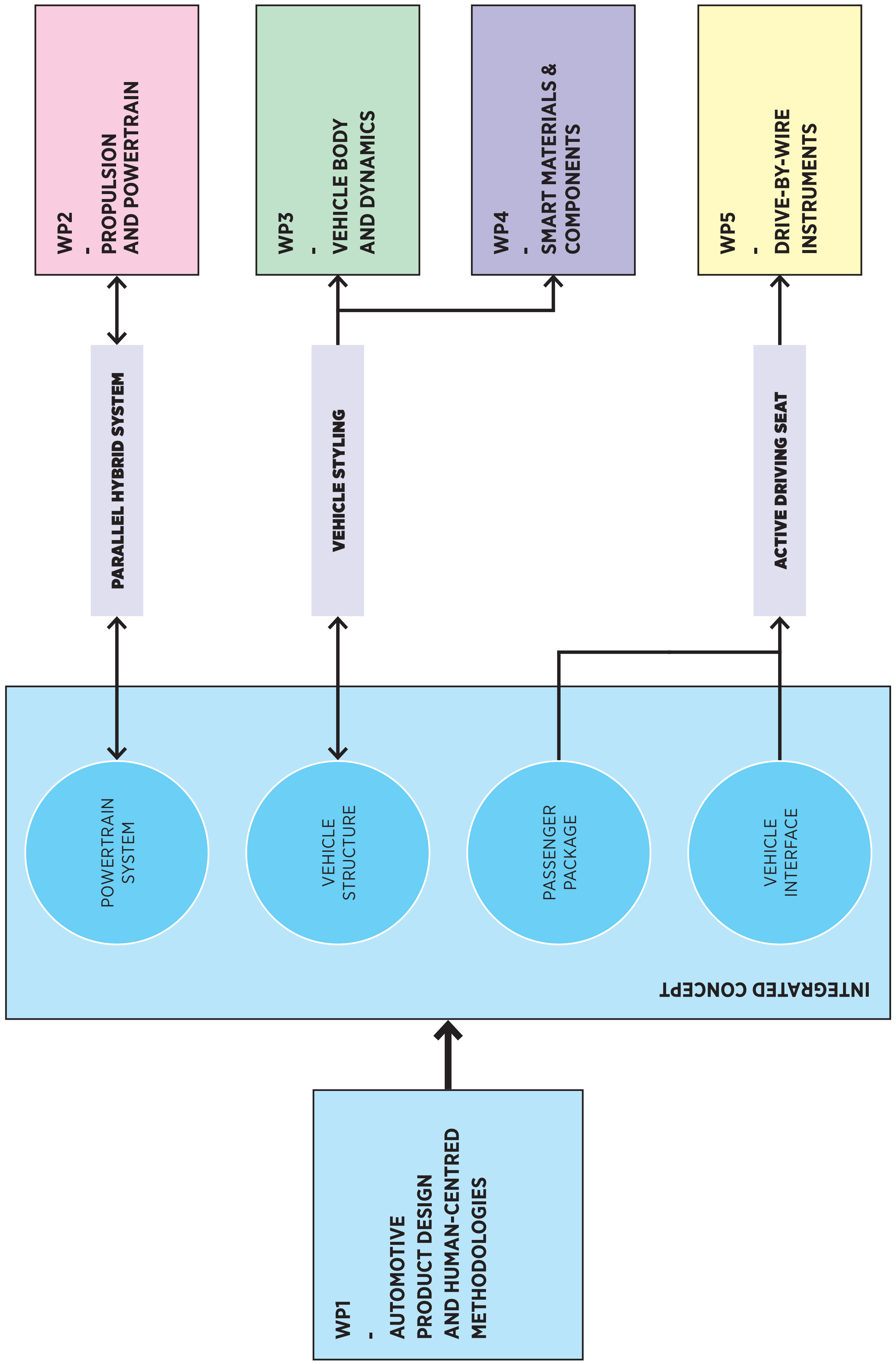
However, when the technology matures, innovation links itself to intangible properties that are highly related to the human beings (Norman, 1999): appearance, usability, personal expression, experience and so on. The qualitative values of an automotive product are sophisticated today as well as the complexity of users' needs. For this reason, innovating a product needs an human centred approach because, if the strategy of every development process focuses merely on quantitative performance, the entire system of the project will risk a failure both in satisfying costumer demands ,and hence, of developing a successful automotive product.

Therefore, being aware about the real exigences of people in the initial phase of the project permits to all the teamwork of the project to continue developing innovative engineering solutions without missing the users' expectations. Moreover, the human-centred approach is very useful also for the next potential developments of the project or within the technical phases of the automotive product development (such as pre or series development), even when the sole engineering design will be largely required. Then, the several outcomes obtained during this research expects to become a starting point for the overall network but also a facilitator during the decision-making process for developing the automotive R&D platform in the coming years.

For example, regarding the work package two, which is addressed to the powertrain system, the users require a car with high performance and the distinctive sensory sensation or the traditional driving experience delivered by the typical internal combustion engine. From another point of view, the end-users want also a vehicle that can be configurable according to the context, in order to embrace environmental sustainability. In this case, if the design was technology-driven, it could indubitably adopt a different hybrid layout respect to the chosen one, such as the series hybrid system. Or maybe it could select a full-electric motor to achieve the same performance with zero emissions. Though in this way, the research would surely develop an efficient solution but without any emotional relationship with the end-users because it would not match their expectations.

For this reason, fulfilling user demands needs a solution that takes into account the qualitative values of the vehicle such as the emotion provoked by the engine's sound. In this case, the best solution was the parallel hybrid system (equipped with one KERS and two electric motors), in which the electric source is able to support the engine – whenever the latter requires energy supply – without eliminating it from the powertrain system. Moreover, since the two front motors are separated from the engine, the powertrain configuration permits to change the power delivery according to the context of use. It includes also the sustainable configuration for the urban contexts. Whilst, the KERS – since it is incorporated in the drivetrain – continuously allows the battery charging including also without any plug as required by the end-users. Thus, the solution avoids potential frustrating situations derived from the manual battery charging as it normally happens with the full-electric vehicles.

The same is for the other vehicle systems that refer to the bodywork (work package three), passenger package and driving interface. Considering the dynamics of bodywork system, the engineers must work on the vehicle



performance to increase stability and decrease aerodynamic drag without compromising both the character and the style of the vehicle coachwork, which together are able to transfer added sing-values to the car. For this reason, the human-centred guidelines permit to drive the engineering design to improve the quality of the automotive product according to the user requirements. Then, the automotive styling is in charge of negotiating with the aerodynamic engineers the balance between the technical characteristic of the aerodynamics and the qualitative aspects of the vehicle styling.

Whilst, the passenger package and driving interface are usually tightly related to a scientific and engineering approach, such as ergonomics. Because it offers technical and standard solutions to the problem in order to design usable product for all. However, ergonomics is a discipline that considers only quantitative parameters of the human being (Bhise, 2016) and it does not incorporate qualitative aspects such as the people's emotions or the experience delivered by the driving activity.

Within an innovative process, ergonomics could be limited because it may create efficient solutions that however are rooted in a scientific background made by rules that limit the lateral thinking. Therefore, the human-centred perspective can help the development process to stimulate new ideas by using abductive reasoning because it takes in consideration all the qualitative aspects of the users' needs, and on them, it creates the scaffold for the entire project.

Evidently, the measurable approach of scientific practice must never be removed from the project because it is always an indispensable element of the holistic thinking that is necessary for successful product develop-

Img. 99 • The interactions of the concpet's guidelines between the other work package.

ment. Indeed, once the entire project has been delineated through the Human-Centred Design method, ergonomics become very important for transforming an innovative idea into quantitative parameters. These factors are therefore capable of observing all the characteristics of the human body, all the government or safety regulations due to the fact they refer purely to scientific and measurable parameters.

The active driving system, which was designed for the integrated concept, is indubitably an example that perfectly corresponds to the aforementioned assumption. Considering this, the concept of the dynamic passenger package, which is integrated with the multifunctioning interface, is a clear result of the Human-Centred Design approach because it was developed through the exploratory method that combines together all the exigencies of both present and future users. The extreme and adversative vision of the driving seat manifested in the ViP's future was interrelated with the characteristics of comfort, safety and versatility required by the users during the first needs analysis of the QFD process.

The qualitative aspects of the vision (in terms of use, form and technology) were perfectly integrated with the technical properties of the sports car segment, which allowed the advanced concept to manifest the character of the driving seat into today's context of the real project. In this case, the final concept's guidelines of the passenger packaged result very useful to develop a new versatile and adaptable sports car that features different driving configurations according to the contexts in which it is experienced: urban roads and track-day circuits.

In addition, the characteristics of the interface, which are related to the work package five, have the chance of becoming useful also for future researches on the advanced driver assistance systems. In this case, unlikely the urban and utilitarian vehicles that are completely eliminating the human being form the primary driving tasks, the research highlighted that in the sports car segment the driver must be predominant on the vehicle's driving controls (Giacobone & Mincolelli, 2020). New future research can, therefore, focusing on how to integrate that assisting technology in the driving system without completely taking out the driver's attention and skills from the driving activities. For this reason, the advance driver assistance systems must be considered useful tools that must intervene primarily in urban contexts to increase road safety. Besides, they can be adopted as training tools to train novice drivers in making practise of their driving skills.

Taking into account the overall research, the human-centred methodology created a great potential to produce innovation in the track-days segment. In fact, compared with the other vehicles that represented the state-of-art, this concept is the only vehicle that features an hybrid system. At the moment, this type of technology is experimented only by supercars or hyper cars because the size of the vehicles permits to develop hybrid vehicle drivetrains without compromise their performance. In fact, the hybrid systems usually require large space to include both the battery pack and the electric motors, which cause a considerable increment of weight. Considering this, introducing the hybrid system also in a lower category of the sports car segment can clearly open new business opportunities to the project because it can place a more affordable automotive product in the market compared to the other exotic cars that are equipped with the same hybrid technology.

Moreover, the active driving seat is undoubtedly a great opportunity for the overall research of developing a sports vehicle that can be more utilized than the other models related to the state of the art due to its versatility. Indeed, the cited solution would make the concept vehicle a profitable business for the entire network because it would be more adaptable than its competitors under many aspects: context, consumption, sustainability, vehicle performance, driving ability and personality of the driver.

Under a methodological point of view, this research permitted to explore a new process that combined two human-centred approaches – as described throughout the previous chapters – that often are used separately as stand-alone design techniques. In particular, in the initial phase of the research, the QFD analysis provided a detailed preliminary overview about user demands during the interaction with the KTM X-Bow in its specific context. This first analysis elaborated partially the deconstruction phase as well, because it revealed a tight relation between the two activities, especially in the data gathered by the two practices. Subsequently, ViP envisioned the expected concept vehicle in the world of tomorrow based on the styling values of the same KTM model. In the end, a third step re-interpreted the vision elaborated by the ViP by combining the qualitative aspects of the advanced concept with the outputs highlighted by QFD in the form of a new and integrated solution.

Regarding the exploratory methodology, the research revealed that QFD and ViP supported each other in producing several integrated considerations that produced a novel design strategy to develop the expected car model. The comparison between the two methods examined that the characteristics of the two models are complementary in many aspects, due to the two different problem-solving perspectives that they used for facing up the same challenge. In particular, four different aspects were recognized as main elements that characterized the value of exploratory method: design mindset; design practise; qualitative outputs and values; time planning strategy of the project.

For the first characteristic, ViP enabled the research to think in possibilities instead of constraints, which are significant elements to come up with innovative and original ideas. Since people tend to reason in terms of current problems and thus, their insights might be rooted in the situation they are in at that moment, ViP detaches the process from the constraints of present, forcing the research strategy to design the expected car in a novel and future reality. Considering this, ViP helped QFD to not focus the attention only on the constraints or insights of the present by making the decision-making process more visionary. ViP starts with an open mind and thus, it increases the chance for innovative solutions. In fact, during the QFD process, when a need is already well satisfied by the competitors' products, that requirement is often covered by one of those solutions offered by the state of the art. Therefore, the process might be affected by the present and so it tend to be not innovative as it would aspect to. Instead, when a need is not satisfied by any competitors, QFD tends to find a new solution, but it requires time and other methods – such as brainstorming (Van Boeijen, Daalhuizen, Zijlstra, & Van Der Schoor, 2014), divergence maps or concept-generating matrices (Kumar, 2012) – to inspire creativity during the process. In this case, the design process's creativity is inspired and evoked directly by ViP's model. It was able to support the QFD in the idea generating because it pushed the QFD's outputs in the future ahead (due to its open mind philosophy), to explore a new solution through its vision, and thus, its advanced concept.

On the contrary, QFD enabled the research to translate the innovative ideas described by the advanced concept into a feasible solution, which is an essential step to ensure that the automotive product would correspond to the technical requirements requested by the vehicle development period. Although the ViP vision must refer to solid scientific sources for creating innovative idea, it always remains a prediction because its context factors belong to the future. In this case, the research may run the risk of not completely matching users' expectations because of the future uncertainty. Moreover, the manifestation of ViP vision is communicated through an abstract concept, which acts as an inspirational model to foster innovation. Consequently the vision needs substantial modifications to be adapted to the company's engineering requirements due to its extreme visual form. For these reasons, QFD mediated its product parameters with the characteristics of the advanced concept to draw the vision closer to a physical and feasible solution. In addition, the outputs of the QFD ensured to the research also qualitative values that can be adopted during the vehicle development period. This because it delivered measurable parameters that are perfectly compatible with the language of the production engineering process (Mincolelli, 2008).

About the second methodological characteristic, the research was conducted by a merging of two design practices that together established a satisfactory balancing between two opposite approaches. ViP, indeed, presents a sort of an "egoistic" model because is driven by the designer, while QFD refers somehow to an "altruistic" approach because it is driven by the end-users. QFD is always an inclusive design tool because it places customer satisfaction first in the design process (Al-Mashari, Zairi, & Ginn, 2005). QFD, indeed, takes into account the heterogeneity of every necessity expressed by the end-users in order to cover most needs as much as possible. It is also participative because it includes the real users throughout the decision-making process to define and weight the list of their most important needs.

Instead, ViP is mostly led by the responsibility of the designer. In fact, the statement definition is entirely managed by the designer who must take a position within the vision by deciding the importance of the context factors according to the domain and the strategy of a given project (Hekkert & Van Dijk, 2011). Although the process is human-centred oriented and the vision is structured around the behaviours of people, the designer is the primary decision maker who decides what kind of factors include or not in the vision and how formulate them for structuring the statement. In the end, the final personal considerations of the designer consequently affects the entire design of the advance concept. Considering these aspects, QFD enriched the individual process of ViP by including the users' perspective in the final automotive concept. In fact, the real expectations of the users (derived from the QFD outputs) were combined with the characteristics of the advanced concept in the third integrated solution.

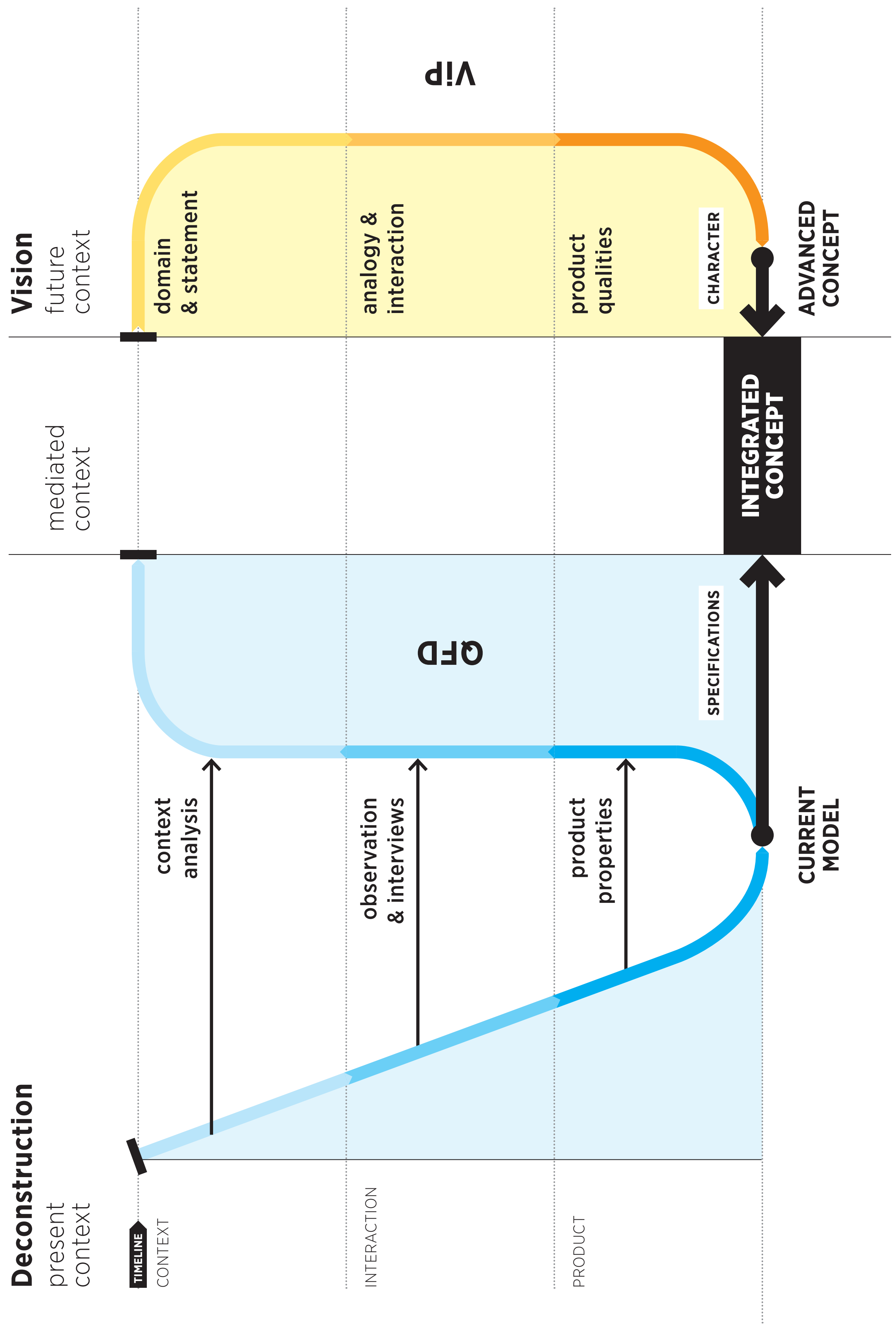
On the opposite side, ViP reinforced the ideation phase of the final concept by giving the research more independency and freedom in the decision-making process. Usually understanding users is a complex task because people are not completely aware about what they want or often what they say do not correspond to what they do (Rizzo, 2009; Sanders & Stappers, 2013). People are also not design experts and so the designer must interpret their expressions in order to translate them in adequate requirements for the project. Therefore, if the analysis of needs is not correctly conducted, it may negatively affect the results of the research. In this case, ViP facilitated the selection of needs that would be incorporated into the integrated concept because it encouraged the designer skills to become more leading in the ideation phase. Moreover, the research was able to acquire more personality from the designer's point of view, because the latter imprinted its position and response to the established world that it had made in the vision.

Considering the third characteristic, complementarity between the two approaches laid on the intrinsic values of the outputs. ViP drove the styling strategy of integrated process primary focusing on people's interactions, behaviours and emotions (experienced through the car), while QFD led the project by concentrating mostly on the technical specifications of the car in order to ensure a qualitative product development process.

In the case of ViP, the human-product interactions are able to elicit behavioural changes, which are considered by the model important elements capable of creating innovative products. The human-product interactions are evoked by the characters of the car expressed in the vehicle form, use and technology. They are essentially the product qualities of the car and they are the main elements that elicits those interactions to ensure to people a new use or experience with the final product. For this reason, ViP transferred the characters of the advanced concept in the integrated solution, in order to maintain specific styling and functions for inspiring new interactions. This operation permitted to support QFD in giving the car a particular identity to the overall project but also it provided to the car an explicit personality, which was able to distinguish the vehicle from the other competitors.

Vice versa, QFD ensured to the integrated solution measurable parameters to develop a technical scaffold for the entire vehicle, on which the vision was incorporated. Indeed, the QFD outputs were employed in the four selected vehicle systems, which in turn, were utilized as a technical framework to package the final vehicle shape of the integrated concept. In this way, QFD supported ViP in providing a tangible structure to the vehicle without missing the qualitative characters or the identity of the vision. As described before, defining quantitative parameters to the project already at the early stages of the design process facilitates the transition period of the vehicle from its final concept to its feasible and tangible prototype.

For the last methodological characteristic, the comparison between the



Img. 100 • Representation of the combined methodology between QFD and ViP. This exploratory combination was utilized as a human-centred approach to drive the development of the expected vehcile concpet during the entire design process of this research.

two human-centred approaches found full complementarity in the time planning strategy of the design process. Taking into account a period of time that start from the present and finish in the future of the vision, QFD can be considered a medium-term approach because it elaborates innovative solutions in response of a current demand. The QFD process focused its activities mostly on the present context and its considerations were elaborated for solving short- or medium-term needs in the near future. In fact, QFD made the ViP's intent more intelligible and acceptable for the third mediated context by shaping the extreme character of the vision around the measurable features of the four vehicle systems delineated by the customer demands. In other words, QFD allowed the advanced concept to manifest itself in the real world without losing its identity. However, as mentioned before, thinking of solving present issues creates some difficulties to reframe completely that existing moment into a completely new context (Hekkert & Van Dijk, 2011).

For this reason, ViP extended the QFD's perspective in the future by producing for it a new environment in which the normal constraints of the present can be limited to not affect potential innovative solutions. Considering this, ViP can be visibly described as a long-term approach because it deliberately designs something in the context of tomorrow without any type of existing restriction. Since the average production time of a vehicle is approximately eight years (Bhise, 2017; Braess & Seiffert, 2013), ViP's attitude seeks essentially to anticipate future trends, market opportunities or upcoming wishes of people by designing an new automotive product in response of those factors. In addition, developing a long-term vision provided a leitmotiv for qualitative requirements, reflected in the car's character and guiding quantitative requirements (Van Grondelle & Van Dijk, 2004). Thus, ViP moved the outputs of QFD forward to create new chances of developing an innovative vehicle that could foresee new market opportunities without becoming restricting only by the contemporary customer demands. On the contrary, since the advanced concept is often unconventional for the real market, it needs technical changes to become more feasible for the engineering production, and hence, this operation can be conducted by QFD.
In the end, the outcomes obtained by the exploratory method are the result of an unedited human-centred method, which was capable of producing an unusual design process. Due to the aforementioned considerations, the exploratory method was able to develop a particular and unique automotive product as well. The latter represents the direct consequence of combining the two stand-alone approaches.

In conclusion, the exploratory research produced its first results that can be considered a valuable starting point for further research investigations of the presented methodology. In particular, the next steps expect to test the integrated method on other new automotive products. The study expects also to evaluate whether the efficacy of the method can be compatible and useful for other categories of products or services.

Currently, the research adopted a linear process that started to use QFD first and successively ViP, to conclude the design practise with their combination. In the presented study the starting point is conducted by analysing the contemporary user demands with QFD, which in turn, produced a list of vehicle requirements for producing the scaffold of the vehicle package. In this case, the real impact of the ViP was in part limited by the influence of QFD because its outputs delineated some technical constraints of the expected car in the four selected systems. Thus, the characters of the advanced concept were mostly concentrated on vehicle styling and less in the use and technology because some vehicle properties were already defined. Considering this, interesting research can be conducted to investigate whether a reversal of the method might be better or how its outputs vary from the previous exploratory method. In that case, ViP would have the same design freedom as it usually has in its normal stand-alone usage. While the QFD would be constructed directly on the user requirements related to the advanced concept.

In any case, including ViP in the research allowed the design process to characterize the entire concept with its intent. Indeed, the QFD process outlined the high relevance of the vehicle styling in the project, but it was not able to find the correct form due to its intrinsic nature, which usually takes inspiration from the state-of-the-art. ViP, instead, motivated every styling decision directly with its main characters. The storytelling, which described the entire process, permitted to better design all the qualitative aspects of the advanced concept through the specific identity of the vision. Nevertheless, other limitations derived from the characteristics of the car segment, government regulations and engineering constraints, which affected again the qualitative aspects of the ViP process in favour of the technical parameters of QFD.

The last limitation is also evident in the lack of a proper specific brand, which did not give the research a coherent company's identity and aesthetics. Those aspects could be very important to trace a stronger styling coherency between the past, the present and the future of the design process. For instance, the history is a crucial element of car styling and during the automotive styling process, it forms a lexicon to which new design shapes must be connected (Van Grondelle & Van Dijk, 2004). Without a specific brand, the research had more freedom in developing the vehicle concept and this might create wide spaces of interpreting the styling factors, and thus, producing discrepancies between the early stages of the research analysis and the final outputs decided during the decision-making process. However, since the project did not present any styling identity to follow, the research utilized a specific case study to fill the gap, the KTM X-Bow, in order to anyway create the adequate coherency of styling strategy as it is an indispensable factor for the automotive development process. The X-Bow, indeed, was selected to give the design process a solid reference as a starting point for developing the project, especially for ViP, which its process expected to have a past model and context on which the vision could be created. Nevertheless, although the X-Bow fully supported the methodological research, sometimes the project struggled to find a common styling point between the goal of research and the branding model of the KTM because both parts referred to two different historical and styling backgrounds. In fact, X-Bow was selected because, as mentioned in the previous chapters, the car provided to the research more information – in terms of vehicle properties and the number of people to analyse – compared to the other models of the same track-day segment.

Though, the XTM's identity did not be really connected to the styling background of the project's territory. The research started with an Italian styling review, but the high necessity of having a brand reference during the styling process forced the method to select an existing brand, especially for ViP. In this case, the research selected the X-Bow also because its identity delivered a particular and unique styling design compared to the selected car segment that would have the potential to increase the change of producing innovative solutions. The only Italian model that could be taken into account for the styling strategy was the Dallara Stradale. However, since the car was released in the middle of the research, the Stradale provided neither sufficient information about its vehicle properties nor the end-users for the analysis of needs. For this reason, future developments of this exploratory research would open the opportunity to test the presented method with a real brand related to the territory in order to study if the process can really improve the overall company's styling strategy in both medium- and long- term periods.

Other researches can be also conducted through participative design sessions. For this research, it was very difficult to prepare Co-Design sections due to the very limited number of users, and hence, deploying that practice for generating innovative ideas was unreasonable. However, Co-Design is growing very fast in many business sectors (Steen, Manschot, & Koning, 2011), and hence, it would be an existing great opportunity to make the automotive process more inclusive. The automotive industry has not traditionally deployed Co-Design tools in its process, but this can guarantee that the needs of people can be addressed not only at the start of the design process, but they can be maintained continuously in-the-loop throughout the product gestation, launch and beyond (Giacomin, 2014). In particular, the next potential research would be developed by incorporating the Co-Design within the ViP process to encourage the end-users to collectively develop the advanced concept, in order to transform ViP into a more inclusive and collaborative method as much as QFD.

6.3 References

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