μcar

Multidisciplinary development of an electric vehicle typology for the city

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Abstract

This PhD thesis discusses the conceptual development of a new electric vehicle typology for the city.

The proposal of a new type of private mobility for the city encloses a vast array of design parameters ranging from urban traffic considerations to user acceptance and contextual considerations. While the body of work from previous proposals covers individual aspects related to the technology of the city vehicle, we still lack a holistic approach to the definition of the typology.

The initial question of proposing a new typology of private vehicle for the city evolves into the following set of questions:

How can we design an eminently efficient urban four-wheeler?

How can we incorporate user acceptance in that new vehicle typology?

How can we align the new typology with industrial goals?

Starting with a historical study of minimal motoring (cyclecars, bubble cars and microcars), my research uses a multidisciplinary approach to analyse the problem of private urban mobility. This includes accepted studies on traffic congestion, pollution and safety, completed with an evaluation of user acceptance and industrial context in the introduction of new solutions. The aim of this holistic approach is to identify design opportunities that could favour the introduction of new vehicle typologies in urban scenarios.

From this analysis, this thesis proposes a new vehicle typology, µcar, expressed in a new design strategy for a minimal electric four-wheeler. This strategy deals with design points such as sustainability, urban integration and modern lifestyle adaptability. Its feasibility is also supported with appropriate criteria such as packaging, safety, manufacturing or quality aspects. The thesis also includes an embodiment of the design principles proposed in the research that has informed the development of the typology by identifying the main design tasks and has contributed to the critical assessment of this work.

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To my parents

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Author's Declaration

1. During the period of registered study in which this thesis was prepared, the author has not been registered for any other academic award or qualification

2. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than for which it is now submitted

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1. Introduction

In 1909, two young Englishmen decided they could do better with less. Henry Ronald Godfrey and Archibald Frazer-Nash, classmates from technical college, transformed the stables of Archibald's home into an improvised R&D lab to build their idea of an affordable and high-performance four-wheeler. At that time, cars were bulky machines with large and heavy engines to propel the similarly hefty comforts of traditional carriages. By contrast, Godfrey and Frazer-Nash used an alternative approach that stripped out all unnecessary weight and complexity: They made an ash frame, installed a motorcycle V-twin engine that propelled the rear wheels by a belt transmission, and covered everything with a rudimentary fairing. The result was a 180kg vehicle that could reach nearly 100 kph with its underpowered powertrain. This prototype was the first model of the GN brand (see picture below), which ultimately became one of the most successful cyclecar manufacturers. They offered both affordable mobility for commuters and solid a base for weekend racers.

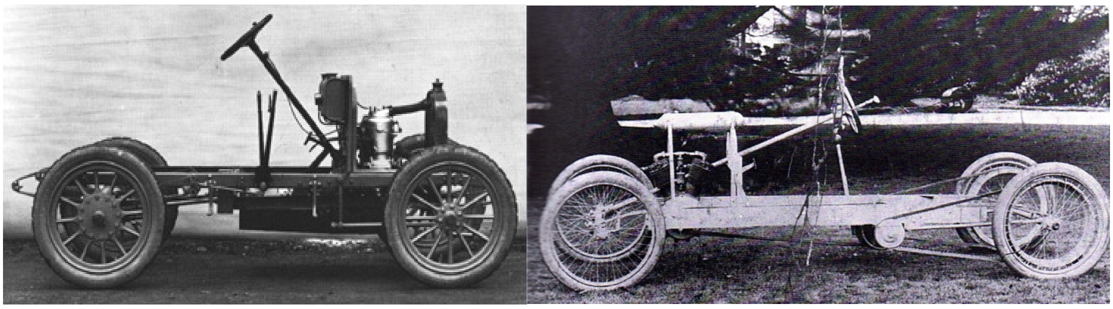


Figure 1: 1909 Austin 7HP, a small car of the time, and the GN prototype

However, in 1922, GN and similar motoring mavericks saw the end of their era. The Austin 7 car (shown below) brought individual mobility and comfort to British population. The crudity of cyclecars became obsolete, for new designs and mass production finally offered cars affordable to the masses. Such was the impact of the Austin 7 that it became instrumental in the beginnings of some automotive companies that forged the motoring history of this country (for example, Lotus or McLaren).

In general, the introduction of affordable cars was a revolution: it provided unimaginable levels of convenience and freedom of mobility. And needless to say, such a love affair with the car was a decisive element of modern culture. But along the years, the ever-increasing number of individually convenient solutions produced a general problem, which has become especially severe in our living nuclei: the cities. The whole picture shows that, what is freedom and comfort for individuals, results in an unbearable waste of time and resource for our society. And we can continue considering the effects of car use on our health, on younger generations growth, on our life quality and even our safety.

Figure 2: 1930 Austin 7

Paradoxically, the individual freedom that constitutes the seed of the problem has also been neutralized by its secondary effects: Congestion charges, low-speed or car-free zones, and insufficient parking spaces drastically diminish the allure of daily driving. Definitely, urban mobility represents a major issue of our times.

In the current circumstances, the need for a solution to urban mobility starts with the question: *do we really need to move at all?* Nowadays, modern job tools and communication technologies make work ubiquitous. While working from home could arguably decrease productivity, the question would be whether it is easier to solve urban traffic problems or to increase productivity for new working scenarios.

Nevertheless, changing the way we work, we live or even our economic system is out of the reach of this research. Generating valid alternatives to cars within urban environments in the short-term future constitutes a more suitable challenge for vehicle design research.

In that sense, short-term scopes highlight the importance of contextual references in the development of new solutions. Such solutions must respond to existing infrastructures, relate to our social implications and respect legislative frameworks currently in force. On the contrary, a long-term scope could favour high-flown proposals for an idealised context, which, in turn, does not have any problem to solve at all. Particularly in such fast-paced times as these, the proposal of long-term solutions seems, to say the least, irrelevant. Thus, despite the enchantments of flying pods or robotic runabouts, their idealised contexts drastically limit their feasibility as serious contenders to cars in our cities. It is important, however, to keep in mind that desirable future as a better version of our present, for our proposal should be developed as a first step towards that desired scenario.

Therefore, the new typology should constitute a change initiator for present and past lifestyles, for existing infrastructures and thinking. It should be a solution of our present to evolve towards desirable futures.

The introduction of contextual influences in the development process of a mobility solution is obvious when we compare private and public mobility. For example, self-driven trains are common in modern urban traffic. They eliminate variabilities and help optimize traffic. The flow parameters to control are fairly simple: acceleration and deceleration commands, and stop times. The only disturbance in the system is due to human delays in the activation of the automatism after verifying everything is OK. Avoiding stops in tunnels is the only emotional factor to consider, for it annoys and scares passengers. Thus, everything can be reduced to an algorithm automatically optimized in unattainable ways for human operators.

On the contrary, the variables affecting car traffic within our cities are much more complex and unattainable. Purchasing criteria, use patterns or social symbolism are just some aspects affecting the control strategies. In order to propose valid alternatives to cars within our cities, we need a holistic approach able to embrace the complexity of the problem. Such an approach should help establish a compromise between social and individual needs, between emotional and objective factors.

To begin with, a small and low-powered vehicle architecture is already a step forward. With urban speeds limited to 50 kph and cars normally used by only one person, this provides enough performance for common urban duties. However, such a humble base already represents a departure from the extravagant standards set by conventional cars. Hence, the first question to address with our holistic approach is how can we maximize its individual appeal. Certainly, reduced proposals have found a place in their users' hearts before, as the Fiat Nuova 500 or the Mini showed in the last half of the 20th Century. Thus, our approach should identify those design drivers that align contextual convenience and individual appeal. In that sense, it may be the right time to dust off GN's ideas about minimal motoring with a twist that updates them for modern cities.

When cyclecars succeeded, some small conventional cars already existed. But it was the cyclecar idiosyncrasy that won the game in that particular context. They represented a **qualitative (rather than quantitative) jump** from conventional car architectures. Their lightness and purposefulness made them more efficient and affordable than conventional cars. Their simplicity fostered a do-it-yourself culture where amateur hobbyists could build their vehicles and even become manufacturers. Such simplicity also made them easily scalable: several well-known cyclecars have evolved, for more than a century, from crispy runabouts into insane racers as technology and builders' skills improved. They were, in summary, not just rougher and lighter cars, but machines that perfectly synchronized with the necessities and spirit of their times against the highly complex and unattainable cars. Our context has obviously changed: It would be impractical and unsafe for everyone to build his or her vehicle, but in the development of new urban four-wheelers, the cyclecar spirit of efficiency, adequacy and adaptability is well worth an analysis.

In times when the joy of mobility has been substituted by low-cost flights and massive traffic jams, the romanticism of cyclecars can be an important ally to reconnect with our cities. Private mobility should not be a source of environmental and social degradation, but a convenient tool to rediscover our habitat. The urban vehicle, thus, should become the instrument to live our cities. It should evolve with its user and allows him or her to know the city, so they will not leave its future on the hands of speculators or politicians.

To offer a valid answer to such a complex and multifaceted question, this research addresses the conceptual development of a new urban vehicle typology that combines efficiency and appeal into a minimal architecture: the *µcar*. It is fundamental to understand the implications of such a task, for it is easy to mistake it for a mere design of a new vehicle. The following quote, by Aldo Rossi (1982), could help illustrate this difference: '*Type is thus a constant and manifests itself with a character of necessity; but even though it is predetermined, it **reacts** dialectically with technique, function, and style, as well as with both the collective character and the individual moment of the*

[...] artefact'. Thus, the main goal of this research is the definition of the general genome for a new family of urban electric vehicles. This genome appears as an answer to the problem of urban mobility, and it is the result of an iterative process that considers the influences of **technology, function and emotion**. Similarly, its genesis considers, not only the individual user, but also its integration within the existing physical and social environment. The following chapters contain the main findings of this process and the design strategy developed to create such a typology.

Chapter 2 initiates the research with foundational reviews on the history of minimal motoring (cyclecars and microcars), relevant case studies that provide a solid starting point of past solutions and approaches and legislative and technical reviews that helped to detect the particularities of the design problem. Afterwards, Chapter 3 outlines the research methodology, one of the most singular characteristics of this work, for it describes the combination of engineering and design with complementary disciplines in the definition of the typology. Chapter 4 starts analysing the problem of the design. A typical review of issues related to urban mobility such as pollution, safety or traffic is completed with user acceptance criteria and a review of the situation of the automotive industry by the turn of the 2010s. After the analysis explained in the previous section, Chapter 5 includes the development of the new vehicle typology combining design and engineering within the same framework. It also explains the original design strategy to generate an eminently urban, efficient and private four-wheeler. Chapter 6 depicts the particular embodiment used in this research. The following section, Chapter 7 includes a critical assessment of the hypotheses proposed in this research. This research finishes with the conclusions and future steps outlined in Chapter 8.

Let us begin, then, with the compilation of relevant historical references that will start this research process.

2. Background Theory

Cars allowed unprecedented levels of progress during the 20th Century, shortening distances and providing freedom of mobility. But last century has also served to discover the limitations of unsustainable growth.

Nowadays, low average speeds, poor air quality, safety risks, noise levels and traffic-biased urbanism challenge the role of cars in our cities and promote the search for alternative solutions. Whilst well adapted to long and high-speed trips, cars are inefficient for city centres: they are too fast, heavy and clumsy. Without losing the advantages of a four-wheeled architecture, other options may be able to offer a better compromise by adjusting their performance to urban environments.

Nevertheless, despite efficiency has never been their leitmotiv, minimal typologies have already tried to defy the car as a better solution for the city. Starting from the early 1900s, first the cyclecars and then the micro and bubble cars stood out as cheaper options during recessional periods. But their ultimate decline proved that economic criteria are not enough to assure long term success of efficient architectures. Thus, a historical review will help to understand their successes and failures, providing support for a new typological proposal based on similar concepts.

This report aims to provide a solid background for the development of a new typology of lightweight electric vehicle for our cities. This background is structured in four main sections:

1. A historical review, analysing context and evolution of past solutions
2. Several case studies related to relevant designs
3. A state of the art of urban four-wheeled vehicles
4. Design considerations for a new urban vehicle typology

2.1 Historical Review

Small four-wheelers (different to cars) can be historically classified in three main groups: cyclecars, bubble cars (including micro-cars) and quadricycles. Despite time lapses, their particular histories run parallel: they emerged as cheap versions of cars, and disappeared once buyers could afford more comfortable and reliable vehicles. Thus, this section will include a deeper analysis of the first cyclecars, which will be completed with the particularities of both bubble cars and quadricycles.

2.1.1 Cyclecars: Minimal Motoring

Cyclecars were a specific vehicle typology with a relatively important role during the 1910s and 1920s. The picture below shows an illustrative example of this type of vehicle, defined between the first cars (heavier and with larger engines) and simpler motorcycles. In the early 1910s, they were classified into two main groups, according to their weight and engine capacity (Worthington-Williams, 1981):

	Maximum weight	Maximum engine capacity
Large class	350 kg (772 lb)	1,100 cc
Small class	300 kg (660 lb)	750 cc

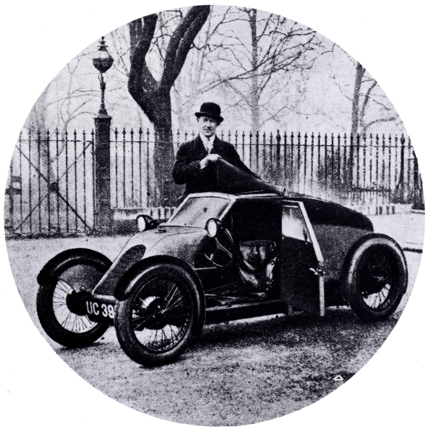


Figure 3: Example of a cyclecar (1928)

While powertrain evolution has allowed using noticeably smaller engines in modern quadricycles, weight has drastically taken the opposite direction (the top weight for current quadricycles is 550 kg).

For the purpose of this research, it is important to analyse the history of cyclecars in order to identify the reasons for their appearance, success and failure. While their technology or design are outdated for current contexts, an understanding of the factors that ruled their life could help to reinforce the definition of the new urban typology. Thus, the following sub-sections will contain analyses of their history and idiosyncrasy.

2.1.1.1 Stimulus, success and ultimate decline

Stimulus

In the 1900s and 1910s, cars were new means of transport only available for the wealthiest buyers. Increasing commuting distances, thus, generated an opportunity for alternative solutions to walking or cycling (Altman, 1971).

In that search for increased range and convenience, reliability or comfort were a secondary matter. Thence, the idea of a four-wheel (or three-wheel) platform built with cheaper and rougher elements seemed obvious. Several entrepreneurs started attaching motorcycle powertrains to minimal wooden frames, creating, thus, the first cyclecars.

These vehicles were significantly cheaper than cars, easier to maintain and, thanks to their smaller engines, they attracted lower taxation too (Worthington- Williams, 1981).

Success

Such an advantageous performance-cost combo, together with their simpler technology defined the success of cyclecars.

Motorcycle manufacturers were the first to support this new vehicle typology as an easy way of introducing themselves to a greater market. Apart from mechanical advantages, these companies enjoyed an age when cars were not the social symbols they are today. They were just another type of vehicle among the variety of machines (i.e. tricycles or motorcycles) that were appearing during the transition from the horse-drawn 19^{th} to the motorised 20^{th} Century.

In that context, cyclecars were the realm of motoring mavericks of the time. Innovators saw a market in the need of mobility and an affordable business in the new vehicle architecture. Most of the cyclecar manufacturers simply bought motorcycle components, although some of them, such as GN, produced almost every bit of their vehicles using original and inspiring designs (Georgano, 2000). In fact, by the outbreak of WW1, GN was one of the best British cyclecar manufacturers, with a total production number under 200 units.

Ultimately, such a manageable architecture also allowed amateurs to build their own vehicles either from kits or following the design of their choice, which would have been unattainable with conventional cars.

Decline

Since affordability motivated their emergence, the birth of low-cost cars marked the end of the cyclecars. The Austin 7 appeared in 1922 and revolutionized the market with the comfort and reliability of a normal car and a cost similar to a cyclecar. It was a new design that applied the minimal ethos of cyclecars (as the picture below shows) to a car architecture. Thus, it was possible to drastically reduce its manufacturing cost and, as it happened with cyclecars, taxes were significantly lower for this model: £ 8 per year (while a Ford Model T cost £ 23).

Thence, people who could afford a car stopped buying cycle cars, while their staunch supporters started to fade away over the years.

By the end of 1920s the presence of cycle cars in the market was just marginal, and it was only after WW2 that there was a place for their heirs, micro and bubble cars.

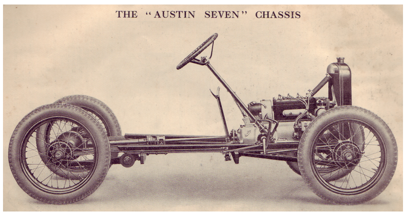


Figure 4: The Austin Seven Chassis

2.1.1.2 Cyclecar Architecture and Idiosyncrasy

It is important to consider the cyclecar architecture, for it is an example of purposefulness in light vehicle design and it also generates the idiosyncrasy of this typology. Its simplicity and adequacy favours user interaction and contributes to generate emotional acceptance within such a constraint package. In times when the love affair with car and fossil fuel, especially in cities, starts its decline, cyclecars can show a way of revitalizing the convenience of a four-wheel platform within more reasonable urban packages. This section will briefly analyse the particularities of the cyclecar architecture and its implications.

Cyclecar architecture

Two architectural factors defined the success of cyclecars: mass de-compounding and accessible technology. The adequacy of each sub-system (powertrain, body and chassis) to their reduced requirements produce significant weight reductions that implied further reductions, or mass de-compounding (Lotus Engineering, 2010), in the other sub-systems. Additionally, the use of lighter elements and materials that were accessible for a wider range of builders and amateurs contributed to the expansion of the use of cyclecars. Let us see how these factors were reflected in the main sub-systems.

powertrain

As we mentioned before, motorcycle engines (e.g. J.A.P. or Peugeot units) were common in cyclecars. Some manufacturers, such as GN (Georgano, 2000), even created their own designs. Apart from offering enough performance, motorcycle engines were also easier to handle, for builders did not need cranks to install them.

Vehicle lightness also favoured the implementation of alternative underpowered powertrains such as the Dodge electric starters used in Red Bugs as motors (Altman, 1971).

Similarly, low power and torque also allowed simplified transmission layouts such as belt-operated systems and solid axles (shown in the picture below). The ultimate simplification, however, was the transference of power to just one of the two rear wheels, as seen in the 1921 Economic (Worthington- Williams, 1981). These configurations offered an acceptable compromise at low speeds, and go-kart handling at higher speeds. Fundamentally, they helped to reduce manufacturing costs, complexity, and were instrumental in secondary weight reduction, contributing to overall vehicle efficiency.

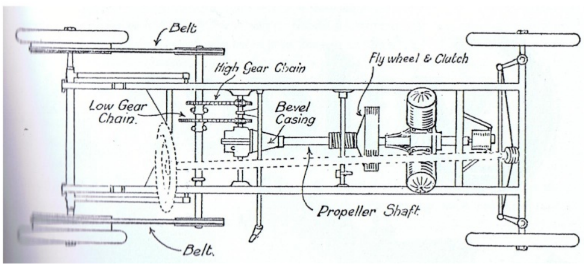


Figure 5: GN powertrain layout

Structure

Again, the reduced design requirements in cyclecars allowed alternative configurations. Thus, while body-on-frame designs were the preferred choice in cars, monocoque wooden frames were common in cyclecar designs. The following picture shows the structure of the 1919 Tamplin, designed by Carden, consisting of a wooden frame and wood body panels (Georgano, 2000). Again, these new layouts further contributed to mass de-compounding, for the reduced design loads of cyclecars allowed the use of significantly more efficient structural configurations. Thus, it is not strange to find cyclecars weighing 200 kg or even less.

Chassis

Suspension solutions ranged from complete absence of suspension elements, through the use of structural compliance as a damping element (Altman, 1971), to minimal designs such as sliding pillars. These light and simple designs were good enough for low speeds and contributed to maintain the minimal and affordable ethos of cyclecars. Similarly, simplified steering systems, such as cable-operated configurations were common, providing cost, complexity and weight reductions.

Figure 6: The Tamplin and its exposed wooden monocoque

Cyclecar idiosyncrasy

The cyclecar architecture had other than purely technical implications, mainly related to its implementation within its context. First, its technology was more approachable than car architectures, increasing its acceptability among niche social groups left uncovered by hefty cars. This fact helped to generate a social acceptance of the cyclecar concept of minimal motoring. While such considerations were results of the industrial and social context of the early 20th Century, its utility in modern context can prove to be crucial in the development of a new urban vehicle typology. Saturated times require a thoughtful use of resources that has to be carefully integrated within modern societies and lifestyles.

The approachability of the cyclecar architecture could be considered as an example of open-source motoring. While the motoring industry heavily relied on metalworking and heavy machinery (only accessible to industrialists and specialists), anyone with an interest found an accessible platform and know-how to start within minimal cyclecars.

The basic material for cyclecar body structures was wood, easily obtainable and handled by amateur builders. Additionally, a network of suppliers provided them with specialized components, such as gears or hubs. Ultimately, a scattered local 'industry' of specialists (e.g. carpenters or blacksmiths) supported them in tasks they could not accomplish.

An example of the technical approachability of cyclecars was Stanley Pontlarge's '*How to Build a Cyclecar. A handbook for Amateur Constructors*', published in 1913. This clearly illustrated book guided builders through the whole process of completing their own machines, from engine selection and installation to bodywork construction. The author also warned about the dangers of accomplishing critical tasks without the right experience and suggested professional support in these cases (Pontlarge, 1913).

Thus, the simplicity of cyclecars defined a very modular and permeable context for their growth as a mobility option. It was a democratization of motoring, opposed to rigid car architectures. Users could build their own machines and adapt them to their needs, establishing long-term links with them. Ultimately, the cyclecar platform became almost an element of self-expression, such as fashion, a social mean of communication in addition to its main function as a mobility solution.

The inherent adaptability of cyclecars, then, allowed them to respond to the needs of niche group of users that were left out by conventional car architectures. There were two specific examples of this phenomenon: racing enthusiasts and leisure commuters.

Among the racing enthusiasts, a wide range of vehicles, from the early low powered and simple machines to the serious racers, such as the charismatic 'Shelsley Specials' (built to compete in the Shelsley hill-climb races) helped to establish the base for the quintessentially British kit-car culture. They offered an answer for those looking for raw emotions, performance and close-knit relationship with their vehicles, and contributed to generate a sub-culture similar to contemporary '*fixie*' cyclists.

A paradigmatic example of such charismatic machines was '*Bloody Mary' (shown in the picture below)*, a cyclecar built by the Bolster brothers (Dixon, 2010) that evolved, along its creators' skills and budget, into an extreme racer capable of completing the Shelsley track in 42.24 seconds, setting the record for non-supercharged cars (and fourth time overall) in 1937.

Figure 7: Bloody Mary in its final version and *Roland Bugatti's Red Bug*

For other users, cyclecars constituted a simple way of moving around in resorts and leisure centres. Their adequate simplicity made them easier to drive, cleaner and quieter than cars. In these contexts, some vehicles became the simplest and minimally chic way of moving around in the trendiest.

The Auto Red Bug was the epitome of such chic minimal motoring. In its last iterations, it was an electric 'buckboard' seating two occupants in a completely exposed fashion. It did not even have suspension, for the inherent flexibility of its structure accomplished such a function (Altman, 1971). But cheap and simple did not translate into a lack of emotional aspects. Its reduced dimensions and weight produced a thrilling machine, much more agile and fun to drive than conventional cars. And from an aesthetic perspective (see picture above), it constituted a example of how to create a visually appealing product in spite of its bare nature and maximum efficiency. Thus, although it appeared as a commuting solution for the masses, the Red Bug found success in European and American luxury resorts during the *Roaring Twenties* (Old Woodies, 2003).

That emotional ingredient inherent to the minimal architecture of cyclecars made them one of the first examples appealing to both the lower classes (*an affordable solution*) and the upper classes (an *amusing and practical item*). From racing enthusiasts to the jet set, the simplicity of these vehicles allowed them to surpass their role as economy mobility, satisfying the needs and amusing those left out by the inflexibility of car architectures. In fact, it could be argued that, had cyclecar manufacturers focused in such markets (racing enthusiasts and resorts) instead of competing against affordable cars, they may have survived as niche manufacturers.

In times when the affair with cars (and fossil fuels) as we have known it may be approaching its end, the cyclecar design philosophy can help to tackle the problem of urban mobility from a different perspective, recovering a human scale and rediscovering the joy of mobility.

2.1.2 Micro and bubble-cars

After WW2, the economic situation again promoted the emergence of inexpensive vehicles able to attract low taxation (Trant, 2004). Additionally, many wartime industries, specially in Germany, were looking for different markets in order to survive. Such an scenario promoted the appearance of a new vehicle typology, again with minimal dimensions, small internal combustion engines and either three or four-wheel layouts. However, it abandoned the do-it-yourself ethos that characterised most cyclecars. The new vehicles were produced by dedicated companies and, subsequently, that sense of a proud and social movement was lost. Moreover, these new vehicles were more often a source of jokes due to their sometimes amusing appearance compared with now nearly ubiquitous cars. However, the new typology was able to generate a new design language, direct result of its industrial idiosyncrasies, and in some cases totally differentiated of conventional car design. Nevertheless, similarly to what happened before with cyclecars, the end of bubble-cars can be traced back to the introduction of small, sexy and affordable new cars, with two clear examples: the ultra-iconic MINI in the UK and Giacosa's Nuova 500 in Italy.

For the purpose of this research, two examples, the Isetta and the Messerschmitt, illustrate the main contributions of bubble car architectures to minimal motoring: differentiated design language and alternative industrial approaches.

The Isetta (shown below) was introduced by Italian fridge (*Isothermos*) manufacturer Renzo Rivolta in 1953. It was the result of his strategy looking for more profitable businesses such as affordable mobility. The Isetta was a quasi-spherical four-wheeled vehicle that became a total success at the 1953 Turin Motor Show. The design reflected its origins (the only door, holding the articulated steering column, opened as a fridge door), breaking the mould of conventional car design. Behind a single bench there was a two-stroke motorcycle. To avoid the necessity of a differential box, rear wheels were installed close, though this solution proved to be poor for its handling abilities. Licences of the design were sold worldwide, with famous derivatives such as the BMW Isetta (Wan, 1997) and the Trojan. Its originality and cuteness made it a design icon (some 50 years before the smart fortwo).

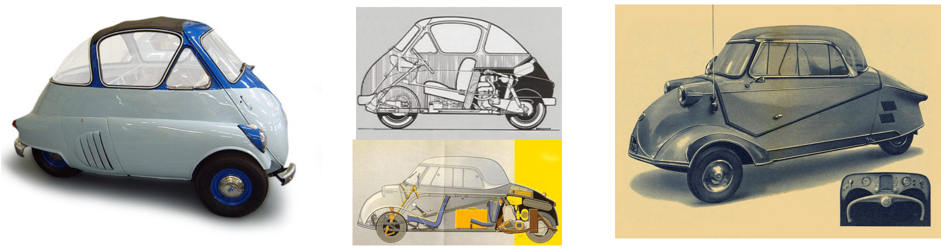


Figure 8: 1958 Iso Isetta and 1955 Messerschmitt KR200

Prof. Messerschmitt also needed an alternative to fighter aircraft in order to keep his company in the market. Aeronautic engineer Fritz Fend found a gap for the development of mobility aids for disabled war veterans. These vehicles were not considered as general-purpose transportation, and, therefore, could be promoted under the Allied control (Cawthon, 2004). Using Prof. Messerschmitt's factory and Fend's design, they started producing the Kabinenroller 175 in 1953 under the Messerschmitt badge. Its design was, essentially, a fighter jet cockpit on three wheels, maintaining the practicable dome that opened to accommodate its two passengers seating in a tandem configuration (avoiding weight unbalances and reducing manufacturing costs). The structure used typical aircraft solutions too, combining reinforcing beams and load-bearing bodywork. A rear sub-frame held drive-train and rear wheel assembly (virtually identical to a motorcycle). The suspension was based on torsion rubber springs without dampers (introduced in the later KR200, shown above). Despite their charisma and performance, these vehicles disappeared with the introduction of cheap small cars like the Mini in the UK. FMR stopped its production in 1968, with approximately 50.000 sold units and Fend's designs became one of the most iconic products of the motoring era.

2.1.3 Modern Quadricycles

The latest incarnation of the cyclecar is the modern quadricycle. It appeared as a reaction to the 1973 energy crisis, having their greater success in France since the late seventies (Auto-Histories, 1996), where legislation did not require a car driving licence. This fact made quadricycles an interesting proposition for those who could not afford owning a car (commonly, elder inhabitants of rural areas). In that sense, quadricycles became some sort of 'micro-2CV'. However, with their rough aesthetic, they lacked the charisma of the iconic Citroën. Modern examples have improved on visual design, resembling pint-sized cars. However, with prices close or even superior to basic cars and limited performance, they do not enjoy a great success out of their traditional markets. In several European countries (unlike the UK), it is still possible to drive a quadricycle without a B2 driving licence. However, this scenario could change in 2013 when these machines will presumably be subject to the new EU driver licensing rules (Department of Transport, 2009).

Test of a modern quadricycle

The 2009 Nice Mycar quadricycle is a representative example of current quadricycles. A drive test was illustrative to show the characteristics and limitations of this type of vehicle.

Ergonomics: The car has a reduced cockpit which cannot comfortably accommodate large passengers. However, the visibility and dimensions facilitates urban driving.

Performance: The vehicle can be considered agile and fast enough for urban speed limits. The electric powertrain, though limited in total output, has immediate response compared with a traditional vehicle. However, in real-life conditions, where legal speeds are clearly surpassed, the power output seems to be clearly insufficient to keep pace with the traffic.

Feeling: The Mycar perfectly illustrates one of the weakest points in quadricycle design. Although, in terms of visual message, quadricycles use car design language (Volume distribution, surfacing, exterior and interior detailing), their tactility is clearly below modern automotive standards. NVH considerations were non-existent and in general, the car felt cheap and poorly finished. Paradoxically, the Nice Mycar, penned by Giugiaro's studio, is among the best modern quadricycle designs.

Figure 9: 2009 Nice Mycar, as tested by the author

2.2 Case studies

2.2.1 Three-wheel cars

Three-wheel cars have been around since the beginning of automotive history (In fact, the first car had this typology). Its evolution was parallel to the four wheelers although it eventually disappeared as a common solution and now it is reduced only to niche high-performance vehicles.

2.2.1.1 Advantages

Losing one wheel has two direct implications: it reduces the chassis weight and manufacturing cost.

Three-wheel cars have fewer mechanical components and the torsional loads are lower than in a traditional four-wheel arrangement, allowing a size reduction of structural members (Riley, 1994). These two factors obviously reduce weight and cost (as there are fewer components to buy and install). Weight reductions also diminish powertrain requirements, allowing the use of low capacity engines that attract lower taxation. Moreover, three-wheel cars can be considered motorcycles in legislative aspects. Even indirectly, such a legal categorization can reduce costs: motorcycles do not have to comply with crash tests, reducing development and manufacturing costs of impact attenuators .

2.2.1.2 Disadvantages

The main disadvantages of this typology are two: handling and social implications.

While three-wheelers can provide an improvement in handling in specific circumstances (they have a better yaw response and can be more agile than a conventional car), their response depends on the load distribution and are not so suitable for high speeds (Riley, 1994). In terms of passenger packaging, the common arrangement of occupants seating side by side has the disadvantage of negatively affecting weight distribution when the mass of passengers at one side is not equal to the other side. This effect is of further importance in light vehicles, especially those capable of providing high performance (Vital, 2010a). Additionally, in order to compensate these disadvantages, the wider and longer they are, the better, which constrains the ability of this architecture to generate an ultra-compact vehicle.

Figure 10: 1973-1981 Reliant Robin

But apart from all the technical configurations, these vehicles have the same problem as many other solutions born under a struggling economy: people lose interest as soon as they can buy 'real' cars. Though it is true that some examples have become design icons, three-wheelers are often seen as amusing vehicles with a total lack of social status. It would be, however, interesting to analyse how a possible change in the perception of future generations of users can affect the acceptability of this vehicles.

2.2.2 Sinclair C5 and the social factors

2.2.2.1 Context

Sir Clive Sinclair has always been fascinated by electric vehicles and in the 1970s, his company began to consider the development of an electric personal vehicle. This project was left aside until 1979, when the energy crisis led to several funds been released for EV's. Sinclair hired a former employee, Tony Wood Rogers, as a consultant who then began to develop the first prototypes (Dale, 1985).

The design brief was simple (Dale, 1985):

- A vehicle for the housewife, the urban commuter or the youngster
- Advantages over a moped: safety, weather protection economy and style
- Target price: £500 (based on the prices of mopeds and used cars)
- Easy to use
- Minimum maintenance and battery size
- Range of 30 miles

- The battery would last 2 years
- Designed and engineered for simple, high-volume assembly, with injection moulding parts where possible and a polypropylene body

In 1985, Sir Clive Sinclair introduced the C5, his solution for urban mobility. The vehicle was a three wheeler that complied with the "1983 Electrically Assisted Pedal Cycle Regulations" (Solar Navigator, 2005). Under the environmental concerns of the 70's, the British government promoted alternative vehicles creating this new kind of classification. Additionally, as long as total power output were below 250 watts, drivers would not need a license to use them.

2.2.2.2 The C5

The new vehicle seemed to be a nice technical solution. Its chassis was designed by Lotus, the electric power train was a Polymotor and the body, designed by Gus Desbarats, was the largest polypropylene single piece ever made by injection moulding (Solar Navigator, 2005). The handlebar was under the user's knees and it had a comfortable seat inspired on those installed on larger cars. It cost £ 399 in 1985 (BBC News, 1985).

Figure 11: Sketch, body prototyping and complete vehicle (Photos courtesy of Mr Desbarats)

2.2.2.3 Failure

It seemed a potential success, but the result was not that good. The main problems since the launch were mainly the dimensions of the vehicle (BBC News, 1985) that were quite low (2 ft 6 in) and with a minimal ground clearance that produced a scary driving position (a few centimetres above the ground and without any type of crash protection) and a lack of agility that only allowed driving on even surfaces. It was this low position that motivated a complaint by the Automobile Association (Duffy, 2003), as neither the vehicle nor the user were visible from the driver's seat of a lorry. The poor range of their batteries and power did not help either.

These two initial points were severely attacked by the media, and the vehicles were subsequently finished off by a host of rumours that sank this new concept completely.

2.2.2.4 The designer’s perspective

The C5’s body engineering and design were carried out by Gus Desbarats, a mechanical engineer with an MA in Automotive Design at the RCA who became Design Director of Sinclair just after finishing his post-graduate education.

For Mr Desbarats, the main problem of the C5 was that it tried to introduce two behavioural changes and the same time: a shift to electric powertrains and to a new typology of vehicle (Vital, 2010b).

The first problem is common to every EV, even today. People are used to the usability of a petrol car and do not deal very well with machines that need daily refuelling and a recharging infrastructure.

But the second problem was inherent to the novelty of the C5. Its design started from a technical approach, rather than a study of its context. It tried to initiate a new vehicle typology without any roots in the past, which confused its prospective buyers, as they were not sure how to use it: It was similar to a bicycle in terms of architecture, but at the same time, too heavy to pedal; it was also confusing in terms of parking, as people were not sure whether lock it like a bicycle, or leave it like a scooter –with the risk of someone just lifting it up and disappearing with it.

Furthermore, no road tests were made until the last stages of development, when a prototype was driven during the night around Cambridge, and according to Mr Desbarats, they could discover the sense of exposure alongside conventional cars (Vital, 2010b).

In conclusion, though C5 was a appealing and outrageous concept, it lacked that analysis of the social need before the technical conception starts.

2.2.3 BMW C1 and the importance of legislation

The C1 was a motorbike for the car driver. With increasing problems of traffic in the city and taxes, BMW tried to produce a new kind of vehicle with a reasonable level of comfort and that was much cheaper to run, aimed at urban European markets (BMW World, 2007). The solution was a new type of scooter aimed at the type of person who would never ride a normal motor cycle.

Figure 12: 2001 BMW C1

This vehicle had a particular focus on safety, a major issue in buying a motorbike for most people), with a structure that incorporated a roll cage, crash absorbers and seatbelts. The concept was basically a car on two wheels.

The C1 introduced three important advantages over conventional scooters (Vital, 2010d):

- Although it still required skills to be driven, it offered a better level of protection.
- It also had the best visibility on the market, thanks to a big screen plus wiper
- It stood out better in the middle of the traffic, assuring than car and truck drivers could see C1's riders more easily.

However, this new idea proved to be another failure. The main problem was how to introduce this new typology within the current legislation of different countries. Though the C1 was developed with the help of German legislators, it struggled in other countries to persuade them of the redundancy of using a helmet. Moreover, the compulsory use of a helmet made other additional features (sound system, mobile phone bracket) completely useless.

Additional disadvantages were a relatively high weight for a scooter, which made its initial purpose of transferring car drivers to two wheels invalid, as it required the skills of someone used to ride motorcycles rather than featherweight mopeds. It also had a high compression engine that did not contribute either to a smooth nor quite ride.

Therefore, the bike, rather than becoming a mass solution for urban drivers, was just another fancy design to sell to a special niche of the market, that is, users looking for a distinctive look or product.

Nevertheless, this proposal could overcome the C5 in two important aspects: it was a new vehicle visible for the rest of motorist and initially appealed a larger portion of the market (possibly due to the fact that it was close to a conventional typology –the scooter- rather than being a radically new concept). It was able to create a group of followers attracted by the appeal of the solution, which is one of the key factors for the success of a new typology, and it still has a core group of loyal users.

2.3 State of the Art

2.3.1 Reva G-Wiz and its success in London

Figure 13: Reva G-Wiz

The Reva G-Wiz, designed by American automotive entrepreneur Lon Bell and Reva's founder Chetan Maini (Leahy, 2009), is a two-door small hatch-back powered by an electric DC motor fed by batteries. This section will analyse its success in London during the first decade of the 21st Century as an example of contextual influences.

As we have seen, the G-Wiz does not stand out for its advanced technology or ingenious design. In terms of vehicle engineering, it is a simplified version of a car with an electric power train. But that was part of its secret: it was a 'good enough' mobility solution able to take advantage of a particular socio-political moment in London.

In 2003 Mayor Ken Livingstone approved a congestion charge for Central London (BBC News, 2003). The goal was to limit the use of private vehicles in the city centre, reducing congestion and investing in public transport. In 2007 the Charging Zone included some parts of West London. In 2009, the congestion charge was GBP 8 per day per vehicle.

Apart from usual running costs (i.e. fuel, tyres or oil) and considering only this new tax, it is easy to see how great was the impact of the congestion charge for car users: Assuming a year of 48 working weeks (240 days), a daily commuter to the city centre would therefore spend 240x8 = 1,920 pounds per year in congestion charges. Considering the average lifespan of 13 years for a car in the United Kingdom, the same commuter would have spent 13x1,920 =

24,960 pounds during the life time of its car. It is obvious that there was an opportunity for manufacturers who could by-pass this expenditure.

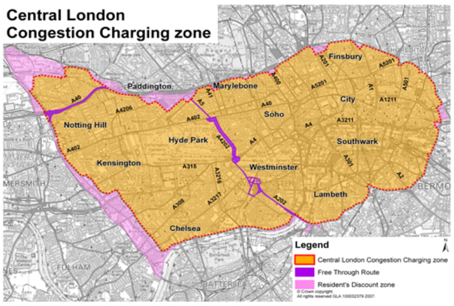


Figure 14: 2009 Central London Congestion Charging Zone

Since 2001, Reva had been producing its electric quadricycle in India, but it was the congestion charging scheme that increased its sales in London. Electric vehicles (including hybrids) were exempted from the charge. Including additional exemptions in road fund tax and free parking, savings obtained with these vehicles were worth enough to consider its purchase for economic over mere environmental reasons.

However, the nature of its design and concept by themselves seemed to limit its future. Despite its obvious commuting capacities, the G-Wiz cost like a normal small car: 8,495 pounds in 2009 for the Li-ion model (Goingreen, 2009). This limitation restricted its market to two different types of buyers: large car owners in need of a cheap urban commuter or urbanites happy to own a machine for their urban trips relying on other means of transport for longer distances.

At the same time, the success of the G-Wiz had a weak basis: its incentives were mere temporary measures with clear deadlines, as the free parking strategy was showing by the end of 2009. Exempting electric vehicles from congestion charge, road fund tax or parking fees is an interesting measure when the local council tries to support a shift from conventional fuels to electric powertrains. And it can be thought that their reduce dimensions further improve urban traffic. But the problem appears when these small electric cars become an important percentage of vehicles in the city. If we imagine a city full of these machines, with nobody paying congestion charge it would not be strange to find higher levels of congestion than those of 2009; nobody would pay for parking either, even when the city would probably have more cars (smaller ones but more in number); and nobody would pay road fund tax, even when the road still needed maintenance.

Subsidizing electric cars is a risky business, it can work temporarily, but in the end, we are left with two options: we either suppress their tax exemptions (indirectly re-promoting fuel cars) or we end up most likely with a worse scenario probably worst in terms of city funding and congestion, though with an apparently less polluted city. It is however important to note the role this type of tax plays in our society. An indiscriminate growth of traffic density is what has produced the current situation and it is not likely that we are going to overcome it by keeping this laissez-faire evolution of the traffic system. Individuals take care of themselves, logically, and in a world where inefficiency is cheaper in the short term, it is arguably the aim of public government to drive towards sustainable growth in the long term.

In short, the G-Wiz shows that the success of a solution can also be based on a specific social-political scenario rather than on merely technical novelties.

2.3.2 smart fortwo and the limitations of the automotive industry

Figure 15: smart fortwo

The smart fortwo is the perfect example of how a new idea for mobility can be affected by automotive methods and transformed into a design item rather than a solution for the urban problem.

2.3.2.1 Hayek and Swatch

In the mid 1970s the Swiss watch industry, of historical fame and leaders of the sector, was in crisis: Asian manufacturers (Design Council, 2008) took over the market with the quartz crystal technology. They were good enough and came at a fraction of the price of any Swiss product. The problem asked for a radically different approach and it came in the shape of a simple mechanism patented by Hayek’s company, Swatch, in the mid 1980s (Swatch, 2009). The novelty of the patent was two-fold: it was completely built of plastic components and much simpler than a normal watch (51 components against 91). The secret of this idea was a total technical breakthrough that shifted the weight from an intensive manufacturing process that could not be made cheaper to a product based on a simple and standard new architecture, which would allow enormous flexibility of the exterior and graphic design -for a fraction of the price.

The idea succeeded and now, Switzerland is the first world manufacturer of watches while Swatch owns a consortium that includes the most important Swiss companies (i.e.: Omega, Rado and Longines)

2.3.2.2 Hayek's idea

Hayek and his ideas were instrumental in the changes experienced by the automotive industry during the 1990s (Lewin, 2004). He partially inspired strategies such as modular architectures and factories, component sharing and especially brand management, which remain the key of success for companies like VW.

However, his idea in the late 1980s was not to change the way automotive manufacturers worked but to produce a Swiss car that would be as relevant as swatch was to conventional watches, the Swatchmobile. This car would revitalize European industry in the same way that his plastic watch competed against Asian manufacturers and their cheap products (Lewin, 2004). By this time, the automotive industry was facing the same problem and Asian manufacturers were the main contender again. Japan was producing better and cheaper cars and threatened to overwhelm the market (as eventually Toyota did). Hayek's proposal was a car, simple and ecological (hybrid power train), with interchangeable inexpensive plastic body panels allowing easy customization (like swatches). This would produce a very affordable solution and one that was good enough for people wanting just a two-seat urban run-about.

2.3.2.3 Evolution of the idea

"To sell a car you need a large distribution system," Hayek explained. "And to sell a large quantity you need the confidence of the consumer that major automotive manufacturers have." The Swatchmobile would, therefore, need collaboration from the automotive industry in order to succeed. However, introducing this industry into the equation also means introducing its methodology and limitations in the development of a minimal solution.

After a collaboration with VW, Daimler-Chrysler joined the venture. Its influence on the final product was decisive: it kept key elements like modular architecture or interchangeable plastic body panels, but also introduced the quality standards expected from its cars (Lewin, 2004). The result was a small car that, rather than an affordable solution for the traffic problem was a premium design item for people willing to pay the price of larger cars such as Renault Twingo. It was not either a profitable business for Daimler either, as the hugely expensive investment may never be recovered from sales (Nahum, 2010).

2.3.3 Good enough motoring

As inhabitants of the developed world, we live surrounded by an incredible number of over-designed products, often developed according to commercial rather than practical concerns. This is mainly motivated by an exacerbate market competence, where manufacturers use performance as a comparison criteria rather than a mean to obtain a predefined goal. For example, modern personal computers in 2009 had performance levels that were rather high for the common uses of text processing, e-mail and internet browsing. Moreover, some mobile phones had embedded digital cameras with capabilities way over normal users' requirements or knowledge.

This non-sense commercial environment irremediably generates a gap between what companies offer and what users' really need. In this particular context, paradoxically, some ideas seemed to find incredible success by following the opposite strategy: just simple solutions or sometimes even imperfect solutions (Capps, 2009).

Figure 16: Flip Video Camera, an example of success by cheap minimalism

Skype, for example, appeared as simple software that would allow phone calls with a computer and an internet connection. The quality of the system was not good, with calls failing and bad sound quality, but it had a great advantage over traditional phones: it was free when calling from one computer to another, and incredibly cheap even when calling to other countries. Users were happy to sacrifice some inconveniences for a free call.

Continuing with sound related technologies, mp3's are another great success based on pure functionality. This solution is a mathematical algorithm that translates analogical sound into a digital file that can be read to produce a compressed version of the initial sound. And that is its secret, the compression method. The mp3 eliminates part of the sound spectrum of the initial sound that is not easily perceived by the human ear. Therefore, the file, rather than being a true copy of the original, is just good enough for normal use and the file size is considerably smaller. The advantages of this system are obvious: it makes possible the transmission of music through the internet or small digital players able to carry a whole discography in a device the size of a chewing gum packet.

Examples like these show how it is possible to break through in a well-established market by introducing a simplistic solution resulting in a much lower price, and providing greater flexibility and convenience at the same time.

It could be argued that the automotive market is rather more complex that those of music or telephony, but some past examples show us how applicable this concept has been throughout the 20th Century, the 2CV being one of the most remarkable.

2.3.3.1 Automotive minimalism: Citroën 2CV

The 2CV was a car that explored the limits of the notion of the car and succeeded, not only as a means of transport, but also as a symbol of lateral thinking and minimalism.

Its design brief was famously defined by the sentence: "Four wheels under an umbrella" and the final product was not far from that. In the 1930s, Citroën's Pierre Boulanger realized the great potential market for a very cheap, simple and reliable small car, for a rural France still reliant on bicycles, horses and carts (Taylor, 1983). The critical factor was price, while appearance was not important (as they believed a beautiful body would add weight). The design process for the TPV ('toute petite voiture' or very small car) included the creation of a small team of engineers (plus designer Flaminio Bertoni), that would secretly work inside the company (a typical method in Citroën), while one of the technicians was sent on a five-month trip to collect information from 10,000 potential buyers. When the market research finished, the design team had already defined an ultra light front-wheel drive vehicle (300 kilograms). Apart from the interesting history of its development, from the initial stages until its launch after WWII (MacQueen and MacNamara, 1982), this car stands out for two specific reasons: its **design philosophy** and the **iconic status** derived from it.

Design philosophy

Citroën engineers knew from the beginning that in order to obtain a cheap machine able to carry two adults plus luggage at 60 kph consuming 3 litres of fuel per 100km the solution should rely on lightweight design strategies. One of these design strategies initially made intensive use of aluminium for the chassis-less body, but this solution had to be finally discarded due to cost issues. A cheaper approach was to minimize the car architecture to a minimum of comfort, weather protection and road holding. Some of these strategies are listed below:

- The leading (front) and trailing (rear) arms of the suspension reduced the length of the structural platform and increased stability with a new patented self-balancing design.
- Seats consisted of simple steel tube frames with suspended cloth centres, while control instruments were minimized to the most basic level of functionality. The picture below (of a prototype version) even shows a manually operated windscreen wiper (!).

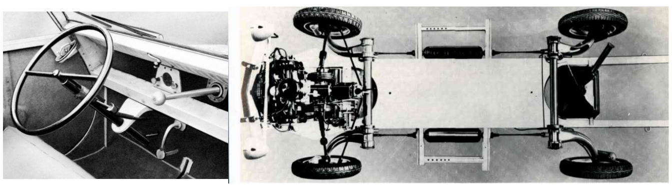


Figure 17: Citroën 2CV chassis and cockpit

- The body was made of steel tubes and thin steel plates shaped in very simple surfaces with canvas acting as roof and boot cover.

The final result was considered as *"the most intelligent application of minimalism ever to succeed as a car"* (Setright, 2004), with 3,868,631 sedans produced from 1949 until 1990 (Motorbase, 2010).

Iconic status

But the 2CV did not only comply with its objective of motorizing rural France (and a great part of the world), it was this raw appearance that allowed it to acquire an iconic status independently of social class. Amusingly (considering a list including Aston Martins, a Lotus Esprit or an Alfa Romeo GTV), it was this car that was the fan's favourite of all the vehicles used by the fictional character James Bond in his films in a survey made by Channel 4 in 2008.

A more recent example of the 2CV relevance was the special edition prepared by the luxury goods manufacturer Hermès in 2008. Here it is particularly interesting how what was initially a simplistic interior now serves as a truly enhancing support for the French craftsmanship, and makes the observer wonder if a standard and more complex interior design could have been so appropriate as the Citroën's is.

Figure 18: Details of the 2008 Citroën 2CV by Hermès

Successors to the 2CV

Since the end of its production, the 2CV has had two main reinterpretations:

The first one was a concept car introduced by Chrysler in 1996 (Azom, 2002). The CCV (Composite Concept Vehicle) was intended to be a cheap car for emerging markets. The exterior design was a revision of the French classic while its main innovation was a body shell made entirely of plastic (PET resin) that was made possible thanks to improvements in the moulding techniques. According to Chrysler, the car performed very well in terms of fatigue resistance and crash absorption, but it never reached the market.

The second example was the 2008 Tata Nano, the cheapest vehicle in the world by then, designed by I.D.E.A. of Torino and built and sold by the Indian manufacturer. Unlike the 2CV, the Nano was not a radical departure from traditional cars. It was more an extreme minimization of the cost of a normal architecture. As in 2011, the Tata Nano is proving to be a commercial failure in

India. Serious reliability issues together with a design eminently targeted at people with limited resources seem to be the main reasons (Economist, 2011). This later fact may prove the fact that a cost-based strategy, without a specific design considerations, could drastically condition the success of vehicles in modern markets. Even in the past, designs as the Fiat Nuova 500 outlived their low-cost nature thanks to intrinsic design values that differentiated from any other vehicle. Maybe, the design approach for the Nano should have made better by applying a different design philosophy to the one already followed in economy cars or even quadricycles.

Figure 19: 1996 Chrysler CCV and 2008 Tato Nano

2.3.4 Motoring perspectives at the end of the 2000s

The problem in urban traffic has existed since cars filled the streets of every city in the world. There has always been a physical limitation to the traffic flow produced by lane dimensions. However, at the end of the first decade of the 21st century, this concern acquires a particular importance reinforced by increasing environmental consciousness and the weaknesses of a system based on mineral fuels.

As in 2010, the industry has failed to propose valid solutions for cleaner and more efficient cities. One of the most influential proposals of the last years has been the Toyota Prius. This vehicle was the first commercial success of a hybrid power train in passenger vehicles and has become an icon of green transportation, introducing even a new design language of aerodynamic efficiency over power or luxury. This new language of efficiency can be the key for more innovative solutions. However, letting alone the iconic status, the technical validity of the Prius is highly doubtful: Although official numbers rank it as a very clean option, the car needs to be driven ‘efficiently’ by the driver to obtain these values, which is not always the case. This introduces a new issue: cars like the Prius (especially when they are backed by favourable tax policies) could make buyers switch from already small and efficient vehicles

(Haan et al., 2005) to hybrids that, apart from new driving styles, require higher mileage to compensate its manufacturing footprint (Paster, 2009).

On the conceptual field, one of the newest proposals is Renault's 2009 Twizy (shown below). This electric run-about could be considered a four-wheeled relative of BMW's C1, aimed exactly at urbanites that use the vehicle to commute. In a more radical departure from the conventional architecture, the P.U.M.A. (product of collaboration between GM and Segway) uses only two parallel wheels to carry a two-seat platform. This simplification is made possible thanks to Segway's electronic stabilizers.

Figure 20: 2009 Renault Twizy concept, GM P.U.M.A. and MIT citycar

On the other hand, it is worth commenting on the research performed by MIT Media Lab. Their proposal is based on substituting traditional architectures with robotic wheels that incorporate steering, suspension and powertrains (Mitchell, 2010). This would introduce a greater level of flexibility of vehicle architecture that can be optimized to be more adaptable to the urban environment (as their 'foldable' city car has shown).

The technical competence of some of these solutions is obvious. However, some of them still resemble updated versions of the old concept cars of the past, those that wanted to define the vehicle of the future and ended up as interesting pieces of automotive history. Some of these proposals, though technically feasible, would come up against both the average bureaucratic system of vehicle type approval and user acceptance.

The above is particularly relevant when we have a look at one of the most successful EV communities of the world in 2009. Retirement villages in Florida are full of people driving around in their electric golf carts. The reasons why they drive these vehicles are mainly the impossibility of renewing their driving licences plus the fact that there is no need for bigger and pollutant cars in small places with all the services they enjoy. It is however paradoxical that these drivers do not normally use any type of ultramodern electric vehicle. Their preferred options are highly customized golf carts, specifically, modified to resemble iconic hot rods, fire trucks or even ice cream vans (Kushner, 2009). While it can be argued that this group has a very particular profile, the truth is that this example seems to show the gap that can sometimes appear between the professional groups responsible for defining future products and average people's predilections and necessities.

In summary, the task of planning a future urban vehicle should include technology as the way to solve specific problems, but that does not mean that the future has to be necessarily based on a revolutionary technical solution. It can work perfectly well as a compendium of current technologies combined with a deep understanding of user's requirements and bureaucratic limitations.

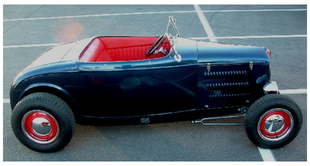


Figure 21: Existing EV vs. GM's proposal (2009 Eroadster and a GN EN-V)

2.4 Design Considerations for a light urban EV

2.4.1 Powertrain requirements

For the purpose of this research, it could be useful to know the real requirements that an urban vehicle impose. Unlike intercity cars, average speed values for city vehicles do not surpass 20 kph (Transport for London, 2010). Furthermore, the speed limit is normally set at 50 kph. The following section will analyse the implications of such reduced design requirements in the functioning of a typical microcar. Attending to the need of propelling the vehicle, powertrains must provide a traction effort high enough to overcome: Rolling resistance, Aerodynamic drag, Hill climb effort and Accelerative effort.

All these components can be grouped in the following equation:

$$F_{te} = \mu_{rr} mg + 0.5 \rho A C_d v^2 + mg \sin(\psi) + ma \qquad [1]$$

Where

μ_{rr} is the coefficient of rolling resistance
m is the total mass of the vehicle (kg)
g is the acceleration of gravity (9.81 m/s2)
ρ is air density (normally 1.25 kg/m3)
A is total frontal area (m2)
C_d is the coefficient of aerodynamic drag
v is vehicle speed (m/s)
ψ is the angle of the slope
a is vehicle longitudinal acceleration

If we want to calculate the traction power for a constant speed:

$$P_{te} = F_{te}\ v \qquad [2]$$

To illustrate the influence of the different elements of traction power, let us consider an example with a mass of 550 kg (including two occupants), a μ_{rr} of 0.015, 2.2 m^2 of frontal area, C_d equal to 0.5 and a slope of 2 degrees. The curves of power values for different speeds are shown in the graph below.
The power required to overcome the slope is the main component up until 60 km/h (over legal urban top speed), while rolling resistance accounts for the second largest component until 40km/h. Power requirement to overcome aerodynamic drag is minimum at low speeds but grows significantly with velocity (v^3).

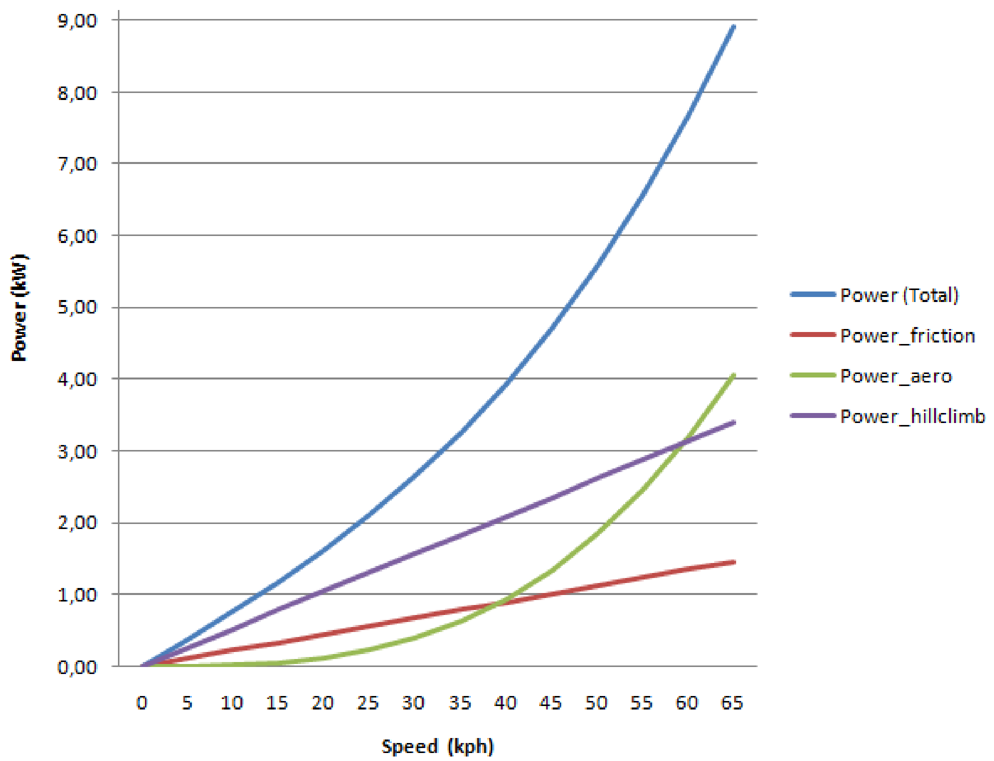


Figure 22: Power requirements for different speed values with a slope of 2 degrees

The following graph focuses on the influence of drag coefficient and frontal area on total power required to overcome drag resistance. As a reference, a Cd of 0.2 corresponds to a very efficient shape while 0.5 can be a value for a boxy design such as a van. It is obvious that above 25 km/h, the effects of reducing frontal area or optimizing overall shape are notable.

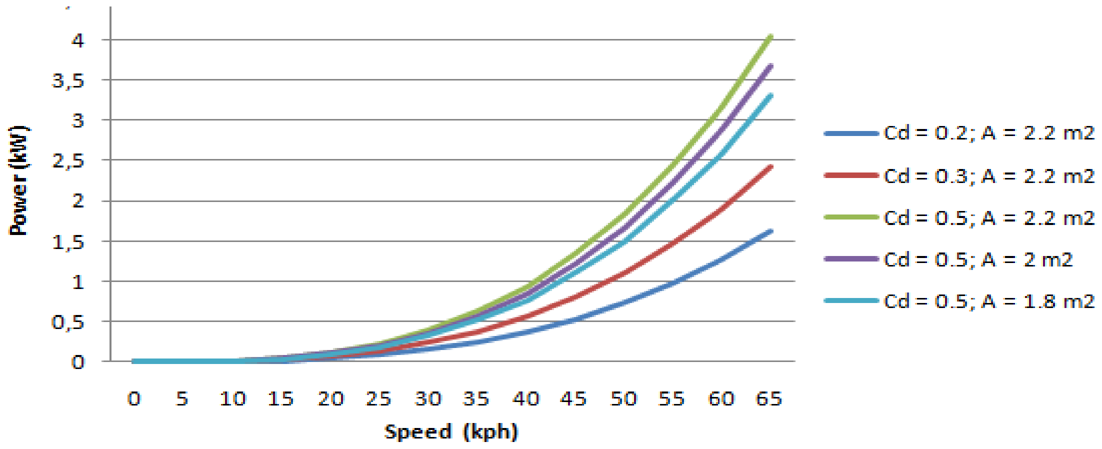


Figure 23: Influence of Cd and frontal area on drag resistance

For flat terrain, the following graph illustrates an interesting fact: while the effects of aerodynamic drag on a conventional vehicle at low speed can be unnoticeable, this assumption starts to lose its validity for extremely light vehicles (under 350 kg). Drastic weight reductions help to highlight previously 'hidden' inefficiencies such as this one. It is not expected, however, to

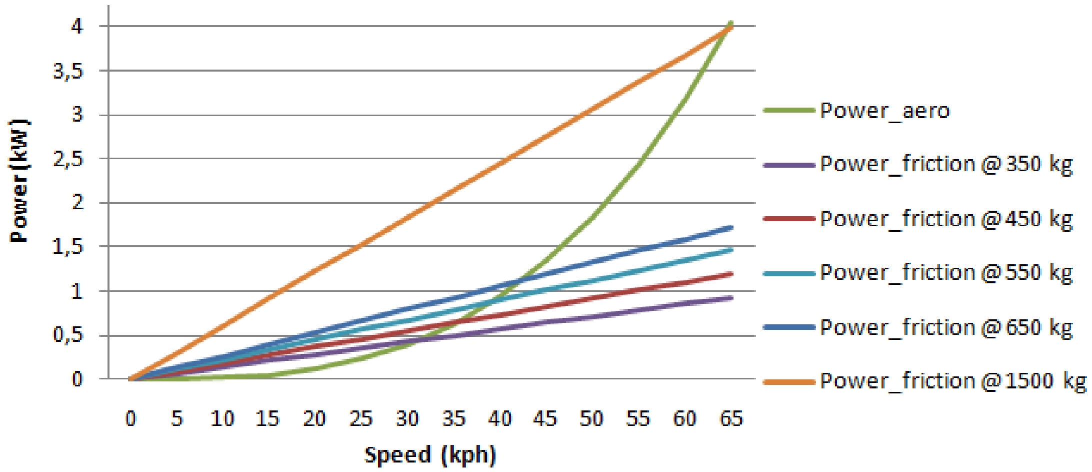


Figure 24: Drag versus rolling resistance for different values of vehicle mass

Nevertheless, it is worth noting how improvements on aerodynamic drag compare to rolling resistance reduction strategies. Next graph shows the power requirement curve for our reference vehicle plus new curves obtained by reducing 25% of weight and 25% of drag. For speed values below 35 kph, the advantages of weight over drag reductions are notorious. Conversely, as speed increases so does the importance of aerodynamics. Considering the design of an urban vehicle, cars spend only 17% of its rolling time travelling faster than 40 kph, according to the ECE-15 driving cycle; if we also consider that the average speed in a city such as London is 17kph (Transport for London, 2010) and the considerable cost of aerodynamics improvements, it seems sensible to invest in weight reduction instead. In that sense, the development of a new architecture purposefully designed for urban journeys can offer great reductions by getting rid of unnecessary sub-systems commonly used in normal cars for no extra cost.

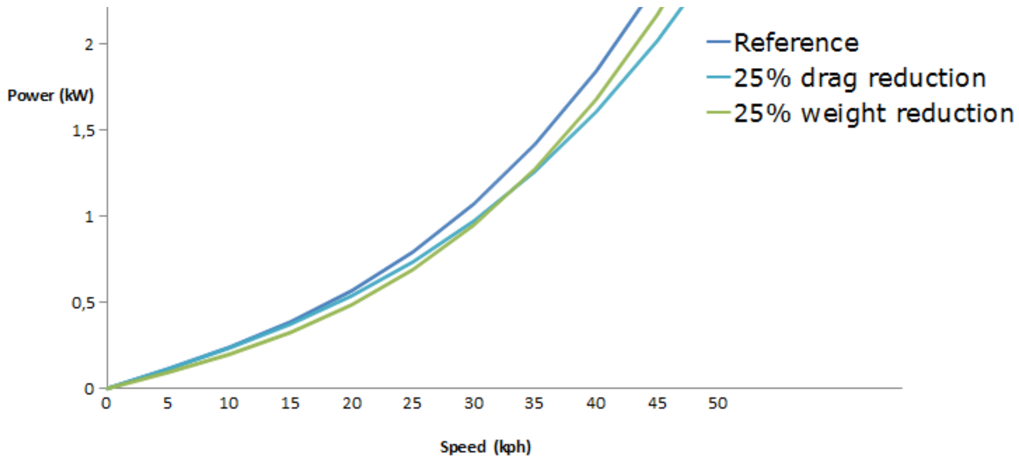


Figure 25: Comparison of power requirements for a standard configuration, a 25% drag reduction and a 25% weight reduction

2.4.2 Powertrain influence

Powertrains are a key element in the development of a vehicle architecture. Besides the obvious effects on performance or emissions, powertrains influence the design of the rest of the structure due to the need of: Supporting structures, Cooling systems, Occupant protection, Required electro-mechanical connections and NVH isolation.

The following table shows a comparison, focused on packaging, of typical alternatives for conventional quadricycles. The value of required energy informs about how the weight of every different option affects overall energy requirements. The options compared included typical petrol (Lombardini) and Diesel (Kubota) microcar engines, a conventional electric microcar motor and the Michelin Active Wheel, as an example of a hub motor.

The results show that the electric powertrains are heavier than either the diesel or gasoline options. However, the packaging volume is significantly lower for the electric versions, with the added advantage that hub motors and modular batteries introduce greater flexibility in terms of packaging distribution.

Type / Features	IC Petrol	IC Diesel	E AC	E Hub	Hybrid (Parallel)
Performance					
Max. Power (kW)	15	14.9	15	15 (17.6)	11
Max. Torque (Nm)	34 @ 2150rpm	45 @ 2600rpm	50 @ 0rpm	@ 0rpm	16 @ 3000rpm
Packaging					
Volume (dm^3)	92	99	28	Hub	
Total weight (kg)	82	96	159.3	136.7	105.3 (approx)
Engine/motor	49	63	42	4x8.8	80
Gearbox	7.7	7.7	0		0
Differential	15.8	15.8	15.8		15.8
Controller	0	0	5	5	0
Cooling	3.5	3.5	3.5	3.5	3.5
Inverter	0	0	6.5	6.5	0
Charger	0	0	6.5	6.5	0
Fuel/Battery* (10kWh)	6	6	80	80	6
$E_{Required}$** (kWh)	0.293	0.303	0.321	0.306	0.285

* Assuming ICE efficiency of 20%, Electric motor efficiency of 90% with 20% of regenerative braking, 12 kWh/kg for fuels and 0.11 kWh/kg for batteries

** For an ECE-15 driving cycle on a generic vehicle (mass without engine and with two passengers = 300kg; coefficient of rolling resistance = 0.015; frontal area = 1.8 m^2; drag coefficient = 0.4) with 20% of regenerative braking for the electric and hybrid options.

2.4.2.1 The choice: Electric hub motors

Nowadays, EV's are clearly unfeasible as substitutes of conventional vehicles. The main reasons are a limited development in battery technology and virtually non-existent charging infrastructure. However, their use as urban runabouts could overcome these issues. This is due to the fact that urban environment are more likely to receive charging points. A good example of this is the proposal to have 25,000 charging points in London by 2015 (Greater London Authority, 2010). In terms of battery technology, letting alone expected advances, again urban environments can facilitate alternative uses of vehicles not as privately-owned goods but as privately-used services.

Ultimately, besides the critical need to reduce air pollution in highly-concentrated city centres, the use of electric powertrains introduce the following advantages in the development of urban vehicles: passive safety (in terms of topological optimization), active safety, visual qualities, reduced NVH requirements, reduced thermal loads, increased driveability, plus tax policies and incentives in terms of purchasing and using costs

Finally, the use of hub motors would further increase the design possibilities of these new vehicles by allowing fine optimization of the structural elements from both technical and emotional perspectives. The only issues related to their feasibility were recently confirmed from an industrial and legislative point of view: Michelin plans to introduce a version of their active wheel concept, specifically for quadricycles in 2013 (Vital, 2011a). Additionally, new regulations would probably allow the use of technical novelties that contribute to improve in terms of sustainability and urban transportation flow (European Commission, 2010).

2.4.2.2 Batteries

The following caption contains a chart with a comparison between three standard technologies for batteries:

Items	Li-ion	Ni-MH	Lead-acid
Working voltage (V)	3.7	1.2	2.0
Gravimetric energy density (Wh/kg)	130~200	60~90	30~40
Volumetric energy density (Wh/L)	340~400	200~250	130~180
Cycle life (cycles)	500	400	300
Capacity self discharge rate (% per month)	5%	30%	10%
Memory effect	None	40%	None
Energy efficiency ($C_{discharge}/C_{charge}$)	99%	70%	75%
Weight comparison for the same capacity	1	2	4
Size comparison for the same capacity	1	1.8	3.5
Reliability	High	Low	High

The use of batteries in an EV has the advantages derived of the electric powertrain, but at the same time, this chart shows us several new challenges introduced by their use. Some of them are as obvious as crucial, such as: limited range, weight increment or expensive cost. But other challenges are more subtle but equally problematic.

Charge management: As we saw before with the Reva, an electric car depends on the electrical grid even when its batteries are full, just to keep them at the right level of charge. This operation requires the use of electronic control units that periodically connects and disconnects the batteries.

Recharging time: While a refuelling stop at a petrol station lasts around 5 minutes, the recharging process of a battery to full capacity is measured in hours.

Limited recharging cycles: Batteries lifespan extends to around five years.

But over all these secondary issues, there is one factor that becomes the main difficulty for the EV success: If we consider the approximately 13,000 Wh obtained per kg of gasoline or diesel, batteries still have a great disadvantage with conventional petrol cars. These old-fashioned machines have a much larger range, are lighter (they need less energy to propel themselves), and at the current fuel prices, much cheaper. Current research by IBM (Schwartz, 2009) is aiming to improve specific energy in order to obtain values ten times over today's best (increasing thus, autonomy from 100 to 500 miles) using nanotechnology and computational simulations. However, this advance still needs to be first, achieved, and then implemented as a real alternative, which makes them a long term solution.

It seems that the application of electric powertrains will be limited to the urban environment where differences between petrol cars and EV are not so noticeable.

2.4.3 Passive safety

In general, safety systems should provide three different stages of functionality: first of all, warning, and after that, avoidance and protection (SafetyNet, 2009). In terms of packaging generation, the main issue is the design of the passive systems aimed at reduce damages. For that matter, safety cage and crumple zones are the main elements in conventional car body design. The safety cage is the module that contains occupants and vital parts such as fuel tanks. It is designed to withstand impacts with minimum deformation. Crumple zones dissipate kinetic energy through plastic deformation or disintegration. These modules are located all around the survival cell.

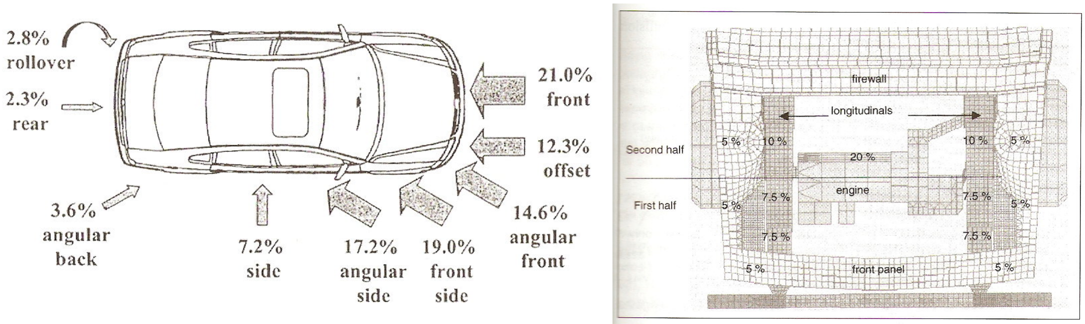


Figure 26: Statistical distribution of accidents in Europe and Energy absorption of the different elements in a front-end crash structure (Seiffert and Wech, 2003)

The whole system is divided in four main sub-systems: front end, rear end, sides and roof. In the case of a front end crash structure, The most common disposition is shown above. The percentage values represent the amount of energy absorbed by separate components during the crash. The engine alone absorbs 20% of the energy. Its collocation in the rear would affect, therefore, to the specifications of the longitudinal beams, which must dissipate all the energy that this part would take. In that case, considering that the darker elements are at the bottom level, we can deduce that the amount of energy transmitted to the lower part of the vehicle is of 62.5%.

For side protection, the main difference is that current automotive design allows for minimum crash dissipation zones. Thus the design goal is to withstand the impact with minimum intrusions (American Iron and Steel Institute, 2002). The sub-system is mainly composed of B-pillar, rockers and transverse floor and roof members. High sills (rockers) improve on intrusion, especially when we consider impacts against SUV, as we will note below.

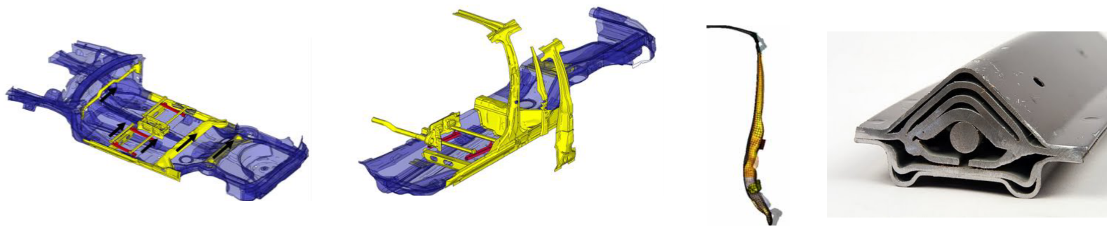


Figure 27: Side-protection strategies and B-pillar section

The design of small lightweight vehicles include several particularities in the approach to passive safety. These particularities refer to three aspects: pedestrian protection, alternative approaches for small vehicles and crash compatibility against other vehicles.

The following table summarizes important aspects to consider in the design process:

Design aspect	Particularities
Pedestrians:	It mainly involves body stiffness and, especially, external geometry (Mizuno and Kajzer, 1998) One of the major concerns is that the pedestrian will often sustain a head injury because of being thrown to the ground following impact. Any contact of the head should be with the windscreen, for any pedestrian size and for a wide range of impact velocity.
Dimensions and weight	Microcars can use additional crush space of larger cars as a way of decreasing injury risk to the driver of the microcar. In that case, the microcar safety cage would have to ideally withstand a maximum force level of 200 kN (Mizuno and Kajzer, 1998). Another strategy would be to maximize the use of cabin space for decelerating occupants. The Volvo 3CC (Schewel, 2008) and Horlacher (Riley, 1994) prototypes are examples of this solution. Composite materials maximize the use of crushable space as they disintegrate under impact conditions. Their specific stiffness is also higher than those of metals (Mallick, 2010)
Crash compatibility	In the event of a crush against a conventional vehicle, AHOF400 (Average Height Of Force during the first 400 mm of front rail deformation) is a crucial parameter to consider. As a reference the AHOF400 for a standard sedan (Chrysler Neon) is 448 mm (Patel et al., 2009). SEAS (Secondary Energy Absorption Structure) help to reduce the effective AHOF400 on sports utility vehicles (Bernquist, 2004). Two design parameters to consider are compartment strength and vertical connections between upper and lower crush structures (Davies, 2006)

2.4.4 NVH

Suppressing vibrations and noise transmitted by IC engines has the consequence of highlighting other NVH sources that were previously hidden by those predominant frequencies. Now the problem focuses on cooling systems for batteries, controller and motor: fans, water pipes.

Considering the importance of a lightweight vehicle for this research, strategies towards a reduction of vibrations and noise should focus on the NVH sources rather than on the use of isolating panels. Thus, the preferable approach will work on silent components and their holding structures.

2.4.4.1 Alternative NVH strategies

Typically, the automotive industry has two different strategies on engine sound management (Cerrato, 2009): engine sound can be either enhanced to provide a sporty feeling from the vehicle or neutralized to offer a neutral and comfortable ride. Both objectives are largely accomplished thanks to the addition of new elements to the vehicle architecture such as active exhaust and intake systems, large mufflers or isolating panels.

The development of a lightweight micro car, however, restricts the addition of additional weight or bulk, forcing to look for additional strategies used in other sectors. Harley-Davidson Motor Co. faced similar issues during the design of their V-Rod model (Pierson and Bozmoski, 2003). For one century, Harley motorbikes have been identified by their famous V-twin air-cooled engines and sound. Thus, when they decided to create a road-going version of their water-cooled super bike, keeping the 'Harley sound' was a must. They also needed to comply with stringent noise regulations.

Even in the motorcycle industry, these tasks would be accomplished by adding covers and cowls that would filter engine noise to acceptable and pleasant levels. Harley-Davidson, on the contrary, had an additional requirement: to keep the look of their bikes, where mechanical components are part of their visual message. What was their approach, then? It was to directly work on the noise sources. They divided the analysis in three main sources: Intake, powertrain and exhaust. By benchmarking their previous line of products, they defined noise levels produced by those three groups. Additionally, their previous experience and market research made them realize that customers prefer an exhaust dominant noise.

The different parameters used for the three noise sources were:

- Intake: Airbox volume (the use of airboxes spoiled Harley's traditional design and ergonomics, but it was required for the race-derived engine)
- Exhaust: Shape and Volume; Mufflers and pre-muffler volumes; Shell vibration attenuators; Front-rear cylinder crossover.
- Powertrain: Gearbox:(Tooth profile of the primary gears, Anti-backlash primary gear); Fuel pump (Mechanism and Mounting system); Engine (Rubber mountings and single balancer, in order to minimize chassis noise), Idle speed.

Their influence is controlled by analysis focused on (Pierson, 1995):

- Narrow-band frequency
- Rotational and contact frequency
- Modal analysis
- Sound intensity
- Spatial transformation

The evaluation of these parameters was both objective (regulations) and subjective (user groups) criteria. In terms of subjective criteria, psychoacoustic techniques (Pierson, 1995) are used to help to define acceptable combinations of loudness, sharpness, sensual pleasantness, fluctuation strength, roughness and even rhythm.

This brief description gives an interesting idea of how Harley-Davidson manages the acoustic image of their product from the essence. This represents a very useful lesson in the development of lightweight urban roundabouts, especially because their engine requirements are close to those of a motorbike (Although the V-Rod, with its 120 HP does not represent a low speed vehicle).

But what happens when we use an electric powertrain? It happens that another acoustic effect enters the scene: noise masking. The noise produced by an IC engine is so loud that hides other produced by ancillary systems. In EV's, all these secondary noises (i.e.: cooling fans, pumps) start to be noticed, introducing a new set of issues that will be analysed in a later section. The case for EV's is particularly interesting, for it suppress noise where it is needed in terms of pedestrian safety (outside) while it highlights internal secondary noises where a powertrain noise would disguise them (Cerrato, 2009).

2.4.4.2 Vibration

The use of an electric powertrain would suppress any concern linked with engine vibrations. However, in order to widen the scope of this research to current standards in microcar technologies, this section includes a brief note on alternative strategies.

Similarly to noise-isolation techniques, typical isolation strategies used in automotive development equal to more bulk and weight in a vehicle where every gram would count. Therefore, in the configuration of urban vehicle architecture, those powertrain units producing lower vibrations would be preferable. Sadly, current quadricycles normally use industrial-type IC engines where NVH control is not a priority.

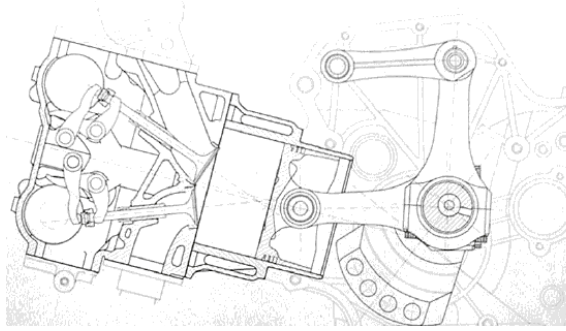


Figure 28: The 1993 Ducati Supermono engine

But then again, we can find a good source of inspiration on disciplines such as motorcycling. The solutions introduced by some manufactures to mitigate vibration are marvellous examples of the possibilities of lightweight and balanced small capacity engines. In instance the solution adopted by Ducati for a single-cylinder racing engine based on its archetypical V-twin is an elegant and simple masterpiece: to solve the vibrations created for the lack of counterbalance of the second cylinder, engineers kept a dummy connecting rod that was attached to a small rod that replicated the dynamic behaviour of the missing piston without friction losses or added mass.

2.4.5 Additional considerations

2.4.5.1 Suspension set-ups

EV's introduce a considerable compromise related to suspension set up. The limited range of these vehicles forces to minimize energy losses in those places that are normally forgotten in cars. One of them is the suspension system: an EV needs harder set-ups in order to avoid wasting energy by swaying the car on its dumpers (Larminie and Lowry, 2003). But, at the same time an urban vehicle, specially one designed for London should offer a level of comfort able to provide an acceptable ride on bumpy streets. This aspect, letting along range issues, can be one of the most problematic in the development of a final vehicle proposal.

2.4.5.2 Weight distribution

Electric powertrains indirectly improves a conventional-sized car handling because the heavy weight introduced by the batteries can be normally placed close to the ground. Additionally, motors can be placed lower to further improve dynamic responses. If we focus on ultra-compact vehicles, this feature reaches an even higher importance. These machines have to be short and narrow in other to improve their agility and parking capabilities in the city. But at the same time, drivers want to seat high enough to better control the vehicle and avoid feeling scared next to big and boxy cars and trucks (as we discussed before with the C5). The problem is that a short, narrow and tall box is inherently unstable at high speeds if its centre of gravity is proportionally high. The best example of this inconvenient is the Smart car that needed to include a stability control in order to comply with the well-known elk test. Had the Smart had a set of batteries under the floor, it may not have to delay its launch because of this.

2.4.5.3 Ancillary systems

At last, another secondary issue introduced by the use of electric motors and batteries is the installation of all the ancillary systems that are normally powered by conventional engines. Examples of this are air conditioning systems or electric appliances. In order to maximize the usability of this new proposal, it will be necessary to distinguish which functionalities are needed and which can be avoided, considering the particular nature of a shopping or commuting trip.

2.4.6 Legislation

The goal of this section is to show how flexible the quadricycle type approval regulations can be for the design of a new vehicle typology. There are four categories of vehicles particularly relevant for the topic of this research: Light Quadricycles (L6e), Quadricycles (L7e), Tricycles (L5e) and Cars. These categories normally attend to weight and power, though, obviously, tricycles are also restricted to 3-wheeled vehicles. The following chart summarizes the main differences between these four groups.

Type	Light quadricycle	Quadricycle	Tricycle	Car
Category	L6e	L7e	L5e	Motor vehicle
Weight	<350kg (no batteries)	<400-550kg (no batteries)	<1000 kg	---
Power	<4kW	<15kW	(>50cc)	-
Top speed	45 km/h	-	>45km/h	>45 km/h
Construction requirements	As 3-wheel mopeds	As Tricycles		
Payload	200 kg	200 kg (person) 1000 kg (goods)	300 kg (person) 1500 kg (goods)	
Dimensions	L < 4 m; W < 2 m; H < 2,5 m			-
Brakes	Service +Emergency+Parking+Braking	Plus Foot pedal		Double, foot
Lighting	Complete			
Safety belts	If weight >250 kg	Yes		
Crash tests?	No			Yes

The most important aspect of this comparison is the absence of any crash test, the most demanding one, for the three first categories. This test affects the car architecture in two different ways:

Introduction of crash absorbers (front and rear) and a safety cell: Crash absorbers must provide a reasonable deceleration of the total mass in the event of an accident by dissipating kinetic energy through their deformation (metal) or disintegration (polymeric composite). On the contrary, the safety cell must withstand the impact without any deformation in order to avoid intrusions into the cockpit.

Car and component tests: A solid structure with the right absorbers are not enough: the interior of the car has to work properly during the impact. This implies, apart from normal crash tests of the whole car, specific tests for crucial components such as dashboards, seats…

Thus, crash protection adds a great amount of work and cost to the development of a new vehicle. Therefore, considering the lower requirements of a city vehicle, the design of these vehicles as quadricycles supposes greater flexibility in the development. Under these two categories (L6e and L7e) it is nearly possible to include any four-wheeled machine as long as it respects the limitations of size, weight and power.

2.5 Summary

Past minimal motoring exposes two instrumental aspects in the development of a new type of urban vehicle. First, the active role of contexts in the validity of the proposals. This fact supports the approach of this thesis, for despite extensive literature on urban vehicle design, there is an evident lack of interdisciplinary literature. The second aspect, mostly a consequence of the first one, is the advantages of qualitative differentiation in minimal motoring architectures. In technical terms, purposely-designed minimal architectures maximize efficiency and adaptability, also favouring alternative technologies and industries. But the advantages are not only technical: a qualitatively different approach also generates a new design idiosyncrasy. New minimal architectures can enhance the connection with users, rediscovering the human scale of vehicles and highlighting their complementary role. Such a connection can be instrumental for this research, considering the problems, especially in mega-cities, caused by car and fossil fuel use. A new vehicle typology could redefine urban mobility, as a new purposeful and more adequate solution than conventional car architectures.

The case studies reinforced this new approach. Thus, the analysis of three-wheelers illustrated the convenience of four-wheel layouts in terms of engineering and acceptance. The case of the Sinclair C5 also illustrated the importance of social acceptance and the adequacy of flexible platforms in the development of disruptive vehicle proposals. Additionally, the influence of legislative frameworks was highlighted in the review of the BMW scooter. The case studies, thus, helped to establish the boundary elements that will guide the development of the new vehicle typology in the next chapters.

For such a development, the state-of-the-art of urban mobility solutions further contributed to the understanding of the research problem. Apparently tangent aspects such as tax policies can be determinant, and at the same time, futile by themselves in the success of the proposal. Quadricycles are a favoured categorisation and that supports the development of a new mobility solution, but as the historical review showed, basing success in mere political decisions is a weak strategy, for favourable conditions to cars can reverse the situation. Similarly, the development of the smart fortwo is another sample of the limitations of following the automotive 'rules' in the generation of a valid proposal, for it risk planning a vehicle with the limitations of conventional cars and none of their advantages (mainly, intercity capabilities). In the end, the proposal, would highlight the advantages of larger vehicles. In that sense, a new approach able to embrace the simplicity and adequacy of the new proposal could help to transcend its apparent limitations and generate desirability in a saturated market, as the iconic status achieved by the 2CV illustrates. In the definition of such a new idiosyncrasy, it is important not to lose that link with the social reality. Egocentric solutions, focusing on idealised and commonly unfeasible futures could lose the link with contemporary society, repeating failures of the past.

Ultimately, it is important to keep in mind the technical implications of the development of an urban typology, mainly in terms of powertrain, for several of the design criteria of conventional cars are out of place. Thus, aerodynamic is not a crucial aspect in the definition of the bodywork. But zero emissions are. Focusing on the urban scenario (and as Chapter 4 will further illustrate), exhaust emissions have disastrous effects on cities. If we consider the lower requirements in terms of performance and range for an urban runabout, the use of electric powertrains is not only feasible for the urban context, but also highly recommendable. The technical aspects do not end there, however, for the plan of a new typology must keep in mind other aspects that could limit its feasibility.

3. Method

3.1 Typological solution for a wicked problem

The development of an urban alternative to cars fits the definition of a wicked problem (Rittel and Webber, 1973). In contrast with designing within predefined vehicle categories, user and contextual criteria revolve the problem solving process in the search for new valid and desirable vehicle concepts. This definition is also shared by Mitchell et al (2010), in their 'DNA' proposal for future cars.

The question, then, is: *How should we address this problem?* There is academic consensus in the necessity of alternative methods to deal with wicked problems (Rosenhead, 1996). This is due to the influence of different stakeholders in the design process, which are mutually independent and operate different objectives and decision criteria.

Before starting with the selection of a suitable method, the first step in the approach is the definition of the nature of the solution itself. In that sense, the uncertain nature of wicked problems favours adaptable solutions for multiple alternative perspectives (highlighting iterations and interactions) rather than narrowly-defined designs (Rosenhead, 1996). The findings in Chapter 2 support this idea (i.e. the example of the Sinclair C5). That is the reason why this research aims to define a new *vehicle typology* rather than a detailed vehicle design. While the definition of a new typology can be challenging, for conventional types have remained constant in the last three decades, current concerns and the emergence of mega-cities show the limitations of the old types.

Rossi (1982) illustrates the particularities of a design typology in his quote: '*Type is thus a* ***constant*** *and manifests itself with a* ***character of necessity****; but even though is* (sic) *predetermined, it* ***reacts*** *dialectically with* ***technique****,* ***function****, and* ***style****, as well as with both the* ***collective*** *character and the* ***individual*** *moment of the [...] artefact*'. The typology, hence, appears as a reaction to a stable need (mitigation of the effects of car use within cities), which defines its core essence (efficient, clean, utile and safe vehicle); then, technology (i.e. electric powertrain, passive safety or manufacturing), function (i.e. urban navigation systems) and style (i.e. retro trends or visual minimalism) actively mould it; ultimately, due to its urban nature, the typology also balances individual and collective needs. The result is a design framework or essence for a new family of vehicles (i.e. different to cars or motorcycles) characterised, in this case, by an eminent urban focus.

What differentiates typology definition from single vehicle design is the absence of the quantitative and detailed considerations found in the later. Thus, in this research, different technologies are considered inasmuch they affect the definition of the typology. But that does not include a systematic and precise definition of parameters such as metal sheet gauges or damper internal designs (Chapter 5 and 6 will further illustrate the scope of this research). This strategy is possible because the limiting factor towards better urban private mobility relates to vehicle definition instead of new vehicle technologies. There are numerable studies on lightweight vehicle design (Hodkinson and Fenton, 2001), materials and manufacturing technologies (Mallick, 2010), electric vehicle technologies (Larminie and Lowry, 2003) and the quantitative particularities of urban vehicles. It is the embodiment into a seamless and coherent design strategy responding to current social and urban contexts that is missing.

3.2 Method depiction

Once we have defined the typological nature of the solution, the next step is the definition of the method used to obtain such a solution.

Despite the nearly abstract typological approach, the selected method should embrace the ultimate *product-based approach* of this research and the methodological *flexibility* that such an iterative and exploratory process demands.

For that matter, French's (1995) Engineering Design Method is the starting point to be adapted to the specificities of type definition. It combines a product-based (adequate for the ultimate nature of the vehicles developed under the new typology) with the flexibility required to adapt to the iterations and additions of this research. Other design methods, as those proposed by Pahl and Beitz (2001), contain detailed stage definitions and tools, and such level of detailing made them stiff in the adequacy to the uncertainties of this wicked problem, mainly, identifying design opportunities out of predefined set of rules. Their use, however, can be adequate to the development of subsequent vehicles under the typology proposed in this research.

Thence, along the evolution of the research through successive iterations the method evolved into a modification of French's analytical approach. This modification accounts for the exploratory and methodological nature of the design embodiments and the ultimate deliverable of a new typological definition. The main differences with French's approach are two: the exploratory nature of successive iterations and the subsequent focus on the relational system that emerges from them, defining the essence of the new vehicle typology. The following diagram illustrates the differences.

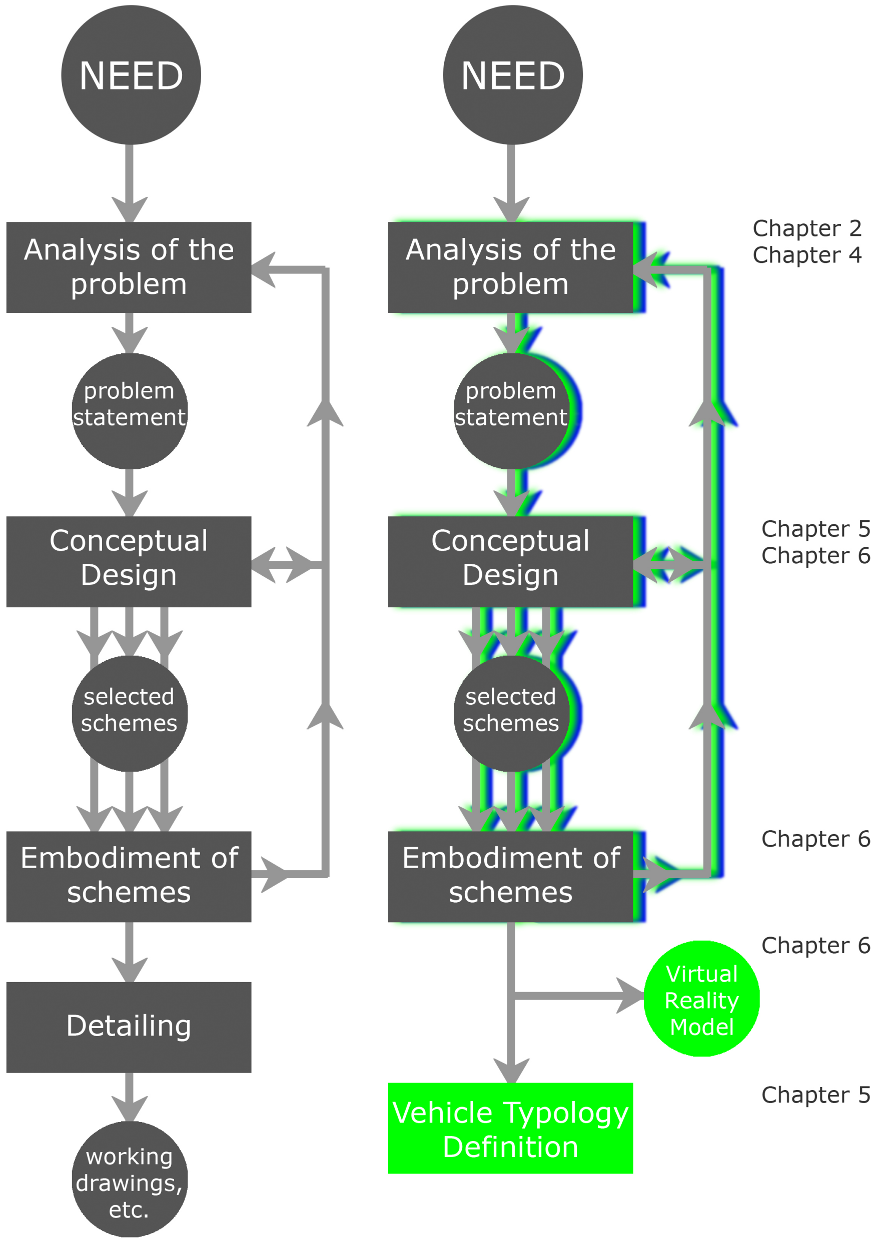


Figure 29: Comparison between French's method and the adaptation used here

Up until the stage of Embodiment of Schemes, the method followed in this research follows French's. However, although the structure is similar, in this research the emphasis is on the iterative and exploratory nature of the process: Instead of proposing well-targeted stages towards a goal, this research uses initial simple problem statement and embodiments to find considerations not included *a priori*. This approach is a strategy to deal with the uncertainty of such a wicked problem.

The biggest change comes in the outcome of the process. While French finishes with detailing and specifications, that outcome is substituted by the definition of a new vehicle typology, developed during the conceptual stages and validated by successive embodiments. The iterations, as we said, were not aimed at polishing a concrete solution, but at identifying design concerns and their effect in the definition on the generative rules of the new typology. Detail designs, in this research are left out when their contribution does not affect the overall definition of the typology. The figure also relates design stages with chapters. The structure of the thesis, however, has not followed the identical sequence as the research for the sake of clarity.

Starting with the process itself, one of the fundamental changes in the research method that the exploratory design introduced was the use of CAD (computer-aided design) tools from early stages in the conceptual process. In conventional car design, this approach may be seen as a restricting environment (Cross and Clayburn, 1996), for the general typologies are fairly constant, and the use of CAD on predefined architectures could tend to produce look-a-like products. However, several particularities suggested this method. First of all, the research aimed at working with simple exterior designs, that while they can be improved using traditional techniques as clay modelling, from a packaging perspective were suitable enough. Second, the nature of the conceptual proposal suggested a different approach to the design process. Unlike conventional cars, the vehicle would not respond to a standard structural layout, which introduced another set of design parameters to play with. These parameters were already restricting due to the short wheelbase of the vehicle (total length is less than 2.4 meters). This made certain regions such as front wheel packages extremely important and interrelated with the rest of the elements. And design constraints to the process increased with the decision of using an exposed vehicle architecture, where the number of covering elements was minimized. In that sense, the use of CAD tools during the stages of conceptual generation contribute to generate more rigorous and robust initial models (Emergence and Design Group, 2004). Thus, considering front-wheel packaging alone, the compact design space, together with the need of interrelate interior and exterior with the different modules of the architecture, the aid provided by CAD tools was crucial to complete these tasks. It provided not only aid on spacial conceptualisation, but also allowed rapid evaluation of changes and different alternatives to the embodiment. The same level of detail in physical models would have required additional budget, manual skills and time, which, considering the nature of this research work (self-funded during the first two years) and its multidisciplinary approach, were unavailable. Thus the use of CAD tools allowed a faster evaluation and change of the design aspects of the conceptual embodiment.

Back to the written work, in order to understand the possibilities and limitations of other solutions, the research started with a background compilation. This included not only case studies on relevant vehicles, but also and mainly, a historical study of past typologies that, despite the fact they were not conceived as pure urban solutions, were relevant in technical and emotional terms. Thus, historical research methods constituted the first stage in this multidisciplinary research. Comparative historical analyses, similar to the one proposed by Toynbee (1987) were particularly illustrative. They helped to identify parallelisms among different type of vehicles, specially concerning the causes of their appearance, success and ultimate failure. Moreover, these studies highlighted the importance of social and cultural contexts, enriching otherwise mere technical or economical reviews.

These comparative analyses were also useful in the study of other examples of modern micro cars such as the Reva G-Wiz, the only electric vehicle that had enjoyed a relative success prior to the start of this thesis. During the later years of this research (specially in 2011), there has been an emergence of alternative takes on the conventional microcar typology. Some of these new proposals even follow similar concepts to those enunciated in this work. As the compilation stage was finished by then but considering, at the same time, their importance as a comparative tool, they were included in the critical assessment of the research. Their analysis helped to identify advantages and limitations of the proposed conceptualization. Similarly, the emergence of electric powertrains, and their proved suitability for urban uses (The Green Car Website, 2011) also simplified the task of this research, for it validated supporting hypotheses such as the adequacy for urban duties and potential appeal of electric vehicles. Additionally, for those case studies referring to relatively recent vehicles, interview to experts also contributed to enrich the approach with insights rarely found in specialized literature. The advantage, in terms of efficacy and time, of expert interviews has already been proved in previous research (Bogner et al., 2009), but here, their contribution was of further importance, for conventional automotive know-how usually forget the design particularities of past or alternative vehicle typologies. There are recent design proposals of modern microcars by car manufacturers that illustrate this point (Autocar, 2011b)

The holistic analysis of past solutions established a design scenario for the methodology. The first and most immediate influence was a richer perspective to address the analysis of private urban mobility. To the normal considerations on pollution, safety and traffic congestion this research added other aspects related to users and industry. For user-related considerations, sociology (Miller, 2001), psychology (Rutherford and Shaw, 2011) and emotional design (Norman, 2004) helped to identify relevant factors. In this analysis, technical factors (e.g. safety) also appeared, but evaluated in terms of user perception. From an industrial perspective, the analysis of the problem included considerations conditioning the future of the automotive sector, and a look to the influence of new patterns of use and business models. The idea was to widen the perspective of this research to propose solutions that would be efficient, appealing and flexible enough to cope with uncertain scenarios. This approach clearly differs, in academic terms, with the detailed design of a particular embodiment.

The analysis of the problem settled the beginning of a design strategy able to integrate such a varied group of factors in the definition of an assumable vehicle typology. Thus, Chapter 5 dealt with the generation of the essence of such a new typology, mainly from a semantic perspective. In this section, technical considerations (e.g. safety, powertrain packaging or modular architectures) were just secondary factors, guiding the generative process, but without any qualitative influence. Hence, the method in this chapter referred to semantics and design. In general, the method focused on product semantics (Krippendorff, 2006), while other sections centred in the application to relevant aspects such as sustainability (Walker, 2006) or urban design (Rossi, 1982). Vehicle design also appears, but it is mainly a counter example to the define the idiosyncratic identity of the µcar typology.

Such a new design identity was a result of the different considerations previously analysed: the fact that the vehicle had to be not only efficient, but also urban, adaptable and affordable favoured the development of a completely new concept, discarding a posteriori re-designs of car architectures. Moreover, the short-term scope of this research, motivating the use of quadricycle legislation to provide feasibility to the new proposal introduced further design problems: The quadricycle typology has existed for a while; they are the successors of the cyclecars and bubble cars, but always lacked the cultural success of their ancestors. Hence, the new design strategy had to offer a new design identity, in contrast with inefficient cars and poorly-executed quadricycles. The multi-disciplinary approach was definitely a useful tool to deal with such a design scenario.

In the definition of the new identity, two design factors were particularly relevant in the design strategy: Sustainability and Contextual Integration. To compensate the limitations against cars, this research used the inherent technical simplicity of the typology to project a differentiating message of sustainability. Similarly, urban integration also constituted a design opportunity that required a different approach. This would be new in car design, from a methodological perspective. As a general rule, cars are designed with markets and individual users in mind. The introduction of context as an active factor in the generative process required the addition of an alternative method. Architecture, with its conceptualisation of space and its contextual implications, was the right tool to find limitations and to initiate the conceptual thinking. Architects' methods to deal with space within urban contexts were highly illustrative. In order to complete this vision and manage concepts such as the combination of public subtleness and individualist appealing, the method required the addition of other tools. In this case, the influence came from the unexpected source of photography criticism. In the semantic analysis proposed by Barthes (1993), the process of creating an attractive visual message is de-constructed into an assumable element and the generator of attraction. Such an approach is highly useful here. Additionally, the introduction of new media also influenced the design method.

The design strategy condensed such a varied group of considerations in a seamless proposal based on three points that would reflect the aforementioned features: Latent Design (summarizing the design within urban contexts), Layered Architecture (using the minimal and efficient vehicle architecture to generate the design essence), and Urban Canvas Design (reflecting the open-ended approach that is favoured in other fast-paced disciplines such as fashion or media).

The next chapter, for the first time in this thesis, used a purely technical approach. The aim was to identify relevant technical aspects that would help to conform and/or validate the proposed design strategy. Some of these considerations included: the use of modular architectures within automotive contexts (Sako and Murray, 2000); a system-level approach as both a technical stage (Sobek, 2006) and a way of enriching the design process theory, as the late Professor Bruce Archer defended (Macmillan, 2005); or the considerations of interface definition as strategies to manage the interaction between engineers and designers (Sanchez, 2000). The particularities that refer to specific aspects of the embodiment were left for the next chapter, for they do not directly affect the design strategy. Thus, the following chapter contains a general description of the embodiment used to develop the new vehicle typology. This description mixes design and technical considerations, exposed in the previous chapters, to levels of detail that relate to the specific focus chosen in the definition of the embodiment.

Finally, for the critical assessment, there were three different tools to assess the research main hypotheses. A virtual reality full scale model and standard three-dimensional visualization techniques were used to show the conceptual development to relevant experts from the discipline of design. Recent interests on new types of quadricycles was also the perfect opportunity to evaluate commonalities and major differences between the hypotheses of this research and modern proposals of the automotive industry. Ultimately, a project with MA students and their feedback serve to test the suitability of such a new design strategy.

4. Analysis of the Design Problem

This section synthesizes the iterative process followed to address the problem of the design of an urban alternative to conventional car architectures. It starts by analysing the problematic of urban mobility to propose an alternative vehicle typology as a partial solution to it. This proposal for a vehicle typology will, then, be completed with the addition of user-related considerations and industrial aspects.

Although a vehicle typology is not a total solution for the problem of urban mobility, its contribution can be crucial both at local and urban levels. A feasible electric urban vehicle can represent, not only a marginal improvement in terms of traffic flow or pollution, but also a catalyst of change for new infrastructures and, which is more important, better lifestyles.

The ultimate goal of this chapter is to finish with a design brief that aligns the design drivers incorporated by urban scenarios, users and industry into a seamless design problem, which will be extensively addressed in next chapter.

Let us begin, then with a depiction of current mobility issues in cities.

4.1 The objective problem or urban mobility

After more than hundred years of motorized evolution, humankind is starting to consider technical development, not only from a discrete perspective that focuses on local parameters (short term), but also from a holistic approach that includes life cycle analysis of the proposed solutions. This reaction looks obvious if we consider the impossibility of a constant growth based on the limited resources contained in Earth. A simple way of analysing these issues from a global perspective is checking the IPAT equation (Eirich and Holdren, 1971), which defines environmental impact (I) as the product of three factors: population (P), affluence (A) and technology (T).

$$I = P \cdot A \cdot T$$

Current projections on the first two factors (population and affluence) for the next fifty years show a long-term growth that would negatively affect our environmental impact (The short-term applicability of this assumption may redefined, attending to our current economic crisis). Letting alone the importance of a behavioural change towards more sustainable lifestyles, strategies to reduce this impact should address its technical implications.

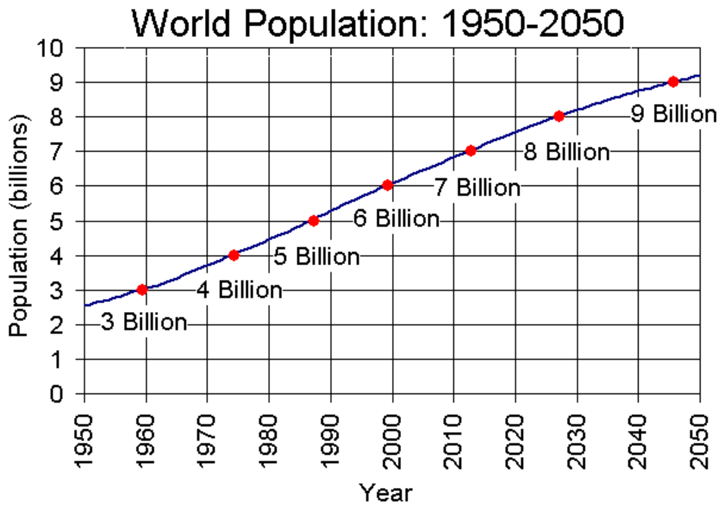


Figure 30: Current forecasting on future world population (Source: US Census)

And an important field for technical changes is urban transportation. Transportation itself is the second most important sector in terms of energy consumption and a great contributor to human-produced CO2 emissions. Additionally, urban transportation has its own particularities in the way they affect the environment, and ultimately, the way cities work.

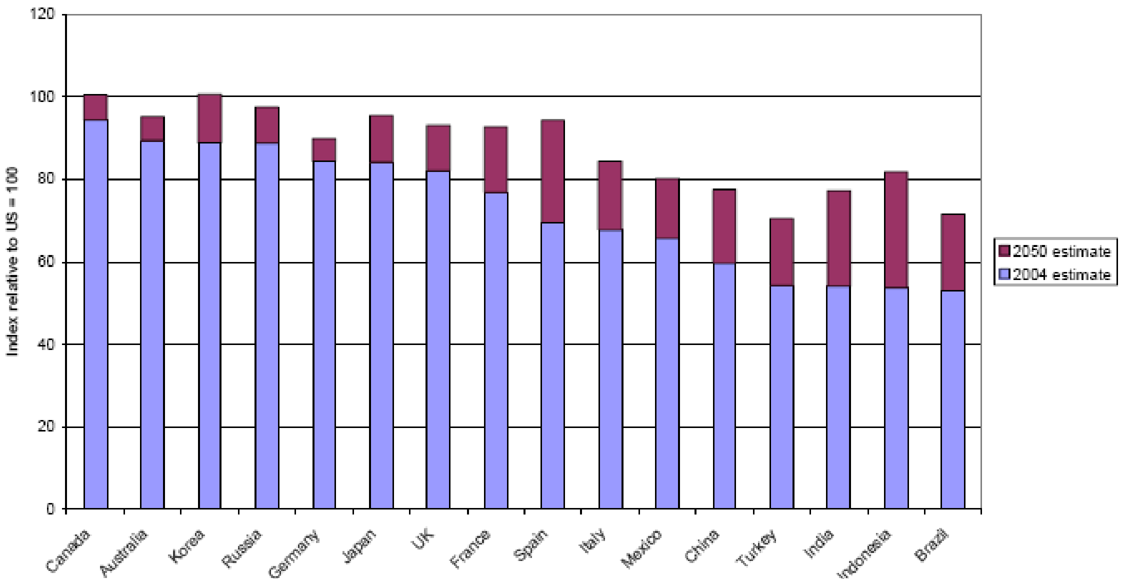


Figure 31: Current forecasting on future GDP growth (Source: PwC)

The three most important issues related to urban mobility are:

Safety: Modern cities force pedestrians to co-exist with heavy metal boxes able to move at 100 kph, unnecessary performances in cities such as London, where average speeds do not exceed 20 kph (Transport for London, 2010).

The situation gets even worse when we consider the deterrent effect of cars on the use of unsafe but efficient vehicles (such as bicycles or scooters).

Pollution: Recent research links exhaust emissions to respiratory diseases (Environmental Audit Committee, 2010)

Traffic: Congestion is probably the most noticeable urban problem caused by cars. Two causal factors of traffic congestion are car occupancy and car dimensions. Large cars rarely carrying more than one occupant each (Office for National Statistics, 2002) block the roads of modern mega-cities. Such a fact plus the large amount of urban space required for parking demonstrate the negative effect of cars on the urban landscape.

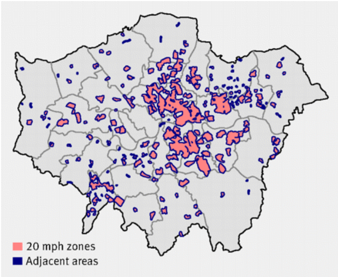


Figure 32: 20 mph zones in London (Grundy et al, 2009)

This section will analyse the problems introduced by urban traffic considering also the point of view of users, urban contexts and industries. The aim is to identify what will be the critical elements in the development of a new typology of urban vehicle.

4.1.1 A technical depiction of urban trips

The average distance for a commuting journey in London is 10.2 km (Demographia, 2005), ranging from 6.2 km for residents of City of London to 13.72 km for residents of the borough of Havering.

In 2008, 41% of those trips (totalling 24.4 million trips) were made by private cars at an average speed of around 17 km/h during peak hours (Transport for London, 2010).

4.1.1.1 Traffic

Congestion

'Congestion is a traffic condition in which vehicles are constantly stopping and starting and in which vehicle concentration is high while flow speeds are low' (Economic Research Centre, 1999). Thence, it requires not only high vehicle concentration but also saturation of road capacity. This situation is particularly critical in the city, as road capacity is limited by urban infrastructure.

Attending to the main sources of congestion, more than 50% of traffic jams occur just because of bottlenecks and bad weather conditions (Mitchell et al, 2010). This fact reveals the limited capacity of our road infrastructure for current traffic flows, an issue that can be observed from two different perspectives: Considering overall improvements of urban infrastructures, and optimizing urban traffic flow.

Modifications on urban infrastructures introduce long-term and complex issues that are not included in the scope of this research, but studies on traffic flow will provide valuable information for the creation of a new typology of urban vehicle.

As we have seen, in 2008, 41% of London urban traffic corresponded to private motorised transport. If we consider road usage, cars and vans account for 70% of the total number of trips. They constitute a critical group in the optimization of traffic flow, specially considering a crucial particularity: they cannot be as easily controlled as buses.

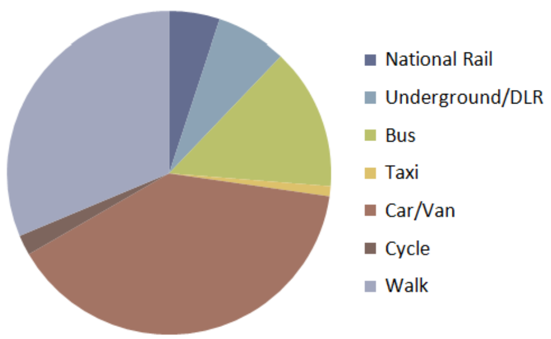


Figure 33: Modal shares of weekday trips for London, 2006-2007 (Transport for London, 2010)

An analysis of car road usage could further illustrate the situation: Cars average occupancy of 1.6 passengers per vehicle (Office for National Statistics, 2002); while the average length among the 2010 ten best-selling cars in Europe was 4 meters for a five-seat lay-out, using data from JATO (2011). Assuming a typical width of 1.7 meters and considering occupied area per seat, this gives 4.62 square meters of wasted road space per car. That means 68% of space wastage.

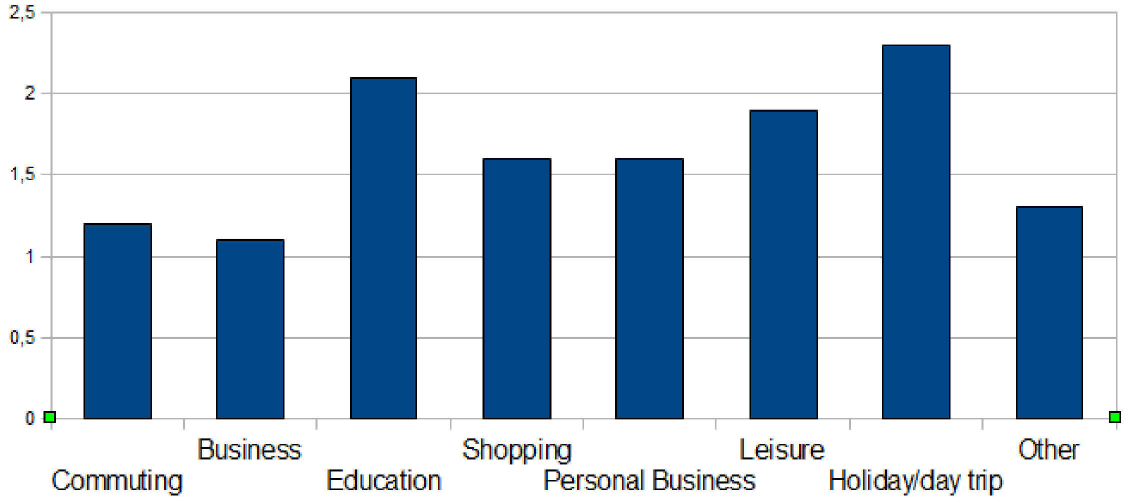


Figure 34: Average car occupancy by trip purpose in Great Britain, 1998-2000 (Office for National Statistics, 2002)

Compared to buses, cars waste a space three times larger. Furthermore, at peak hours, bus occupancy drastically increases, while car values remain similar.

Parking

Additionally to traffic congestion, the effects of parking in our cities are notably negative. Parked cars fill up our streets impeding other uses of the space they occupy. This issue can be analysed from different perspectives:

Economy: In 2010, the average cost per square meter by the Thames, in London, was around 12,000 €. Considering a typical parking space of 2.4 meters x 4.8 meters, the cost of having a space to park a conventional car on the street would be 138,240 €.

Life quality: Space occupied by parked cars is space that cannot be used for other tasks that would surely contribute to improve citizens' life quality. Instead of green zones, wider pavements or playgrounds for kids, or just clean views of historical city centres, we have given priority to these machines over more important human beings. Similarly, they also condition psychologically and physically development of several areas within our cities. Although people used to conventional cars can oppose the reduction of parking spaces, the development of new solutions must keep in mind a careful use of human habitats.

Traffic flow: As we saw, road space has a crucial role in order to establish smooth traffic flows. If we consider how restricted road space is, every lane in our city devoted to parking is contributing to disturb optimum flows.

4.1.1.2 Pollution

Air pollution

Apart from other environmental effects, air pollution has direct health effects on population. It accounts for 5% of mortality in Europe and the transport sector alone produces 55-70 % of this impact (De Santi, 2002). This effect is particularly relevant within urban areas, where noxious effects of exhaust gases mix with higher exposure to population. There are thus two main aspects to consider in the analysis of air pollution due to road transport: nature of exhaust emissions and exposure.

The main species present in exhaust emissions and their effects on human health are (Gorham, 2002):

Lead: It produces cardiovascular disease, premature death and behavioural and development problems in children

Particulate matter: It causes permanent interference with respiratory function

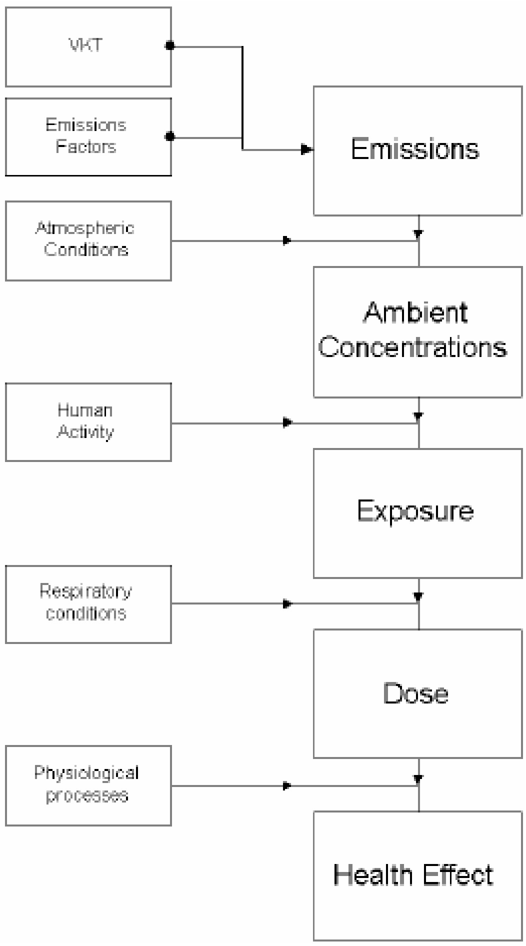
Volatile Organic Compounds: They contribute to ozone formation that seems to impair respiratory function in the short-term; they also have unclear long-term effects, and contribute to particulate formation; moreover, some VOCs are also toxic and hazardous.

Oxides of Nitrogen (NOX): They contribute to ozone formation in general. NO2 is toxic, impairs respiratory function and can damage lung tissue.

Carbon monoxide (CO): It causes cardiovascular and coronary problems, impairing learning ability, dexterity and sleep; it is involved in the production of ozone from VOCs and NOx (elevated concentrations of CO may, therefore, help to contribute to ground-level ozone formation)

Oxides of Sulphur (SOX): They have effects on bronchial function

The effects of these pollutant species also depend on the grade of exposure to them, which is a function of different factors such as concentration or atmospheric conditions. These factors are summarized in the following graph, from emissions to health impact.



Note: VKT = vehicle kilometres travelled.

Figure 35: Pathway from emission to health effect (Gorham, 2002)

Acoustic pollution

Noise pollution introduces further risks to human health. According to World Health Organization Guidelines for Community Noise (WHO, 1999), the main effects of noise on human beings are: Noise-Induced Hearing Impairment; Interference with Speech communication; Sleep Disturbance; Cardiovascular and Physiological Effects; Mental Health Effects; Effects on Performance; and Effects on Residential Behaviour and Annoyance

If we consider that the same report indicates that about half of the European Union citizens live in zones that cannot ensure acoustic comfort due to transportation noise, the necessity of silent urban vehicles seems fairly obvious.

Visual pollution

Visual pollution is relatively unknown compared with air or acoustic pollution.

While the previous types of pollution have obvious and harmful effects on population, we cannot forget its psychological and emotional influence.

Although the analysis of this type of contamination is an obvious section in many environmental impact studies, it seems that an application to the urban environment is not so established, apart from obvious consideration such as traditional architecture preservation. But the truth is that cars fill our cities, not only occupying vital space, but also impoverishing our urban landscape (and in some case, sadly, modifying it).

Maybe current generations got used to grow up with cars as an integrating element of urban views, but the development of a new typology for the city must consider the appearance of the vehicle, not just from a buyer's perspective, but also from the point of view of an urban planner.

4.1.1.3 Safety

The problem of safety in urban traffic includes pedestrians, cyclist, motorcyclists and car users, showing an increasing level of protection (active and passive). The next graph gives an overview of casualties registered during 2006 in London. The vulnerability of pedestrian is highlighted with the highest number of deaths or serious injuries. This is particularly relevant when we compare the proportion of car with pedestrian casualties (more than twice as much).

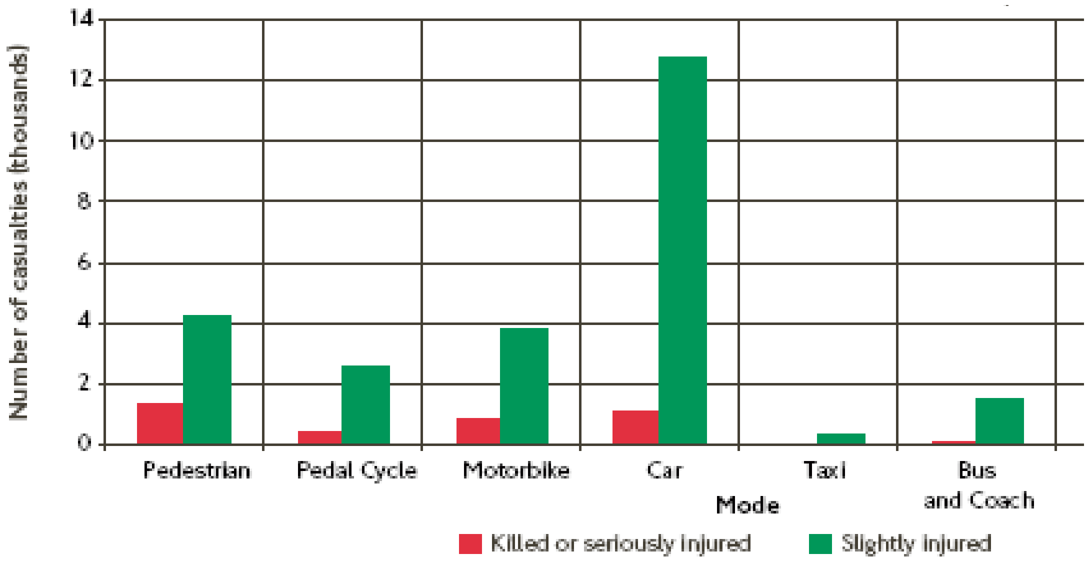


Figure 36: Total road casualties by type and mode, 2006 (Source: Transport for London, London Road Safety Unit)

There are three main factors, referred to vehicles, which influence traffic casualties: speed, weight and protection.

Speed: The positives effects of lowering speed in reducing traffic casualties are widely shown in technical literature (Grundy et al, 2008).

Weight: Vehicle mass mismatches are determinant in accidents. Normally, lower vehicle mass imply lower risks in car-pedestrian collisions. However, in an environment filled with heavyweight cars, users of lighter vehicles would immediately become more exposed (NHTSA, 1997). This introduces an important trade-off in urban vehicle design, as, while weight reduction would improve on pedestrian safety, it would also make drivers more vulnerable to crashes against heavier cars.

Protection: Pedestrians, cyclists and motorcyclists are completely exposed in terms of passive safety: whenever they get involved in a crash, their bodies will directly receive some type of impact. This is reflected in a much higher proportion of deaths and severe injuries per casualties, as shown in the graph before. On the contrary, cars offer much more protection for their occupants, but when we consider car-to-car collisions, factors such as crash compatibility play a crucial role. Crumple zones are designed to absorb kinetic energy by deformation or destruction of those zones. However, when crumple zones are not aligned in a head-on collision, cars with lower structures tend to suffer greater damage (Patel et al, 2009).

4.2 A new typology for the city

Car drivers are one of the main factors in terms of potential to improve urban transportation. Acceptable solutions have to deal with the issues highlighted before without excluding common motivations for the use of cars. In order to accomplish this task, let us analyse alternative technical architectures. Riley (1996) propose a classification of urban vehicles listing: passenger cars, commuter cars, urban cars and sub-cars.

Passenger cars would be out of the question as they represent conventional cars. Commuter cars introduce an improvement, specially narrow-lane vehicles. However, their adaptability to urban scenarios can be limited by their highway capabilities. Mega-cities are segregating urban landscapes from intercity scenarios. As it happened with off-road vehicles, the specialization of normal vehicles in intercity trips make them unsuitable for restricted urban scenarios. Furthermore, the role of commuter cars as pseudo-urban vehicles that allow conventional journeys can be almost undistinguishable from new mini car proposals such as the 2012 VW UP.

On the other hand, urban cars (Riley, 1994) perfectly enclose the nature of four-wheel architecture for the city. The emphasis is put on efficient use of space, air quality and allowance for low ranges. They define a range of solutions that, not only could gather followers from the car user group, but also do not require any kind of additional infrastructure. And what is more, these flexible typologies can be seen as a change initiator for new infrastructures (i.e.: electric charging point grids). Another positive point is the greater design freedom to interact with its context in terms of navigation and infotainment, opening new opportunities for business models such as customized car-sharing schemes. Ultimately, the definition of specific urban scenarios motivate a change in the set of safety requirements.

Sub-cars also introduce a new approach, valid in those scenarios where the separation between conventional cars and new city vehicles is well defined. That is actually happening in cities and areas where traffic is closed for four-wheel vehicles other than electric-powered vehicles (The Auto Channel, 2011).

Therefore, we can classify our proposed typology either as an urban car or a sub-car. In legislative terms, these range of solutions are enclosed under the L6e and L7e vehicle categories, known as light and normal quadricycles.

Nevertheless, this is just the first step. The definition of this typology, however, is not complete unless car users' perspectives are included in the analysis. As we know, although quadricycles have existed for a while, they have not been able to succeed as valid alternatives to conventional cars in our cities.


Figure 37: 2010 Aixam Mega quadricycle and 2010 Ford Ka

4.2.1 A user-centred perspective

A unidimensional approach to traffic-related issues in the city could bias us towards apparently obvious solutions similar to public transport, for congestion is easier to handle: from automatic operation of underground train services to central control of bus traffic, regulators manage problematic situations by changing speeds and adding or eliminating vehicles from a particular line. Even under that perspective, it is easy to see how small vehicles, such as micro cars, mopeds or bicycles can drastically improve road traffic flow. However, urban traffic is also affected by subjective variables introduced by car users. Cars are perceived as private and safe spaces able to offer convenience, impossible for public transport. Thus, it is important to consider the perspective of car users, from social to individual implications.

From a social perspective, demographic and lifestyle factors can affect mobility patterns in Europe and UK. Three relevant examples to consider are an ageing population, the emergence of one-person households and the influence of communication technologies in modern lifestyles.

In design, the first implication of an ageing population is an emphasis on aspects such as accessibility, visibility and practicality. Ricability (2011), a research consultancy for older and disabled people, lists the following features in the selection of a suitable car:

Doors: Low, narrow door sills or no sill at all; high and wide doors

Seats: Height adjustable and easy to move seats; back and lumbar support

Interior: Plenty of leg and foot room; no intrusive central consoles; wide, flat access to the boot

Others: Strong and useful grab handles; parking sensors or cameras; electric mirrors, comfortable seats.

The potential of these design considerations have been highly supported by research done by the Helen Hamlyn Centre on Inclusive Design. According to Professor Coleman, rather than a social stigma, design for ageing population is both a design perspective for our future ourselves and an implicit study of extreme users that helps to improve the acceptance of the overall design (BBC News, 2005). I actually had the opportunity to experience the advantages of inclusive design during the Methods Lab workshops in 2008.

But ageing population also introduce a rich design field in terms of emotional images, as nostalgia can play an important role in the definition of design preferences. Professor Coleman refers to Darwinian design steps in the way to produce designs with increased acceptance by minimizing the rejection associated with radically new products (BBC News, 2005). This can illustrate the apparent failure of futuristic proposal for urban mobility during the past forty years. In that sense, some authors have found that tastes on car design are normally established in the years from late adolescence to early adulthood (Rutherford and Shaw, 2011). Such findings would explain the success of retro designs such as BMW's MINI or Fiat's 500 in trendy cities. It may be worth remembering that the original versions of these cars coexisted with other design icons such as Trojan and Messerschmitt bubble cars. Even the surviving cyclecars of the sixties are making a come back with the recent resurgence of the Morgan three-wheeler.

Figure 38: The return of the bubble?

Besides ageing population, one-person households are another important aspect to consider, with direct influence on consumption and usability patterns. The number of one-person households worldwide grew from 153.5 million in 1996 to 202.6 million in 2006 (Hodgson, 2007). This trend is especially relevant in the developed world. One-person households include three different groups: single young professionals who can afford their own place; middle-aged divorcees; and elderly people on a tight budget.

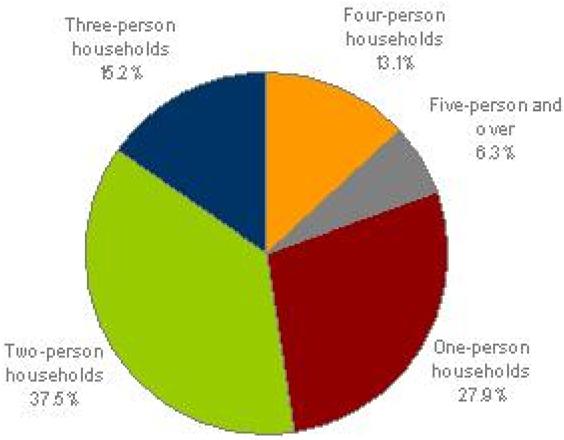


Figure 39: British households in 2006 Source (Hodgson, 2007)

In general, these three groups are particularly relevant as they consume more space, energy and resources per capita than any other household. Particularly, young professionals are the reference group, not only because of their increasing number, but also because they often lead changes in consumer lifestyles. In instance, they lead the way in the online communication and entertainment markets. Moreover, their emergence generates the need to build new accommodation, which directly affects urban planning and, hence, urban mobility. One of the main changes that they include in usage and consumption patterns is the requirement of wider ranges of convenience for conventional products. For example, they lead the trend towards food that is not only convenient but also healthy.

In the future, with estimated growth rates of 1.6% for one-person households compared to 0.9% per year of the rest of households, their importance could become determinant. Governments may consider the introduction of occupancy taxes to compensate for this 'less efficient lifestyle' (Hodgson, 2007). Furthermore, considering their typical cultural levels, these groups could favour the use of sustainable and efficient solutions by themselves, to offset their per capita consumption rates.

Another aspect of today society in developed countries closely linked to young professionals is the integration of media technologies in current lifestyles. Since the appearance of commercial internet in the 1990s, information technologies have evolved from occupying a fixed space in households as a computer unit, though the increased freedom of laptop, to their latest incarnation as smart phones and tablets that allow ubiquitous connectivity. From checking work tasks to finding spots for a night out, communication technologies have being fully integrated on many people lives. This technical integration can be a double-sided sword in the sense that unmanageable information could lead to saturation. Regarding the links to private mobility, infotainment has negative effects on driving distractions requiring seamless design integration in private vehicles. In the smart phone sector, product success is clearly based on usability: capacity of accessing information in an easy and convenient way.

Actually, such is the predominance of smart phones in modern context that younger generations consider them more desirable than cars. It began in Japan (Murphy, 2008) and is already noticeable in other developed countries such as UK (Rayner, 2011) and US (Wheeler, 2011). In an intermediate level, this cultural shift has generated a design trend in car design towards new proposals that could reflect the convenience and adaptability to modern urban lifestyles of current smart phones.

Alternatively, the increasing 'intrusion' of technology in modern urban lifestyles reflects in a bi-polarization of society into groups of technology-dependant people and supporters of a 'slow way of life'. This slow movement appears as a reaction against the frantic pace of today's society, promoting a return to more 'humanized' lifestyles. It reflects on aspects such as food, professional career and even several cities around the world categorize themselves as slow centres (Cittaslow UK, 2011). In summary, slow cities restrict traffic and embrace life quality, local businesses and traditions over the general trend.

From an individual perspective, when people buy cars, typical criteria include: total vehicle costs, comfort, infotainment, agility, passive safety, theft deterrence, reliability or sustainability (Weber, 2009). But in reality, first impressions and more complex mechanisms play even more important roles. Thus, personality, friends and society make this matter a highly subjective task to deal with (ACNielsen, 2006).

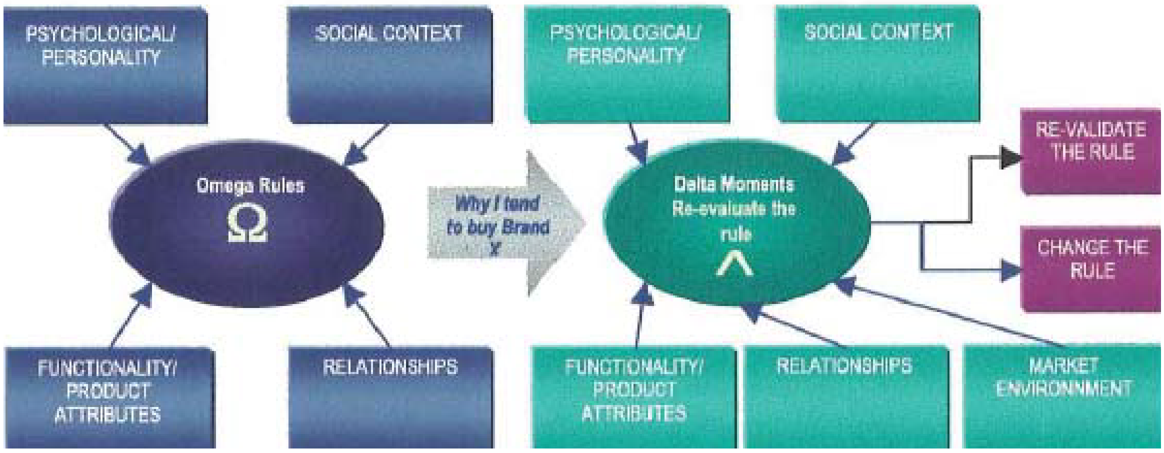


Figure 40: Car buying factors, according to ACNielsen (2006)

And the situation gets even more obscure when we include car use: The reasons used by drivers to explain why they use cars are often contradictory, compared with objective situations.

In those cases, sociological studies can help in the analysis of subjective aspects of the relationship user-vehicle. Some authors have discussed justifications to car use, as the way people provide reasons to why they use private cars instead of other transport alternatives. Four of these 'discursive repertoires’ can be listed as: Utility, Freedom and independence, Risk, and Social meanings and negotiations of car use (Miller, 2001).

While some of these justifications can be considered highly contradictory (i.e.: where is the utility of private commuting on congested roads?), others have a grade of implications that are not so obvious: Some drivers use their cars as the safest available option when travelling through potentially dangerous spots late at night or early in the morning. Should we focus on persuade them to go walking or using public transportation instead of analysing how safe certain regions are?

4.2.1.1 Extreme users group: SUV drivers

A particularly relevant group among car users is that of SUV drivers. Their vehicles tick in every box of urban inefficiency: they are large, pollute more and constitute higher risks even for conventional cars (Patel et al, 2009). The very essence of this car typology is worth a look indeed: while some still keep their off-road pedigree, the most successful examples abandon those capabilities to become enlarged and aggressive family cars. It is, thus, relevant to analyse the appeal of these vehicles.

Some of the qualities of these cars are easily recognizable, such as their value as icons of power or luxury, but the same values can be attributed to compact sports cars. Other factors, however, are more subtle and refer to the use of cars in social life (Miller, 2001): people use their vehicles to pick other family members up and SUV normally offer them the highest level of protection and on-board practicality for that task.

Figure 41: 2010 BMW X6, the epitome of the 'on-road' sports utility vehicle

If we consider that those passengers are normally children or elderly members, drivers’ concerns are obvious. It is very important to highlight this fact, as behavioural changes can be even harder if they affect not just users but also people they are responsible for.

Whichever the case, it is clear that there are contradictions in social and individual requirements with respect to traffic. It is, thus, responsibility of vehicle developers to propose alternatives that, while solving traffic issues, can also be presented as acceptable options to user groups.

4.2.1.2 Towards a user-friendly typology

The emergence of mega-cities together with new mobility trends and urban scenarios are fostering the development of microcars as the new urban runabouts (Shankar, 2011). Increasing running cost of cars, especially due to congestion charging and ever higher oil prices also represent a critical role in this new trend, plus a taste for new technologies and design strategies in an industry that cannot keep up with the fast rhythm of the main cities around the world.

However, there are also important barriers for the acceptance of this new type of vehicle. Current microcars have evolved as niche products aimed to a customer group with very specific needs. This has isolated them from standard material environments, and particularly, from the evolution of the automotive context. It is important to analyse this context in order to propose solid contenders that help to deal with the problem of urban traffic.

Expected product attributes

<u>Safety</u>

Here we have two different sides of the way users evaluate vehicle safety: 'certified' safety and perceived safety.

The first type refers to the classification of a vehicle according to standard tests. Their importance reaches levels where automotive manufacturers use them as design requirements to project differentiated marketing strategy (i.e.: Renault and the EuroNCAP tests). These tests evaluate cars under standard conditions that define crash speeds and dimensional constrains.

Figure 42: IHS crash tests of the 2001 Ford F-150

The second refers to the sensation induced by the car itself using visual and tactile means. Although this sensation should always respond to inherent design qualities of the vehicle, it is possible to find incongruous messages. A cliché in perceived safety is the Sinclair C5 and the effects of its low and exposed seating position. Despite the inadequacy of that design for open-road traffic, we can conclude that the vehicle perception suited its qualities. On the other hand, there are several examples of vehicles that, projecting high levels of protection, fail by far to comply with those expectancies. An illustrative example of this erroneous messages is the 2001 Ford F-150 pick-up truck.

Back to the design of a small city vehicle for open-road traffic, there are two aspects to consider: the design of proper crash structures and perceived safety.

<u>Performance</u>

In terms of speed, urban vehicles should keep up with normal traffic conditions. Speed limits and the proliferation of 20 mph zones in cities like London let out of the equation greater performance levels.

However, two other concerns connect with the requirements for urban vehicles: fast acceleration and manoeuvrability. High torque engines help to improve traffic flow and to dribble tedious driving scenarios while tight turning circles allow for greater usability in constraint spaces.

For electric vehicles, however, the main concerns are related to the available range between charges. Here, frugal use of stored energy and convenient charging infrastructure are the Achilles' heel of this type of proposals.

<u>Quality</u>

After more than a century of motorization, vehicles have become an integrated element of our material culture. Specially during the past decades, the perceived quality of car and motorcycles has drastically increased from initially raw technical solutions.

A new solution for the city should consider this aspect. Sound, vibration and tactility of the elements compounding the vehicle will help to validate or reject new proposals from users' perspective.

It is interesting to highlight, though, that perceptions are linked to the type of vehicle. Users evaluate cars upon criteria such as cabin noise and vibrations, while motorcycle buyers guide themselves by other aspects such as tactility (RCA, 1999), or even idiosyncratic engine vibration. The definition of this new proposal, in order to align with its simplicity could take cues from these facts to project a coherent and favourable perception to users.

Cost

Obviously, cost is an important factor. Vehicles that are going to be used in a regular basis for commuting or shopping must be affordable in every sense. Purchasing cost is the first parameter to consider, but insurance, road tax, congestion charge and fuel consumption are important too.

As a simple reference, a 2011 super mini car such as the Kia Picanto costs around GBP 7,800 when new. As its emissions do not surpass 100 grams of CO2 per kilometre, it is exempt of both road tax and congestion charge (in London). Assuming fuel costs of GBP 11 per 100 miles (Honest John, 2011) and an average mileage of 10,000, we have GBP 1,100 per year. Typical insurance costs could be around GBP 800. Distributing owning and running costs in three years, we have GBP 3,200 per year. And that amount excludes consumables such as tires or oil changes and parking expenses. Compared to public transport, a bus & tram yearly pass in London costs GBP 712 while an underground yearly pass for Zones 1 to 4 costs GBP 1,576 (Transport for London, 2011).

New values

As cost is required but not enough, the new typology should provide further urban functionalities than those given by conventional cars. The architecture of cars has evolved along more than hundred years due to technical and economical reasons. Now, with well-defined urban scenarios claiming for purpose-built mobility solutions, a new proposal should combine physical mobility with a physical-informative integration with its surroundings.

Physical mobility on four wheels from an emotional point of view, and aligning it with the necessity for minimal solutions can be addressed by a reinterpretation of the cyclecar concept: four-wheelers with lightweight simple structures and minimal mechanics that could even outperform cars in particularly tight urban scenarios. Here, the circuit is the city, with dense traffic and constraint spaces for moving and parking.

But it would be a modern cyclecar that also consider the journey through the digital scenario, providing augmented reality to their users and to by-standers (when it is parked and becomes part of the static urban landscape). To adapt to different use modes such as car-sharing schemes, to fast pace lifestyles and trends, so characteristic of our urban environments.

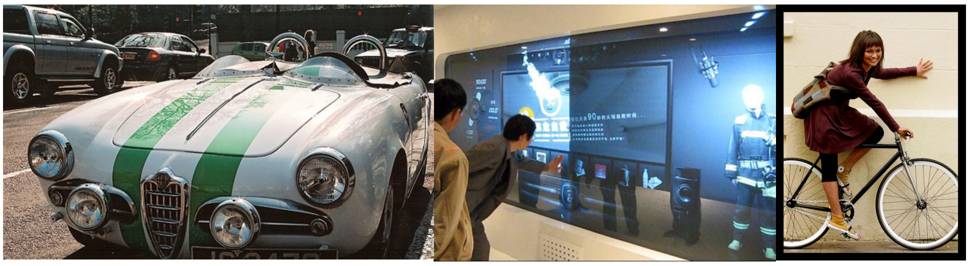


Figure 43: Unexpected and modern influences in urban vehicle design

We started with microcars as a viable technical solution for the city. However, after considering the failure of current proposals to appeal users, the initial idea has evolved into some new type of modern cyclecar for the city, retaking illustrious roots as those initiated by the likes of Carden or GN.

Now we have to complete this approach by considering a business perspective for this matter. We will look at the current situation of the automotive sector at the turn of the first decade of the 21st Century (a relevant aspect for the economy of the UK).

4.2.2 Automotive-related business outlook

If there is anything clear from the climate of economic crisis by the end of the 2000s, it is that current models have flaws. While it seems there is no defined solution, it is certainly the right time to consider different approaches for planning crucial aspects of economies. Considering the climate of uncertainty and the decisive role of businesses on communities and the environment, flexible approaches seem the right way to go in order to avoid mistakes from the past that could condemn future generations because our short sighted strategies.

Within decisive sectors, car industries are one of the main manufacturing sectors in the world, having dramatic effects on local communities and countries. They are normally based on economies of scale. And this is a risk. It is not the goal of this thesis to propose a new economic system, but a new proposal should be able to be integrated in less harmful industrial plans that the ones reigning today's world.

Particularly Great Britain has had a relevant role in the automotive history from mass vehicles such as the Austin Seven or the iconic Mini to luxurious vehicles and high-performance cars. This rich history extends to relevant historical references for this thesis, such as the original cyclecars.

But now the crisis in this sector is notable, promoting a search for alternative solutions. The emergence of countries with lower wages and industrial emporia call for alternative solutions. This proposal should be able to enclose the potential of British industry in a new architecture, able to change form and functions for unexpected futures

As a reference to evaluate future trends in the automotive industry, the Global Automotive Executive Survey, by KPMG (2011) helps to define the main concerns in the sector.

The main factors influencing the roadmap for the Automotive Industry in the future:

- *Vehicle Design will adapt to the environment*

A vast majority of respondents (76%) cited urban planning as a main design driver. 73% considered that design would also adapt to specific purposes

With growing environmental restrictions and modern urban planning making streets car-unfriendly (i.e.: the new city of Masdar by Foster and Partners), customers would need to consider the use of specific urban vehicles to commute or access city centres in the near future. This fact would mean to go beyond single platform locomotion, as these vehicles would not suit other conventional car uses such as family weekend trips. In that sense, car-sharing, although they are not totally accepted yet, has the potential to allow access to several vehicles for different purposes.

This trend supports the hypothesis of other report (Shankar, 2011) that showed microcars as a relevant solution for mega-city traffic scenarios.

In the aperture of markets for purposed-design urban solutions, the importance of value-added elements will increase. Specifically, if we consider the importance of navigation systems and infotainment in urban scenarios, designs that favour the integration of these added functionalities could gain competitive advantages.

- *Changing business model*

49% of respondents to KPMG survey consider that the automotive value chain will completely change

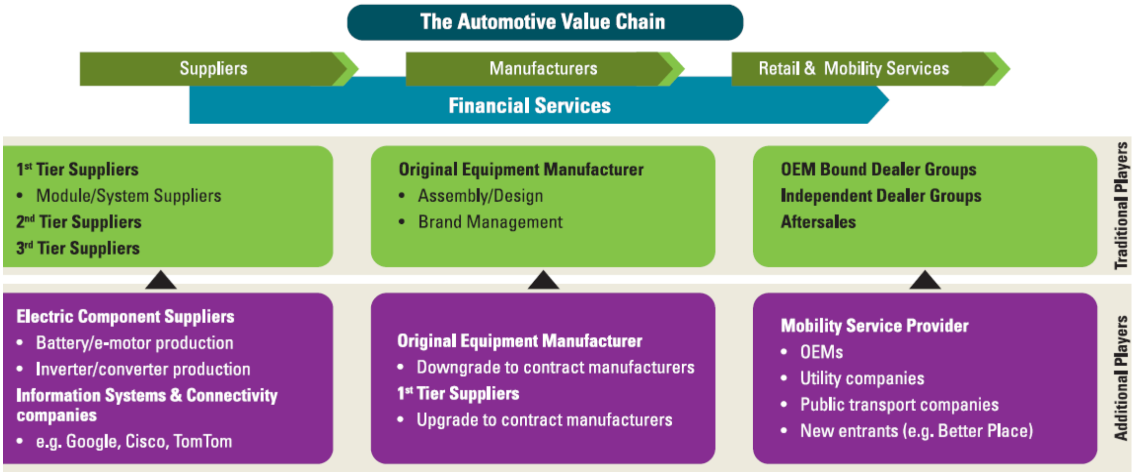


Figure 44: The changing automotive value change (KPMG, 2011)

One of the most significant changes is suppliers moving up in the chain adopting the role of contract manufacturers, which links with the redefinition of value-added elements cited above. A very recent example, StreetScooter, could lead this way. It is a short-distance electric car developed by a consortium of 50 automotive suppliers (Streetscooter, 2011). The car has a modular architecture that has been independently developed by each member according to their area of expertise. The project is based on research aimed to look for alternative industrial scenarios for Germany upon the emergence of new competitor in Asia. A similar role of contract manufacturer is also envisioned for current OEM, suggesting the introduction of new external companies in the automotive business.

In terms of business models, new mobility solutions introduce novel approaches to conventional sale strategies. Car sharing, as we mentioned above, allow users to access different type of vehicles without the worries linked to full ownership. The advantages of this model also favour the use of urban spaces, for one car-sharing vehicle can substitute fifteen privately-owned cars (Gavan and Nicholson, 2010), substantially saving in local parking spaces. Reflecting the interest of OEM's in these alternatives, KPMG cites Daimler car2go, Peugeot mu and Renault agreements with Project Better Place as examples of the new trend.

Another aspect in the change of business models is the role of niche players as potential game changers. In the definition of new types of urban vehicles, planning uncertainty can favour the success of specific vehicles such as urban microcars (Shankar, 2011), able to better adapt to restricted urban scenarios.

To further illustrate business trends, the largest increments of investment by goes to new products (97%), followed by new powertrains (93%), safety technologies (87%) and platform standardization (85%). For suppliers, the largest investments are placed on R&D.

Paradoxically, while OEM consider public subsidies crucial for the success of electric vehicles, 43% of the respondents believe they will decrease. This assertion suggests a critical need of ideas for developing feasible vehicles able to travel across restricted city centres.

Other aspects included in the survey are a consumer focus on safety and fuel efficiency, the later motivated by economical rather than environmental reasons. This affects the predicted dominance of ICE engines over hybrids and electrics up until 2020. Overcapacity is another concern for the automotive industry. Initially overseen and promoted, the economic crisis by the end of the 2000s placed manufacturing overcapacity among some of the main concerns. Considering the relevance of this facts in employment and local economies and the lack of a strategy to manage this problem (KPMG, 2011), the only consequence to extract from here seems to be that past trends in mass production and industrial strategy fail to offer flexible and controllable outcomes.

In terms of the technology roadmap, 71% of the respondents believe that OEM will dominate powertrain technology until 2020 while they do not expect a reasonably priced EV in the next 5 years (2012-2016). Despite this, hybrid (37%) and electric (31%) motorizations dominates technology investment.

Finally, the survey highlights the growing importance of emerging markets. China, India and Brazil will supposedly lead the production of cars in the world.

Summarizing, the main points that will define the future of automotive-related businesses lay on:

1. Integrated mobility solutions
2. designs defined by their scenario: *urban planning, environmental restrictions and customer needs will become design drivers*
3. safety

4. pooling knowledge to obtain technical superiority
5. seeking operational efficiencies
6. alternatives to manage industrial overcapacity

4.2.3 Defining the typology

4.2.3.1 A solution for cities: a new type of quadricycle

The starting point for this research was to offer a feasible proposal able to alleviate typical problems caused by private urban mobility. Thus, the first part of the design brief has to focus in each of the aspects listed above: traffic congestion, pollution (air, noise and urban landscape) and safety (for both occupants and pedestrians-cyclists).

Traffic congestion

Quadricycles have enough potential to cover the performance levels required for urban runabouts and, at the same time, they keep the convenience of four-wheel architectures. From a design perspective, this categorization limits powertrain outputs to 15 kW and limits weight to 350 kg for light and 400 kg for conventional quadricycles (batteries not included).

Dimensions are not particularly constrained in quadricycle legislation. However, in terms of road use, this is a crucial aspect. Here, there are two considerations: car occupancy and traffic.

As we have seen cars able to transport between one and two passengers cover the vast majority of urban journeys. Considering the crucial importance of space use in the city, we can say that two passengers plus some shopping establish a reasonable top limit.

In terms of traffic, theoretically, narrow-lane vehicles have the potential of doubling the flow of conventional lanes (Mitchell, 2010). At the same time, reduced width proves advantageous in tight urban spaces and can reduce turning circles. However, the advantages of this configuration in terms of traffic flow depend on changes on the current traffic regulations. It also requires a vehicle length of less than 2.4 metres, in order to avoid wasting half parking space by parking perpendicularly to side-walks.

Focusing on keeping such a tight length while keeping a standard width still has the advantage of allowing perpendicular parking, offering more space for side-by-side seating layout or increased lateral protection.

Pollution

Current state of the art in batteries and current infrastructures, designed around traditional petrol cars, still make electric vehicles unfeasible as substitute of conventional cars. However, urban environments can prove to be more 'EV friendly'. Short trips adequate better to their reduce range and local addition of recharging grids seems more plausible in the city than updating motorway infrastructures. In fact, some cities, such as London (Greater London Authority, 2010), are starting serious projects on recharging networks for their inhabitants.

Moreover, electric cars directly tick on boxes such as air and noise pollution reduction. In terms of air pollution there can be an argument about well-to-wheel analysis of energy models (European Commission, 2007), but from a local point of view, they expose inhabitants to zero emissions. Another advantage of electric motors is that they also provide higher torque values from start than equivalent IC engines (Larminie and Lowry, 2003).

Indirectly, they are favoured by small sizes and lightweight vehicles, which minimize their drawbacks, and, furthermore, allow greater levels of flexibility in the design of micro vehicles. Architectures can be tailored to optimize crash performance while offering design freedom, especially when they are combined them with lesser regulations such as quadricycles (Vehicle Certification Agency, 2010).

Therefore, electric microcars have a great opportunity as a solution to our congested and polluted cities.

With air and noise pollution covered by electric powertrain use, the only aspect left is visual pollution. Visual pollution has been rarely considered in car design. However, considering the ubiquity of vehicles in modern cities and the negative effect that they often cause in streets when they are parked, new solutions aiming to minimize this impact would suppose quite an improvement on urban landscapes and, subsequently, life quality.

Safety

Current regulations on quadricycles do not specify crash test requirements. However, the use of quadricycles as urban runabouts is relatively new.

Revisions of the regulations are starting to consider the introduction of frontal and rear crumple zones, but details are still vague (European Commission, 2010). In this regulatory uncertainty, the approach to follow with this proposal is to improve on existing levels of protection without losing the design flexibility inherent in the L6e and L7e categories.

The design of a small urban vehicle should cover not only microcar-to-car and microcar-to-wall collisions, but also pedestrian protection. The design trade-off introduce by shorter wheelbases must be compensate too with the use of optimized structures, thanks to the flexibility provided by the use of an electric powertrain, and alternative materials.

4.2.3.2 A solution for users: the modern cyclecar

Design philosophy. Step one: avoiding rejection

In the end, the new proposed typology is going to suppose a change from traditional cars. Thus, the first task is to avoid either rejection or incomprehension. As a concept, it has to be intellectually acceptable and avoid any negative state of mind in its potential users. According to the acceptance parameters mentioned above, the car needs to project a (real) sense of safety, with prominent enclosures surrounding its occupants. Within its limitations, it has to exude tactile quality.

From a visual perspective, despite its novelty, it has to be perfectly assumable (We saw the negative aspects of blue-sky proposals). In that sense, there are two useful cultural references: cycle cars and their latest socially-accepted reincarnation, bubble cars. They can be used as starting points to generate modern design proposals.

In terms of practicality, the design strategy must aim at solutions that maximize the use of a constrained wheelbase. While terms like car occupancy are valid from a cold technical perspective, the design of this typology must humanize those impositions with a flexible approach. The interior could be an open-ended product rather than an encapsulation of occupants. Thus, reconfigurable designs can adapt to different lifestyles and necessities (i.e.: shopping, commuting, picking up kids, carrying pets, special equipment).

Design philosophy. Step Two: Generating desirability

Modern microcars, unlike cyclecars and bubble cars, are similar, in terms of visual language, to conventional cars. The only noticeable difference are abnormally reduced dimensions, a fact that together with relatively high prices and poor building quality, defines a very poor overall picture. Due to the inherent incapabilities of microcars to improve on the cited aspects, differentiation with respect to cars seems to be the way to create desirable proposals. But such differentiation that has to make the most of the idiosyncrasy of this design project.

To begin with, the new typology has to be small and underpowered to comply with traffic-related requirements. Besides, the use of electric powertrains on low-speed vehicles emphasizes weight reduction. Thus, we can identify smallness and minimal weight as our two main design drivers. The design philosophy should use these inherent features to generate visceral differentiation from conventional cars. In that sense, the simplicity and feather-weight of the proposal could be translated into a concept that enclose efficiency on four-wheels: a level of efficiency unable to be achieved by heavy and bulky cars.

At the same time, that simplicity can link to the need for a truly urban proposal, targeting design aspects such as the combination of visual pollution and appealing or seamless integration of urban augmented reality. Thus, parked vehicles could become media shelters for lost pedestrians or become part of the urban landscape when nobody requires their services. And they will be able to keep up with the urban vibe when they are used.

All these concepts should be completed with a sense of fun and emotional connection, usually absent in standard 'green' vehicles. Here, cycle cars and bubble cars can offer support too with unexplored design fields for solutions echoing their trendiness, agility and racing pedigree. These historic references could help to gain the heart of seniors aiming for a fun ride, our younger generations looking for chic and sustainable ways of moving around cities. In that sense, a design aspect such as ingress-egress lay-outs could help to provide a sense of drama that distinguishes this typology from conventional vehicles (Riley, 1994). Even though accessibility could be reduced, novel solutions could also help to compensate the short wheelbase with additional sense of protection by using, for example, high-sill configurations.

4.2.3.2 A solution for the industry: a new flexible microcar platform

The climate of economic uncertainty by the end of the first decade of the 21st Century prevents against the use of 'detailed' production expectancies in this academic research. Even history show us that the ultra iconic Mini, despite its remarkable qualities, was not a commercial success until fashionable people started buying it (Golding, 2007). Thus, what the design proposal must enclose is a high level of flexibility that allows it to offer a robust feasibility in these rough times. That flexibility must be seen as a strategy to adapt to:

New manufacturing scenarios

The predominance of Eastern countries may definitely transform European factories into assembly units of prefabricated modules. Or, maybe, new technical development could lead to manufacturing facilities aimed at exploiting particular know-how (i.e.: by using new manufacturing methods for composite materials). Urban spaces and emerging markets can push towards the development of small vehicles.

Vaguely specified products

The influence of urban environment on vehicle design could lead to unexpected new product specifications. Moreover, customers could favour unexpected functionalities in a new type of urban runabout

New use/ownership modes

Car-sharing alternatives could motivate customizable products able to adapt to that public/private usage pattern.

In automotive terms, flexibility means going from integral to modular architectures. Thus that minimal ethos of the design philosophy could be reflected in a vehicle architecture that maximizes reconfigurations to adapt to different economies, demands, functionalities and urban scenarios. At the same time, it would have to minimizes initial investments in costly tooling or large factories. Platform strategies are used by the main automotive manufacturers in their mainstream products. However, that option has not been applied to microcars up until now. Although maybe demand for urban runabouts can be small, the use of a flexible strategy that also include other small vehicles such as gardener and delivery vehicles, indoor people carriers or even fun vehicles could increase the possibilities of such platform.

5. The µcar typology

This chapter constitutes the core of the research. It integrates design and engineering to assimilate the design problem and to generate a solution in the form of an efficient and desirable new urban typology: the µcar

After the previous problem analysis, the goal of this section will be double: *to deal with the objective mobility issue* and *to propose a serious contender for both the emotions and convenience that cars provide*. Thus, the generative process must be able to align the objective and subjective elements of the design problem. The conceptual development included here will de-construct the emotional-technical baggage of conventional cars to bare elements. From there, a cyclecar design ethos, urban possibilities and current technologies will help to generate alternative design value to conventional cars within urban contexts. This approach will, thus, generate a distinguishable and purposeful new type of four-wheel vehicle for cities, opposed to the concept of a 'handicapped' car.

To deal with the wicked design problem, semantics and system-level approach will be used to integrate engineering and design in the generation of the typology. It is important to understand that, despite the linear exposition of this process, it has been highly iterative in the search for unexpected factors and interactions.

Thus, the process will start by translating the objective needs (reductions in pollution, risks and traffic congestion) into technical considerations and a design 'toolbox'. Both will serve as references and creative generators along the process. From that engineering-based beginning, the next section will establish the design goals for the new typology: urban integration, sustainability and lifestyle considerations. These design goals, unlike the problem analysis of Chapter 4, will appear as a iterative redefinition of the design problem influenced by the solution (as a result of the wicked problem idiosyncrasy). Thus, urban integration explores how the vehicle design relates to the city and serves as a link between it and the user; sustainability completes aseptic life cycle assessments with the individual and social perception of such a concept; ultimately, lifestyle considerations are included to reinforce the complementary role of the vehicle within its user routine and personality. In the end, the role of these goals is to establish a road map to appeal, as Stephen Bayley says, the irrational side of buyers (Vital, 2010c).

From those three design goals, semantics and a system-level approach will be combined to define the three-stage design strategy that will generate the µcar typology. In this strategy, the system-level approach makes the vehicle architecture manageable from its conception; while semantics are crucial to align the design goals with underlying technical considerations.

The decision to end with the layout design of the µcar typology responds to the fact that the main design advantages will be due to the qualitative minimisation from conventional car architectures, rather than from detail optimization of specific components. Furthermore, details would limit the applicability of this research to a wider scope of scenarios.

Let us start, then with the technical factors driving the generative process.

5.1 Technical factors

The previous chapter analysed urban concerns on pollution, safety and traffic, mainly caused by car use. In this section, those collective aspects will be translated into a set of product-based technical factors. Thus, in the development of the vehicle, the factors to consider will relate to: electric powertrain implementation; design particularities for a small four-wheeled vehicle; quality management; pollution reductions are translated into technical issues related to the use of electric powertrain and the extended concept of vehicle life cycle assessment and cost.

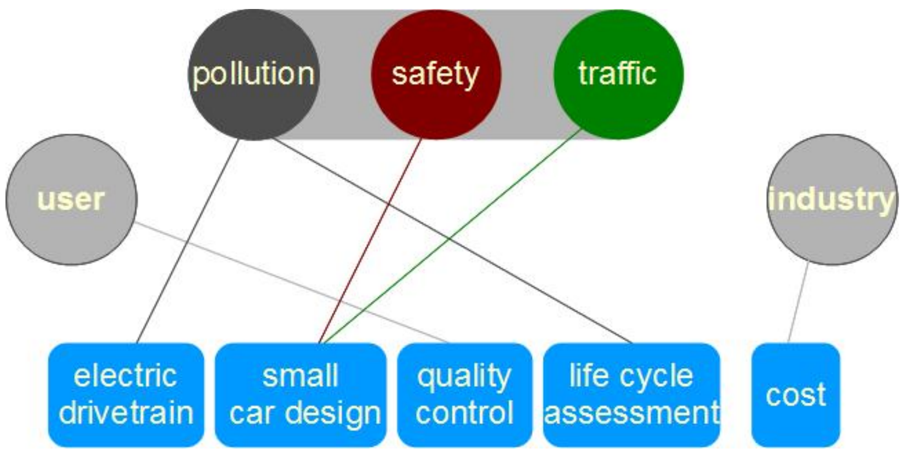


Figure 45: From collective issues to vehicle-based technical factors

5.1.1 Electric powertrain

As we discussed earlier, electric powertrains have great advantages in urban use (zero tailpipe emissions, zero noise and increased 'driveability'). Furthermore, the use of electric vehicles within cities has proven technically feasible (Anegawa, 2009). Therefore, it is important to exploit the design opportunities of the new urban typology in order to maximise the feasibility of this option.

Battery technology is the current bottleneck. There is no expectation of any significant short-term improvement in energy density, but manufacturers will tend towards cost optimization. In that sense, Li-Ion can be considered a reliable standard (AAB, 2010) adopted by several manufacturers. Thus, optimized performance and charging limitations (in terms of charging time and required infrastructure) emphasizes a frugal approach to the design of the vehicle.

In that sense, two factors contribute to reduce loads on the battery pack: *weight* and reductions of *accessory energy demands*. As we saw in Chapter 2, for a low-speed vehicle, weight is more important than aerodynamics in terms of energy consumption. Additionally, ancillary sub-systems such as air-conditioning can reduce range by 25% (Scoltock, 2011a). Beside local optimizations, the approach must include a complete rethinking of the vehicle architecture, distinguishing essentials from accessories. Thus, the design must tightly adapt to the reduced urban requirements (and increased possibilities).

5.1.2 Small four-wheel vehicle design

A small platform suits urban needs and favours the implementation of an electric powertrain. It introduces, however, a set of specific considerations, in contrast to conventional cars. Besides component packaging, these particularities affect passive safety and handling.

5.1.2.1 Passive safety

There are two particular aspects that affect a small and urban typology: impacts against heavier and larger cars; and pedestrian protection. As we saw in Chapter 2, that requires a strong safety cell (with two rigidly-connected vertical levels) to activate the crumple zones of the other vehicle; the absence (or careful design) of a windscreen frame; and the possible implementation of new technologies such as external air bags. Crumple zones may also require, due to the vehicle compact dimensions, the use of composite materials to maximize the use of the available crumpling distance.

5.1.2.2 Chassis design

In terms of handling, the main challenge is sensitivity to load variations (two passengers could represent 50% of the weight of a light microcar). There are two different ways of addressing this sensitivity. The easiest method is to increase suspension stiffness to minimize ride height variation (Riley, 2011). While this option would reduce ride comfort, considering the mobility patterns for this vehicle (short journeys at low speed), the solution can represent an acceptable compromise. Furthermore, this is the cheapest, most reliable and lightest alternative. And it could highlight the fun of go-kart handling (English, 2008). However, for increased comfort, self-levelling systems allow softer suspension set-ups and minimum ride height variations (Hodkinson and Fenton, 2001).

5.1.3 Quality management

Beside safety, perceived quality is one of the greater differences between cars and current microcars. Instead of following the development process of the automotive industry (with its consequently added weight, cost and development time), the urban and electric qualities of this typology can open a new field to generate a idiosyncratic perceived quality.

Road and aerodynamic noise can be considered irrelevant at low speeds (Cerrato, 2009) and electric motors do not introduce the same vibrations as an internal combustion engine. However, without the sound-masking effect of internal combustion engines, squeaks and rattles become critical (Cerrato, 2009), and the contributions of controller coils and the cooling sub-system can be evident.

Nevertheless, instead of typical isolation, the minimal nature of this proposal embraces alternative approaches focusing on transfer path and source control. Simple and optimized structural layouts (i.e.: without cantilevered members or MacPherson domes), part consolidation and minimal interactions will help to manage these issues.

Additionally, the new kind of vehicle can set its own rules. As we saw in Chapter 2, NVH criteria for motorcycles (even mountain bikes) is not the same as for cars. The µcar typology could also define new criteria in line with its minimal and lightweight qualities.

5.1.4 Life cycle assessment

The idea of a simple and light architecture, favoured by the previous factors, is in line with considerations related to life cycle assessment. Additionally, there are other aspects to consider relating to manufacturing, use and 'recyclability'.

In terms of manufacturing, weight-saving materials incurring on higher energy and residual impacts must be restricted to those applications able to offset the initial disadvantage (i.e. due to longer life spans or positive part consolidation). Also, the lighter the vehicle the less energy it takes to manufacture it, as it happens with motorcycles. In that sense, modularisation can introduce a qualitative improvement by reducing the architecture to a set of elements easily handle by mere man-power (cyclecars, with their motorcycle powertrains, enjoyed the same advantages).

Another opportunity to qualitatively reduce vehicle life cycle assessment, also linked to modularity, is the definition of detachable architectural sub-assemblies attending to their life span. Unlike conventional cars, the new typology could renew different elements (i.e. bodywork maintaining the same frame) along the total life span of the complete vehicle. This concept is widely known, in instance, in bicycles, where their technical simplicity allows high levels of user customization.

5.1.5 Cost

Similarly to life cycle assessment, the particularities of this typology (simplicity and reduced design requirements) must generate cost reductions to compensate for its lower raw performance compared to cars (in terms of space and speed). This factor is important (especially considering expected low production volumes) to avoid the definition of the vehicles under the new typology as expensive design items. Alternatively, new modalities of use, such as car clubs, with different business models can offer wider opportunities in terms of materials and processes. However, there are some areas to keep in mind. For example, interior trimming accounts for 22% of the vehicle cost while chassis components add another 13% (Lotus Engineering, 2010). Considering a standard GBP 9,000 electric microcar, those two groups sum up to GBP 3,150.

5.1.6 System-level toolbox

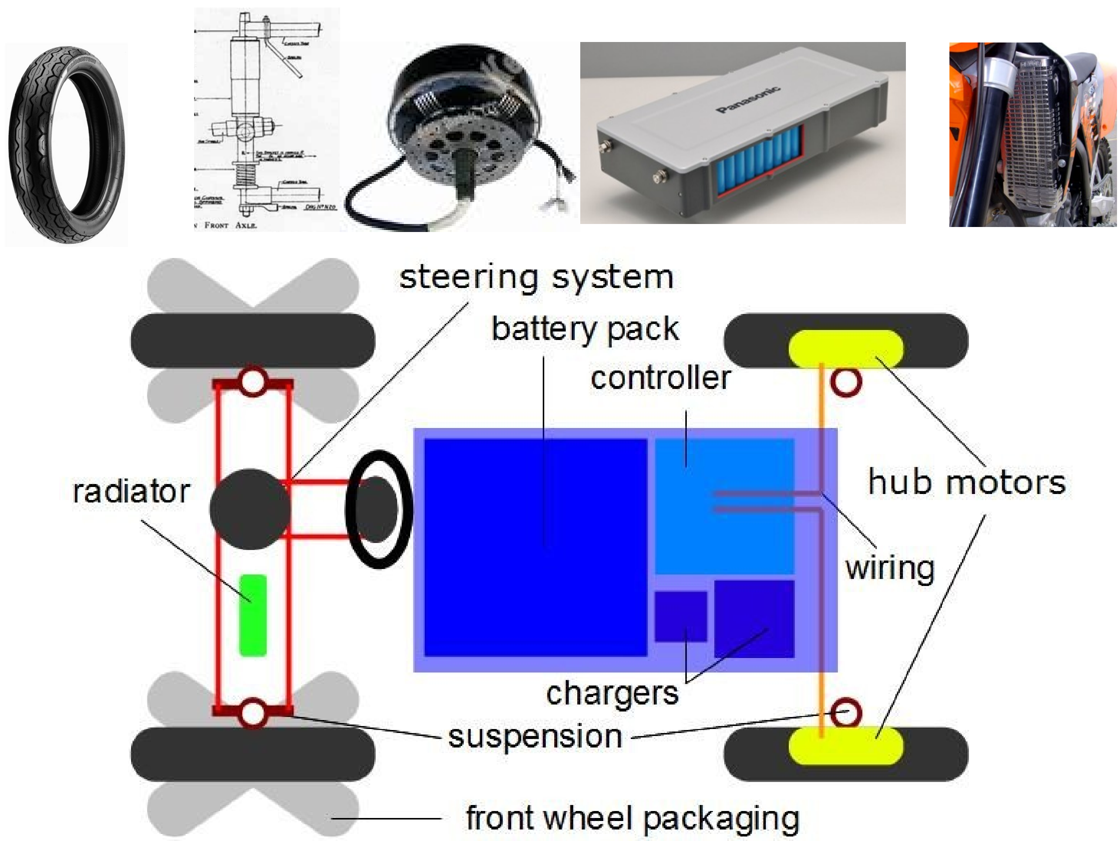


Figure 46: Examples of key components (tire, sliding pillar, 7kWhub motor, 1.5 kWh battery module and compact radiator) and a top view of their layout

Complementing the listed factors, a system-level toolbox will define the main layout of fundamental systems: chassis and powertrain. The diagram above illustrates a starting layout (Body structure will be the objective of the three-stage design strategy contained at the end of this chapter). The idea behind this toolbox is to propose both local solutions, adequate to the reduced design requirements of this urban vehicle, and system-level design triggers, for subsequent improvements in the rest of the architecture. The approach is intentionally '*low-tech*', in order to maximise feasibility while allowing later updates to more modern technologies such as drive-by-wire, or even driver-less control. This toolbox, thus, constitutes an upper limit in terms of packaging.

The original contribution of the typology begins with this design toolbox.

Independently, most of the elements involved are well-known, but the novel combination is a direct response of the modern cyclecar minimalism used by this research to integrate design and purposefulness in the µcar typology.

5.1.6.1 Chassis system

The wheels for the new typology will use large and narrow tires. This option help to decrease rolling resistance (Genta and Morello, 2009), improves ride comfort and favours in-wheel packaging. It introduces, however certain challenges in terms of front-wheel packaging to allow tight turning circles.

For the suspension, attending to the reduced design requirements (low speed and lightweight), this research proposes the use of updated sliding pillars. Besides packaging and cost advantages, this simple layout allows improvements in the resulting vehicle architecture, relating to structural optimization, simplified design parameters and reduced life cycle assessment.

The steering system may be the most original contribution here. It is a cable-operated mechanism with telescopic steering links that are installed concentrically to the suspension pillars. Thus these links transmit steering torque to each wheel while allowing vertical displacement of the unsprung elements. This arrangement neutralises bump steer in the sliding pillar design, while the cable-operated actuation helps to reduce weight, improves front-end packaging and safety (as there is no steering column). The lightness of the vehicle also helps to avoid the use of steering assistance (Hodkinson and Fenton, 2001).

5.1.6.2 Powertrain

Powertrain packaging is one of the main design factors in vehicle architecture. For this study, the components to be included are: motors, battery pack (including cooling), controller and chargers (for battery and ancillaries). For the motors, hub-installed units offer the best solution in terms of packaging for a small low-speed vehicle. They provide 7 kW per wheel, which is enough for the legal limit of 15 kW for heavy quadricycles. The battery pack (Li-Ion) will suppose an approximate packaging of 42 litres and 75 kg for a 9 kWh battery, which layout will be explained in the next chapter (Berdichevsky et al., 2006). This pack will exceed the requirements for typical commuting distances of 10 km (Demographia, 2005). Considering the possibility of fast charging, a cooling system may be required, normally consisting of radiator, pump and pipes. For the the controller, a typical size for a double assembly (one controller per wheel) is 350x400x100 mm. A typical battery charger for a quadricycle occupies 230x135x70 mm, while the dimensions for a DC/DC charger will be approximated to 100x100x70 mm (Kelly Controls, 2011).

5.2 Design goals

After the engineering base for the typology, this section will continue with the design goals that will influence the generation of the µcar: urban integration, sustainability and additional lifestyle considerations.

By embracing its inherent simplicity, the new typology can align those goals with technical minimalism to propose a distinguishable and refreshing concept that responds to aspects unattainable for economically and strategically capped cars. The µcar, thus, allows a fresh start, less constrained by historical references, symbolism or industrial strategies, and more permeable to current social and individual realities, opening possibilities for a better future.

In fact, the reduced absolute performance of the µcar must be considered a catalyst rather than a constraint. Because it will not generate appeal for its size or power output, the new typology must concentrate on its other aspects, thus, becoming eminently urban, an expression of sustainable mobility and a representation of its user individuality.

Let us start the definition of the design goals and, at the same time, continue with the process towards the new typology.

5.2.1 Urban integration

Contextualization as an active element in vehicle design is a relatively novel approach that could help the µcar both to increase its urban validity and to differentiate it from conventional cars. A brief comment on automotive history can illustrate this new design opportunity..

Nineteen Twenty-Seven was crucial in automotive history. It was the year when cars evolved from Victorian technical marvels into the origins of current designs (General Motors, 1958), from niche products for hobbyists or professionals to consumer goods. This shift introduced the necessity of using covers to isolate inexperienced users from dangerous and complex mechanisms; in addition, economies of scale required increased product variety to maintain feasible levels of demand. This situation, with a dose of technical ingenuity (as a result of early stages in technical evolution), contribute to produce iconic products as the ones shown below. All of them are suggesting designs, part of motoring history, but they also illustrate an evolution towards a semantic dimension: *their role as mobility solutions slowly evolved into becoming the object of their users' affections*.

This fact introduces an apparently obvious, but still important, concept in this research: When designs are good and desired, people find joy in their contemplation. But what happens when bystanders do not require such a contemplation? This is especially relevant in urban environments, where cars often become unconnected and obtrusive objects within local spaces. They disturb urban landscapes, claiming for attention with their volumes and highlights and occupying areas otherwise devoted to inhabitants. Moreover, the highly exposed evils of consumerism further highlight this negativity. In that sense, cars do not talk about speed or freedom any more. They express dehumanisation, pollution and burden of human habitats.

We may forgive those sins in examples as the ones shown below, but when smart phones start emerging as the new social symbols (Rayner, 2011), cars can easily become the bullseye of modern developed societies. Thence, the design of the µcar must consider the new context. Its simplicity and limited performance should be used to its advantage, addressing questions that conventional cars cannot. One of such questions would be how to integrate the µcar into sensitive urban environments.

Figure 47: Traditional car design has produced a rich array of motoring masterpieces

5.2.1.1 Designing for new contexts

Nowadays, as a result of globalisation, mega-cities have entered a supranational competition in which life quality is the new battlefield. The need of friendly and adaptable environments is motivating the search for new models of mobility. Cities have to turn back to their citizens, extending pedestrian and green zones. Thus, mobility solutions should be subtle and integrated, adding a sense of community over individualist impositions. However, there is a risk of switching from an individualist perspective into the bland aesthetics of mass standardization. Solutions that neglect personal idiosyncrasies in favour of statistical values will not be able to deal with well-established private mobility (Miller, 2001).

Figure 48: Zaha Hadid's Wirl

We can find illustrative examples of alternative strategies in singular urban interventions such as those by Zaha Hadid (shown above). Her Wirl, in Hong Kong, is an example of 'public' emotion without exclusion; at the same time, it enhances its environment.

5.2.1.2 Designing for new uses

Martin Buber's philosophy can help to guide a design strategy for modern contexts of use and ownership. For him, people normally have a relationship of I-it with objects (Buber, 1937), where the aim is to use or experience a particular object. This is a sign of our pragmatic culture. On the contrary, a relationship of I-you highlights the importance of the object as the catalyst of social (rather than individual) experiences. Although his ideas have been linked with the concept of sustainability (Walker, 2006), here, Buber's thinking is also in line with the modern switch from owning to using objects.

In the present scenario, the µcar should not be a mere object of desire. As we mentioned, it would be difficult to compete with cars in terms of absolute performance or comfort. The charm of the µcar should come from its use instead. It should connect users to the city in ways that car drivers or pedestrians are unable to experience. It has to be a mobile interface with the city, showing it and enhancing the interaction user-context. Thus, the pragmatic I-it between owner and car becomes an I-you between users and cities. The µcar is the new joining element instead of a consumerist end by itself.

5.2.1.3 Designing for new vibes

Mega-cities represent an enticing context for design. These centres are generators of activity. Their rhythms are vertiginous and require constant adaptability. In terms of material culture there are two examples that can help to illustrate how time scales are critical in the development of user-centred design within urban environments: Fashion and Communication Technologies.

Fashion is a powerful semantic tool within urban environments. Their cycles vary with each seasons, thus shows are typically planned 6 month before the season. The evolution of a particular trend follows, then, a fast evolution from introduction, rise, peak, decline to, ultimately, obsolescence (Bharathiar University, 2011) that will also lead to a new introduction. These cycles are becoming even shorter in modern contexts, where everyone can become a trendsetter thanks to new media and, as a consequence, even the seasonal separations are getting blurred (Reddy, 2010). The importance of capturing the rhythm in fashion is evident in the strategy established by Zara, the world's number one textile manufacturer, which is able to develop new products in a record time of 15 days, a huge advantage compared to its main competitors (Ferdows et al, 2004).

The second example, communication technologies, with their latest incarnation, smart phones, is 'usurping' the role of cars as objects of desire specially among the younger generations in urban nuclei (Rayner, 2011). In such a context, the iPhone can be considered the new Ford Model T in Western markets: Four years after its introduction in 2007, more than one hundred million iPhones have been sold worldwide (Warren, 2011). To illustrate how fast this product is evolving, the original iPhone appeared in June 2007; the second new version, iPhone 3G, was launched in July 2008; there was an update, the 3GS, in June 2006, but a completely new model was not available until June 2010 (Taylor, 2011). These fast-paced evolution is a technology-push effect, precisely described by Moore's Law. And that is only considering standard technologies. New technologies could still generate qualitative jumps that increase this rhythm even further.

How does the automotive industry compares with this? Such an example in short time-to-market response as Italian Fiat takes 15 months from technical concept to reality (Wester, 2010), excluding the generation of a new vehicle concept. One of the main obstacles to shorten this time scale is type-approval legislation, especially in terms of safety. Returning to our previous examples, clothes and phones are fairly simple items, which designs are easily evaluated upon standard safety controls. On the contrary, cars are much more complex products that require the coordinated labour of thousands of professionals to manage the design parameters affecting the completion of a single design. And that design has to be evaluated both as a group of independent elements and as a complete assembly, using costly tests. These particularities tend to increase development times to time scales that difficult a synchronization with urban trends or temporal necessities. And this represents a vicious problem: as a result of long development processes, components susceptible of synchronizing with fast trends have to be designed upon long-term criteria in order to be feasibly integrated with the rest of the vehicle architecture.

That is the legislative advantage of quadricycles: As in 2011, European Commission (2002) do not require full-vehicle crash tests, which drastically simplifies the development process of a new vehicle or independent elements. However, such an exemption also contributes to project the unsafe image of current quadricycles. A new type-approval legislation should incorporate safety considerations, while maintaining some of the advantages, in terms of design flexibility, of the quadricycle category. As a reference, some of the most demanding motorsport disciplines require independent evaluation of modules such as crumple zones and safety cells (FIA, 2011) instead of full vehicle tests. Similarly, independent sub-assembly approvals would allow safer and still flexible µcar layouts.

5.2.1.4 Balancing individual and urban acceptance

Typologies based on quadricycle type-approval legislation can contribute to improve life quality in our mega-cities. We showed in the previous chapter how quadricycles pollute less, occupy less urban space and result less aggressive to other citizens. However, in the end, these vehicles have to be either used or owned. Traditional product-centric strategies might help to sell more units, but the proposal of an integrated concept requires a holistic approach that considers the interaction of user-owner and bystander-citizen.

The design challenge, then, is how to propose an acceptable and unobtrusive concept based on a microcar typology. In terms of acceptance, the µcar should appear as an assumable, clear and unobtrusive proposal.

Assumable: As an initial step towards desirability, the vehicle has to avoid rejection or confusion, either intellectual or as a state of mind; this has implications in two different aspects: scale and visual language.

In terms of scale, safety and status have made cars grow bigger. But unlike in intercity trips, urban travelling happens at ever-decreasing low speeds. At the same time, electric powertrains do not require the addition of hoods any more. This allows for human-scaled vehicles, as we will see in the next section.

In terms of semantics, despite their reduced footprint, these vehicles have to remind us of a nutshell. We must certainly move towards a future of smart vehicles able to avoid accidents, but our present is still far from that. Those vehicles designed to share common ground with traditional cars still have to provide a sense of protection.

Clear: The essence of the µcar as a mobility proposition should remain appreciated over the complementary role of typical accessories (even a fully-specified vehicle should keep the minimal appearance of the µcar). This approach could go to the extreme of visually separating essence from accessory, as a metaphor to illustrate how the addition of common accessories can spoil efficient mobility.

Unobtrusive: In terms of exterior design, the approach to the design of µcars should consider it part of urban backgrounds rather than foregrounds. From an individual perspective, µcars should be integrated in users' environments with unassuming and subtle design languages. Such design languages could even foster the generation of secondary patterns with parked vehicles.

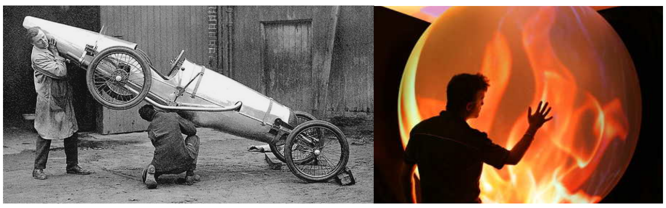


Figure 49: Cyclecar human scale and new technologies generate design opportunities

Ultimately, the µcar could become a useful link between citizens instead of a passive element. New communication technologies combined with the human -friendliness of cyclecars (as shown above) can generate a new breed of vehicles that help to navigate the city in new and seductive ways. Thus, the µcar could become a pair of moving goggles to perceive physical environment through augmented reality. Furthermore, parked vehicles can become virtual interfaces for bystanders, instead of passive metal boxes.

5.2.2 Sustainable vehicle design

The design of the µcar is an opportunity is to explore new design methods that can redefine the relationship between private mobility and sustainability. This section will align the aseptic idea of life cycle assessments with the social and emotional implications currently attached to the concept of sustainability. Such an approach aims to define the new typology as both efficient and inherently meaningful. Similarly to the previous section, an analysis of the current automotive context can help to increase the implementability of the new proposal. Let us start, then, analysing how current vehicle design relates to sustainable design.

Two Thousand and Four was a good year for sustainable mobility, or maybe not. Toyota launched the Prius worldwide (Reynolds, 2004), and it quickly became the icon of green cars in the 2000s (IDSA, 2011). Certainly, as the picture below illustrates, it was not a design revolution, with its bland aesthetics and a well-known K-tail layout (Cumberford, 2009). In fact, it looked like any other vehicle until you opened the bonnet, where a parallel-hybrid powertrain marked the difference. The marvel of reduced fuel consumption and emissions, and the magic of its silent ride contributed to place the Prius in motoring history. But at the same time, discordant voices criticizing the myth appeared. The significant influence of driving style on overall efficiency (Carlson et al., 2009) and doubts about its manufacturing footprint (Power, 2008) made the icon stumble on its way to the automotive Olympus. Clearly, the sustainable message projected by the Prius was more *reflective* than *evident*. This example shows that, in the development of a sustainable four-wheeler, the first step should be to address the implications of such a statement in the visceral, reflective and behavioural dimensions of the design proposed by Norman (2004). A study on the evolution of car design can help to start such considerations.

In the early years, car were conspicuous machines, where their mechanical materiality was obvious in its visual message (see the picture below). Some people loved the technical novelty and the freedom and speed those machines provided; other people considered them menacing, dirty and noisy (Incidentally, those were the reasons for the initial success of electric cars). In other words, what you got was what you could see.

Figure 50: 1908 De Dion-Bouton Type BN and 2004 Toyota Prius

A fundamental change came with the arrival of enclosed bodies and cockpits. As we mentioned before, safety (Maldonado, 1977) and market strategies (General Motors, 1958) motivated the use of panels to conceal the mechanical systems of cars. This fact indirectly contributed to isolate people from the materiality of cars, elevating their connection from a physical to a semantic level. In the best cases, those 'skins' illustrated hidden qualities. But some exceptional designs also concealed poorly executed machinery and, similarly, hideous shapes ruined technical masterpieces.

Either way, the myth of the car grew to become one of the icons of our man-made environment (Barthes, 1993). The new semantic dimension fostered the dichotomy of modern cars in two dimensions of understanding: a functional one, where cars provided freedom and speed, and a mythological one, where cars received human affections. While the mythological dimension was richly nurtured with constantly renewed references to speed, status and freedom, the functional essence of the vehicle became less comprehensible for general users. But as in any mythology, an evil antagonist raised against the idealized image of these vehicles. Thus, in our polluted and congested world, cars also became demons on wheels. Both approaches may be partially right and wrong; however, the inherent complexities of car technical architectures and the automotive industry limit the design field to break out of such a vicious circle.

That is when the µcar typology comes in: its minimalism could be a useful resource to redefine the relationship between urban vehicles and society. How? The first step should consist of a de-construction (and demystification) of the car architecture in order to explore efficiency gains. The new typology has to undress that artificial union between the essence of the vehicle and its accessories, its luxuries. It is not a matter of negating the convenience of four-wheel vehicles (versatile, safe and comfortable), but questioning the need of a V8 and massaging armchairs to travel from Victoria Station to Shepherd's Bush.

From that de-construction, the new typology should define a minimal design that reconnect users with the materiality of the vehicle. Once we understand the real impact (in terms of materials, energy and origin of resources) of our particular way of urban mobility, we will be able to identify the µcar as a truly sustainable four-wheeler.

To analyse the strategy towards this new sustainable design language, such a sustainable perception of the vehicle responds to three different stages, as proposed by Norman (2004): visceral, functional and reflective. The following sub-sections will analyse design opportunities within the automotive context to align the minimal architecture of the µcar with a perceivable and differentiated sustainable message.

5.2.2.1 Sustainable at first sight

To compensate the limited performance in absolute terms, the µcar should offer a clear visceral message that sets it apart as a valid alternative to conventional cars. Its first task will be to transmit safety and quality within the limits of its platform. And, immediately after it, it will have to show its best game: *the µcar will be efficiency on four wheels*.

A recurrent issue along this research is the search for a balance between the accepted image of cars and highly-efficient vehicles. Considering the limitations with respect to conventional cars, the µcar has to appear as a more sustainable design at first sight. At the same time, it should keep some of the most desired features of cars such as safety and convenience.

In order to propose a compelling new concept, it is important to start analysing the automotive context in which the µcar would have to exist. First, we must establish significant similarities that could induce a direct comparison, in order to identify potential weaknesses. Then, we should explore those gaps that conventional cars have left uncovered, in order to define a distinctive image.

The definition of the visual message consists of three design levels volume, surfaces and detailing (Weber, 2009). The next pages will analyse the design opportunities within these levels.

Volume

Let us continue the analysis of the automotive context to position the new typology. The figure below shows the six best-selling cars in Europe during 2010 (JATO, 2011). It gives an approximate picture of our common automotive landscape. Beside differences in detail design, there is a clear pattern: all of them have a *two-body configuration*. The presence of two-body configurations do no stop here. In the same figure, the profile on the right has been obtained by combining the profiles of three different models belonging to the product range of Ford Motor Co (Ka, Fiesta and Focus). The profiles are adjusted to the same dimensions of height and length. In the picture, the division of engine and cabin coincides in each profile, and the only significant differences are found at the rear end (the shorter the vehicle, the higher the rear). Thus, roughly speaking, we can conclude that the resulting designs are mere geometrical transformations over the same theme, even when the Ka is a significantly smaller car.

Figure 51: Top 6 best-selling cars in Europe (2010) and superimposed profiles

In the two-body configuration, the main part is dimensioned according to human metrics. Door width and greenhouse area are decided upon criteria such as accessibility or visibility, intimately human-centred considerations. However, the second part allocates an artificial and independent element: the engine. While engine compartments are usually used to generate strong visual messages (General Motors, 1958), current concerns such as air pollution are transforming the message from a status assertion into '*Internal Combustion Engine Inside*'. The alien artificiality of the engine compartment is further

Figure 52: Prioritizing status symbolism, some cars reach dehumanized proportions

highlighted in modern cars due to modern safety standards and conventional market trends. Ultimately, the extrapolations of these factors have contributed to the development of cars as independent artificial entities that sometimes lose their relationship, in terms of scale, with their human users (see picture below) .

Beside human-scale concerns, recent social awareness on sustainable mobility also highlight the aerodynamic advantages of one-body configurations. The iconic 2004 Toyota Prius (Cumberford, 2004) has popularized the efficiency of one-body configurations. Despite this step forward, its conventional front-engine configuration still defines it within a two-body configuration. However, unlike the other design resources that integrate technical and emotional qualities, the use of aerodynamic design in the definition of a low-speed vehicle can be more emotional than rational, for the influence of aerodynamics at urban working speeds is unnoticeable, as we saw in Chapter 2.

Surfaces

Traditionally, panels have enclosed mechanical components in cars. An outer 'skin' responds to aerodynamics and general packaging, while the inner skin offers an isolated and comfortable interior (the picture below illustrates this idea). This enclosures also add value by design, especially useful in current platform strategies, where common vehicle architectures need differentiation from a user's perspective (Sako and Warburton, 1999).

Figure 53: Conventional vehicle design uses panels to hide internal architecture

However, in current car design, covers have surpassed their enclosing nature and acquired an independent entity by themselves. They form the first impression of a vehicle. Their importance is such that they have motivated new engineering disciplines aimed to consolidate their visual message with tactile and acoustic support (Kunkel, 2006). A similar approach in the µcar would introduce two main disadvantages:

- Increased cost and development time
- Increased life cycle impact caused by the extra weight and additional components (i.e.: ribs or NVH isolating panels)

Moreover, as we saw at the beginning, the 'black box' concept of conventional cars complicates the transmission of visceral efficiency.

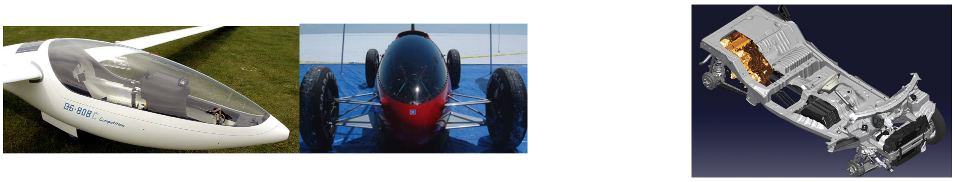


Figure 54: Glider and lakester cockpits and the Mitsubishi I sandwich platform

In contrast, the μcar has to avoid ambivalences, presenting simple surfaces in line with the homogeneous exterior. Such a task is also easier to accomplish with the μcar, thanks to its reduced requirements. Thence, for the exterior, the surfaces should define a continuous and smooth enclosing space. This approach would produce designs resembling highly efficient cockpits, such as those used in sail-planes and 'lakester' race cars, shown above. In terms of interior design, the organisation of space should highlight the importance of the user within the cockpit. Concepts such as sandwich floors (also shown above) easily conceal dangerous sub-systems under the floor panel (Iwao and Kawamura, 2006), creating an open design space. Electric powertrains can minimize packaging intrusions even further, for they can help to avoid mechanical connections. We are left, then, with the need of isolation in terms of passive safety and weather. Exposed structures can be designed to provide the sense of protection we required in Chapter 4, while the external shell would provide weather isolation.

This idea of a uniform shell covering a de-constructed interior helps to highlight the efficient use of the elements conforming the vehicle. Protecting skins would not conform unattainable and artificial volumes any more, for their enclosing nature is highlighted by their segregation from the rest of the structure. In that sense, the materiality of the surface increase the design possibilities with novel interpretations. These can range, as the captions below illustrate, from vehicular cowls or 'jackets' (with outer layers and inner linings) to Möbius-like proposals (playing with the interaction of inner and outer spaces).

Figure 55: Examples of design possibilities for detached enclosures

With respect to the tactility of surfaces, it is interesting to consider some recent reflections on the unsustainable messages emitted by pristine, polished and fragile surfaces (Walker, 2006). Unfinished or natural surfaces seem, then, less industrialized and more in tune with current trends in sustainable design. However, there is a caveat to this rule. The fact that we try to reduce the number of enclosures to a minimum establish a more direct relationship between surface and functional message. In other words, some of those uncovered elements may show some type of 'unsustainable' surface such as those resulting from pressed metal fabrication. This can be seen as a disadvantage, but, cleverly used, it can highlight the tensions between the sustainable future we try to achieve and our imperfect present, defined on the advantages of mass-production methods.

Detailing

Detailing is one of the main resources to generate variability in design. Current business models require continuous detail design variation in order to maintain sale levels. While useful from an economic perspective, this fact can be easily identifiable as a visual sample of consumerist and unsustainable industrial practices. The µcar can reinterpret it to further enhance its 'sustainability by simplicity' message.

Its simple volume and external surfaces help to decide the strategy to use in the outside, as the formal minimalism must be kept to basic elements, in instance, lights, door handle and windscreen wipers. Thus the only detailing should be the result of a *transparent* approach, showing local aspects that cannot be enclosed by the simplicity of the external shape. In fact, this approach is typical in car design, where engine (see the picture below) and wheel packaging on high-performance vehicles originate protuberances in the bodywork to accommodate enlarged elements. Any other detail on surfaces must respond to the strategy enunciated below for the interior. This strategy is based, as it has been the case before, in a demystification of the vehicle. Continuing with this approach, details have to be visual solutions to immediate problems.

Figure 56: Hood detailing as a direct result of concealed packaging

In contrast with the exterior, the interior of the new typology does not have to attend to contextual influences. Its goal is to create an enticing place for occupants, which allows greater design freedom. Thus to continue with the sustainable self-explanatory approach, the first step will be a de-construction of the interior into its compounding units. A design issue with modern products is that they are often conceived as integrated entities and finished units (Walker, 2006). Despite the marketing advantages of this approach, it often contributes to a long-term disconnection between owners and vehicles: cars become impenetrable entities, where users have nothing to do but accomplishing predefined actions. This non-sense reaches the point of some users confronting interiors filled with equally unknown and obtrusive functionalities.

Figure 57: Car and bicycle cockpits

Thus, in the new typology, interior detailing is an opportunity to establish a clear contrast with conventional cars, exposing visually detached functional units that will complement the simple image of the µcar. Thus, air conditioning or audio systems could be disposed as add-on units. The example of a race bicycle cockpit, as the picture above shows, can illustrate this approach. Thus, as in a bicycle the relationship between brake levers and their actuation is evident, in the interior of the µcar typology, users would be able to identify independent systems and their contributions to the whole unit. In that sense, interior details highlight the *relational nature* of the typology, instead of representing mere visual eye-catchers.

Additionally, once these elements are detached from the whole, its physicality will become evident. And here is when we can even use the new design strategy to even question our material culture: We have grown surrounded by an industrial aesthetic that can even be unnoticed in today's life (Dorfles, 1970). Craftsmanship and assumable designs have been relegated to a secondary plane, where only experts or aficionados spend time and money on objects normally outperformed by their mass-produced counterparts. This would not be an issue except for the fact that we may lose the ability to perceive the environmental cost of an object. Unlike with hand-made products, industrial products do not normally visually inform about the material, energy or human effort needed to complete it. In contrast, the new de-constructed approach to the design of the interior can help in this matter: from the initial segregation in elemental units, particular design embodiments can use the organization of internal systems, geometries and textures of independent elements and their interrelations as resources to project self-explanatory cockpits. In such designs, the vehicle would stop being an incomprehensible entity to become manifest in the way it was built and is used.

This reinterpretation of the design of the cockpit relates the visceral perception of the sustainability of the µcar with its functional understanding by users, that will be discussed below.

5.2.2.2 Sustainability by use

Even in the way it is used, the µcar has to transmit obvious sustainability through its minimalist materiality. This affects: the way it works as a vehicle and the way it enchants through interactions with its interior design (briefly described above).

Starting with the first point, the whole user experience has to say 'sustainable' from the moment users open it. That initial sense of unit transmitted through a homogeneous volume and smooth surfaces will continue with the door disposition. Unlike conventional cars, the reduced dimensions of the µcar justify the use of a single door that opens the interior space in the same way as a jewellery box would reveal its content. Occupants or goods enter the space through the same door, reinforcing the idea of the µcar as a contained space. Additionally, this feature can contribute to stiffen the cage in order to protect its occupants.

Minimalism continues when the driver enters the cockpit. Seat belts embrace rather than tie her or him to the structure, reinforcing the idea of the occupant directly linked to a vehicle made to her/his measure, with no intermediary. Seats are part of the structure too, creating aesthetics similar to those of racing cars or lightweight planes.

Inside the vehicle, the occupant faces a console with nothing but elemental driving controls and a dock for smart phones or tablets. The µcar is pure minimalism until the device is tethered to the dock. Then the user can download its own digital universe that will shape tactile interfaces and visual personalization of the interior.

Ultimately, all that minimalism has to be translated into an agile and fast machine. Power output is limited for quadricycles but there is more space to play with acceleration. Low weight and high torque values should be able to produce crisp accelerations. That low weight, together with a quick steering and the low centre of gravity thanks to the battery pack should also contribute to an agile handling in urban driving conditions.

Then there are interactions with added functionalities such as loading space, air conditioning or sound systems. As we started analysing in the previous section, in the µcar nothing is taken for granted. Any added functionality will be clearly differentiated from the essence of the vehicle, even during its use. Boxes will be attached to the structure in case of needing to carry small goods. Air-conditioning systems will be closer to attachable features as those used in racing cars than to conventional vents and concealed ducts. And it will be the same for sound systems. This concept tries to reinforce the idea of minimal motoring explained before.

5.2.2.3 Reflective Sustainability

From a reflective point of view, the role of cars as status symbols has been rich in meanings: designs with long hoods imply power and wealth, mid-engine layouts refer to sportive and young spirits, all-wheel-drive wagons express power and toughness. In contrast, the µcar should be the minimal expression of four-wheeled urban mobility: understandable and close to its user. Its role will be to question the importance of current models of private mobility: do we need all the hype; moreover, do we really need to own the vehicle? The key is to propose demystified designs in line with the spirit of icons such as the Austin Seven or the Mini: it would be a return to accepted minimal motoring to tackle modern urban evils.

Therefore, the main advantage of the µcar is its apparently limiting simplicity. Correctly applied, it can produce an easily assumable vehicle where either the whole product or individual components can physically (visually, acoustically or tactilely) inform about their pure performance. Thus the new microcar can become, not only a tool for urban mobility but a tool for provoking a reflection about the resources and energy employed in such common activities as commuting or leisure urban trips.

This has a secondary effect that connect this future microcar with its Zeitgeist:

the fact that the vehicle makes us consider mobility rather than its own entity displaces the initial attraction generated by cars to our current world where use is more and more important than ownership. This also motivates the switch of mentality to think about this vehicle more as a digital canvas for mobility than as a mechanical or electrical marvel.

That demystification of the vehicle and the emphasis on its use introduces the considerations analysed in the next section, which studies the contextual integration of the vehicle within its urban environment.

5.2.2.4 Towards a sustainable design guideline

Summarizing the previous points, there are two factors favouring the sustainable message that the µcar typology can project: reduced design requirements and flexible packaging. Without the need to load the luggage for a summer holiday or to pack a four-cylinder engine, the main element to package in the architecture of the µcar is at the same time the most important: its occupants. This typology has to be an expression of socially-concerned purposefulness as a private and urban mobility solution.

Thus, the new approach to generate a new aesthetic based on sustainability is the definition of a real one-body configuration in a *manageable* scale. Steve Jobs once said that you identify good design when you want to lick it (Clinic, 2011), in this thesis that idea is reformulated: *You know you have a sustainable µcar when you want to hug it.* This starts with having a physically graspable volume, but it affects to other parameters too: it must contain soft and tactilely rich surfaces and avoid aggressive detailing, hot spots or dirt. Also, it must show this friendliness and human scale through its use.

Inside the vehicle, the interior must provide an embracing and meaningful layout that continues the sustainable message by differentiating essentials from accessories. Moreover, the interior must allow users to reconfigure it, taking away what is not needed or adding customized elements. In that sense, this interaction would reinforce a long-term relationship with the vehicle as a lived moving space, reducing its life cycle assessment by prolonging total lifespan.

Ultimately, this humanisation of both exterior and interior conforms a reflective message of the vehicle as a mobile manifestation of the individual inside rather than an imposition or domination of the surroundings.

5.2.3 Additional considerations on lifestyle

To finish the exploration of these design goals, the last point will centre in the role of the vehicle as an enhancer of lifestyles, relating to the role of the vehicle as an interface to reconnect with the city and studying two examples of minimal motoring converted in lifestyle. Let us start with the urban interface role of the typology.

Our times often forget the joy of travelling. It is true that now we can move across the world in hours, but planes, high-speed trains just *transport* masses. They do not allow travelling. That romantic sense of discovery and experience has been buried in a mess of low-cost flight tickets and bullet trains.

This fact is even more worrying in the cities, where people generally move around without knowing them, without travelling across their streets. This indirectly contributes to an emotional disconnection from the act of moving through urban landscapes until the moment it becomes annoying, in terms of traffic congestion.

New proposals for urban mobility should consider, not just the physical act of moving from A to B, but also the emotional link with the journey. New technologies can help in this matter: Smart phones with augmented reality already allow us to navigate through the city detecting the best spots for leisure or just illustrating relevant facts about our surroundings. It may be useful to consider how this simple technology can help make our lives easier.

With modern smart phones, we can be in a traffic jam (because, despite the µcar, people will still use SUVs to commute in the short term) learning something new about our location instead of being stressed and shouting. We could discover the history of that particular place. That discovery could enhance our state of mind and, moreover, our relationship with the city. Now that we know more about it, it is not a mere stressful environment any more. It is an spoiled place, that had its charm, its humanity but a place that thanks to politicians and speculators lost its soul to become a generator of stress. Now that we know more about it, we will care about it, and will get involved in its care. We, as citizens rather than disgruntled commuters, will not leave its future to people without any concern about it.

Sadly, the use of smart phones while driving is not advisable. But what if we could integrate this functionality in a purpose-designed vehicle interior? Continuing with the minimal ethos of the previous sections, the definition of the new typology should consider this aspects in order to propose interiors designed as a stage to understand the surroundings. Considering the visually and digitally rich environment where these vehicles would work, cockpit design must keep basic detailing to a minimum in order to highlight this organisational role.

Beside this role as a mobile communicator, the new typology must also present itself as a physically interacting platform for user lifestyles. The simplicity of the architecture must be used to highlight this interaction, as opposed to conventional cars, which are normally perceived as inviolable units. For such a task, two sociological phenomena such as café racers and hot rod culture can serve as illustrative examples of urban mobility made emotional and appealing. Café racers appeared during the British counter-culture of the 1960s. These were purposeful motorbikes that started life as standard Nortons, BSA's or similar machines, and were modified eliminating any superfluous equipment to race between trendy cafeterias (see picture below). Riders normally built their own bikes, introducing a high-level of product customization where only base models and idiosyncratic elements such as clip-on bars or tank-seat combos remained constant. One of the most famous examples were the Tritons, bikes that were born from combining Norton's respected chassis with Triumph's powerful engines.

For the μcar, café racers showed that minimal and purposeful vehicles can find its place in certain cultural movements, becoming the ingredient of a lifestyle. A lifestyle that has survived in clothing fashion and modern motorcycle designs, evoking the simplicity and rawness of the original café racers. In a scenario where minimum has to be linked to sustainable, café racers propose an interesting link of desired minimal motoring.

Hot rods provide another interesting guideline in terms of long-term desirability. They appeared as low-cost drag racers for American aficionados. They were 'recycled' old cars, preferably roadsters, where any superfluous equipment such as fenders or body panels were taken away, while power outputs were largely increased. Some of the most iconic hot rods were those based on the 1932 Ford Model B roadster, shown in the picture below. Back in the day, these cars were made famous as getaway cars for the likes of John

Dillinger (Ford Social, 2009), due to the astounding power of their flat-head V8 engines. In the 1940s, these models were stripped of all unnecessary component, saving weight and drastically increasing their performance. Even today, demand of classic vehicles like these is so high that several companies make profitable businesses out of selling replica shells that are completed by enthusiasts and custom shops.

Attending to the design of the µcar, hot rods are an example of how an old platform can survive throughout the years, being infinitely modified and evolved in a process that, despite any objective performance establishes strong emotional links with their creators and users.

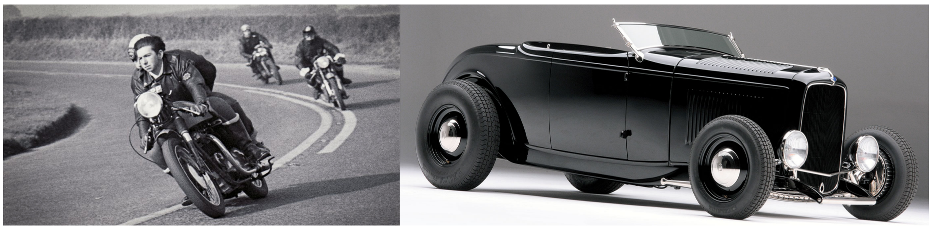


Figure 58: Café racers and the iconic Model B Roadster hot rod

5.3 The Three-Stage Design Strategy

The design goals enunciated in the previous section are integrated here in a design strategy divided in three different stages relating to the external definition of the vehicle (*Latent Design*), its internal essence (*Layered Architecture*) and its subordination as a catalyst of urban experiences (*Urban Mobility Canvas*). Although apparently independent, these stages are mutually influenced with respect to the original goals of producing an urban, sustainable and self-expressive vehicle typology. The exterior is defined by Latent Design, as an strategy to deal with urban integration, individuality and implied efficiency. Layered Architecture outlines the generative process for the internals of the typology, as the generator of emotion for Latent, the humanization of the generic space as a liveable one, and the maximum representation of the efficiency of the new typology. Canvas is a regulatory stage that reinforces the role of the new typology as a framework to self-expression within urban contexts, in the line of fashion and consumer electronics. The following pages will extensively introduce each of these sequences in the definition of the new µcar typology.

5.3.1 Latent Design

The µcar needs a new design strategy, not only because it has to make a sustainable statement that places it as an alternative to conventional cars, but also because, to be a locally-accepted solution, it needs to win over users and citizens with its design. This change is a rupture with those conventional design strategies that try to gather buyers' attention without considering the contextual integration of their product.

How will it be possible to combine two apparently incompatible design requirements: passing unnoticed for citizens and attracting users? This research tries to solve this design problem with a new strategy: Latent design. It is summarized in two different design principles:

- Minimal external design
- Internal spatiality

The core concept of Latent Design is not new. We can see examples in nature and other design disciplines such as fashion. But a systemic approach that minimizes other design resources to the minimum is new in this research.

Figure 59: Nature and fashion already 'use' Latent Design

The major switch comes from a skin based approach that isolates users from material essence of vehicles into a new vision where depth of field takes the protagonist role, where the appeal of the design is latent rather than obvious.

But how could we develop a design approach that combines subtle and individualistic qualities, depending on whether we consider bystanders or users? We may find some help in Barthes' photographic analysis. He identifies two common elements present in singular photographs (Barthes, 1993): Studium and Punctum. Studium refers to the conventional qualities required in a fine picture: balanced composition and correct use of light are examples of Studium. In contrast, Punctum is the unexpected, what enchants and cannot be easily explained with words: any element that is out of place. In the picture below, we find Studium in the composition of the still-life. The Punctum, however, emerges in the unusual treatment of the bottle, which materiality appears ambiguous: is it a glass bottle or just two black stripes?

Applying that analysis to the µcar, Studium refers to the design resources aimed to project both subtlety for bystanders and acceptability for users. Alternatively, Punctum refers to any other resource aimed at attracting users' attention within our self-imposed external constraints. In other words, Studium help to produce an assumable starting point for the design, while Punctum is the latent element that generate attention or the desire to use the vehicle.

The next pages will continue this approach focusing on external design and also considering the implications in terms of interior design.

Figure 60: Light treatment generates the Punctum of this photo (by Lino Vital Hidalgo)

5.3.1.1 External shape: unobtrusive container

The key in the design of the exterior of the µcar is how to communicate the message aimed to users with such a subtle language to avoid any visual disturbance in the local environment.

Here, visual minimalism is the key. It starts by defining the message that needs to be transmitted to users in the most simplistic way. In instance,

moving space open to the city

It is a space (the user's personal space) opposed to public scenarios. It is a moving space, because it is a mobility solution. And it is open to the city, because we still have to navigate through urban environments.

Once we have defined the message to transmit, we should express it using as few design resources as possible to continue the frugal ethos defining this typology. We must transmit the message without any supplementary signifier.

Space

One of the most universally-accepted symbols of private space is the image of an egg. It has been recurrently used by artists and designers as a symbol of primal shelter, protection, origin, friendliness or even love (some car-related references are shown below). In chaotic and stressful urban environments, where users look for physical and psychological shelter, the egg appears as an embracing space, a promise of relaxation and protection. And, unlike more complex volumes, its essence is constantly assumable from any point of view: The sense of compactness and containment is unspoiled even from a three-quarter view, so important in the design of a new car (Squatriglia, 2010).

The pure oval shape also relates, as we saw before, to structurally and aerodynamically efficient designs. In instance, sail-plane cockpits, where weight is a critical factor, resemble this archetypical shape. It breaks with the aggression of artificial environments too, forming an isle relating to the spiritual dimension that sustainability has acquired in our time (Walker, 2006). It is also an assumed shape that do not produce any discordance nor tries to gather attention because of its novelty. We can say that is the minimum expression of a private and embracing space.

This approach is not, however, an intent to reach a future of bland neutral shapes. The egg image also provides a sense of mystery to the design: It is a question about its content. The focus is then on the 'universe' contained within its surface rather than on the surface itself. It does not talk about speed or powertrain but about its content: a liveable space.

This role as a link to its interior rather than a mere isolator also enhance an ambivalent relationship in-out, so much needed in a vehicle aimed to relate to its environment, instead of occupying it.

Figure 61: The simplicity of the egg enriches the semantic possibilities of the µcar, from abstract concepts, through childhood memories to the iconic bubble cars.

Another advantage in the use of ovoids is the new possibilities it opens in terms of pattern formations: identical shapes or eggs of different proportions can visually interact with the others forming urban design compositions, where we can imbue concepts such as rhythm and movement for the whole picture. This approach is clearly contrasting with conventional parking lanes where heterogeneous shapes normally create visual disturbance and annoyance.

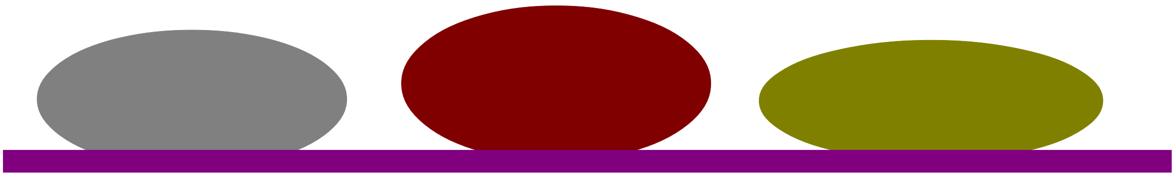


Figure 62: Simple ovoid shapes can help to conform new urban patterns

Moving

Mobility, in this case, is communicated by the presence of four wheels. In order to preserve the purity of the initial volume, an open-wheel configuration will be used. This approach eliminates, in instance, the added meanings that wheel arches can provide and keep the bubble shape easily identifiable. It also suppress the existence of unexplained black spaces normally generated between wheels and arches in fully bodied vehicles. Moreover, this visual simplicity relates the typology to ultra-efficient vehicles such as bell tank racers or Shell eco-marathon racers.

The use of open-wheel configurations has an important role in the visual message, apart from obviously technical implications. The absence of details that help us to redefine the perception of proportions leaves that task to wheels. Furthermore, the necessity of distinguishing the image of the µcar from conventional cars can motivate a change in the relationship of scale of wheels to wheelbase. Thus, the wheels can be used as a design resource in two different ways: *Position* and *Size.*

Position: As the photo next photo illustrates, in the early days of car design, the relative position of wheels was a resource to produce a sense of dynamism or status (Amado, 2011). The design of the µcar will recycle that design principle.

Size: A uniform oval shape around occupants and basic packaging can produce a challenging shape from the designer's perspective. Diameter and width are two elements that can be used to find a new balance and define a new solid image, different to that determined by conventionally enclosed cars.

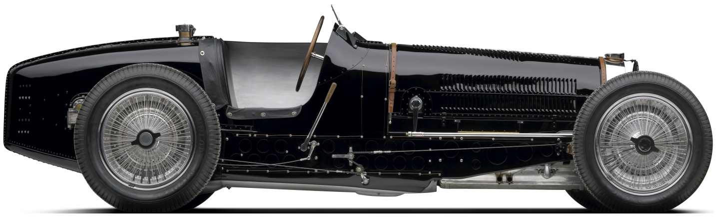


Figure 63: Open-wheel layout as a design element in a Bugatti racer

Open to the city

New technologies will presumably give us autonomous driving while smart materials are opening new possibilities in design, such as glazing that can switch from opaque to transparent with the twist of a knob (The Glass Radiator, 2009). The essence of the µcar concept is compatible with those developments, which would enhance the urban qualities of the new typology. However, the µcar also responds to a short-term scope. And besides technological readiness, we may be still too far from having such devices approved for open-road traffic.

Therefore, there is still a need of driving and navigating through the city. It is even desirable considering a multi-media relation with the city. This introduces the necessity of having a transparent opening. Visual minimalism continues to drive the method here. Traditional greenhouses can be considered car-centric resources. They gather attention to technical architectures and tend to constrain visibility from the inside. Furthermore, they introduce hard-points in the body structure representing serious risks in terms of pedestrian safety. The approach here follows the division of the initial shape by purely geometric transformations that help to maintain that simple approach to the totality of the vehicle.

As there is another obvious requirement to open the vehicle for ingress-egress reasons, the visual minimalism can be taken to the extreme of combining those two openings in one element, similarly to transparent canopies in gliders.

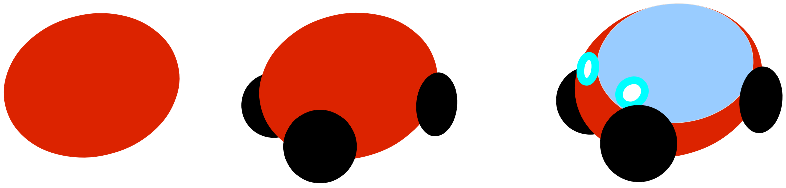


Figure 64: The sequential definition of the exterior (space, moving, open)

5.3.1.2 Internal shapes: latent appeal

Latent design opens new creative possibilities in the definition of the internal shapes. While exteriors are defined as collective urban elements, interiors are the link between the generic shapes and the individuality of their occupants. Thus, occupants are ultimately the target of the interest generated by the vehicles. In that sense, we can appreciate a switch from protagonist skins to membranes aimed at highlighting the content space.

That perception through skins can be visually enhanced using a vast array of resources such as:

- spacial distributions, generating a depth of field
- different grades of transparency, filtering and highlighting different shapes
- colours, modifying the spatial perception
- lights and shadows, enriching semantic possibilities and modifying the spatial perception too

Figure 65: Examples illustrating design possibilities with simple enclosures

Continuing with the photographic analogy, those resources will generate the Punctum of the µcar, which could be expressed through physical or digital elements: Physical elements are mainly aimed at satisfying expectancies of protection, comfort and performance; Digital-lighting elements are aimed at both enhance physical elements and facilitate communication.

Those digital-lighting elements become more important considering the variability of Punctum upon contextual conditions, time and different types of users. In instance, frightening environments could favour sheltering messages, while relaxing contexts would foster extroverted interpretations. It would be costly to offer individual physical solutions to each situation. However, an integrated approach where interiors are designed to interact with different lighting conditions and virtual elements can help to tackle this variability.

5.3.2 Layered architecture

In the previous section, we started defining the µcar as an ovoid on four wheels, containing a self-expressive interior. With layered design, we analysed the definition of the vehicle architecture that generates this new vehicle typology. As it happened with Latent Design, two goals characterise this stage: minimizing the drawbacks of car use within cities, and in doing so, proposing a desirable alternative to cars themselves.

This differentiation to cars and the search for increased efficiency is what initiates the generative process. Paraphrasing McLuhan's (1967) famous quote ('*The medium is the message*'), in current car typologies, *the skin is the car*. Structural and packaging optimizations have reached such levels of visual complexity that user perception is mostly limited, letting performance aside, to the image and materiality of body and trim. Thus, reacting to the 'black box' concept of current cars, the µcar presents itself as a a stratified whole. It is a de-constructed unit where exposed relations among sub-systems become a design resource to highlight purposefulness and efficiency. The bodywork of this typology is just the external layer, an enclosure for the interior. Other independent layers under it will add new properties to the whole vehicle jointly conforming.

In certain ways, reduced urban requirements offer an opportunity to return to the nearness and simplicity of old motoring icons such as the Citroën 2CV. In a vehicle where the only abundant resource is simplicity, a de-constructive approach to its design can project a differentiated image of efficient mobility.

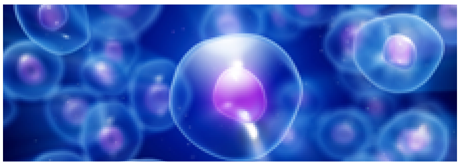


Figure 66: As in a cell, the bodywork of the µcar is just one of the layers forming the whole, a layer that simultaneously isolates and constitutes a communication tool

In addition to supporting sustainable design, this de-constructed or layered architecture also embraces a novel approach to vehicle modularity as modularity-in-use. Modular architectures allow reductions in investments, development costs and time-to-market in vehicle production (Wester, 2010); specially for a disruptive vehicle typology aimed at fast-paced and uncertain urban contexts, the effects of aspects such as time-to-market are even more important. Modularity also aligns with recent and more human-centred industrial strategies such as economies of scope over impersonal mass-production (Sako and Murray, 2000). Even from a perspective focused on mass customization, modularisation can be successfully combined with Decision Point Analysis or 'de-coupling' (Holweg, 2000), contributing to more efficient synchronization between manufacturing push and market pull.

To define this eminently modular architecture, system-level analysis can open up the creative possibilities embedded in the technical architecture. Automotive design processes use this stage to link abstract concepts with detail design phases (Sobek, 2006). Here, it is used as a tool to enhance the design possibilities of the new architecture, in line with the creative role defended by Prof Bruce Archer in his days at the Royal College of Art. It becomes a reflective method that analyses the functions that a vehicle has to perform, distinguishes essentials from accessories and, ultimately, organizes them into feasible, coherent and appealing manners. This approach is illustrated by the work of Frank Gehry's studio, where processes are divided in two stages: an introductory stage, where the goal is to assure the feasibility of an initial standard proposal; the second stage, where, knowing that it is possible to find a logic solution, architects work on the problem from completely new perspectives (Boland and Collopy, 2004). Here, the initial stages of feasibilities are covered with both numerous examples of local solutions (Hodkinson and Fenton, 2001) and small city cars and microcars (that have shown the possibilities, in terms of safety, range or packaging, of producing feasible proposals). The new approach of this research aims to recombine the vehicle architecture to provide further efficiency and design identity.

The next sections will describe the process of development of the layered architecture, which consists of three different stages: definition of functional groups, interfaces and, finally, architectural layers.

5.3.2.1 Functional groups

The first stage consists of the decomposition of a standard vehicle architecture into elemental functional groups. The goal is to detect heterogeneities and other factors that would trigger the stratification of the µcar architecture. This includes topological constraints attending to their function, lifespans and relative importance within the whole vehicle architecture.

Thus, we can define the following groups: basic mobility, safety, type-approval requirements and added conveniences.

Basic mobility refers to the function of the vehicle as the simplest embodiment of four-wheel mobility. It packs chassis (wheel assembly, suspension and steering) and powertrain (battery, controller, chargers, motors and cooling) systems in a simple structure which main requirement is supporting both components, occupants and luggage. In terms of topological constraints, the electric powertrain avoids the need of using a mechanical transmission, but even though, there must be a structural connection between wheels. This fact, plus the convenience of providing a flat loading surface and stability suggest a low and centred layout. In terms of lifespan, because of its essential nature and relatively slow rate of technical evolution for both chassis and powertrain, we could define it as a durable element. It may be true that batteries could evolve towards more compact packages, but even though, an original design considering a larger unit will not be invalidated but improved by such changes.

Safety will add passive protection for occupants and pedestrians to the basic mobility group. As we explained before, it should consist of a safety cell surrounded by crumple zones, arranged in a two-level layout able to withstand impacts and minimize intrusions. Additionally, considerations on pedestrian protection introduces the need for either a careful design of the windscreen frame (to avoid head injuries), or a alternative frame-less design all together.

Another functional group includes the requirements stated by type-approval legislation (in this case, European L6e and L7e) for vehicles used on open-roads. These requirements mainly refer to lighting (lower height limit and minimum left-right separation), anti-tampering measures and windscreen accessories for bodied vehicles.

In the deconstruction of conventional car architecture towards the definition of the μcar, the last set of functional systems encloses all those functions that can be considered secondary to those considered essential for mobility. While these functional systems are taken for granted in conventional cars, the seek for an efficient urban dweller motivates questioning any single element compounding the vehicle, and its relationship with the whole system. Thus, the last functional group refers to aspects related to comfort (weatherproof or air conditioning) and additional functionalities (navigation or sound systems). The lifespan of these elements can be significantly shorter too. In instance, even though the basic external form defined by Latent Design may not change at all, trends or even technologies can introduce variations in materials and processes (from an IKEA-like injection-moulded shell to a handmade textile canvas). Similarly, communication technologies and smart materials could also motivate short-term renovations of external enclosures or internal sub-systems. The following table summarizes the proposed groups.

Functional group	Topological constraint	Time scale	Relative importance
Basic Mobility	Low, centred, structural access to wheels	Long	Basic mobility
Safety	Upper and lower levels (rigidly connected), protection against intrusions and roll cage Possible packaging of additional elements such as external and internal airbags (front and side)	Medium	Open-road mobility
Type-approval	Front, rear and lateral areas for lighting and windscreen packaging	Long	Open-road mobility
Added convenience	Weatherproofing, infotainment interfaces, air conditioning	Short	Accessory

We can see the utility in the definition of these functional groups relating them to different use scenarios. For example, the requirements of an indoor low-speed application (such in an airport or shopping mall) would be efficiently covered by the Basic Mobility group, generating a practical flat-bed vehicle similar to the original Red Bugs. An open-road application in warm climates may only need the addition of passive protection and type-approval requirements, proposing a concept equivalent to a 'naked' motorcycle or a beach buggy. Ultimately, a urban run-about for London would also require the convenience of a bodywork.

The concept behind this functional categorization, which will be ultimately materialised with the definition of the architectural layers, is the use of adaptability as a core value in the generation of the typology, to achieve increased sustainability and business opportunities.

The next step to concretely define them is to explore their relational possibilities with a definition of the interfaces.

5.3.2.2 Interfaces

The second stage of the definition of the Layered Architecture consists of a definition of the connecting possibilities that will allow the subsequent definition of architectural layers within the µcar.

In projects where modularity defines the architecture of the product, interface specifications must be defined in the early stages of the project. In fact, this definition clarifies the degrees of freedom designers will have in the subsequent design process (Sanchez, 2000). The importance of adequate interface management is also crucial if we consider aspects such as lean manufacturing (Holweg, 2000).

From the perspective of the design of the µcar, interfaces refer to the links between layers and within them. Moreover, the particular exposed nature of the typology increases the relevance of these configurations: both visually and tactilely, interfaces have to adequately perform, additionally to their technical specifications. The heterogeneity of the different layers will also influence interface configurations. As the life cycle of a flat-bed platform (Layer Zero) will probably outlive that of the cage, it is important to consider design-for-disassembly in the design brief.

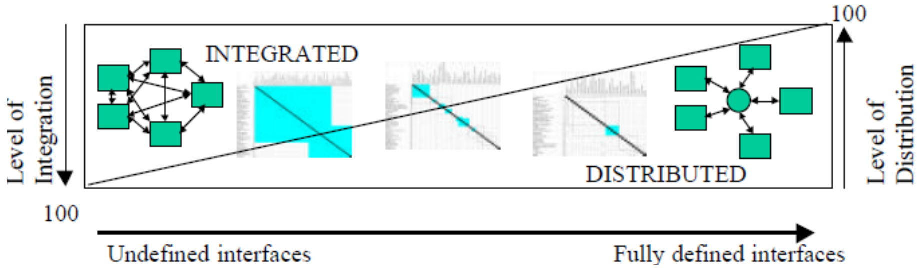


Figure 67: Extracted from Bylund (2002)

In the interfaces, we can distinguish the following types (Sanchez, 2000): Attachment interfaces, Spatial (volumetric) interfaces, Control and Communication interfaces, Transfer interfaces, User interfaces and Environmental interfaces. Specifically for the µcar typology, we have:

1. Attachment interfaces: They refer to the physical connection between components of the technical architecture.
2. Spatial interfaces: In simple terms, we can refer to them as packaging constraints. In this proposal, due to the simplicity of the architecture, they practically define the design field.
3. Control and Communication interfaces: It refers to communication links between components. It could be physical (i.e.: wiring connections) or virtual (i.e.: wireless connections).
4. Transfer interfaces: It refers to the links between what enters the system and what exits it.
5. User interfaces: They include two different types of interfaces
    1. Those related to user interaction with the µcar, or a sub-assembly (human interface)
    2. Those related to how the µcar interacts with a user's "macro-system" context (i.e.: smart phone interaction)
6. Environmental interfaces: Again, there are two different types
    1. Those referring to the interaction of the µcar with the intended urban environment. These include:
        1. Functional constraints, such as passive safety protection, recharging connectivity, public/private infotainment
        2. Life cycle footprint
        3. Visual integration within urban contexts
    2. Those referring to the ways one component could affect the functioning of other components in the µcar in unintended ways. We can mention the thermal loads imposed by the powertrain.

From this extended list of interfaces, we will synthesize it in two main groups: *Layer Interfaces (*including attachment and control interfaces) and *Design*

*Interfaces (*including spatial, user and environmental interfaces).

Layer interfaces

Among layer interfaces, we can talk about primary and secondary interfaces. Primary refer to interfaces between layers, and can be structural or non-structural, depending on the role of each layer within the architecture. Secondary interfaces relate to connections within the same layer.

Primary interfaces

Structural connection

The design considerations to define this interface are: Load transferring, Life span discrepancy and Design exposure (both visual and tactile).

In terms of load-bearing capabilities, it is important to select an interface configuration that allows optimal structural performance for those Layers containing the bearing elements needed for basic mobility and passive protection. The load cases for a vehicle are bending and torsion, with allowance for suspension and crash impact loading. As the performance of the flat-bed element is limited in each of these modes, another layer will likely work as a reinforcement.

Another important consideration is life cycle assessment minimization. As we mentioned, the sub-systems related to Basic Mobility could easily outlive a particular body layout (that may evolve to incorporate different functionalities on to the same platform). In that sense, a detachable architecture would help to minimize overall environmental impact. However, this layout could also introduce a design compromise, for a seamless integration could favour structural efficiency and perceived quality. Although it is an aspect to bear in mind, the uncertainty of the social and economical context this typology may be fitted in suggest, at least in the early stages, the selection of temporary attachments.

An ubiquitous choice for a temporary structural connection is the use of bolts. Automotive manufacturers successfully use them in the attachment of structural sub-assemblies such as suspension sub-frames.

The only consideration to make on bolted joints is referred to the exposed nature of this vehicle typology. Interface design should allow for preferably invisible wiring connections between layers. Hollow beams could help in this matter, by internally routing wires and pipes. This solution has been adopted in bicycle and motorcycle design and can be easily implemented in an architecture developed from scratch. Beside visual connections, in terms of NVH, it is important to consider that the use of sound-deadening materials is restricted in the µcar. It increases design complexity, weight and cost. Thus, special attention must be paid to the source of noise and vibration. Considering that the µcar is designed to travel at low speed in urban journeys, the main concern will be to minimize squeaks and rattles. For bolted joints, there are two solutions that can be combined: rubber bushes and the use of double-shear joints. This latter solution adds clamping capabilities to the joint, which helps to improve the structural efficiency of the architecture. As a result of this clamp force, it also minimizes the relative displacement and friction between connected elements, subsequently reducing the appearance of squeaks and rattles (Wang, 2010).

It is worth to mention that in the definition of this structural interface, there is a compromise between ride comfort and handling that refers to the position of the bolts and the use of body isolators. Direct placement over the main load nodes (either input or transmission nodes) would help to optimize the structural design of the vehicle; however, it would also create a 'clearer' transfer path for NVH sources, specially those caused by road inputs. That is the reason why in body-on-frame architectures where comfort has priority over weight reduction (i.e. American pick-up tracks), the design guidelines are exactly the opposite (GM, 2012). Additionally, the NVH benefits of using body rubber insulators in the structural must be compared with their effects in structural design. In terms of handling, these isolators will tend to reduce overall stiffness. For passive protection, the impact behaviour of rubber bushes would affect the behaviour of the overall structure (Centeno, 2009), especially here, where their influence on the modular architecture could be higher. Nevertheless, the eminently low-speed application of the µcar typology reduces the relative importance of road-sourced NVH (Cerrato, 2009), allowing a simpler and structurally optimized layout.

Non-structural connection

The design considerations affecting non-structural interfaces are: Life span discrepancy and Design exposure (both visual and tactile).

As there are no structural requirements involved, the design of the interface panels-frame is more flexible. The disparity between life cycles for aspects such as passive protection and weatherproofing again induces the use of detachable joints rather than bonding or welding. Furthermore, easily de-attachable panels could increase the adaptability of the typology to temporary trends or weather conditions.

Thus, with the absence of structural requirements, design considerations relate to product design issues, fittings and, principally, minimization of squeaks and rattles. In that sense, the most important aspect is, first, to assure solid fixtures and, second, to minimize NVH panel radiation. The latter affects the layout of the connection points of the panels with respect to the surrounding structural elements. Thus, loads must be transferred through the frame, avoiding transfer paths that include the panels themselves (Wang, 2010).

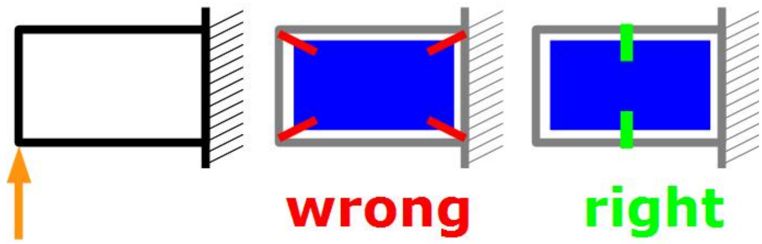


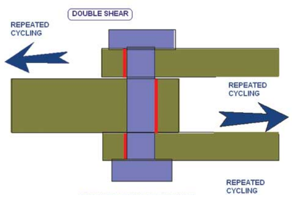
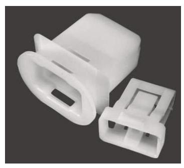
Figure 68: Example of attachment layout to avoid panel radiation

The previous diagram illustrates with a simple example how panel radiation affects the layout of the connectors. Considering a rigid square frame (i.e. door frame), supported by one side and withstanding a vertical load, a panel attached to the main nodes of the structure would tend to constrain the degrees of freedom of the frame, becoming a bearing member, and, thus, radiating vibrations and noise. On the contrary, the connections of the panel shown on the left do not interfere with the natural deformation of the frame (similar to a parallelogram), but moves with it (assuming minimum moment transfer). While this is an extremely simple example that does not account for the geometrical complexities involved in common arrangements, it still illustrates the design principles to follow in the definition of the μcar architecture and specific embodiments.

After considering the requirements for the non-structural layer connections, snap-on connections seem the preferred choice. These joints are easy enough to allow users to change panels (preferably plastic-made) by themselves with simple tools. For the μcar, considering the requirement for unobtrusive and visually seamless joints, snap-on types such as bending hooks or resilient clips (Bosch, 2011) can allow convenient and compact local designs. This solution is a proven attachment method for interchangeable panels as the one used in the smart fortwo, where external body panel is attached with clips and bolts.

<u>Secondary interfaces</u>

In terms of secondary interfaces, we can distinguish between those related to modularisation in assembly, and those linked to modularisation in use. The first type relates to manufacturers. They normally define them to assure interchangeability between their existing modules. The second type refers to user customization. Anchor points for luggage sets or different accessories have to be included within the layers, especially those containing basic functionalities. These systems exist as fairly standard designs in both the automotive and motorcycle industry. Again, the main concern in the design of secondary interfaces is to minimize squeaks and rattles, through well-fixed and simple designs, and to integrate them in the visual message of the µcar. In that sense, the current offer of fixture designs provides a high level of possibilities to both enhance visceral and functional design. The following table summarizes the design considerations and includes some examples of the proposed joint solutions.

Type	Design Considerations	Example	
Primary structural	Compromise between structural design and NVH issues	Double-shear bolt	
Primary non-structural	Avoid either structural loads or NVH issues	Snap-on clips	
Secondary	Important role to increase emotional and functional possibilities	Numerous options	

Design interfaces

While layer interfaces are biased toward the technical aspects of the µcar architecture, design interfaces define the playground between designers and engineers. We can establish three levels, corresponding to the layers: base interface, external interface, frame, front-wheel wells and canopy opening

Base interface: It is the initial constraint imposed by the flat-bed platform. Its main task is to locate occupants and cargo space. In a conventional vehicle, this interface could be just a flat floor. The minimal ethos of the µcar, however, suggests the integration of seat lower segments and cargo support.

External interface: It is what defines the space of the µcar, as we saw in the previous chapter, a simple shape developed upon contextual and individual parameters.

Frame: It is the space interface defined by the protective cage. Its role is crucial in the organisation of the internal space contained within the ovoid exterior. It relates to mechanical components, but more importantly, to users. In that sense, safety is a priority. For example, the design of the interior will have to allow for large run-down spaces that could help to decelerate occupant masses in the event of a crash (Riley, 1994).

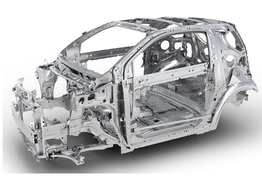
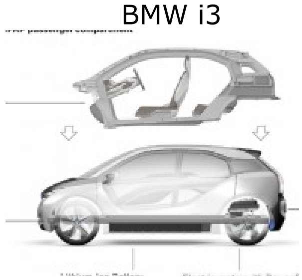
Front-wheel wells: One of the most important design aspects in the µcar, the space around the wheels. Apart from obvious packaging constraints, the definition of this region is crucial to project a message of simplicity and efficiency, especially if that space interferes with more than one layer.

Canopy opening: Another important region in design terms is the canopy opening. In the µcar, the absence of conventional door layouts helps to simplify the image, but, at the same time, concentrate design parameters. Ingress-egress, visibility and even safety have to be combined into a single design element. Moreover, the opening could cut across different layers, having to offer a clean and appealing interface.

5.3.2.3 Layer definition

After the definition of functional groups and interfaces, this section will describe the layers that form the new architecture.

The first step is a brief analysis of recognised structural layouts within four-wheel architectures to decide which one is more suitable for the topological requirements of this architecture. Three are the most typical configurations for four-wheelers (Hodkinson and Fenton, 2001):

Type	*Body-in-white*	*Punt structure/ space frame*	*Body-on-frame*
Example	Toyota IQ 	Lotus Elise 	BMW i3 
Pros	Maximum structural efficiency	Low volume production Design flexibility Reasonable efficient Allows open-top designs	Design flexibility
Cons	Null flexibility Mass production	Medium solution	Inefficient

Modern cars use body-in-white layouts, which provide the highest structural efficiency, for the body itself is a structural member. For the design of the µcar, however, the architecture needs to be flexible enough to cope with, first, the uncertainty linked to any disruptive proposal, and second, urban trends and contexts. At the same time, it needs to offer a reasonable level of structural efficiency, as weight reductions are critical both for the general concept and the use of the electric powertrain. These considerations, together with the expected low-volume production expected for the short-term future of the microcar market (Shankar, 2011), bias the choice towards a punt structure. Using a punt structure has also the advantage to develop open-top designs as required in the design strategy with the canopy, and suggested by safety design criteria for pedestrians.

Now it is time to adapt the initial punt layout to the particularities of this typology, specifically, distributing the previous functional groups in a three-layer lay-out that correspond to different utilitarian scenarios suited to the design strategy. The conventional punt configuration consist of the following elements: Floor, Front bulkhead, Dash upper panel, Side panels, Rear parcel shelf, Rear bulkhead, Boot Floor and Boot sides.

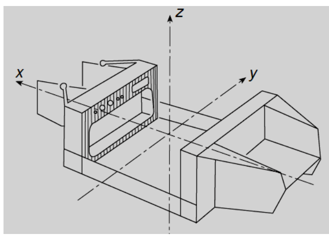


Figure 69: Conventional layout of an automotive punt structure.

The µcar, however, introduce the following particularities: ultra-short wheelbase and layered segmentation. Due to the reduced dimensions of this vehicle, the front bulkhead directly receives the anchor points for the front wheels sub-assemblies. To allow packaging space for the front wheel and optimum load distribution, two additional elements connect bulkhead and side members behind the front wheels. The dash upper panel also integrates with the forward bulkhead. Due to the simple architecture and thanks to the use of hub motors, it is possible to replicate this configuration for the rear section, creating an almost symmetrical layout. This allows to maximize the use of internal space while greatly simplifies the design.
Referring to the disposition of the layers and the assignation of functional groups to them, the following diagram shows the structural layout while the table below explains the configuration:

Layer	Systems contained
Zero	Basic mobility (indoor areas, resorts) • Chassis • Powertrain • Basic driving loads • Integrated floor-seat structure Safety: Lower level of the safety cage, withstanding 60% (approximately) of horizontal impacts
One	Type-approval requirements (i.e. Lighting systems, Parking brake) Safety: Upper level (withstanding 40%, approximately, of horizontal loads), roll cage, seatbelts anchor points and crumple zones
Two	Added functionalities (specific scenarios) • Body systems ◦ Canopy/door subsystems ◦ Body panels subsystems • Information systems ◦ Controls: tactile, visual, gestural ◦ Output: projected screens, physical screens, visual systems

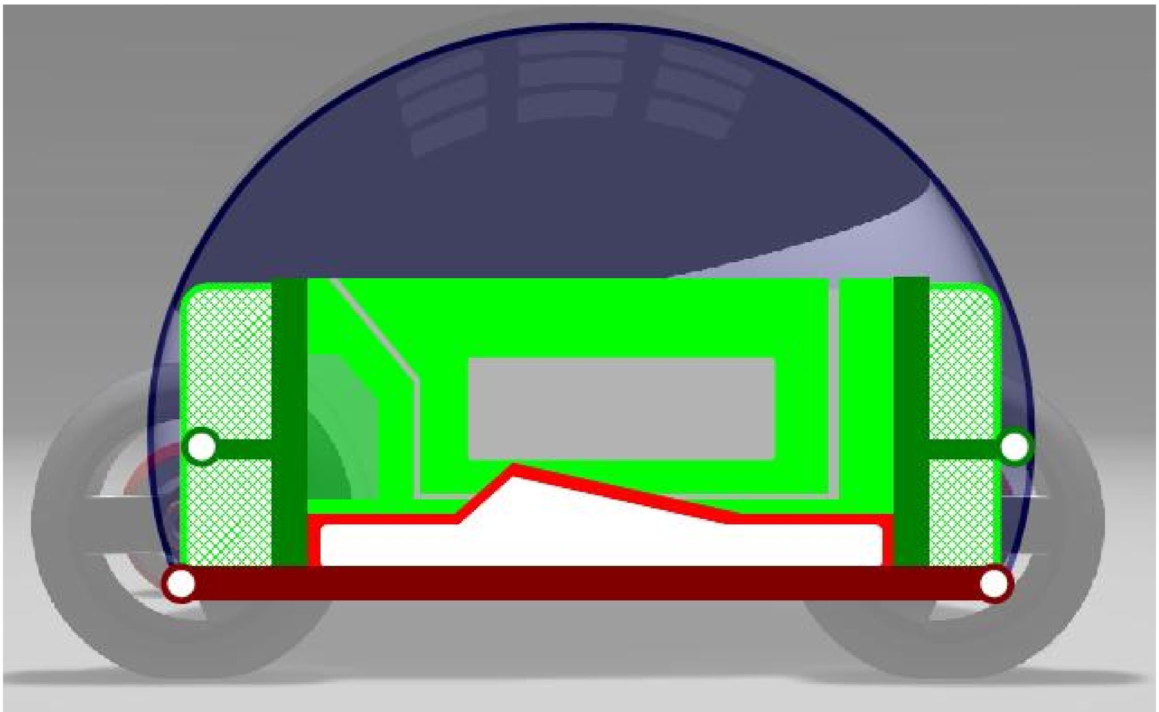


Figure 70: µcar structural layout, with Layer Zero (red), One (green) and Two (blue)

Thus, in the Layered Architecture, the platform corresponds to what has been called Layer Zero, the middle structure is Layer One and the enclosure corresponds to Layer Two. The next pages will further describe and provide design guidelines for each of them.

Layer Zero: Basic four-wheel mobility and structural core of the µcar

Layer Zero provides the basic convenience of a four-wheeled vehicle platform. It constitutes the lower boundary for any µcar design proposal: A common core that identifies all µcars as vehicles defined within the same family. In that sense, it represents for the µcar what Harley-Davidson's archetypical V-twins represent for every custom motorcycle developed around their engines.

In automotive terms, the closest equivalent to Layer Zero would be the concept of shared platforms. However, in conventional cars, shared platforms are hidden in order to generate product differentiation (Sako and Warburton, 1999); while Layer Zero is an exposed design element that provides identity to a family of µcars. It is visible for users and must be also designed attending to aesthetics, tactile qualities and isolation from hazardous elements.

The diagram below outlines the general layout of Layer Zero. The structural layout is a straightforward balance between enclosed packaging and load paths. it consists of two main rails that join the suspension pick-up points of both sides. Front and rear cross-members join both rails while the integrated seat-floor frame also serves as a reinforcement. Relating to packaging, Layer Zero encloses the sub-systems providing basic mobility. Battery, controller and charger are contained inside a structural box element formed by the floor and an under-body panel. The hub motors are placed inside the rear wheels (next Chapter will explain the reason for this configuration). Also, this layer supports the chassis sub-systems (suspension, steering and braking). Thanks to the packaging space saved with the sliding pillar suspension, the powertrain radiator can be placed in the area occupied by conventional front control arms.

For structural calculations, Layer Zero can present two different scenarios: independent body structure or core module of a complete vehicle. As an independent structure, this Layer can create a flat-chassis vehicle, adequate for indoor low-speed activities or recreational use. In that case, the loads are mainly static. However, for the whole vehicle, Layer Zero must withstand an important part of the impact loads in terms of passive safety (approximately 65% of the total impact). Additionally, the main members will be used to connect Layers Zero and One.

As core of a complete vehicle architecture, Layer Zero is also a critical element for NVH. It either transmits (road input) or contains the main NVH sources (cooling system and controller coils). Additionally, the multiplicity of components included can be a source for squeaks and rattles. Here, careful structural optimization and simplicity, apart from their obvious advantages, can help to manage these quality aspects. Additionally, the use of a sandwich panel for the floor-seat combo and the minimization its apertures can also isolate occupants from the main NVH sources.

In terms of manufacturing options, Layer Zero allows greater flexibility compared to Layers One and Two. Attending to its functional requirements, variability of powertrain or chassis elements is slow. And even when, for example, battery packs can be reduced, the initial design space could be filled up to obtain increased performance. Thus, Layer Zero allows the adoption of more expensive or less sustainable manufacturing processes, for their advantages during the use of the vehicle will be able to offset initial costs (Mallick, 2010). However, options will be limited by break-even points that, considering typical quadricycle figures, will be well below 80,000 units per year. Thus, rather than pressed steel, Layer Zero will likely use aluminium or composite materials, which have lower tooling costs (Mallick, 2010).

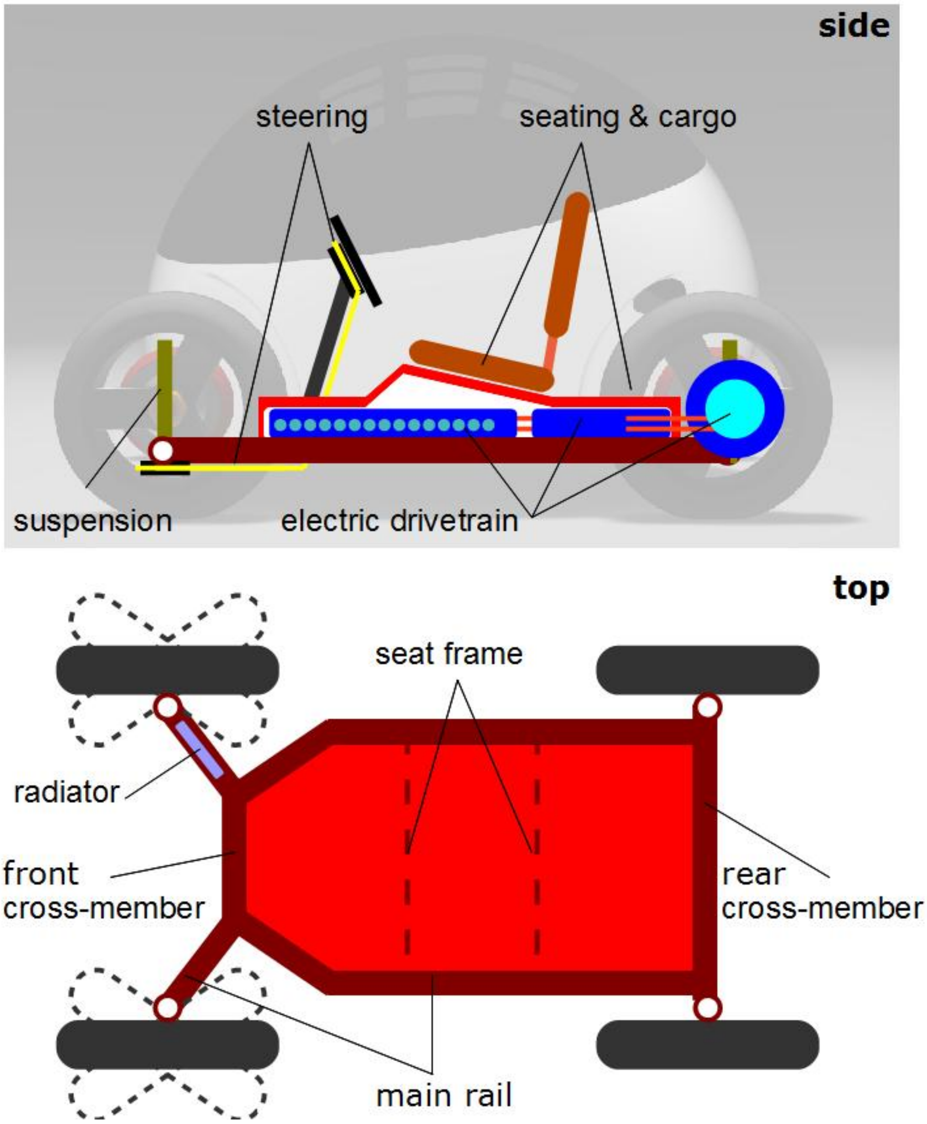


Figure 71: Layout of Layer Zero

<u>Design considerations</u>

Considering the simplicity of the element and its long life cycle, the design of Layer Zero should be marked by structural optimization, interaction with the different sub-systems (elements and interfaces) and a minimal design language able to withstand temporary trends.

Another important guideline in the design of Layer Zero is imposed by its long life span. As the basic constituent, whose requirements would remain constant, Layer Zero can sustain the longest life cycles among the different layers of the µcar. This will reduce its environmental impact and justify the use of a different approach in the selection of materials and processes in order to minimize weight. Its longevity could be even taken to the point where the same unit can have different types of vehicles attached to it along a single lifetime. This fact favours atemporal design strategies rather than futile trends. It can be an interesting design resource in ethical terms too.

In that sense, Layer Zero is our reference point for a desired future. Mass-production aesthetics and industrial materials with long-lasting finishing can generate obvious contrasts with, for example, a natural-fibre composite frame. And this contrast can be a powerful reminder of our starting point: The current context that has allowed us to have mobility, even by means that could ethically scandalize us. Even worse, solving some of such dilemmas is our reach as individuals. This tension manifest our inability to project a better future by ourselves (Eco, 1973). But, in the end, it motivates our actions to walk towards it.

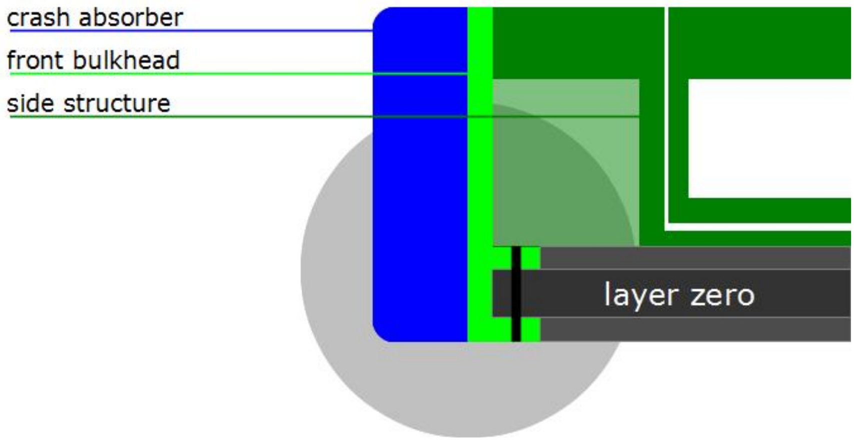
Layer One: Open-road mobility

To the basic mobility provided by Layer Zero, Layer One adds impact protection and type-approval requirements which allow the use of the vehicle on open-roads. Beside this functional addition, Layer One is the core of the design individuality within the framework defined by Layer Zero and the external layout resulting from Latent Design. As the design of this layer is expected to embrace a greater share of creativity for each particular design, the definition expressed here is more flexible than those related to both Layer Zero and Two. It merely refers to the basic principles and layouts based on the main functionalities.

An automotive equivalent of the vehicle resulting by adding Layer One to Zero would be a type of buggy. An exposed vehicle that lacks weather protection but offers, however, full structural support and protection.

As we mentioned before, the use of electric motors and batteries allows a nearly symmetrical structural disposition. Thus the following diagrams illustrate the front and lateral sections. The front section shows the front bulkhead, attached by a double-shear bolted joint to Layer Zero. This component is crucial within the architecture, for it distributes impact and handling loads to both the Layer Zero and the upper part of Layer One. It also offers support for the upper pick-up points of the suspension; the front crumple zone; lighting modules with sensors and, possibly, front external airbags for pedestrian protection; and the pedal set (brake and throttle). The rear end of the vehicle presents a similar layout, excepting airbag or pedal set packaging.

Front layout



Middle-section layout

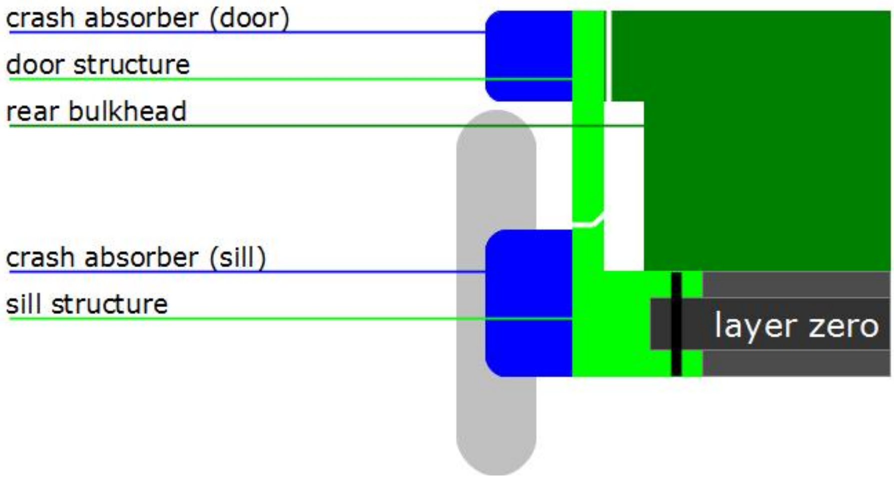


Figure 72: Layout of Layer One (main sections)

In the lateral section, we can see the door/lateral frame again attached by double-shear bolts. Although the structure remains symmetrical in the layout, the use of a single opening only requires a door side. The other shares the same layout but would be fixed for increased overall strength. The lateral also shows the packaging space for upper and lower lateral crumple zones. The inclusion of these elements is due to the urban use of the vehicle (where lateral impacts at crossroads can be more common) and the need for improved passive performance to offset the reduced size and low weight, compared with conventional cars.

Layer One is also important in terms of wiring packaging. As the µcar minimizes the use of cockpit enclosures, the Layer layout must allow a clean packaging of the wiring for lighting or other functionalities. This can be accomplished by placing such elements between the main frame and the crumple zones.

In structural terms, Layer One completes Layer Zero to provide full impact protection and dynamic handling. As we mentioned before, this affects the location of the structural connections, placed at the bottom of the front and rear bulkheads and between the wheels and the lateral frames.

Layer One will also play an important role in NVH management. Although it does not contain any direct source of noise or vibration, it represents a an exposed transfer path where squeaks and rattle can become an issue. Furthermore, as the surrounding frame will support the body panels and canopy, the structural optimization of this layer will help to reduce panel radiation (Wang, 2010).

Compared to Layer Zero and considering the modular adaptability of this architecture, the choice of materials and manufacturing processes can be more limited by life cycle assessment. However, as it was mentioned before, the ultimate selection would be the result of a detailed comparison between the weight saving potential and the lifespan of specific components.

<u>Design considerations</u>

As we mentioned before, Layer One must generate the differentiation between µcars, and thus, the design guidelines must be kept open. However, there are some design aspects that are common, such as the need to highlight the protecting elements in a type of vehicle (quadricycle) commonly perceived as unsafe. Thus, unlike powertrain and chassis, safety systems must be noticeable design resources for the µcar. While a future of autonomous impact-avoiding vehicles is inspiring and increasingly feasible, the short-term scope of the µcar restricts the design options to current urban environments. In such contexts, the µcar would be significantly smaller than the average four-wheeler. Thus, it is crucial, not only to offer a safe design but also to use protection systems as a design resource. In the end, perceived safety motivated the commercial success of pseudo-off-road vehicles in urban nuclei.

Therefore, semantic obviation of the protecting role can both work both as a resource to enhance vehicle perception and also align the design with the required structural optimization (topological and local).

However, Layer One is not just a space frame for the µcar. It is the linking element between occupants and the enclosed space defined by the outer layer (Layer Two). It is the differentiator, which provides to every µcar its individuality; it is the generic space humanized; it is the mobile platform becoming part of its users, embracing and interacting with them.

It concentrates all the lyricism, based on a system-level approach enriched with meaningful detailing. This minimal technical architecture maximizes the design possibilities of the components contained, and it can use basic functionalities as design tools too.

The fact that Layer One is also the distinctive element for every µcar induces the adoption of a triple perspective for the design, considering:

- Interior design
- External visibility of the interior through Layer Two
- External exposure of the interior for uncovered versions

This process can also establish an iterative process between Layer One and Two, as the divisions and transparencies on the enclosure can be used to enhance the external exposition of Layer One.

Its design resources are both physical and virtual. Among physical features designers will be able to combine three different groups of elements:

- Protecting structures become entailing elements that visually organize and complete exposed internal elements
- Technical detailing can enhance the visual qualities of the interior.
- Seat and cargo area constitute scenarios for possible lifestyles, evoking the chicness of minimalist mobility.
- Additional functional sub-systems can add design resources for differentiated proposals

Layer Two: Full urban mobility

Layer Two is the external enclosure of the µcar, which establishes its spatial limits and isolates occupants from weather and indiscreet looks. We can associate the idea of the µcar covered by Layer Two with the iconic bubble-cars. But, unlike conventional cars, Layer Two also works as a link with the exterior: It showcase the essence of the µcar and, with the help of new technologies, it can become a tactile interface for urban augmented reality.

The only concern, in terms of packaging, is to keep the minimalist exterior, outlined by Latent Design, unspoiled.

Considering its life cycle impact, Layer Two would have the shortest lifespan. With supporting structures carrying all the loads in the vehicle, the functions assigned to Layer Two are fairly simple and susceptible of being aligned to short-term trends. Thus, it is important to consider materials and processes with minimum waste and energy consumption. At the same time, recycling stages play a significant role for their design.

In terms of manufacturing and recycling, shortest scope, easily recyclable and simple materials. Considering additional functions, important design for disassembly, clips.

<u>Design considerations</u>

In terms of design guidelines, the main strategies for defining Layer Two were exposed in the previous section on Latent Design. It is also worth mentioning the importance of the following factors in the design process:

Ingress-egress: from a design perspective, this is an important element in the behavioural interaction with the car. Common strategies can pursue maximum practicality while other approaches can seek suggestive resonances or simply highlighting other values such as protection.

Internal exposure: As we have seen, this research proposes a design strategy were the generator of Punctum (see Latent Design) resides in the internal disposition of elements rather than in its generic enclosure. Thus, from this design perspective, a fundamental role of Layer Two is the enhancement of its content. The design of this element may include iterations in order to highlight Layer One.

It is worth mentioning, at the end of the definition of the Layered Architecture, that in the design process, each of this layers are interrelated. It is an iterative process where the value of the final design resides in both each individual layers and their combination.

Such a cyclic process open a new field of creative possibilities with the only constraint, (at a design level) of responding to the contextual and technical requirements enunciated above. Assuring this values in the design is the main purpose of the third stage of this strategy.

5.3.3 Urban Mobility Canvas

The last stage of this design strategy has a supporting and regulatory function linked to the other two. It must reassure that both the exterior and interior of each design proposal fits within the urban and individual character of the typology.

An interface with the city

Relating to its urban nature, the µcar has to be, not just an urban mean of transportation, but a tool to recover that link with the journey, with the city.

Here is where the use of simple shapes proposed in previous sections becomes an important resource: minimally shaped volumes do not distract from their main role as ordering spaces, as individual mobile 'universes' from which we process all the information coming from urban environments.

In that universe, the transparent canopy becomes our personal celestial dome, a viewpoint for road traffic and urban environment. It enhances the view (providing safety and emotion) instead of distracting our attention towards the interior of the vehicle. This simplicity can also establish a synergy with new communication technologies as augmented reality and projected information on windscreens. Here, the absence of conventional divisions and constraints imposed by headliners and A-pillars enhance the possibilities of the interior as a digital interface with the city where users can find navigation information or, more especially, contextual information about their surroundings.

And this functionality of the µcar as an interface with the city is not restricted to drivers. Modern business models such as those followed by car-sharing companies can support the production of private-public vehicles. In this case, canopies of parked vehicles can also serve as interacting interfaces with by-passers, showing targeted information such as local marketing or information about the place.

A canvas for mobile lifestyles

The example of café racers showed how relatively accessible vehicles as 1960s motorbikes allowed high grades of customization according to some users lifestyle. As in 2011, thanks to the ubiquity of internet, everyone can become a trendsetter. In order to produce a meaningful proposal for the city and taking advantage of its minimalism, the µcar has to provide a canvas for those innovators within a motoring context. The new vehicle should increase its possibilities of customization by adapting physically and digitally to its users. In order to maximize its role as canvas, the µcar must restrict its physicality to those design considerations unattainable for common users. These considerations include general design parameters, safety systems or general vehicle technology. The idea is to propose a platform able to open a new field of expression, currently closed for trend-setters or social innovators, through urban mobility.

At the same time, technical minimalism and reduced requirements allow new possibilities to rediscover the joy of the journey in a short-distance scale. The minimalist µcar can become an updated heir of that lineage of idiosyncratic raw minimal motoring of the past. Space limitations in the µcar do not allow the same grade of convenience of conventional cars. However, the design of the µcar as an adaptable platform, rather than a finished container, reinterprets old design clues based on add-on luggage sets and purpose-built platforms. The potential reopened by these design possibilities is immense. To the common element that would be the 'neutral' µcar, the addition of personalized suitcases or boxes can help to project a complete 'mobile image' of its users. Commuters could add stylish laptop cases and a modern picnic set for after work amusement; artists could attach specialized boxes to contain photographic equipment or paintings. Thus, the image of the µcar in use is structured by its common elements and individualized thanks to each users' necessities.

This personalization could even extend to users garment too, reincorporating elements from the past, such as goggles, helmets and dust covers, in modern keys that allow to integrate new functionalities, as those generated by new media technologies. Thus, we could imagine fashion lines directly identified with the vehicle, or luggage sets with forms defined by the vehicle.

The following figure include some inspiring examples of past motoring, which can be revitalised thanks to the minimal definition and modularity of the µcar interior.

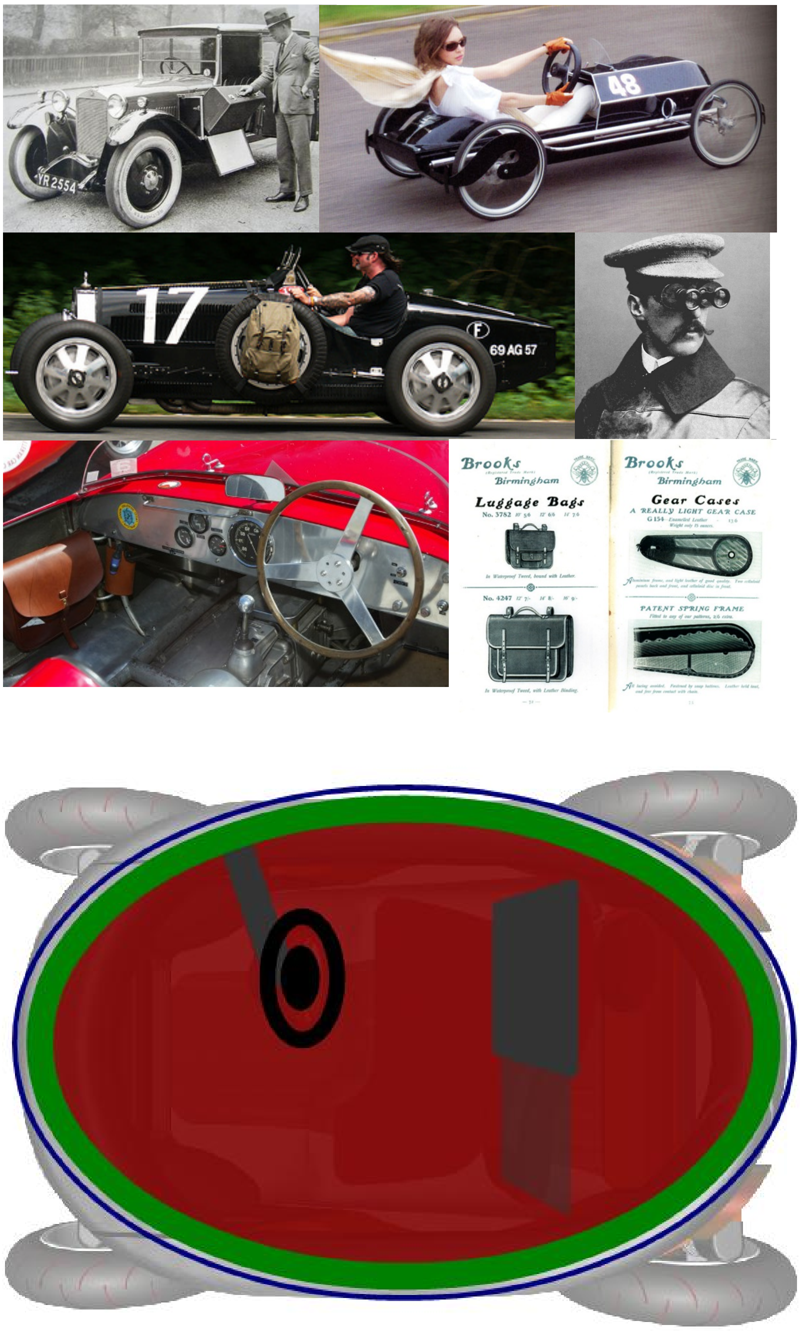


Figure 73: Lifestyle add-ons could foster a long-term relationship with the vehicle

To assure this adaptability, the Layered Architecture must be filtered through a sub-stage that manage the influence of the complexity of the different sub-assemblies on the whole proposal.

5.3.3.1 Complexity management

Using motorcycles and hot rods proves to be a vast source of inspiration on the design of bare metal concepts. However, there is an important aspect to solve in the application of these influences to create a new design language: in both café racers and hot rods, mechanical elements can be considered idiosyncratic. Similarly, their common audience has a well-defined taste for these types of raw vehicles. But what happens when the proposal has no direct historical links in terms of vehicle architecture? What would be the equivalents of the flat-head V8 engines or the Norton chassis for the new typology? Moreover, how would a naked vehicle architecture appeal wider audiences than motor enthusiasts?

It is worth noting that, in general the concept should be easily identifiable as a friendly small vehicle and an efficient way of moving around within the city, with the convenience and safety of four wheels. Visual elements blurring this message would have to be filtered, and every contributor must be placed in context.

Therefore, this design needs a strategy to help in the definition of the visual disposition of the different elements forming the vehicle. This strategy should enhance elements that could help to 'complete the picture' and hide or minimize those that could spoil it, applying what Krippendorff (2006) calls *cognitive smoothing*.

The strategy followed in the design of the µcar establishes a sequential filtering process for different elements of the vehicle architecture. This filtering process starts by selecting meaningful elements. From a visual perspective, there are technical elements that are simply too complex, dangerous or enclose too many design parameters to introduce visual requirements in their design briefs. Thus, the first stage would separate them into the group of components that would be hidden. The next stage evaluates the convenience of using certain elements upon the predefined design philosophy. Those withstanding have also to avoid local design conflicts within the vehicle architecture. Ultimately, the filtering processes helps to decide which, among the selected elements, would acquire a predominant role in the design, and which would be visual supporters.

Within this filtering, electric powertrains have greater potential than conventional engines as design resources. The substitution of mechanical for electrical connections and formability of batteries increase their visual possibilities. And, especially in a vehicle architecture such as this one, where exposure is favoured, they can introduce new design values of simplicity and efficiency. In that sense, from a design perspective, most of the mobility sub-systems can be considered a design 'commodity'. These groups of elements are normally composed of standardized components with little to negative (due to their complexity) visual effect in conventional vehicles.

Therefore, we can conclude that the design of elements related to mobility sub-system has little, if not negative (considering induced complexity), possibilities of adding value to the visual message proposed with the μcar.

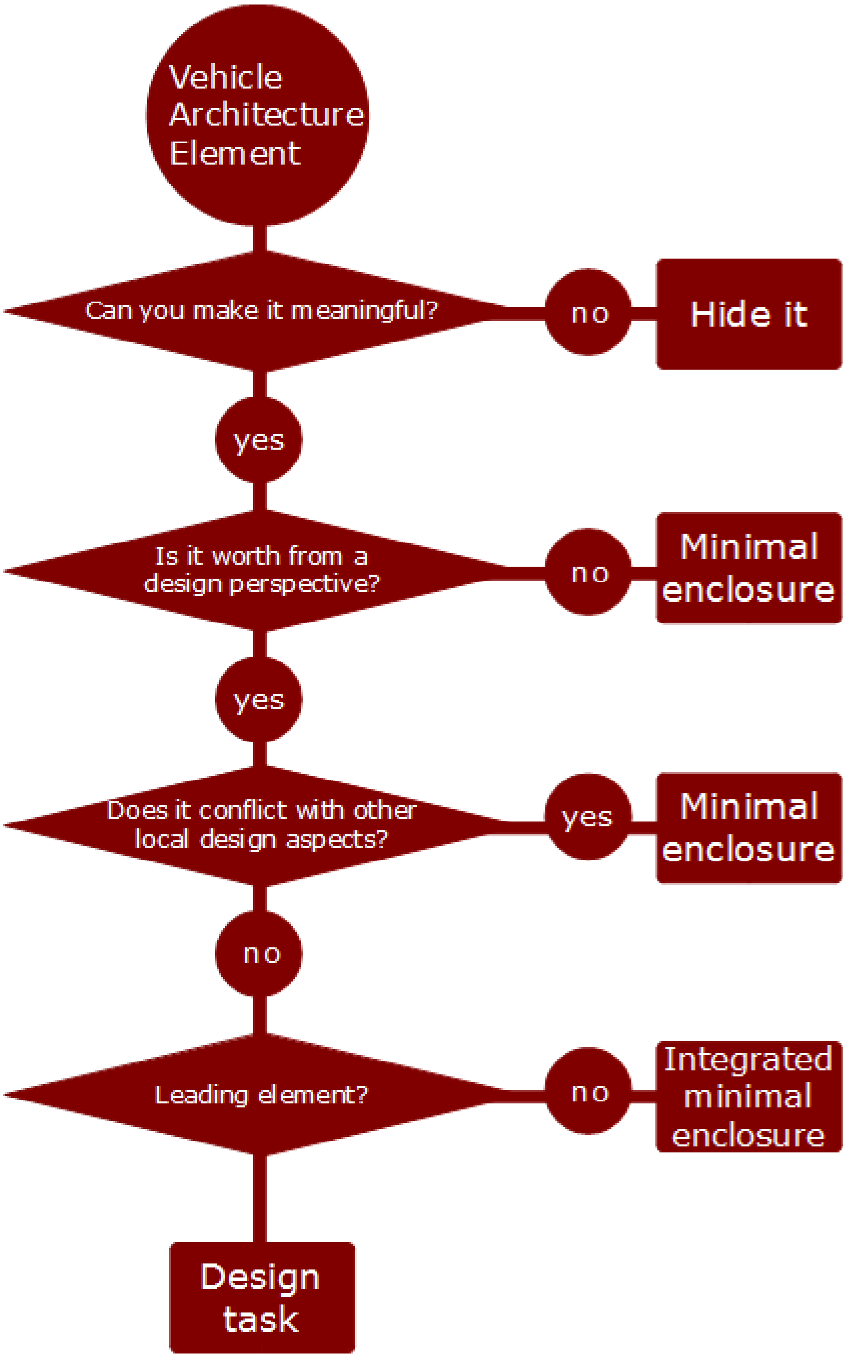


Figure 74: Decision tree proposed for the management of design complexity

The previous diagram shows the decision tree presented in this stage to manage the use of the different sub-systems as design resources.

5.4 Summary

This chapter has contained the design strategy for the new typology of urban electric vehicles: the µcar. In this section, the need of sustainable design was aligned with the inherent simplicity of the new architecture to generate a distinctive and idiosyncratic image. Similarly, the consideration of the context, both physical and social, as an active element in the definition of the design further differentiated the µcar as a valid and purposeful alternative to cars within modern mega-cities.

Such an extensive analysis ended with the definition of the original 3-point design strategy, that integrated the cited design factors with other secondary aspects into a systemic definition of the new typology. Latent Design concentrated on the definition of the exterior of the µcar as a subordinate and assumable shape that translates individuality to the definition of its essence, treated in the staged named as Layered Architecture. Here, the typical definition of the car is de-constructed in a new way that highlights the efficiency and adaptability of the new proposal. Ultimately, the design principles defining the vehicle as a catalyst of urban experiences is exposed in the Canvas Design sub-section. Such a strategy has combined semantics and a system-level approach to integrate the subjectivity linked to design with the objective goals related to technical aspects and life cycle assessment. Let us remember how the main lines in this design strategy align with some of the main technical concerns: The performance limitations of current batteries is addressed with the minimal design, which contributes to save weight and reduce the number of components. This approach also contributes to produce vehicles with reduced life cycle impacts. Layered Design also used the modular strategies of automotive platforms as a design resource to enrich the possibilities of the new typology.

Chapter 6 will focus on the particular embodiment that helped to validate this typology and also exemplifies a particular design within this rules.

6. Methodological embodiment of the μcar

As we saw in previous chapters, the methodology for this research includes the development of a concept vehicle that will help to support and verify the main hypotheses introduced. That concept vehicle has been evolving along the research work into a particular embodiment of the new typology. It is worth mentioning that despite the relative importance of this design in the completion of this research, it is a mere example of the design strategy proposed here. Thus, while general packaging and design aspects are relevant to validate the new vehicle architecture, detail design can be considered a by-product. With respect to the work shown in the previous sections, this vehicle, shown in its latest version below, is an embodiment of the design principles: a short-wheelbase proposal for two occupants, designed upon Latent, Layered and Canvas guidelines.

Nevertheless, despite the secondary importance of design particularities, the embodiment required a further definition of the design strategy in order to complete the aspects not included in Chapters 5. This section illustrates those points and also describes the evolution process of the design proposal, parallel to the accomplished research. The general idea for this embodiment was to maximize the importance of simple shapes as design resources to evoke emotional links to automotive design history. Ideally, the design includes hints from socially recognizable (i.e. hot rods, *barchettas* or sport motorcycles) within the neutrality of a generic package.

This simple physicality is also aimed at projecting an assumable and interactive shape that do not distract from the message of cuteness, safety and personal space.

Figure 75: μcar embodiment (final version)

6.1 Introduction to the design

The embodiment shown here is a quadricycle (L7e), defined by the main specifications listed below:

Powertrain:	
Motors	2 electric 72V 7kW DC brush-less hub-motors, inside the rear wheels
Battery pack	9kW Li-ion battery (6 x 1.5kWh 18965-type modules)
Controllers	2 x 72V 400 A
Chargers	220 VAC and 12VDC
Dimensions and weight	
Length x Width x Height	2.256m x 1.440m x 1.470m
Turning circle (radius)	3.085m
Weight	300 – 550 kg (including batteries)
Seating	1 +1 staggered layout
Cargo	Open space within the cockpit

6.1.1 General design process

As it has been mentioned before, it is worth noting that the development process of this embodiment has been highly iterative. Here, the design is fitted within an accepted method to offer a clear depiction (Macey and Wardle, 2009).

6.1.1.1 Package and design ideation

Package and design ideation started with two key decisions: *keeping the length of the vehicle under the 2.4-meter mark* and *using a sandwich platform to enclose the powertrain components*. These choices allowed nose-to-kerb parking and an optimum weight distribution despite the reduced size of the vehicle.

The following diagram illustrates the initial package concept. The battery pack (1) is placed under the cockpit floor, low and centred. The first packaging considered the use of a standard motor (2), with a rear differential (3). As we will see, the final version included hub-motors because of the gains introduced in cargo space and the expected availability in the near future (Vital, 2011a). The idea of using sliding pillars (4) and steering-by-cable (white) was one of the first decisions, motivated by the lightness and low-speed use of the vehicle. On the right, the diagram also shows the two-level safety cage with front, rear and lateral crumple zones.

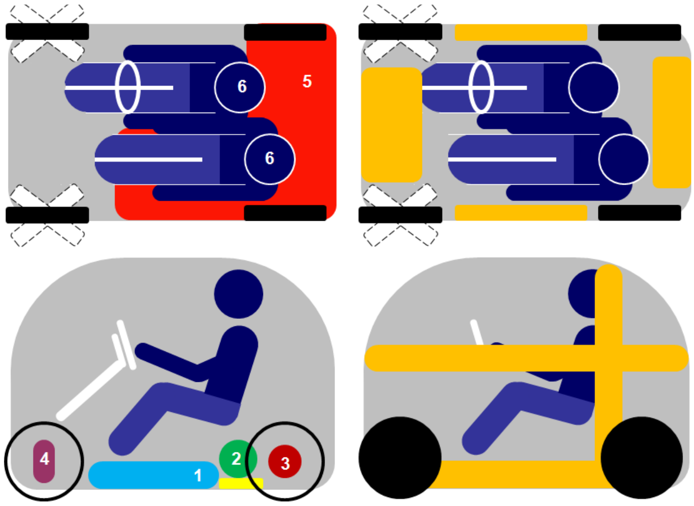


Figure 76: Initial package concept

In terms of the design concept, after several iterations, the decision was to use the simplicity of the typology to project an instant message of *protection*, *cuteness* and *sportiveness*. The aim was to appeal a wide range of users in a city such as London (i.e. from young professionals interested in design to seniors wishing to recapture the thrills of minimal motoring within forgiving traffic conditions). For it is the representative embodiment of this new typology, the design also highlights each point of the design strategy (minimal exterior, de-constructed architecture and flexible interior). In fact, this embodiment allows three vehicle configurations within the same proposal (flat-bed vehicle, urban buggy and full-bodied version).

In terms of automotive references, instead of proposing a complete rejection of car design, the idea was to use the inherent simplicity of the typology to revitalise past motoring design clues, unattainable for modern cars but still able to generate desirability. Thus, the picture below how the starting idea uses the friendly proportions of an Austin 7, reinforced with tire dimensions from modern sports motorcycle and the belt line of the classic Fiat 500. Simple round headlights evoke also classic designs. Furthermore, the versatility of the architecture is also used to increase the design possibilities: the urban buggy shows the inspiration in the belt line of the 500-based Simpatico 595 *barchetta* combined with the raw nature of a 'naked' motorcycle. For the interior, minimal layouts, typical in American hot rods, aligned with the intention of proposing an embracing and flexible space.

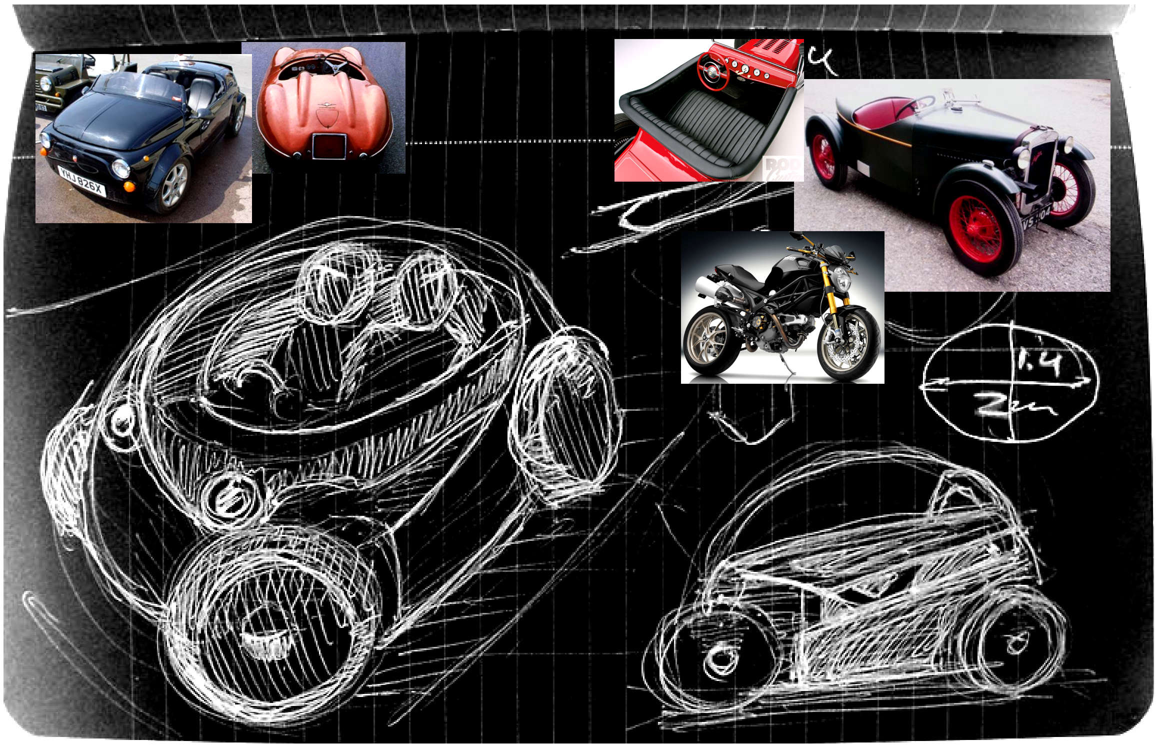


Figure 77: Design ideation

6.1.1.2 Occupant packaging

With the design ideation already settled, the next step was occupant packaging. Statistics demonstrate that the majority of urban trips are made alone by drivers (Office for National Statistics, 2002). However, there were two reasons to discard a single-seater design: more design constraints would limit the acceptability of an already disruptive proposal (as the case study of the C5 illustrated in Chapter 2); moreover, a design centred on mere statistics does not seem to capture the human element that a private vehicle should have. Thus, a 1+1 layout could offer comfortable seating for the driver and enough space for a short urban journey with an occasional passenger.

There are two possible layouts for a 1+1 arrangement: side-by-side and tandem. Tandem seating has two important advantages in the design of a small and lightweight vehicle: it minimizes the transversal migration of the centre of gravity with one passenger; it allows a narrower design too. However, the use of a tandem configuration would either increase wheelbase or passive protection for the occupant in the even of a rear impact. Additionally, the same reasons that supported the 1+1 choice motivate a side-by-side configuration, introducing an accepted layout by car drivers, and contributing to an interior that highlights social contact. Despite the side-by-side layout, the seating position of the passenger is slightly offset (as shown in the picture below) to allow narrower packaging, which will be useful to include lateral crumple zones.

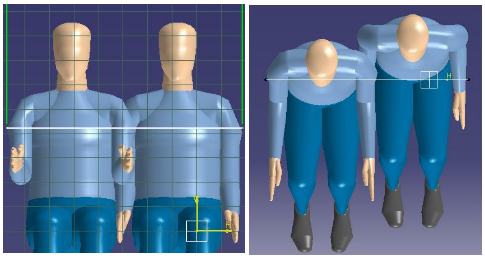


Figure 78: Staggered seating layout

These choices (and the others only mentioned in this chapter) illustrate the particular nature of this embodiment: Different contexts or designers can generate alternative design decisions that will ultimately form other vehicle proposals under the same typology.

The next step was to position the occupants in terms of height and posture. The H-point height for this design is 512 mm, a value slightly higher than conventional passenger cars, which will help to offer a greater sense of protection in open-road traffic. Additionally, the sandwich platform determines a higher position for the heel point (350 mm) and a shorter distance H-point to heel point (162mm), in the range used in sports car design. Finally, the back angle is 15º to maintain a good visibility and enough cargo space at the rear. This parameters define a characteristic driving posture for the vehicle, higher than car passengers but seating almost at the level of the sandwich floor. This compromise allows increased packaging space inside the sandwich floor structural and higher ground clearance (increasing the versatility of the vehicle).

6.1.1.3 Powertrain packaging

Electric powertrains offer greater possibilities as their components can be easily located inside a sandwich floor pan, and motors do not require mechanical connections. The components included in this embodiment were: motors, battery pack (including cooling), controller (one per motor) and chargers (for battery and ancillaries).

For the motors, hub-installed units offer the best solution in terms of packaging for a small low-speed vehicle. They have been successfully used in scooters (such as the Vectrix) and suppliers are already offering them for quadricycles. Concerns such as unfavourable unsprung/sprung mass ratio can be considered secondary in a vehicle that would average no more than 15 mph in short journeys. But even though, the influence of hub motors in a mid-sized hatchback seems minimal (Anderson and Harty, 2010). Finally, the decision by Michelin to choose quadricycles as the first commercial application for its Active Wheel reassures its short-term feasibility. The motor used as a packaging reference is a simple model offered by Kelly Controls (2011): It provides 7 kW per wheel, which is enough for the legal limit of 15 kW for heavy quadricycles.

In the definition of the battery pack volume, the battery technology developed by Tesla Motors served as a reference. Their design philosophy is to use numerous small low-powered cells rather than a fewer larger units (Berdichevsky et al., 2006) to increase the robustness of the pack. The cell form factor of choice is a 18650 cylindrical type (diameter: 18 mm; length: 65 mm). Tesla Motors packs include control/safety circuitry and cooling system (coolant: 50/50 water and glycol). For a total energy storage of 53 kWh, the total weight is around 450 kg. 9 kWh is an accepted value for current electric quadricycles, which is more than enough to cover average commuting distances in London of around 10 km (Demographia, 2005), even with depth of discharge values of 50%. If we choose a 9 kWh unit, using Tesla Motors values, the weight for the whole pack would be approximately 75 kg (assuming proportional reductions of cooling system and electronic weight values). As a dimensional reference, we will use Panasonic's high-capacity modules. These stackable modules (shown below with the cells) are designed for home and vehicle appliances, using 140 18650 cells each, with a capacity of 1.5 kWh and an approximate packaging volume of 7 litres per module (Panasonic Corporation, 2009).

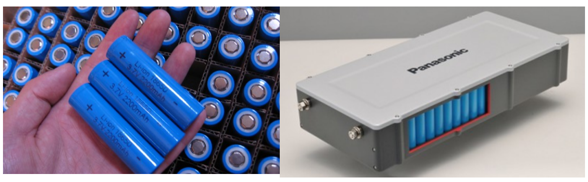


Figure 79: 18650 cells and 1.5 kWh Panasonic battery module

For the the controller, a typical size for a double assembly (one controller per wheel) is 350x400x100 mm. A typical battery charger for a quadricycle occupies 230x135x70 mm, while the dimensions for a DC/DC charger will be approximated to 100x100x70 mm (Kelly Controls, 2011).

The lay-out shown below place the motors inside the rear wheels. This choice allowed a front bias weight distribution to compensate the rear offset of the driver's centre of gravity. The reason is that, as the controllers (18 kg) should be close to the motors to minimize the use of high-amperage cables, placing the motors at the back allows the batteries (75 kg) to be placed forward. Tight spaces will not allow for a lateral offset of the battery pack to compensate for the weight distribution when only the driver is using the vehicle. However, the controller can be laterally displaced. Chargers, thus, smaller and lighter are located on the other side.

Finally, it is important to consider rubber mountings for the controllers, as their coils are the biggest source of noise in power electronics (Diem, 2010).

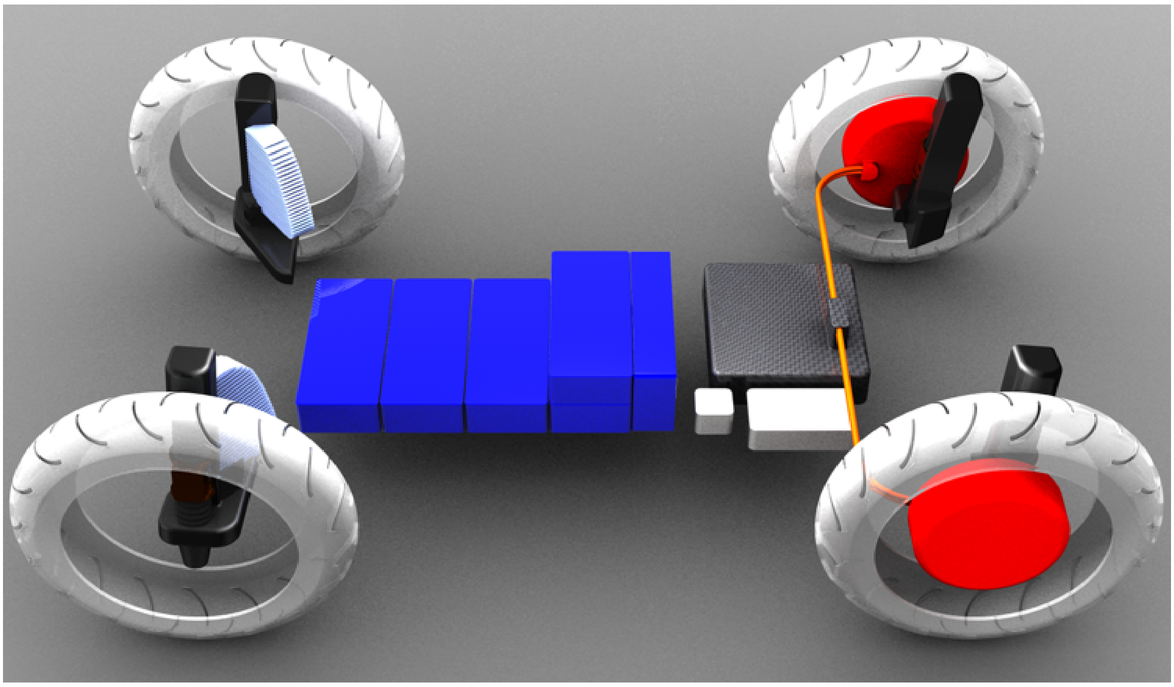


Figure 80: Battery (blue), controller (dark grey), chargers (white), motors (red) and radiators (light blue)

6.1.1.4 Chassis packaging

For the wheels, large and narrow tires help to decrease rolling resistance (Genta and Morello, 2009), and they also improve ride comfort over irregular surfaces. In terms of packaging, larger wheels allow the integration of motors, steering and suspension modules within their enclosed volume. Additionally, this option could be useful as a design resource and would reinforce the visual link with historical cyclecars too. Incidentally, there is a recent trend among new efficiency concept cars towards taller and narrower tires (Scoltock, 2011c). For a final design, the width of the tires used should be settled after testing the vehicle. Thus, as this is a packaging conceptualisation, the decision was to use a tire wide enough to exceed the capabilities of the powertrain as a worst-case scenario in terms of packaging. A 130/80 R18 motorcycle type (shown below with the Active Wheel) was chosen for that matter both at the front and rear axles.

Figure 81: 130/80 R18 motorcycle tyre and the Michelin Active Wheels

For the suspension layout, three features of the vehicle typology influence the selection of a suitable suspension configuration: light overall weight, low speed and flexibility in the allocation of the centre of gravity. Stiff suspension layouts for small light vehicles together with low urban speeds decrease the importance of sophisticated geometries. Moreover, thanks to the flexible packaging distribution of the electric powertrain, dynamic handling can be improved by optimizing the position of the batteries and controllers, as we saw before.

Thus, although MacPherson struts are an accepted solution (Honeywill, 2009), with even optimized versions for microcars (Tingwall, 2010), this configuration still introduces several disadvantages: It requires significant design compromises in terms of packaging (a crucial aspect in a 2.2m four-wheeler) and it is a source of NVH issues (Genta and Morello, 2009). Michelin will introduce an alternative solution for microcars with its Active Wheel. This hub-mounted design substitutes the damper with a pinion-and-rack mechanism controlled by an electric motor. Thus, it incorporates a self-levelling system too. Tests of this solution as a passenger in a development vehicle showed that it eliminates pitch and roll, offering a comfortable ride slightly spoiled by high-frequency vibrations (a result of using an adapted car). Despite its advantages, this solution is still at a pre-production stage and would add complexity and cost over other conventional options.

As we express before, the idea is to take advantage of the reduced design requirements of the µcar and propose a simplified adequate solution. In that sense, sliding pillars allow to achieve not only local improvements, but also system-level gains (in terms of cost, weight and design possibilities) in the resulting architecture.

From a local perspective, sliding pillars have fewer moving parts: load-bearing telescopic damper plus upright and two pick-up points per wheel. Thus, this solution is potentially cheaper and easier to install. Sliding pillars also occupy less packaging space and, more importantly, there is no moving linkage to consider around the wheels.

From a system-level, the fixed pick up points for the suspension can help to optimize the design of the structure in terms of crashworthiness. Moreover, significant packaging reductions can create new design opportunities around the wheel wells (as the location of the radiators, shown above, illustrates).

The disadvantages of this solution can be offset by the simplicity of the vehicle and modern technologies. Thus, the issues of past examples, pillar stinction and bump-steer (Costin and Phipps, 1974), can be corrected with modern low-friction coatings and bearings, and alternative steering systems. Body roll and camber can be minimized with stiffer set ups. Otherwise, the simplicity of the concept make it scalable to incorporate hydraulic or mechanical self-levelling sub-systems.

This old-fashioned concept appears to be increasingly rejuvenated: a 2010 patent by Toyota shows an application of this configuration for the rear axle (Yamada, 2010); similarly the Michelin Active Wheel system is a rack-and-pinion variation of the sliding pillar, a rather accomplished while complex solution.

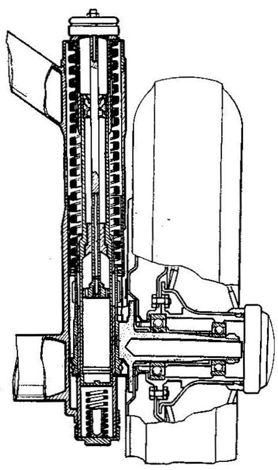


Figure 82: Sliding pillar in the Lancia Aurelia

Similarly, the particularities of this type of vehicle are decisive in the selection of a steering system. The torque at the steering wheel needed to turn the wheels of a lightweight vehicle is of around 20 Nm (Hodkinson and Fenton, 2001), which could be achieved with a cable-operated system, instead of conventional rack and pinion. This option would introduce significant packaging flexibility and use the existing structure to hold the loads transferred by the cables. Additionally, an sliding steering link at each front wheel pillar would eliminate bump steer. Varying lengths in the pulling arms of each steering link would allow an Ackermann steering geometry.

This arrangement would drastically simplify the front end architecture of the car, making it more spacious, lighter and safer in the event of a crash (as there is no steering column to collapse).

6.1.1.5 Wheelbase

The next steps is related to the definition of the total length. We saw in Chapter 4 that the standard depth of European parking space is 2.4m, which sets the upper limit for the vehicle length, in order to allow nose-to-kerb parking. However, with this embodiment, the decision was to go even further. Thus after occupant packaging, instead of using a conventional trunk, the cargo space was configured as a flexible area within the interior (the occupant area could be used as cargo space when the driver travels alone, and there is additional space behind the seats). This allowed a shorter wheelbase (1.575m), contributing to an agile vehicle (turning radius is 3.085m), with new proportions that remind of a typical sports bike (see picture below).

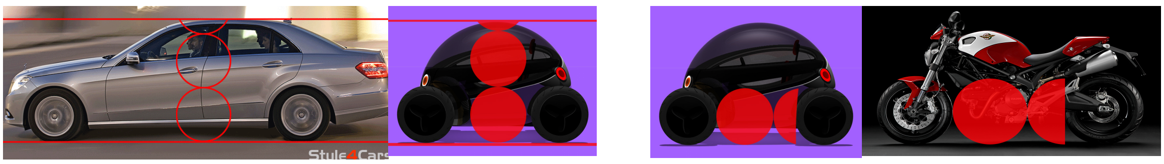


Figure 83: Wheel proportions in the μcar

From this point, the different layers where developed, attending to the design principles outlined in the previous chapter. The next page contains a table with the decisions used for the development of this embodiment applied to the decision tree shown in Chapter 5. Below, the picture illustrate the forming layers (which design will be explained in the 6.3 section).

	Can you make it meaningful?	Is it worth from a design perspective?	Does it conflict with other local design aspects?	Is it a leading or supporting design element?
Drivetrain	Y	Y	Y	
Suspension	Y	N		
Steering	Y	N		
Braking	Y	N		
Seating	Y	Y	Y	
Controls	*Y*	*Y*	*N*	*Supporting*
Lighting	Y	N		
Infotainment ancillaries	Y	N		
Space-frame	*Y*	*Y*	*N*	*Leading*
Body&canopy	*Y*	*Y*	*N*	*Leading*
Wheels	*Y*	*Y*	*N*	*Leading*
Interface Wheel-layers	*Y*	*Y*	*N*	*Supporting*
Interface Layer0/Layer1	Y	Y	Y	

Figure 84: Layer embodiment

6.2 Life cycle assessment and cost gains compared with conventional quadricycles

As a methodological embodiment, the goal of this proposal was to validate the design strategy in terms of general packaging and layout, as this is the design phase that concentrate the main qualitative improvements of each new design (Genta and Morello, 2009). For a detail calculation of sections and total weight, we would need finite element calculations of the body structure, especially to evaluate impact performance, that exceeded both the scope and resources of this research. However, the layout design proposed here is enough to complete some rough estimations about the performance of the embodiment, considering its architectural particularities.

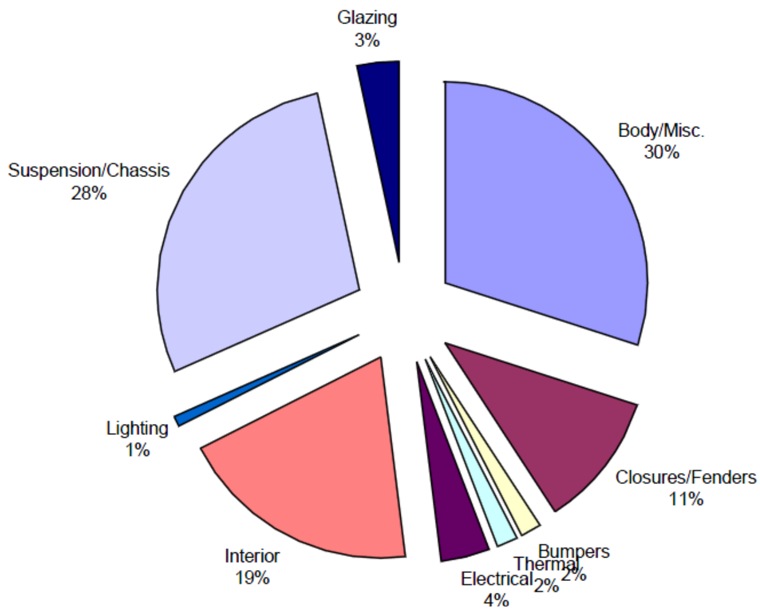


Figure 85: Weight contribution of each element within the vehicle architecture.

The previous graph has been extracted from a report about weight saving strategies by Lotus Engineering (2010) and allow us to compare a conventional 500 kg quadricycles (without batteries), with this µcar embodiment. As the interior components are reduced to cushions, back seat and controls (there is no trimming), from the 19% shown above, this proposal would approximately save 15% of weight. For the chassis, we can approximate the absence of suspension control arms, steering column, rack and pinion as a 14% weight reduction. Therefore, the µcar weight could be around 355 kg (without batteries). If we consider the modular concept and the possibility of running without a bodywork (Layer Zero plus One), then, during summer time or in warmer locations, the vehicle could save 20% in closures, body panels and glazing, reducing the total weight to 255kg (without batteries). For indoor uses, utilising just Layer Zero, the reductions would go even further. And these approximations do not account for the secondary weight reductions in chassis and structure as a consequence of the reduced loads these components have to support.

That weight reduction has noticeable effects in terms of life cycle assessment. In terms of manufacturing, a 145 kg weight reduction translates in less materials involved. For example, for an interior trimmed with unreinforced plastic, a 15% weight reduction equals to an energy reduction of 5,925 MJ for the production of the material involved, considering a value of primary production energy of 79 MJ/kg (Mallick, 2010). For chassis sub-assemblies, the 14 % weight reduction equals to an energy reduction of 2,100 MJ in steel or 14,000 MJ in aluminium. Furthermore, the modularity of the structure and sub-systems requires less energy during assembly.

But it is during the phase of use (the most important in terms of life cycle assessment) where the µcar has a greater potential for improvement. Weight can account for 23% of energy consumption in urban driving (Pulman, 2010), in other words a 100 kg reduction equals to approximately 10g/km CO2 less. Thus, the µcar will pollute between 14 (full-bodied) and 24 ('naked' version) g/km CO2, less than a conventional quadricycle (approximately 50g/km CO2). Furthermore, the modularity of the architecture also contributes to reduce overall life cycle assessment, prolonging the lifespan of core components and adapting the architecture to different use scenarios along its lifespan.

For the electric powertrain, weight savings also translate in significant cost reductions for the battery pack. According to Mr Gordon Murray (Squatriglia, 2011), each kg saved equals to approximately GBP 19 of battery cost, which equals to cost reductions of GBP 2,755 (full-bodied) and 4,655 GBP ('naked') compared with a conventional electric quadricycle.

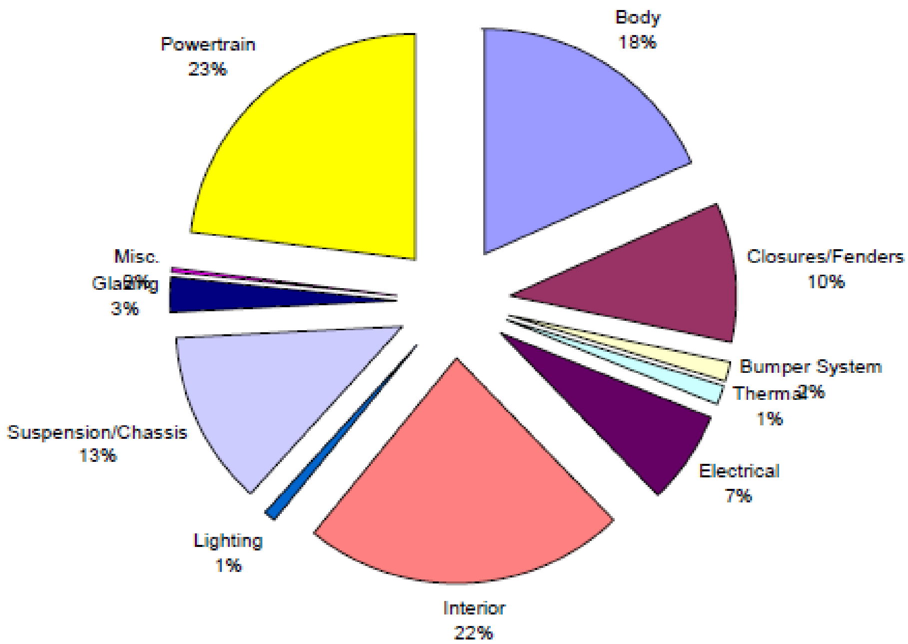


Figure 86: Cost contribution of each element within the vehicle architecture.

And the cost reductions would also apply to the rest of the architecture. The previous graph also belongs to the same report (Lotus Engineering, 2010). Considering a typical GBP 8,000 petrol quadricycle (the graph applies to a petrol car), reducing the interior components by 80% would suppose approximately GBP 1,340. For the chassis, GBP 520.

6.3 Digital embodiment

This section contains the particularities of the design of the embodiment. For the reasons exposed in Chapter 3, the validation of the typology relied on digital modelling. The first part of this section includes the design of each layer, while the last section explains the implementation of the full-scale virtual model.

6.3.1 Layers

6.3.1.1 Layer Zero

It is important to consider that, in this embodiment Layer Zero is not only a finished element but also the first part of the whole vehicle. Thus in the design lay-out, the procedure would be standard in the definition of the main elements, and then particularized for the flat platform. The advantage of the µcar electric architecture is the possibility of optimizing its topology for structural performance. Without axles or engines to avoid, the location of the main nodes of the structure can be at the pick up points for loads. The importance of this fact is illustrated by projects such as the USLAB, where a conventional steel body-in-white was topologically optimized saving 25% in weight and 20% in part count without cost penalty (Hodkinson and Fenton, 2001). In that sense, the main loads are bending, torsion and impact loads, normally introduced at the front and rear ends, plus lateral impact.

The first step is, thus, the definition of the bulkheads (Costin and Phipps, 1974). As we saw in the previous chapter, the µcar architecture uses a punt-like frame where secondary bulkheads are substituted by lateral connections to the front and rear main bulkheads.

The front bulkhead will define the front end of the flat chassis. It should be placed closed to the front wheel centres. Using a sliding pillar design, the lower part of the bulkhead could be solved in a simple manner with a beam member that transversally connects both front suspension towers. The same solution could be adopted at the rear end, thanks to the use of hub motors.

The anchor points for the pseudo-bulkheads should be placed to allow ingress-egress and front-wheel packaging. Thus, the front pseudo-bulkhead anchor points will be after the front wheels while the rear ones can be placed close to the rear wheels. In a flat chassis configuration, the simplest solution would be to connect both front and rear lower bulkhead sections with longitudinal members. The only challenge here is allow for enough turning space for the front wheels without introducing inefficiencies in the transmission of design loads.

The only two parts left to define are the lower and upper plates of the flat chassis. The lower part could be solved with a flat sheet, maybe with reinforcing indentations. The upper part has to be designed keeping in mind that will double as floor and lower seat structure.

Now that we have a rough idea of the structure, let us revise the packaging of the defined modules, looking at the spaces left unused to have an idea of the design space for the structure. As we can see the battery pack can be placed forward leaving enough space for the front wheels and structural members in between.

Once we have an initial idea of the structural layout for the flat structure and of the design space left by the main elements of the chassis and powertrain, let us analyse different options to solve the design of the structure.

<u>Alternatives for the flat structure and embodiment</u>

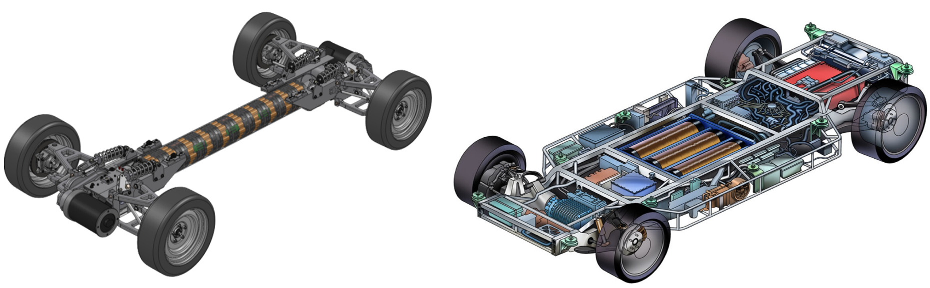


Figure 87: Trexa's backbone and GM's conventional sandwich configurations

One of the simplest ways of structurally connecting front and rear axles is the use of a backbone connecting front and rear bulkheads (see picture above). This idea has been elegantly used in the Maserati Barchetta club racer (Heywood, 2004). Here, a double-walled prismatic beam is bolted to the mid-front and mid-rear subframes, respectively holding front suspension and engine sub-frame. An American company, Trexa, even uses this configuration to carry battery and controllers of their EV architecture inside the beam (Trexa, 2011). Working as a body-on-frame, the rest of the components of the vehicle would be attached on top. This neat configuration has the following disadvantages as an element of the μcar architecture:

- It makes difficult the implementation of a simple swappable battery system similar to the standards set by companies such as Better Place.
- It is difficult to seamlessly incorporate the rest of the structure. The torque tube do not allow enough space for seats and cargo space, making difficult the use of Layer Zero as a stand-alone vehicle configuration.
- Despite its simplicity, it is difficult to obtain a flat floor configuration.

Another option for a simple configuration would be to construct a structural box out of extrusions and triangulating sheets (shown above). Two longitudinal members would close the sides while front middle and rear members would transversally connect the main beams. Then, top and bottom plates would triangulate the structure for horizontal loads. This fairly standard approach has been proposed by Lotus in a city car concept (Honeywill, 2009), and by GM in their 'skateboard' vehicle architecture (Mitchell et al., 2010). Even Tesla partially incorporates this concept in the design of their floor pan and bolted flat battery pack for the Model S (Tesla Motors, 2011).

Such a solution is perfectly valid for conventional vehicles produced in small series but it finds limitations considering the simple nature of the μcar architecture

- Part consolidation to minimize assembly costs and quality issues such as lightweight NVH approaches would be still an issue.
- Structural optimization and simultaneously, visual quality could improve with the reduced requirements and alternative design strategies.

One of these alternatives could be the use of stamped aluminium profiles to completed a twin-tube structure that could be bolted to the rest of the space frame to provided improved performance. Back to the origins, that approach would be similar to the one used in the 1936 Fiat 'Topolino' (Giacosa, 1979).

Similarly, this idea visually connects with the imagery of archetypical hot rods such as the 1932 Ford Roadster.

But if we consider the simplicity of the µcar architecture, and the absence of moving linkages, the opportunities for cleaner, efficient structural designs are wide open. In that case, methods such as resin transfer moulding for FRP allow greater levels of design freedom, weight saving, part consolidation, NVH improvements and lower assembly costs. Moreover, due to the reduced number of elements forming each µcar, added cost of this structure can be economically compensated, especially if we consider the influence that the whole vehicle weight has on the cost of the battery pack. According to Gordon Murray's own analysis, each kg saved in the vehicle could account for 30 USD of battery cost (Squatriglia, 2011). As an initial reference of the cost that a resin-transfer-moulded composite floor pan for a conventional car could have, for production runs of 25,000 units is 740 USD/unit. If we consider the minimal design implied in this proposal and its reduced dimensions, that cost could be easily reduced.

In terms of life cycle considerations, the importance of the stage of use is clear. As Layer Zero represents the simplest level of mobile functionality, its useful life can be extended along different top configurations, allowing for the use of materials with higher environmental impacts such as composites.

The structural idea is to have a two part flat monocoque. The upper part is the resin-transfer-moulded element while the lower part is the pan that hold batteries and electronics and it is bolted as a structural member to the resin-transfer-moulded floor pan from underneath. The upper shell is topologically divided in two different parts: a surrounding frame and the floor planar section. The only function of the latter is triangulation of the frame. The frame carries most of the loads, bending, torsion, seat and boot frames. It incorporates the pick up points for the suspension pillars plus bushings, it routes the cable steering system lower section. In other words, it contains the structural nodes of the lower structure.

This facilitates the design of the composite shell in terms of robustness of the pick up connections. It also helps in NVH aspects, minimizing noise and vibration transmission by panel radiation and assuring proper point mobility targets and easier to handle transfer functions for the main structural nodes. To further reduce road-induced NVH, the use of a sandwich panel for the floor would filtrate noise and vibration offering, at the same time, a robuster structure.

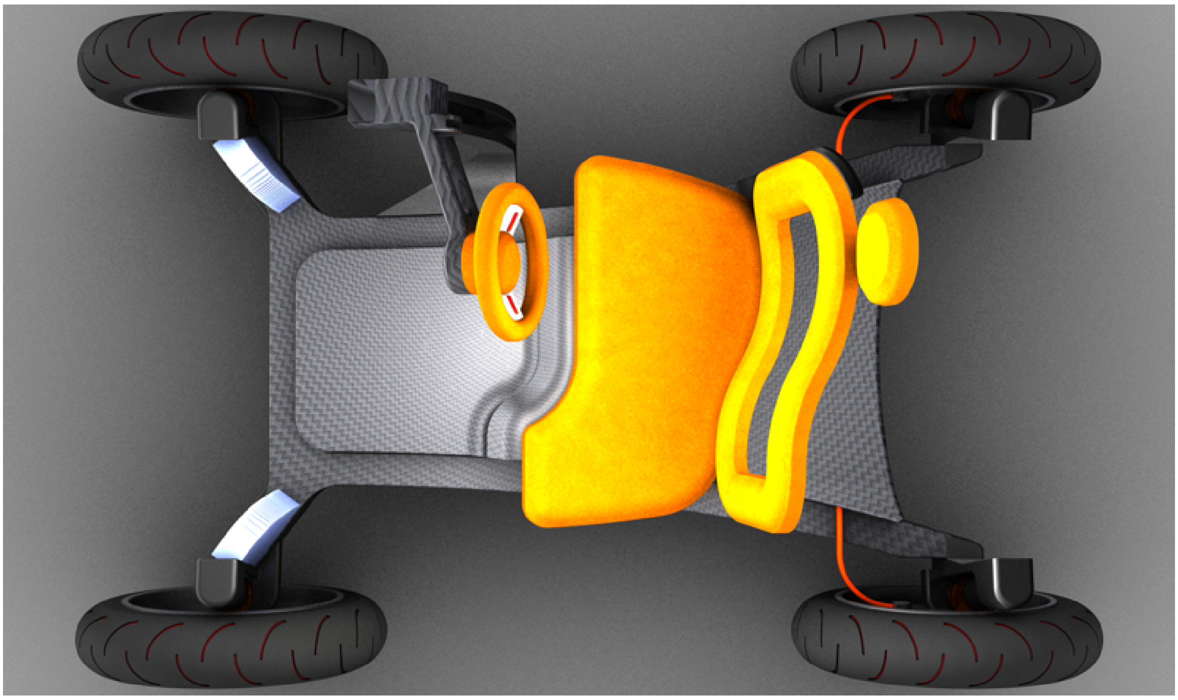


Figure 88: Layer Zero

The shape of the frame is defined (as the picture illustrates), at the front by wheel packaging and the possibility of using the front 'arms' as part of the passive safety system. The longitudinal arms connect to the rear pick up points by elliptic arches. The use of curved beams refers to structural design inspired by Nature. In case of a front impact, these members would withhold compression. The curvature eliminates uncertainty on possible buckling modes (Matteck, 2007) by favouring one mode, which would be reinforced by the floor element. The attachment points for the modules of Layer One (bulkheads and pseudo-bulkheads), are easily integrated as double-shear bolted joints, allowing better structural and NVH performance. At the same time, they leave the option to apply future variations on the same platform, elongating the life cycle of this component.

The floor panel is mainly flat, with a protuberance in the middle to allocate occupants lower seats and a reinforcing cross member and battery packs underneath. Reinforcements are internal, leaving a clean upper part.

The cited embodiment allows different local variations, as the use of integrated stamped beams for the main members (that would simplify the design of the pick-up points) or sandwich panels (improving on NVH isolation and structural performance).

6.3.1.2 Layer One

While Layer Zero is a flat package and Layer Two a generic membrane, Layer One humanizes the inner space of the vehicle. Its obvious function is to provide protection and help to enhance urban interactions for their users, providing a minimal cage. Unlike conventional structures, Layer One must also have intrinsic visual and tactile value, as interior trim is limited. In that sense, it is important to organize the way elements are distributed, deciding what is hidden and what is shown.

In this particular embodiment, it was decided to highlight a protective structure, to compensate for the normally weakness associated with microcars. Thus, the embodiment looked at design clues that would help to provide a clean visual message. Due to the need of having a two-level cage (as we saw in Chapter 6), these two levels would work as the main design elements. Café racer motorcycles, with their simple seat-and-tank combos provided inspiration for a minimal surrounding ring for the upper section. For the lower section, high sills as those seen in the Mini Moke or Mercedes 300SL 'Gull wing' inspired a solid design that enhanced lateral protection.

Figure 89: Layer One (plus Zero) and some of the inspiration

Packaging

Compared with Layer Zero, the packaging is much simpler. Beside the protecting structure, lighting and wiring are the only elements to consider within the cage. Other systems such as controls or seating can be separated in terms of volumes. Lighting can be integrated within front and rear crumple zones. Similarly, wiring and lighting can be easily packed into the upper section of the structure, and channelled towards the platform making use of the middle structure.

However, a crucial aspect in the definition of Layer One is the visual organization of the different elements. Without any panel to cover elements, the location of each sub-assembly is key to keep an easily assumable design. In that sense, classic rules on sculpture techniques helped to organize the space. As in classical sculptures, the idea was to define clean shapes based on the two level approach that would receive the main highlights, while the shadowed sections would serve to locate secondary volumes (Goethe, 1970). This helps to enrich overall design minimizing visual complexity.

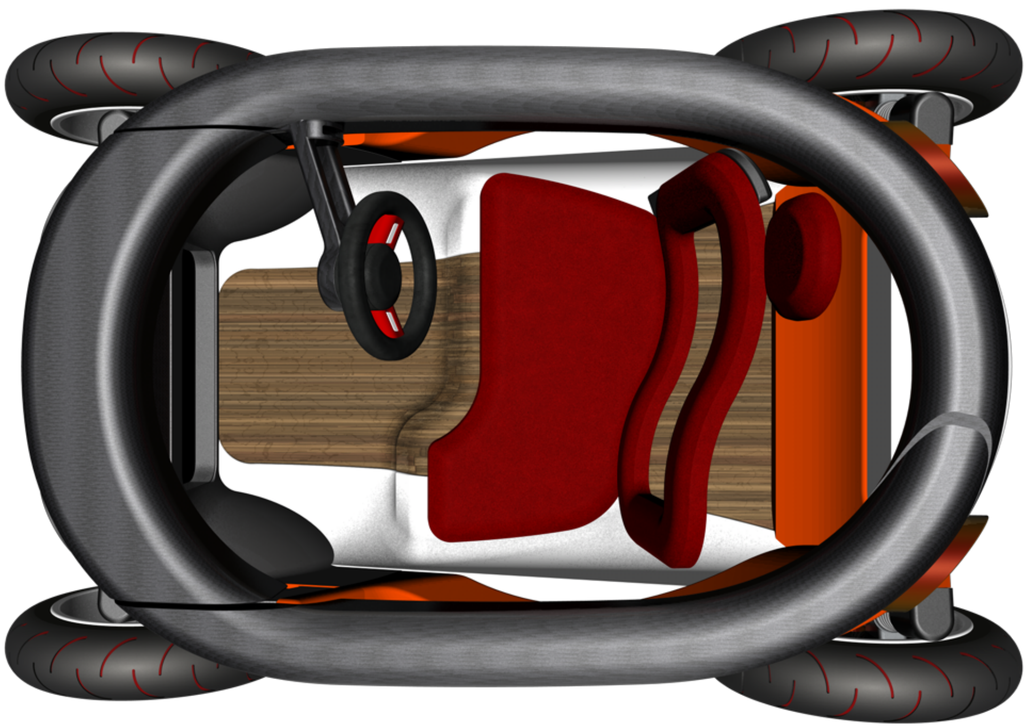


Figure 90: Simplicity on the main highlight defined by the structure

Layout

In contrast with the definition of Layer Zero, there are no technical antecedents to the design of such an exposed structure. While roll cages are well-known in vehicle design, they are normally integrated with conventional interiors or exposed as in race cars, where visual and tactile comfort are not required. Thus, it was up to this research to investigate the implications of such a design element. Having mentioned the problem of packaging, the other aspect to consider was NVH. In that sense, considering low urban speeds, the main concern was on minimizing squeaks and rattles. That translates into solid structures with controlled stiffness and clear load paths. Cantilevered elements had to be minimized into a structure that should connect the main load pick-up points. This task is easier in a vehicle with such a flexible architecture. Another aspect to control was to leave enough dimensional tolerances to allow for vibration of components without rubbing or hitting against each others. Finally, considering that this structure is closed to that of a convertible vehicle, scuttle shake could be minimized with the use of a single door instead of two, structurally connecting front and rear sections.

Focusing in the different sections, Layer One can be divided into front, rear, door side and closed side.

The front section is bolted to the front section of the platform frame and includes:

- Front bulkhead, which connects the upper anchor points of the suspension towers (unused by Layer Zero), forming a strong structure, able to hold and distribute running and impact loads
- Front crumple zone, attached to the bulkhead
- Headlamps and sensors carrier, also attached to the bulkhead, corresponding to the front section of the upper ring

Lateral sides are connected to the front by structural wheel wells, and bolted along the side beams of the platform. They include:

- Structural wheel wells, consisting of a semi-monocoque design that connects to the front bulkhead and to structural arches behind each front wheels
- The cited arches, which contain the door sliding mechanism or internal wiring routing, depending on the left or right side.
- Door sills, fixed structures that include frame and crumple zones for lateral impacts

- Lateral sections of the ring, for the door frame and the fixed structure, depending on the side.
- Middle structures, that connect lower and upper sections, completing the safety cell.

The rear structure is similar to the front section, consisting of a bulkhead, crumple zone, and headlamp carriers. They also contain the lock system for the single door.

6.3.1.3 Layer Two

The goal was to obtain a shape that appeals by its simplicity and human scale. It had to evolve visual cues from historical motoring towards a futuristic and purposeful design able to, not only melt with its context, but also become an active element in the definition of the urban landscape.

Figure 91: Layer Two and inspiration

Initially, the first reference to the design of the proposal can direct to classic bubble cars. However, the idea, rather than merely updating bubble car design language, was to refer to the concept of space: A space that is personal, that surrounds occupants and provides a dual function of isolation (from uncomfortable weather conditions or dangerous traffic) and integration within the urban environment. Unlike long-distance vehicles, the eminently urban nature of this vehicle would have to be translated into a shape that enhance the experience of the city. And not only as a movable space that allows to physically travel, but also as a space able to integrate multimedia content to project a seamless experience of augmented reality. In that sense, even modern smart phones, where minimal physicality enhance the digital experience, served as a reference. However, in the proposal, the volume had to surround its users instead of being hold in a hand. Thus, the simplicity of a display had to be combined with the protective feeling of a bodywork.

The minimal and more efficient way of surrounding is the sphere, the water drop, the bubble. It also refers to a protective and personal space. Moreover, it can be a membrane that help users to filter and comprehend external reality too. And, ultimately, it is such a simple and assumable shape that can be integrated in urban landscapes as a piece of subtle street furniture, minimizing visual pollution. Those were the main reason to choose a bubble.

For the open-wheel configuration (a departing point from conventional bubble cars), a particular type of hot rod constituted an important visual references: the belly-tank 'lakester' typology. These vehicles were made using recycled fuel tanks from air planes and present very simple external shapes. Other open-wheel examples, as old designs of cars and cyclecars were also considered.

In terms of greenhouse definition (integrated with door opening design) and detailing, fashion provided a resourceful tool to define detail design of the bodywork within minimal visual resources. The way that some dresses enhance human body by using simple lines and clever openings helped to find a design proposal that, without altering the idea of the body as a space container, provided a suggesting vision of the structural and design elements underneath. Specifically, the dress shown above, by Tom Ford, inspired the diagonal cut line that characterizes this embodiment. The way the hole at hip level reveals both the model's body and the belt was used to show the surrounding belt and the simple internal space inside the µcar, together with the duality between openness to pedestrians (normally on the left) and protection against rolling traffic (right). This last element is clearly illustrated in the caption below.

Figure 92: Asymmetry to reveal the layered arrangement and the duality of urban environments (car and pedestrian zones)

Design issues

The design of the bodywork includes two main groups: body panels and canopy.

<u>Body panels</u>

There are four elements: front, door side, closed side and rear. Due to the simplicity of the design, it would be feasible to conceive each side as a single element, stamped or moulded. Care must be taken to provide weather isolation and NVH performance considering that the interior of the panels would be exposed to occupants.

The fact that body panels do not carry structural loads allows using different types of materials, increasing the creative possibilities of the design. Thus, printed plastics or even old-style framed textiles could be applied to generate unique aesthetic propositions.

<u>Canopy</u>

The idea of the single-piece canopy tries to keep the visual minimalism of the embodiment while maximizing the possibilities of the component as a visual and tactile interface. There is no visual interference from the inside, and, from the outside, it is easier to create a large projected display. Additionally, as we discussed before, a clean canopy, without reference to conventional greenhouse designs minimizes the sense of smallness of the vehicle. On the other hand, it is important to offer a clean surface to serve as an interface. The absence of detailing helps to avoid distraction from the information and maximizes the possibilities of digital customization: users can upload their own 'screensavers' and configurations, that projected over the canopy could modify the character of their own vehicle (which is even handier if we consider car club schemes). Similarly to the rest of the body, it helps to create a moving stage for digital and mobile experiences of cities.

In the definition of the cut line for the canopy, there are three aspects to consider: visibility, ingress-egress and digital functionalities. In this embodiment, a single plane defines the intersection with the bodywork, diagonally cutting it, and assuring:

- driver visibility, with a cleaner field of vision
- ingress-egress, with a door sill height of 450 mm from the ground (which contributes to an sportive and safe feeling)
- a clear surface to be interacted with from both the driver seat and a bystander when the car is parked.

The single-piece canopy consists of the shell and an integrated structure (made of metal or composite materials) that provides strength and minimize cracking. The main design problem is the single-piece moulding. Instead of conventional glazing, this embodiment look at acrylic materials as an alternative to glass. This allows for greater moulding capabilities and weight savings, while keeping more than adequate protection. To illustrate how safe a full size canopy can be, the FIA recently tested a single-piece canopy by throwing an F1-sized wheel at 225 kph (Whitworth, 2011). The canopy elastically absorbed and deviated the mass, keeping the interior totally untouched. The use of such canopies is well-known fin the aircraft industry.

Figure 93: The design of the door

Canopies, in their most simple type, can be blow moulded. However, to obtain geometric consistency, vacuum moulding should be used. In order to improve cracking resistance, thermal control of the process is an important factor. An oven can be required to avoid optical distortion and to provide annealing treatments.

Rain and dirt wiping is another important aspect in the design of a canopy, while it would be possible to apply conventional windscreen wipers, they would damage the surface unless specific coating or layers, such as those from aircraft technology, are used (Saint-Gobain Sully, 2011). An alternative approach could be to substitute conventional wipers for jet nozzles that project pressurized air onto the canopy. The Acura TL concept (Car Enthusiast, 2003) and Fioravanti Hidra (Car Design News, 2008) use this solution, combined, in the later, with nanotechnology applied to the glazing surfaces.

Another aspect to consider in the design of the canopy is the use of a head-up display to project information. Currently, head-up technology requires high precision glazing, with angle variations smaller than 0.045º. Additionally, there would be the need to package the physical unit, which currently accounts for 2 to 4 litres of space after the instrument panel (Scoltock, 2011b). The main limitation in terms of volume reduction seems to be the optical system. However, considering the open interior space of this concept, this should not be a problem.

As we mentioned before, the advantage of this embodiment is that it allows a clean vision from the interior of the vehicle, enhancing the visualization of both data and physical environment in order to create a seamless integration of augmented-reality technologies.

Figure 94: Driver's point of view in the μcar

6.3.2 Virtual Reality Model

The digital model previously described was ultimately transferred to a virtual reality environment, where it was evaluated. In the development of a new typology, the use of this tool was crucial, for it allowed quick evaluations of the solution, especially a full-scale perception of the new proportions without with cost, time and the lack of accuracy associated with a simple mock-up.

The advantages of this system are particularly relevant for the proposed typology, as the emphasis, compared with conventional cars, is on the particular proportions rather than surfaces or detailing. The perception of protection or human-scale of the architecture is, thus, perfectly achieved within the virtual environment.

This technology currently allows quick transfers of files from the original CAD to the full-scale visualization. And the possibility to walk around and enter the vehicle further increases its potential.

6.3.2.1 System description

The environment used in this research was the EON Mobile Ifloat located at the Design London facilities (see picture below). It is a PC based system that allows users to be immersed into a virtual space of floating and interacting objects. It has two screens, one vertical and one on the floor. It includes two stereo projectors (1,920x2,160 pixels), two workstations (3.3 GhZ, 500 GB HD, high end graphics boards and 6 GB Graphics Memory), a stereo front projector and interactive devices (16 wide angle cameras and infra-red tracking devices for viewing and interaction), EON Icube (two walls) software to import and manage CAD files, keyboard, 3D tracked glasses and a video game controller.

Figure 95: The virtual reality environment at Design London

6.3.2.1 Work-flow

Current technology allows a user-friendly interaction with the system. The original CAD files were easily transferred to the virtual environment following the process described below, belonging to the Design London virtual reality training program.

The first step was transferring the CAD files to Deep Exploration software. This tool is used to configure the model before sending it in a valid format to EON visualization software. With the files opened in Deep Exploration, all the normals to the surfaces of the model were checked (they should point outwards to assure a correct representation of materials and textures). The next step was to group the components of the model (i.e. tire, rim, glazing) into manageable groups (i.e. wheel assembly, Layer Zero, Layer One and Layer Two). This step was particularly relevant as it allowed later visualizations of the different configurations allowed by the vehicle architecture (flat-bed, buggy, 'spyder' and fully-bodied). In the next step, the pivot points for the door mechanism were introduced. After that, the model received materials and textures. Because some incompatibilities between Deep Exploration and EON, a later check was needed to assure that the original materials were supported by EON. After assigning studio lights to the model, the resulting file was transferred to the EON viewing software and visualisation hardware, where the vehicle was placed in virtual environments and the different points of views were predefined. This step finished the process and allowed to start interacting with the full-scale stereoscopic visualisation of the µcar.

To conclude this section, the following picture tries to illustrate the importance of scale in this proposal, and the necessity of using a virtual environment to apprehend its peculiar proportions.

Figure 96: Approximate representation of the µcar scale.

7. Critical Assessment

This chapter contains the assessment of the hypotheses enunciated in this research. Fundamentally, the hypotheses refer to the proposition of a new electric vehicle typology, based on quadricycles, as a city friendly alternative for cars, and the method described to obtain such a typology.

The main hypotheses to assess where:

- The development of a new vehicle architecture, different to conventional cars, using a multidisciplinary approach to produce an adequate solution for urban journeys.
- The use of Latent Design as a methodological resource to propose vehicles visually integrated within their urban surrounds.
- The validity of Layered Design as a design enhancer that aligns the necessity for a minimal architecture (both as a medium to improve private mobility efficiency and as an enabler for current electric technologies)
- The validity of Canvas Design as a regulatory stage of the design aimed to integrate new vehicle proposals within social and technological contexts.

The conceptual and timely nature of this research suggested the use of an specific method for the critical assessment that included the feedback provided by relevant experts in design practice, a comparative analysis with relevant alternative proposals and an evaluation of the design brief with students of the RCA MA program.

The selected experts had architectural and vehicle design backgrounds, which allowed to cover the aspects of the urban functionality of the typology (latent canvas design) and the generation of the vehicle typology itself (canvas, layered, latent)

The second part of the assessment, centred on the comparative analysis, was a result of the recent interest on new types of quadricycles as valid alternatives to urban cars. New proposals appeared along this research period served to establish a contrast or support some of the strategies proposed in this work.

Nevertheless, the design approach of this research introduced several particularities in the practice of vehicle design. Thus, the design project with the MA students helped to illustrate the validity of the new approach from the perspective of vehicle design professionals.

Let us start, then, with the first part of this critical assessment, the section containing the feedback by relevant design experts.

7.1 Experts' feedback

7.1.1 Professor Peter Stevens, Owner, Peter Stevens Studio

On February 24th 2012, I met Prof Peter Stevens to expose my research and receive his feedback as part of this critical assessment. The process started with a brief presentation that served as an introduction to the general topic of the research, followed by an explanation of the design strategy defined as Latent Design, Layered Architecture and Urban Canvas Design using the three-dimensional full-scale virtual model at the Design London visualization facilities. One week after this presentation, I interviewed him to gather his opinion on the results of this research.

7.1.1.1 His feedback

In general, Prof Stevens considered that the most valuable part of the research was, from a design perspective, the fact that the new typology represents a total disruption with modern car design. In his opinion, following accepted design clues is the easiest way to gather users' acceptance, for the automotive market criteria is well-established at an individual and social level. And it is a trend repeated both in microcars and electric cars. However, he considers that the designer’s role is to explore the limits of user acceptance, increasing the perception that people can form about vehicles.

He valued the fact that the new typology aligns the technical inherent qualities with a new and self-explanatory design ethos, working with different scales and proportions to conventional cars.

Compared with other electric cars, he considered that one of the main problems current electric cars have is that, by mimicking conventional car design, they generate a set of expectations unattainable for their electric powertrains. He cited the example of a car manufacturer whose electric cars only differ in detail design, seemingly inspired by electric home appliances, maintaining the same proportions and surfaces of their petrol range.

Considering that, despite comparative limitations, electric cars can perfectly perform as urban vehicles, he thinks that their implementation will be favoured by honest and unassuming design strategies as this. These design strategies must highlight both the efficiency and the adequacy for normal urban duties of new vehicle typologies. And at the same time, establish an essential separation from conventional car design.

Referring to the proposal and, specifically, the Layered Architecture, Prof Stevens positively valued the combination of vehicle architecture and design in the generation of the vehicle. He considered the result of this process honest, and because of its honesty, attractive. In that sense, this honesty is crucial for this type of vehicle, for in addition to its electric powertrain, it happens to be significantly smaller than conventional cars. Thus, the easy route of conventional car design could spoil the whole acceptance of this new typology for the reasons explained above.

In the definition of this honest approach to the design of the vehicle, he considered the historical review of cyclecars particularly relevant as a starting point for the process. Similarly, these vehicles also had a completely different aesthetic to the cars of those days. And he considers there was nothing more honest than the cyclecars in engineering terms: just by looking at the vehicle, you could figure out, not only how it worked, but also how it was made (the materials used and the processes involved).

Continuing with the importance of the honest design approach and cyclecars, Prof Stevens continued evaluating the role of the typology as an individual canvas for its user. The importance of cyclecars was that, beside their technical contribution, their minimalism appealed certain type of people with alternative ideologies. For them, cyclecars became a motoring instrument to manifest both themselves and their political response to social realities they criticised (in this case, the use of bulky, dirty and noisy cars). Thus, when the cyclecars disappeared, some of these people might have switched to the similarly honest Austin 7, but automotive evolution left them without a mobile instrument of self-expression. The arrival of the 2CV provided these groups with a new solution, but nowadays, the options have disappeared. Those who want to make a statement can buy vehicles such as the G-Wiz, but the lack of style in its design also requires important doses of self-confidence to be seen in such a peculiar vehicle. Thus, he considers that people have given up seen cars as an expression of their ideology, but the necessity is still there. In fact, some fashion brands exploit this social need by selling garments that, with their artificial patina and obvious functionalism, appear to be 'socially-conscious' items, opposed to the typical aesthetics of consumerism.

A typology like the one contained in this research, in his opinion, allows again to make an individual statement with one's mobility option, but in a stylish way. He considered this feature important for the success of the new typology, as it could help to compensate a likeable inability to compete on a cost basis with conventional cars. Even if people had to pay slightly more, the fact that owning and using this vehicle can be understood as a symbol of a particular lifestyle and social responsibility can ultimately increase its success potential.

In terms of the urban integration strategies contained in Latent Design, Prof Stevens highlighted the 'invisibility' of the vehicle. The minimalism of the shape would make it completely secondary to the details that would surround it in the streets. In that sense, the vehicle could serve to enhance the beauty of singular surroundings, as even in groups, its human-scale would generate the imposing wall formed by conventional park lanes.

He shared another thought in terms of urban integration. For Prof Stevens, it is particularly interesting to see children of well-off families being taken to school by their nannies in incredibly imposing SUVs. That particular routine may be forming a strange mindset in those kids, for the only way they interact with the city in terms of mobility is by climbing huge vehicles that virtually conquer their surroundings. In that sense, a vehicle such as the one proposed here may be an influencing example to foster socially-conscious future generations.

In conclusion, Prof Stevens highlighted the originality and honesty of the typology as an open end flexible enough to incorporate other designer’s contributions based on a common architectural framework.

7.1.2 Frank Stephenson, Design Director at McLaren Automotive

On December 1st 2011, I visited McLaren Technical Center to present my design embodiment to Mr Frank Stephenson in order to further develop the critical assessment of this research. His successful experience in car (including the design of the new MINI and the direction of the design of the new Fiat 500) would help to analyse the design goals that this strategy tries to cover.

Unlike the presentation to Prof Stevens, the model was shown on a 'Powerwall' rather than in a virtual reality room. This system is a standard evaluation procedure on car design and allows to see the model in real size but within the boundaries of a 2D representation. However, it did not allow the same level of perception as a virtual walk-around. Mr Robert Melville, Senior Designer at McLaren Automotive and RCA graduate, was also present during the session and his feedback was equally useful for the purpose of this research.

7.1.2.1 Feedback

The first impression was disruption. Mr Stephenson remarked the fact that the vehicle responds to general design, similar to product design, rather than to conventional car design. At first glance, it seemed difficult to analyse it from the same perspective as a conventional car. Considering that one of the points of the design brief was to establish a differentiated design language that would distinguish the µcar from conventional cars, this fact would confirm the accomplishment of such a task. Cuteness and minimalism were words used to describe the proposal. This description also agreed with the initial design brief, were human-friendliness and embracing the simplicity of the proposal were two aspects that should be obvious at first glance.

In terms of perceived sustainability, the minimalism of the vehicle, together with its organic exterior contributed to a sustainable image. However, Mr Melville noted that while the bubble shape would look efficient to the general public, a truncated rear end could reinforce that image of efficiency. The cockpit treatment, with an exposed structure seemed to have potential to express sustainability with the use of ecological materials.

In terms of appealing, Mr Stephenson expressed that, while it did not have typical emotional links of car design, its simplicity could help to create a halo image similar to products such as the ipod. He continued by saying that even when the ipod did not look like nothing in the market when it appeared, its clear lines and purposed design converted it into an instant icon. In that sense, he considered this vehicle to have the potential of generating the appeal of a luxury item for trendy urbanites. In his opinion, the use of digital customization in such a simple design could be enhanced, establishing further links to Apple's product success.

Mr Melville continued with that idea by mentioning the simplicity of the physical design. In his opinion, the µcar was the vehicular equivalent to a bucket in terms of functionality. The minimal design of the bucket allows unexpected uses such as an improvised stool over its typical function as a liquid container. In that sense, in his opinion, the vehicle represents a new field for unexpected functionalities. His comments aligns with the canvas design strategy, that aimed at creating an open ended proposal where users could add the final touch, enhancing the urban experience and their relationship with the vehicle.

Both Mr Stephenson and Mr Melville opined that the minimal ethos of the vehicle, as well as its lack of emotional links with conventional car design could be 'compensated' with use of functional detailing. This idea also agrees with the design strategy exposed in Chapter 5.

For them, elements such as the headlamps could cleverly integrate new and unexpected functionalities such as jet nozzles to work as windscreen wipers. Design strategies as those shown in Dyson products were highlighted as useful sources of inspiration. Function integration is a useful tool in weight reduction techniques as recent automotive research suggests (Goede et al., 2008), but in this context also proves to have the potential of being an interesting resource to reinforce the functional appeal of the proposal.

Finally, this presentation proved useful in order to evaluate the way the concept was shown. As a conceptual development of a typology, the use of an embodiment proved to be difficult as a demonstrator in vehicle design, for both professionals tended to evaluate it as a final design. A generic volume mock-up or even abstract models could be explored as alternatives to conventional tools in car design for such a generic approach to vehicle design.

7.2 Comparative analysis with conceptual electric microcars

When this research started in 2008, microcars were a forgotten vehicle category. The relative success of the Reva G-Wiz, a perfect example of 'being there at the right moment', was an isolated sample of the possibilities for a small electric quadricycle for urban journeys. The concept of a new type of vehicle, which would fully exploit current legislation, and good enough for urban journeys was completely unheard of. However, since 2009, the interest by car manufacturers in this sector has been increasing. Moreover, recent reports in the transportation sector seem to agree with the initial idea of this research, considering microcars as one of the best available solutions for private urban transportation.

A recent market study estimates a spectacular growth for the microcar market in the next 8 years. Apart from this particular statement, the appearance of such a report is an example of the increasing interest of new forms of mobility for the city.

Some of the key points of this study are (Shankar, 2011):

- The emergence of a new class of micro-car, the sub-A segment, defined between L7 quadricycles and A-segment cars (15-40 kW and 550-1100 kg).
- 35 new quadricycles and 19 new sub-A cars will be launched in the next 3 years.
- By 2013, every European manufacturer will have launched new models in their range.
- Around 100% of those quadricycles and 85% of the sub-A cars will be offered as EV, including hybrid options.
- In a conservative scenario, the sales of microcars will reach 220,000 units per year in 2017.
- The main market drivers are: The emergence of mega cities and new mobility trends; congestion charges; growing interest on low emissions and

fuel consumption; upcoming technical developments and the possibility of city driving without a driving licence.

• On the contrary, the main restraints are: low performance of quadricycles; safety concerns, increasing legislative control and poor recharging infrastructures.

While this report highlights several important facts on the future of urban microcars, it also lacks some in-depth analysis in terms of vehicle typology definition. Initially, it seems that the definition of sub-A segment is quite open. One of the vehicles included in this category, the 2011 Renault Twizy, resembles a four-wheeled scooter. On the other hand, BMW's proposal seems a rather standard car, only differentiated by their renewed version of a body-on-frame architecture (carbon fibre body on top of an aluminium frame). Figure 3: According to Frost & Sullivan, examples of sub-A segment cars are the 2013 BMW i3 or the 2011 Renault Twizy.

Additionally, the similarity of new models to existing proposals is remarkable. Current models normally lack modern levels of quality, even when their price tags are similar to small conventional cars. Low volumes, rudimentary manufacturing methods and basic development processes can be blamed for these results. It is, therefore, intriguing how this sector is going to be able to motivate such an outstanding market growth.

Despite those definition issues, the fact is that microcars are stirring the sector of urban transportation. Originated as a kind of accessible DIY vehicles and later evolved as affordable post-war transportation, modern microcars start to transcend their current scope to become the next big thing in our streets.

Furthermore, London appears on top of the list of the European cities more likely to accept this microcar revolution (Shankar, 2011). This fact looks reinforced by a set of particularities that minimize the entry barriers for the microcar market. One of them is its mega-city nature, which can make urban traffic extremely slow (average speeds of around 12 mph), ruling out the necessity of high performance vehicles. An increasing charging infrastructure for electric vehicles also helps, with a plan to have 2500 street charging points by 2015 (Greater London Authority, 2010).

Due to these recent interests, it is extremely useful for the purpose of this thesis to evaluate the hypotheses proposed with respect to recent manufacturer proposals that have been appearing afterwards.

Starting with the design methodology, it is worth noting that none of the recent proposals seem to have been developed according to a multidisciplinary approach. While, as we will notice, there are strong links between technology and design in some of the concepts, none of them seem to embody aspects such as sociology or urbanism. In that sense, the design methodology for most of these vehicles seems to follow conventional car design strategies. This is normal if we consider that these are industry proposals, rather than the object of similar academic research.

Considering this difference, the analysis of these concepts will aim at evaluating the specific hypotheses of these work attending to particular design embodiments presented by different manufacturers. These main hypotheses can be listed as follows:

- Redefinition of the quadricycle typology
- Sustainable design
- Urban environment and lifestyle integration

Attending to the redefinition of the quadricycle typology, most of the recent examples seem to agree in a self-imposed constraint for vehicle length, as this research proposed. While European legislation merely imposes a limit of 4 metres (European Commission, 2002), several manufacturers have highlighted the importance of a short vehicle to allow parking flexibility and mobility.

The emergence of this proposal is thus a great opportunity of critically highlighting common approaches and differences. Let us start by analysing the main examples of this new breed of urban quadricycles to synthesis the typological analysis afterwards.

<u>2009 Renault Twizy Z.E.</u>

Figure 97: 2012 Renault Twizy (production version) and 2010 GEM E2

The first of the new design proposals was the 2009 Renault Twizy. It is the first recent proposal launched by an automotive manufacturer. Its design clearly differs from conventional cars, aligning with this research proposal on an open-wheel minimal vehicle. It is a small quadricycle with a total length of 2.3 meters and an electric powertrain of 15 kWh (Renault, 2011).

The Twizy is probably one of the most serious contenders as a feasible urban vehicle. By December 2011, Renault had already started manufacturing it in Valladolid (ICAL, 2011) and it is expected to go on sale in the spring of 2012. Its upright seating position and narrow body seem to fit urban tight driving conditions. In that sense, it can be understood as a four wheel scooter, which is reinforced by the tandem seat configuration and space.

However, that design does not fit within the concept of the vehicle as a personal space. If we consider users' alternative perspectives to vehicle use, such as using the vehicle as a mobile storage unit, the concept of a pure scooter with weather protection could be limited. In fact, such approach can encounter the same problems found with the BMW C1 scooter.

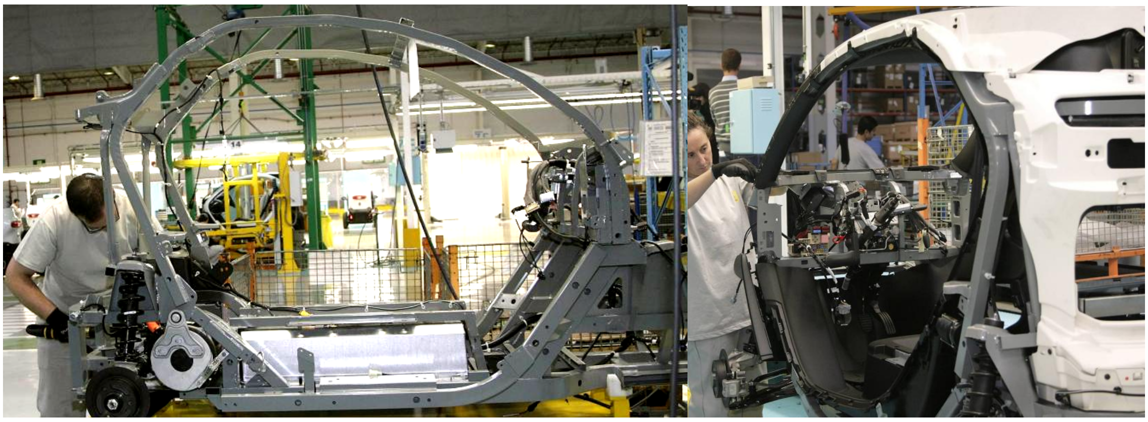


Figure 98: Assembling a Renault Twizy

In terms of sustainability, the design strategy partly aligns with the hypothesis of this research defending a minimal approach. Open-wheel configuration and an apparently exposed structural element are common elements. However, an in-depth analysis (see the picture above) of the vehicle reveals that, despite its apparent minimalism, the design follows conventional car body engineering: the structure is a cage made of square steel tubes, to which plastic body panels are attached to form the image of a safety cell similar to the smart fortwo. As we mentioned in Chapter 5, this approach requires the use of additional panels (shown in white), placed between the structure and bodywork, to provide a solid tactile feeling. This inefficient approach to the design, justified by production reasons, may be the cause for the high weight of the vehicle (450 kg for a 2.3-meter buggy). Other plastic panels, front and rear sections also remark the conventional design nature of the approach, even introducing visual complexity in an otherwise simple vehicle. This effect is clearly highlighted in the interior, where plastic panels, steering wheel and controls seem to be directly taken from Renault's more conventional models. In that sense, the GEM E2 shown at the beginning, with its simpler roll cage would possibly be more efficient.

There is, however, something noticeable in the assembly of the Twizy: as the pictures illustrate, the components are assembled mainly by human power. There is no robotic system adding environmental impact to each vehicle. That idea shows the validity of the considerations listed in Chapter 5.

Relating to passive safety, according to Renault, they had performed finite element simulations of crash tests, which put the Twizy above the current offer of quadricycles. The following picture, however, shows that the tandem configuration practically occupy the space for a rear crumple zone, restricting the protection for both driver and, especially, passenger.

Figure 99: Occupant packaging in the Renault Twizy

Similarly, in terms of urban integration, the design do not show any particular purpose, apart from its scooter-like profile.

Despite the different approach, it is worth noting that the first 'real' example of the new generation of small microcars shares the same open-wheel layout and minimal design ethos proposed in this research.

<u>2009 Peugeot BB1</u>

The BB1 seems to be another concept close to production and one of the most innovative and disruptive in some conceptual aspects. It is a small (2.5 metres) electric quadricycle that, thanks to an innovative seating layout is able to seat four occupants (Peugeot, 2011). It uses an electric powertrain composed of a battery package and two Michelin hub motors at the rear. Its innovative concept mixes the exterior of a modern bubble car with a scooter-like interior. Occupants seat in saddles that allow passengers seating behind to surround with their legs the front seats. Another remarkable feature of the interior is the clean canopy, only cut at the sides, that allows an open point of view, countering the claustrophobic feeling that small cars can provide.

Figure 100: Peugeot BB1

In terms of sustainability, apart from a small size and zero tail-pipe emissions, the BB1 does not present any differentiation from conventional cars. The design seems an exaggeration of Peugeot's visual language for conventional cars, which hinders the minimal nature and apparent user-friendliness of this proposal. Moreover, the whole concept responds to the same old concept of cover panels hiding the structure and systems, despite its technical simplicity. That may be the cause for its high weight (600 kg).

Regarding urban integration, again, its dramatic design style does not differ from conventional cars, rejecting the possibility of considering either visual or functional integration within urban landscapes. Moreover, its car-like approach also limits its ability to keep up with the urban vibe in terms of determinant lifestyle factors such as consumer electronics and fashion.

However, its imminent production and innovative powertrain, specifically developed by Michelin for quadricycles, can make this concept an interesting take on the design of feasible urban vehicles.

<u>Nissan Pivo 3</u>

Figure 101: Nissan Pivo 3

Nissan has been working on the Pivo concept for years, and its most recent incarnation appeared at the 2011 Tokyo Motor Show. Like the MIT City Car and the other Pivo's, it works on alternative chassis concepts based on steerable rear wheels (Autocar, 2011). It clearly has mobility advantages, with a 6.6 foot turning ratio. However, such a technical concept is clearly unfeasible attending to current type approval legislation, which deems the concept as futuristic by now.

Nevertheless, it is worth noting that the Pivo presents a profile similar to the proposal of Nissan's partner company, the Twizy. That profile, applied to enclosed wheels give an image too reminiscent of conventional quadricycles, accentuated by a strong use of surfaces and greenhouse definition.

<u>VW Nils</u>

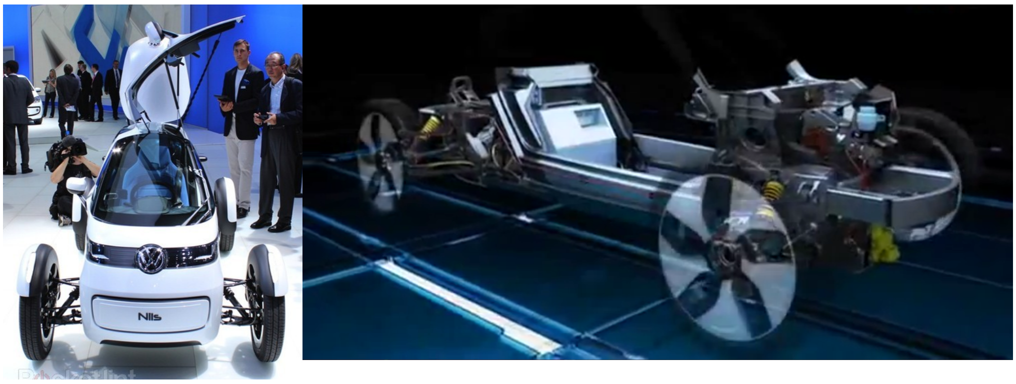


Figure 102: VW Nils and technical architecture

During the 2011 Frankfurt Motor Show, VW presented a new concept of commuting vehicle, different in design and powertrain from previous proposals such as the L1 or the XL1. The idea under this vehicle derives from cooperation with the German Minister of Transportation. Its single-seating layout attend to current car occupancy figures for commuting in Germany (One person per car), and VW claims the vehicle capabilities in autobahns, in terms of speed and protection (Pollard, 2011).

Attending to some considerations, this vehicle agrees with the boundaries established in this research for the design of an urban commuter. First of all, it uses a simple volume supported by four exposed wheels. Despite its profuse use of VW graphic design, this volume seems inspired by efficient vehicles such as gliders. It also tries to reinforce the sense of protection by exposing a structural belt that surrounds the cockpit. Additionally, its detailing is mainly functional, which reinforces its purposeful and efficient ethos. In that sense, it also agrees with this research in the use of an approach close to product design, inspired by bubble cars. Finally, the proportion of its wheels also show the cyclecar inspiration.

Nevertheless, there are several features that conflict with the hypotheses of this research. Despite statistic values, a vehicle of more than 3 meters, 460 kg and as expensive as a city car does not seem an efficient or affordable option. Moreover, private mobility succeeds because of its convenience and freedom. How could a single-seater with such a tight trunk compartment cover typical urban tasks such as shopping or picking up a friend? Mega-cities are dynamic environments where adaptability is crucial in the success of certain products (i.e.: smart phones), but this proposal seems to be excessively constraint from its design brief.

Furthermore, despite the initial novelty of the open-wheel design and seating layout, its vehicle architecture is the same used in conventional cars. Thus, as in other low-production cars, the designers used aluminium casts, extrusions and stamped sheets for the chassis. Similarly, internal and external panels cover the structure and mechanicals. As we mentioned before, this approach does not fully exploit the possibilities of the minimal set of requirements for an urban vehicle. Not to mention the claustrophobic feeling such a tight cockpit must produce.

The automotive approach is further highlighted in the design surrounding the wheels: conventional suspension links and dampers, brake lines and steering links create a confusing image that confronts the general clean lines of the concept. In that sense, it is easy to see how solutions such as sliding pillars can contribute to produce a seamless design.

There are also, other points, from the point of view of the conceptual generation of the vehicle that do not seem clear either: On the one hand, the proposal goes as far as offering a single seat to improve on occupancy efficiency; on the other hand, despite its intended use in autobahns, the car uses exposed wheels, which are a clear disadvantage in aerodynamics terms.

In general, this proposal seem to be exposed to the same risks that the Sinclair C5 faced: it tries to introduce more than one substantial change at once, and its narrowly defined design drastically restricts its potential success.

2011 Audi Urban Concept

Audi's concepts take on the racing pedigree of the old cyclecars, repeating the concept of cockpit on four exposed wheels (with large diameter and thin thread too). Both the spyder and the closed version are low-slung proposals longer than 3 meters, which does not seem to relate to the design ethos of a small urban vehicle.

Figure 103: Audi Urban Concept and Urban Spyder

Similarly to older VW proposals and the embodiment of this research, Audi opts for a 1+1 seating configuration (Kacher, 2011), introducing, in that sense, more practicality than the Nils in a similar package. It also uses an open tub configuration for the interior, with exposed composite structure and integrated seats, which represent a fresh approach to the design, similarly to the strategy proposed in this research. Also in line with the embodiment of this research is the strength image of the spyder configuration, thanks to a body design that highlights strong upper and lower rings surrounding the cockpit.

However, there are other design aspects that show the limitations of this embodiment. First of all, an obvious disadvantage for these concepts would be their tight cockpit and low seating position. While seating close to the ground in a sports car can provide a strong sense of sportiveness and even status, a low small vehicle can prove to be frightening in normal traffic conditions. The Sinclair C5 is the best example to describe that effect. It is obvious that those concepts have a surrounding structure that the C5 lacked, but that cage would also contribute to encapsulate their occupants in a tub inches away from the ground.

Figure 104: A four-wheel c5?

Additionally, the cyclecar philosophy does not continue throughout the design: suspension, steering and powertrain have similar configurations to those found in conventional cars. Again, this is a lost opportunity, and contributes to spoil the seamless and efficient aesthetic of these proposals. In fact, the suspension arrangement in the functioning prototype seems similar to the one used in the Nils. For the motor show cars, this design issue is cosmetically disguised by covering the steel wishbones with covers that give the appearance of carbon fibre, and the dampers are installed inboard, more likely with one of the wishbones doubling as pushing or pulling rods.

Figure 105: Concept, working prototype and 2012 version

In terms of manufacturing, the use of carbon fibre could be difficult to justify in production vehicles. Italian ATR Group (which manufactured the tubs for cars such as the Ferrari Enzo or the Porsche Carrera GT) has been selling a 300-kg quadricycle with a carbon-fibre monocoque since 2005 for 28,000 € (Bassoli, 2005). This company uses their own process, based on resin transfer moulding, which is an alternative to lower manufacturing costs of composite components (McLaren uses their own version for the MP4-12C chassis). For the Audi, if we consider its electric powertrain and bespoke component, prices can easily surpass 35,000 €. The fact that Audi may sell 999 units of this car for 9,999 € each (Kacher, 2011) suggest that this proposal should be consider more of a halo car for Audi than a detailed urban proposal.

Figure 106: ATR's microcar and tub

In spite of the limitations of this designs, the interest shown for both VW and Audi in this type of architecture can suggest the development of a quadricycle platform within the automotive group. Should this platform embrace the design advantages of a modern cyclecar, it would suppose a great impulse for a new generation of urban efficient vehicles.

2011 Opel RAK e

Figure 107: Opel RAK e: top, front and rear

In 2011, Opel also introduced their own proposal for an urban vehicle inspired continuing the line of old cycle cars. Its concept appears to be a mix between the architecture of the classic Isetta and the aesthetic of a jet fighter. It weights 380 kg and has a 15 kW electric motor, which would qualify as a quadricycle. According to Opel representatives, it is meant to be designed with production in mind (Autocar, 2011b).

From a design perspective, the Rak e and this research share the minimal sportive ethos linked to motorcycle technology and design. Similarly to what this research discuss, Opel representatives see this minimal vehicle as a more plausible option to develop an urban electric vehicle (Autocar, 2011b).

As we saw in Chapter 2, sharing components with motorcycles was one of the distinctive aspects of the original cyclecars. The Rak e, however, opts for a layout and design aimed at motor enthusiasts rather than a wider profile. Its interior exposes the complexities of the technical systems and the exterior highlights a low line and racing canopy, with a tight enclosed space. Similarly to the Audi, that specific target has the risk of losing focus in the functionality of an urban vehicle, where higher seating position and wider interiors are favoured in such a small concept. Unlike the Audi, though, the Opel presents a cleaner line in the design of the body, which contributes to somehow minimize the sensation of smallness from the outside. It also differs in the way the space around the wheels is managed: contrasting fairings are used at the front disguise the weak image of exposed suspension links, while a motorcycle-inspired rear swing arm contributes to a stronger visual message.

In terms of the technical development, some particularities of this design, contrasting with the hypotheses of this research, are worth a brief analysis. The first and most notorious aspect of the design is the chassis layout. According to its designer, the initial design was meant to use a single rear wheel. However, considering passenger weight (seating in tandem behind the driver) and stability, they decided to go for a second wheel (Autocar, 2011b), converting the car in a modern day Isetta. Riley (1996) defines this configuration as the worst of both worlds: having the complexity and weight of a four-wheel chassis, with the instability of a four-wheel configuration. It does not seem to be any reason to justify this decision, apart from keeping the particular aesthetic of this vehicle. Even staying within the three-wheel configuration, automotive history and physics have shown that the best configuration to produce a reasonably stable vehicle is to follow the Morgan way, with the engine (or batteries) placed before the front axle (Incidentally, Morgan has reintroduced its proven three-wheeler, which could be a contender to some of the largest concepts proposed here). Either way, as we saw in Chapter 2, the stability requirements would still tend to make the car wider and longer, which is contrary to the design principles of an urban vehicle.

Another technical aspect to consider is the choice of materials. The RAK e has been designed using a structural core made of high-strength steels (Autocar, 2011b). That choice differs from what this research and other manufacturers proposes. Considering the market size that these vehicles could have, the use of stamped steel is difficult to justify on a cost-basis. The break-even point for conventional steel is around 80,000 units per year, which is exceptionally high for a vehicle that, in an optimistic scenario, could reach 20,000 units per year. Aluminium and composites seem better options for the expected low production volumes of urban quadricycles.

The choice of high-strength steels also goes against the general concept of the vehicle. If the proposal were more flexible in its design approach, as the original Isetta, its adaptability could favour a bigger market stake that would justify those materials. However, with such a defined design personality, the

Rak e risks to limit its potential to reach a reasonable market share as an urban vehicle. Again, the Sinclair C5 is a good example to illustrate how a lack of flexible approach can condemn an otherwise interesting idea.

<u>Other proposals</u>

There have appeared other examples, specially along 2011, of vehicles that would be within the reach of the typology described in this research.

Motorcycle manufacturers have also shown interest in new types of vehicles within quadricycle legislation KTM, in instance presented the E3W, an electric two-seater somehow reminiscent of the classic three-wheel Piaggio Ape. Even Piaggio itself presented a four-wheel vehicle initially aimed at emerging markets as a contender to the Tata Nano. Both proposals opt for a utilitarian approach with designs that maximize internal habitability. The NT3 is even able to carry three occupants in a seating layout à la McLaren F1. These proposals also use motorcycle mechanicals.

Figure 108: Proposals by KTM and Piaggio

Japanese manufacturers showcased their ideas about urban micro cars at the 2011 Tokyo Motor Show. They have followed their own path in small vehicle design for years, with a wider range for European standards. In 2011, two proposals combined the quadricycle typology with a sense or urban integration driven by the use of electronics on the bodywork. The Daihatsu Pico proposes a cleaner take on the Renault Twizy layout, with simple surfaces and a protective belt that contains an array RGB LEDs to show warning and status messages to other street users. Despite its simplicity and limitations, it is interesting to start seeing proposals including such elements in the design language of future quadricycles.

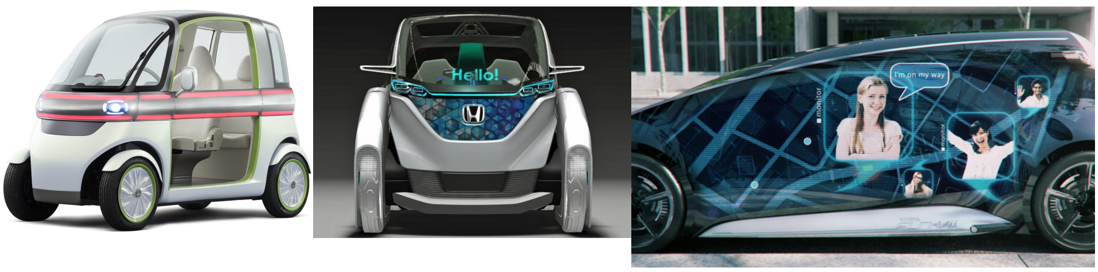


Figure 109: Dahiatsu Pico, Honda Micro Commuter and Toyota Fun-VII

Honda followed a different approach with the Micro Commuter. While the profile is also similar to the Twizy, and other cars such as the smart, it uses the T.25 seating layout, allowing 2 passengers behind the driver. Its design is much more outrageous than the Daihatsu, with futuristic fenders and body graphics, that also incorporate multimedia messages to be displayed to transmit messages or simply customize the exterior. The Honda is particularly illustrative to show the disadvantages of conventional contemporary car design for an urban vehicle that integrates multimedia as part of its body work.

The design of this car is rich enough in terms of surfaces and detailing by itself. In the 'off mode', the car projects an active visual message, aimed at potential buyers or by-standers. But this abundance of physical design plays against digital customization or message projection. In this proposal, the message projected onto the windscreen get lost in the middle of the array of surfaces compounding the bodywork; while the digital customization is restricted to a predefined area of the car, which clearly limits its visual potential to differentiate among vehicles.

A cleaner physical design, as the one proposed in this research, can maximize the possibilities and integration of digital systems within the design of the urban vehicle. This idea is parallel to recent consumer electronics design, where the physical object gets reduced to a minimum set of physical qualities, in order to maximize the digital experience. In fact, in the same show, Toyota presented a vehicle that, without being a microcar, was closer to this design thinking.

Suzuki and Kobot also presented concepts for urban runabouts that match the concept of moving space proposed by this research. They respond to the concept of a bubble on four wheels, although as it happens with the majority of the proposals, the rest of the design approach relies on typical conventional car design methods. Thus, as it happens with the Honda, their bodyworks are detailed by an array of elements that introduce unnecessary complexity and visual distraction within urban contexts.

Figure 110: Kobot and Suzuki Concepts

The µcar and other proposals

The previous analysis of recent vehicle proposals related to this research has had two functions in the critical assessment of this work. First, by identifying common design strategies, it has served to ratify some of the hypotheses exposed in this thesis. Second, in some cases, proposals developed upon different approaches serve as counterexamples of what this research proposes.

Let us start with those points of the design strategy that have being agreed by other recent developments in quadricycle design.

Common design aspects

- Conventional four-wheel layout

  The only version close to production uses a conventional four-wheel architecture. This research defends this solution as the only way, using conventional technology, to produce a stable short-wheelbase vehicle. For example, alternative layouts as the Opel and KTM surpassed 3 meters of length.

- Vehicle length restricted to 2.5 meters

  While the legislation for quadricycles is very flexible in vehicle length, this research originally suggested a reduction to 2.5 meters (ideally, to 2.4 meters or less, attending to standard European parking spaces). Such a constraint allows greater parking flexibility and improved urban traffic flow at low speeds.

  Most of the recent proposals follow this approach, with the Twizy even reducing its total length to 2.32 meters.

  While some proposals surpassed 3 meters of length, they seem to prioritize other design values such as sportiveness, instead of urban qualities. The Audi and the Opel, with their low seating position and profile, are examples of the later trend.

- Electric powertrain

  All the proposals listed here (except the Piaggio) use electric powertrains. In some cases this choice is a departure from previous concepts, as it happened with the VW Nils and its diesel-fuelled ancestors. The suitability of electric motors for urban driving convenience perfectly fits current performance levels of this technology. Its immediate response and simplicity makes urban driving more intuitive and easy. Similarly, the range required for these vehicles is considerably less than what is required for inter-urban journeys. Thus, it is possible to reduce battery cost and even to recharge at home.

This hypothesis is further supported by recent practical research on electric vehicle usability, such as those accomplished by CABLED (2011) and BMW (The Green Car Website, 2011). Their results both highlighted the limitations of electric vehicles for intercity traffic and their adequacy for urban duties.

Furthermore, once we agree on the advantages of electric vehicles within cities, the next step would be to define purpose-design vehicle architectures. The new architectures would take advantage of their reduced requirements to save weight and, implicitly, battery costs. Such an idea also supports the propositions contained in this research.

- Safety requirements

  The majority of these proposals also consider crash protection in their design brief. Current legislation does not include any specific requirements, but the increasing importance of quadricycles as urban vehicles starts to motivate change in the regulations.

Considering the design strategy, all the proposals shown by car and motor manufacturers represent a clear departure from conventional quadricycles. This thesis sustained from the beginning that an eventual success of the quadricycle will rely on a differentiation from both current microcars and city cars. Technical minimalism and urban nature were two decisive factors to determine the visual message of the new typology.

Visual minimalism is clear in every recent proposal: Most of them use the concept of cockpit on exposed wheels, as opposed to conventional fully bodied cars. Some of these new proposals even agree to choose old cyclecars. This research included a study on cyclecars in order to explore new design possibilities to create, not only visual differentiation, but also an inherent emotional connection that current quadricycles lack. Those old vehicles were a perfect example of machines that, despite appearing due to economic reasons, were able to generate emotion by their simplicity and rawness. Favourable power-to-weight ratios made them serious contenders in racing disciplines such as hill climbs. Additionally, their simplicity allowed users to build and customize their own vehicles, which even helped to foster British kit car culture. Those recent proposals for future cyclecars (especially the Audis and Opel) highlighted the same original concept and media interest gave a hint of the validity of such approach.

In terms of interior design, only Audi's and Opel's concepts continue with differentiated and minimal design proposals. The Audi aligns with this research embodiment in three aspects:

- It shares a 1+1 seating layout
- Its exposed surrounding structure dominates its interior design
- The instrument panel is reduced to a minimal design unit.

Equally minimal, the Opel presents a machine-like interior where steering systems and canopy arms are used as design elements.

As part of the differentiation process, together with other design requirements, another aspect proposed in this research and used in several recent proposals is the introduction of a canopy instead of conventional doors. This solution can reduce the cost of having two doors and can also increase habitability.

<u>Counterexamples</u>

The conceptual proposals shown in this chapter have renovated the design of urban vehicles in the most popular motor shows. Some of these concepts have received praise by media for their convenience (Renault Twizy) or the additional emotional side added to otherwise simplistic vehicles (Audi Urban and Spyder Concepts). This fact highlights the adequacy of some of the hypotheses enunciated in this research.

Nevertheless, despite the similarities, there is a clear difference. The academic approach of this research looked from a holistic perspective at the design of a new typology based on quadricycle legislation. The convenience of multidisciplinary approaches to tackle sustainable and environmental design problems has been previously proved in design research (Inns, 2007). Thus, for the design of a new type of urban vehicle, the approach outlined in this research added to the usual stakeholders of the vehicle design process (user, legislation and automotive industry) other valuable sources such as urban context, society or alternative industries. This different approach to the design process has apparently generated two main differences with respect to the conceptual proposals shown by the industry.

The wider approach of this research constitutes the first difference. It includes design aspects that relate, not only to the design of the vehicle itself, but also to urban and industrial considerations. The academic nature of this proposal, free of corporative policies or market targets to comply with, facilitated it.

Subsequently, the second difference is that the design embodiment forms a seamless proposal. While the historical reference to cyclecars and bubble cars is visually obvious, it also appears in the minimal vehicle architecture and urban design proposal, reinforcing its purposefulness.

After reviewing the main concept vehicles that have appeared along this research period, there are four specific aspects of this multidisciplinary approach that have been highlighted:

Historical reviews are an important resource in the development of a new urban typology.

'Those who forget history are doomed to repeat it'. More than a century of motorization has left a plethora of technical and design solutions for any type of urban vehicles. Some could be inspiring and some constitute a list of past failures. Avoiding such a study can drive us towards ideas already proved wrong. The development of the 2011 Opel RAK e could illustrate this point, for it apparently tackled three-wheel architectures and problems from scratch. This concept and the Audis also share low seating position and small size with the Sinclair C5, a feature that was decisive in its ultimate failure. Similarly, the C5 problems reappeared in the VW Nils and its narrowly-defined spirit, disadvantageous in uncertain and dynamic environments.

In contrast, the historical review in this research supported the choice of a four-wheel configuration for such a short vehicle (or at least, it identified the design problems to consider with three-wheel layouts). It also suggested a change to higher seating layouts from the initial concepts shown in Chapter 7. Again, despite statistical studies included in Chapter 4 apparently backing single-seating layouts, the embodiment had a more flexible approach, still focusing on the driver, but also considering the eventual presence of a passenger.

A comparative analysis of old open-wheel vehicles with contemporary aesthetics also suggested the redefinition of the space around the wheels, to project a sense of solidity and efficiency that most of the recent proposals lack. And as the third point will illustrate, such a design analysis is reinforced with the integration of technical solutions.

Urban and social contexts analyses enrich the design process

In the development of disruptive technologies, it is important to identify where current solutions are in terms of their life cycle. A product or technology can be nascent, evolving or dated. In that sense, conventional urban cars could be considered dated. In general, technological evolution is purely quantitative and the car itself has become a social concern within the city. Moreover, as Chapter 4 explains, recent reports assert that the role of cars as objects of desire for younger generations is decreasing. The design process must account for this facts, identifying car-related problems and relevant social drivers in urban contexts.

In contrast, the quadricycle designs shown by the main manufacturers seem to respond to unidirectional design processes. Apart from their reduced dimensions or singular details, such vehicles seem conventionally designed attending to branding and marketing strategies and forgetting additional concerns. Exterior design tends to obviate visual integration within urban contexts by proposing the same type of eye-gathering products that tend to generate visual pollution when parked in groups. Functional integration of parked vehicles to create human-centred environments constitutes another common omission. Ultimately, despite their increasingly secondary role in our culture, most of this proposals do not consider flexibility and mass customization, instrumental in the success of communication technologies and the fashion industry. Thus, the emphasis on artificial product semantics and branding neglects an 'open-source' approach that could intimately relate them to users and society. Ultimately, most of them also obviate the possibilities that the urban journey itself could open. State-of-the-art technologies such as head-up displays or navigation systems present no further integration in vehicles destined to travel along such visually rich environments.

In contrast, the multidisciplinary approach of this research deeply influenced an alternative take on urban vehicle design. This approach was embodied in the Latent and Canvas design strategies. Latent design helps to define a new type of vehicle architecture within its context: it is an efficient and minimal design around a tight and tidy package. From the exterior, it is an easily assumable volume, susceptible of being subtly integrated in urban environment (even enriching them, as Prof Stevens suggested). Similarly, the interior is there (exposed through the bodywork) for those interested in it. It exhibits the inherent qualities of the architecture without major constraints to further customization. This customization is the goal of the Canvas design strategy. Such a simple design enhance the functionalities of digital systems that allow each user to reflect their own style or to show and gather information (both for driver and by-standers). This redefines the vehicle within its context, from being an intruder in human spaces to interacting with the surroundings.

Integral approach to efficiency enhances the conceptual proposal

Efficient vehicles, such as gliders or high-performance bicycles, have something in common: design and technical aspects are closely interrelated from the early stages of the conceptual development. In the case of this research, the conceptual development of such a minimal vehicle architecture must consider, not only topological aspects, but also vehicle sub-systems. The design requirements for this type of vehicle (short journeys at low speeds) allow to play with the concept of 'good enough' solutions, that allow cost reduction, efficiency gains, system optimization and even added visual values.

Some of the recent conceptual proposals seem to prioritize design over technical developments, exploiting just the image of old cyclecars and directly transplanting car systems into the package. This approach produces not only vehicles that do not exploit the advantages of quadricycle regulations in terms of functionality and efficiency, but also incoherent design proposals, where clean lines are mixed with inherited sub-systems such as suspension or steering modules. This approach can be due to short-term projects that tend to re-utilize existing components and could improve considering the support that main industry suppliers such as ZF or Michelin are providing to the microcar industry.

Alternatively, the multidisciplinary approach of this research settled a close interaction between design and engineering in the conceptual generation of the new vehicle architecture. While this thesis does not cover detail design, the constant presence of technical considerations enriched the process with solutions that combined performance and design qualities at a conceptual level.

The Layered Design strategy is the embodiment of this approach, transforming technical concepts such as efficiency and modularity into inherent design values of the typology. Another example is the importance given to the design of the elements surrounding the wheels. A conventional approach merely exposes linkages and hubs that are normally hidden in wheel wells. With this integral approach, the proposal combined design importance with technical solutions. It integrated structural elements (arms and wells), suspension and steering systems with a novel design language, expressing the efficiency, solidity and purposefulness of the µcar.

Industrial context analysis conditions vehicle architecture

Finally, another important aspect is the consideration of the industrial context in the proposal of a new typology. The lack of such an analysis in recent concept vehicles can be due to their nature of design proposals. Nevertheless, considering the delicate times that countries are living by the turn of the first decade of the 21st century confers greater importance to these facts.

In terms of vehicle architecture, this climate of uncertainty in the introduction of new solutions should be translated into modular concepts that increase the possibilities to adapt to different contexts and trends. Considering proved theories as platform strategies within the design of urban vehicles, wider design targets (from passenger to utility vehicles) should enhance the success possibilities of a new concept. Again, the Sinclair C5 is very illustrative in this matter.

As we have seen, there have been fundamental aspects of this research that have not being explored by other conceptual developments. In order to prove the validity of such aspects within a design context, the last part of this critical assessment includes several interpretations of the main hypotheses of this research by vehicle designers studying the MA in Vehicle Design at the RCA.

7.3 MA Project: alternative explorations

In the last part of this critical assessment, the design possibilities of the design strategy outlined by this thesis was evaluated in a design project with vehicle designers studying the MA programme at the Royal College of Art. Unlike the in-depth outline of the thesis, the design brief tried to be as open as possible, focussing on the aspects related to the vehicle design discipline. The aim was to start with the same idea of for a visually subtle proposal (volume on wheels) and favour alternative approaches to generate differentiation within a common volume layout. The students had the option of playing with simple volumes such as spheres, cubes or tetrahedron for the cockpit than conventional design.

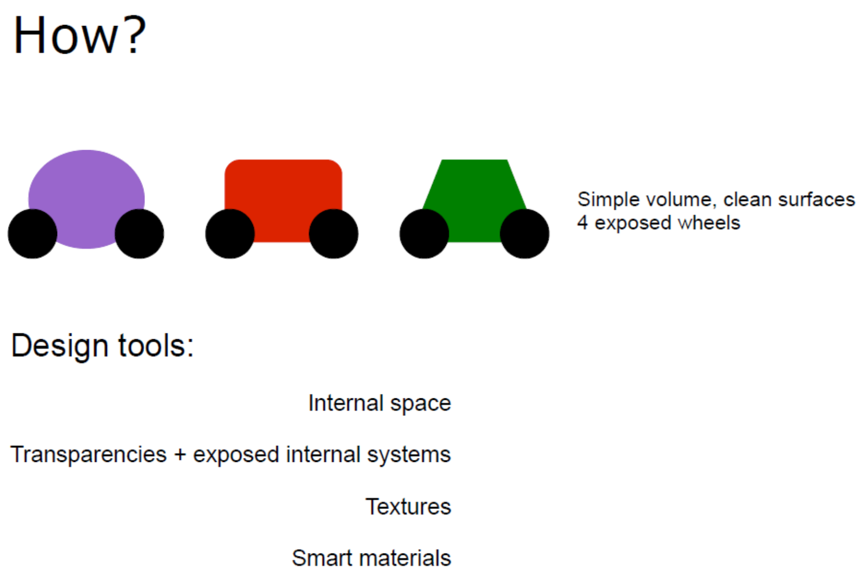


Figure 111: Slide from the design brief

Their proposals should incorporate a sense of efficiency, safety and fun to eminently urban proposals. Ultimately, their target user would be a young professional, single and living in Central London, one of the most problematic profiles in terms of private urban transportation (Chapter 4).

The ultimate goal was to evaluate, through their design thinking and proposals, the creative variability that such a design brief could offer, and to see if car design professionals would follow the same strategies that this thesis exposes.

The proposals

One common element to almost all the ideas was to provide a sense of style, considering that the vehicle would be used in professional environments such as the City, where the dress code is formal. For them, avoiding the toy-like image that such a simple bodywork and small size would have was important. Thus, graphic design was one of their main concerns.

Ian Slattery looked at different interior layouts to highlight the simple shapes of the exterior: Instrument panels, seats or structure become visual elements to play with and organize in visual compositions. He was also interested in the concept of using different design layers (without any knowledge of the details of the Layered Design strategy) to reinforce the concept of a protective cocoon around its users.

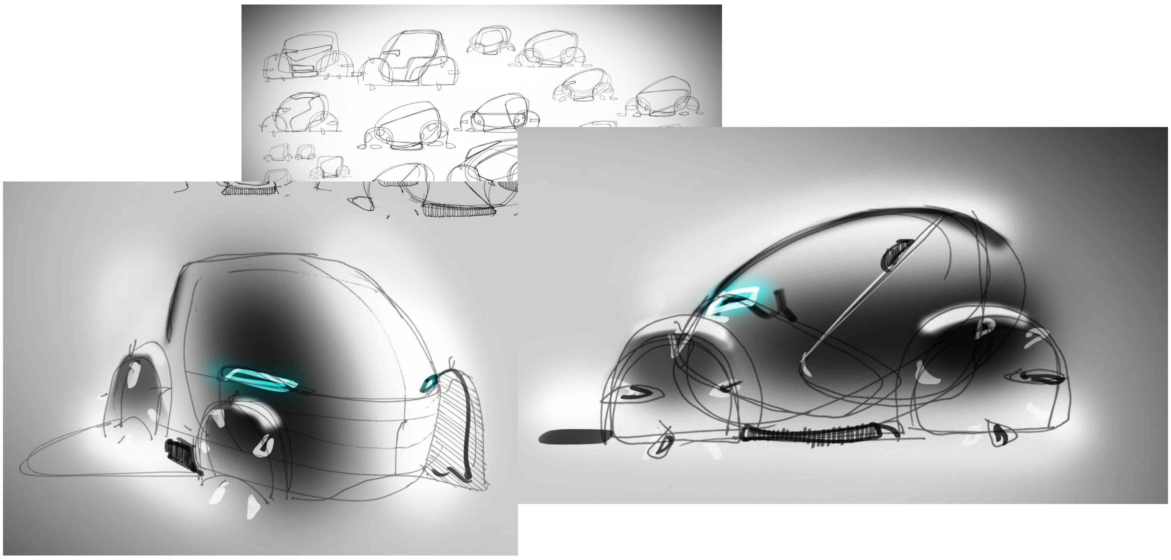


Figure 112: Ian Slattery

For the exterior, he decided to keep it as simple as possible, choosing an oval shape that fits the concept of surrounding cocoon.

His emphasis on the use of internal elements to define the visual message of the vehicle is very close to what this research propose. In that sense, it would be interesting to see how a system-level approach could be used with vehicle designers to enhance the visual qualities and feasibility of their proposals, as conventional approaches with 2D sketching could constrain the creative process.

Nir Siegel took the use of the single-volume bodywork further. He looked at the car as a functional element within the city, considering it as a mobile storage unit for normal items that a person would need during a normal day at work. Consequently, the car becomes some kind of base camp for urban living.

That sense of utility translated into boxy shapes that maximize contained space. The treatment of his bodywork proposals highlights the idea of open interior design, where panoramic visibility helps to avoid the claustrophobic feeling that small vehicles could provoke. While the canopies are clean of A-pillars or other type of frames, the cut lines of their supporting frames try to project a sense of protection, exposing angular internal belt lines and raised profiles next to the seats.

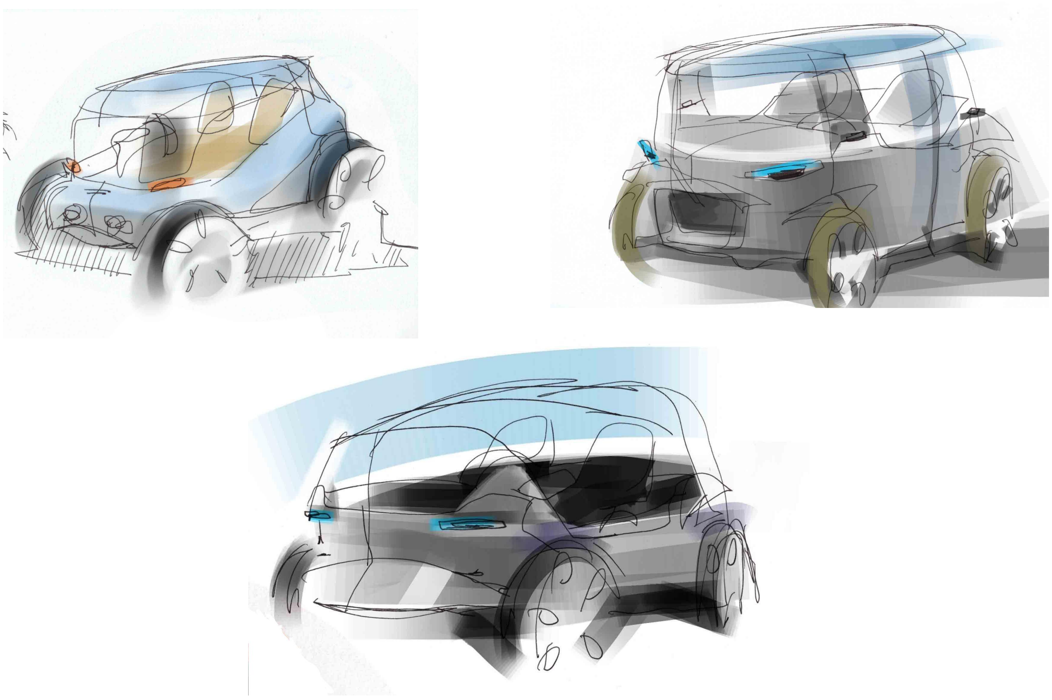


Figure 113: Nir Siegel

Centring on the design details of the proposals, his designs represent a mix between the utilitarian box with the fun touches of a beach buggy. They are somehow reminiscent of SUVs, reinterpreting the emotional and apparently dysfunctional nature of such sought-after vehicles. The results are a good starting point to redefine that protectionist, utilitarian and rugged style into social conscious packages.

His take on the design of a modern urban microcar also considers the definition of distinctive design details, such as the fake A-pillars of the proposal below, that do not reduce visibility and simultaneously offer packaging space for navigational systems or other control component s. This detail defines again the exterior as a reflection of the internal layout.

Exploring more futuristic approaches to aesthetics, Siduo worked on two interesting alternatives to the design of an heir for cyclecars and bubble cars.

Starting from the requirements for a business car, Siduo thought about the use of the car as an experience enhancer. Thus the vehicle would assume a closed nature for daily commutes, favouring urban mobility. But for leisure moments, the body work would open-up. Rather than the traditional idea of a convertible car, his proposal would embrace the surroundings creating a moving version of the *brise soleil* architectural concept. Bodywork panels would separate from the underlying structure to increase the total size of the vehicle and the interaction with natural environments. In that sense, he decided to choose functional de-construction of the simple bodywork as a design resource.

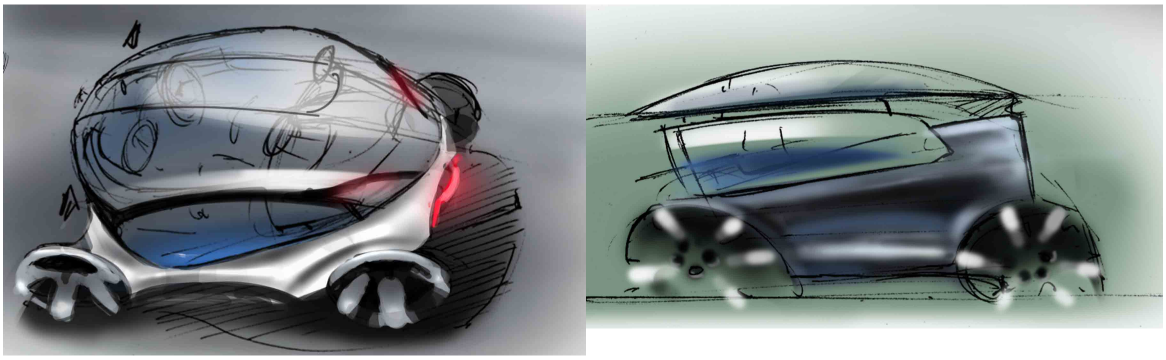


Figure 114: Siduo Wong

His embodiments follow to different takes on the concept. The first one draws inspiration from bubble car design with a prominent chassis that reinforce the sportiveness and sense of protection of the vehicle. The visual qualities of the canopy and the exposed interior represent the main design resources in the proposal. His second approach uses a cubical layout formed by a first layer of expandable body panels and an underlying structure. Glazing panels are connected to flexible elements that allow the morphing configuration described above.

In general, the student proposals fit within the latent approach described here. Their designs shown the possibilities that minimal layouts can offer. To cope with the open wheel layout (without the possibility of adding fenders or connecting elements), the students used similarly sized wheels, thin and of large diameters.

Layered design was another concept commonly accepted as a design resource. Ian's explorations showed an interest for the inner physicality of the vehicle that could be further explored with the system-level approach described in Chapter 6. Nir saw it as a resource to enhance the perception of the vehicle as contained space, using large and clean canopies that completely exposed internal elements. Using an alternative approach, Siduo decided to highlight the separation between minimalist exterior and the structure underneath by de-constructing the architecture into a vehicle that is able to expand the space covered by its body panels. Again, this idea highlights the materiality of panels as space dividers rather than cosmetic and unrelated covers.

An aspect that did not received particular attention, however, was the use of open-ended design strategies. Their need to add a degree of formality to the design had the risk of producing well-defined vehicle images, which is common to the aesthetic of contemporary cars. Users would have to choose between products with clearly defined personalities, which do not enhance either physical or digital customization.

Nevertheless, the general conclusion was that the design proposals identified two of the main design strategies (Latent and Layered Design) and defined a varied array of solutions within the constraints of minimal external layouts.

8. Conclusions

This thesis contained the development of an electric and urban vehicle typology, the μcar, able to offer a more efficient while desirable alternative to conventional cars.

The first part of this thesis contained the compilation of information that helped to define the design playground for such a new typology. The second part contained the development (especially in Chapter 5) of the typology using a system-level approach and semantics to integrate objective and subjective design goals. The proposed typology (exemplified in Chapter 6) appears as an answer to the problematic of private urban mobility, considering the influence of users and industry to propose a feasible solution. Such a solution aims to be not a mere local embodiment but an initiator of change for the urban habitat to recover its human-friendliness.

This chapter will explain how the proposed typology answers the initial questions that motivated this research, mainly related with a softening of the entry barriers for a disruptive and efficient urban typology.

How can we design an eminently efficient urban four-wheeler?

By the end of the 2000s, urban coexistence and its mobility implications are a manifest design problematic constantly growing. It is not about the individual and his/her life as an isolated issue, but about how our decisions make our lives easier without spoiling our neighbours'. In order to increase its validity, the urban quality of the new typology, must embrace not only a quantifiable improvement in terms of pollution, space use or safety, but it must also use existing technologies to propose a catalyst towards better urban environments, for now and the future.

Chapter 2 illustrated the influence that the context can have in the success of a particular typology (how tax policies can favour otherwise normally unappealing vehicles, or how forgetting this contextual influence can produce a mere lab experiment without any real-world applicability). However, apart from benchmarking process (that merely refer to market contextualisation), the influence of contextual factors is not explicitly present in modern vehicle design.

In the µcar typology, this influence appears as an active element that suggest a balance between the collective and individual, both in terms of spacial and relational aspects. In Chapter 5, Latent and Canvas Design consider such aspects both affecting exterior vehicle design and defining the functionalities thanks to the flexibility provided by the electric powertrain. Such an approach converts the designed vehicle into an actively relational element within its context, instead of a mere intruder in the collective space.

The µcar, thus, helps to conform a more human habitat, both from its own effect and with the changes it can inspire. It is a vehicle that embraces its simplicity to highlight its environment. It is not conceived for the showroom fight, but for the city. And not from a merely physical stance, it is also an interface with the city that can become an information point, or the framework for digital street performances. And in that sense, it has the potential to out-date the sempiternal and divisive street parking layout towards new open spaces where parked vehicles foster a relation and comprehension of the environment to by-standers.

At the same time, this proposal does not forget the individuality of mobility, generating new dimensions for design individualisation. Moreover, it uses the minimal platform to highlight its connecting role with the travelled space, fostering a re-apprehension of the lived space that would hopefully re-involve citizens as active elements in the future of such space, opposing the de-humanizing trends that both speculators and politicians often introduce.

The embodiment contained in Chapter 6, with its simple exterior and panoramic interior illustrate this design philosophy, devoting large areas of its design to interactive duties for both occupants and by-standers.

How can we incorporate user acceptance in the new vehicle typology?

Although the consequences of car use within cities are becoming unbearable, their presence in our society is still well-rooted. From the technical marvels of the early days, these vehicles have surpassed mere functionality to reach an emotional role in our lives. Thence, the proposal of a valid alternative for urban contexts must deal with the social implications attached to the use and ownership of these vehicles.

For such a task, narrowly-defined vehicles become vulnerable in front of such an adverse and volatile environment, which is why this research addresses the design problem defining a typology instead of a unique vehicle. The examples analysed in Chapter 2 illustrate how apparently valid proposals have been unable to contend cars. In the search of efficient individual mobility, it is important, not only to keep the safety and convenience provided by cars, but also to propose a desirable alternative. This assertion is particularly obvious attending to the lack of success of current quadricycles. Thus, quantitative downsizing, while helpful, is not enough. Mass-production allows such low levels of manufacturing costs to the automotive industry that the proposal of a low-volume urban platform would be comparatively more expensive to make (the smart fortwo is the best example).

Therefore, the µcar typology reformulates the approach by minimising the architecture to both increase its economical feasibility and generate a new and differentiated design language. As Layered Design defines in Chapter 5, the reduced design requirements and the electric powertrain allow a de-constructed architecture that becomes self-explanatory in terms of life cycle assessment and adaptability. This approach shows the µcar as a differentiated alternative to cars, for the complexity of the latter limit the development of meaningful technical layout. It also recaptures the the minimal allure of cyclecars or the 2CV both as mobility solutions and challenging ideological assertions.

It also establishes a creative dialogue with the contextualized exterior to generate a new design playground where users can find a new and idiosyncratic appeal, once again, revealing the inherent qualities of the new typology.

This vision is completed with the 'open-source' approach conferred by Canvas Design (again in Chapter 5). Quadricycle legislation and the µcar de-constructed architecture are the ideal resource to convert the vehicle in a framework to express individualisation. This would help to align vehicle architectures with other socially-generated industries such as retail fashion and consumer electronics. In such convoluted times, it also deletes the stigma of individual mobility and converts it into social expression. Ultimately, this aspect would foster a redefinition of commuters as active individuals within their local environments.

The embodiment presented in Chapter 6, thus, is not a mere pint-sized car, but a whole new entity, a moving space that remarks its personal essence, surrounding their occupants rather than asserting market trends or technical archaisms.

How can we align the new typology with industrial goals?

Beside the problems linked to private mobility, the automotive industry is currently suffering both from the global crisis and as a result of structural issues. Overcapacity is a recurrent problem for practically every manufacturer and the most successful seem to be those with the most integrated platform strategy and wider portfolio. However, both the structural issues and mass-production are what limit the possibilities of the automotive industry to adapt to such uncertain times and local contexts.

Chapter 2 and 4 showed two aspects to consider in this matter: first and foremost, the traditional role of cars as status symbols is starting to decay worldwide; and at the same time, motoring history illustrated the increased flexibility that minimal platforms introduce, in terms of industrial players. The latter fact can be seen as increased competition, as new industries could enter the market, but at the same time, is an opportunity for manufacturers to reinvent themselves within the urban mobility sector, integrating their business model into a myriad of companies ranging from location-based business, communication technologies to fashion accessories.

The µcar exploits this design opportunity in two complementary ways. First, it proposes a modular approach, conditioned by groups of distinguishable functions (mobility, safety and added convenience). Second, through a de-constructed approach, it highlights such modularisation. The vehicle design evolves then in a relational set between segregated layers of functionality and design, where mobility systems are the core of a relational architecture in which alternative manufacturers of a vast array of products can contribute to the whole adding their area of expertise. In some ways, it is an extrapolation, at an architectural level of current collaborations with suppliers of sound and infotainment sub-systems.

It also enriches the possibilities of local customization of the outer layers, which can reinforce the sustainable image of the manufacturer, increase the acceptability of its product, and apply a platform strategy to lower costs in those core elements such as main structure, chassis or powertrain.

In summary, the µcar is defined from the concept of modularisation-in-use.

In addition to the design goals enunciated by this research, the µcar also responds to the initial objective of defining a vehicle typology able to offer the urban convenience of the car with reduced impact.

In terms of pollution, the use of an electric powertrain, a proved option within urban contexts, generates zero emissions at the point of use. Furthermore, to the equivalent emission value of around 50 grams of CO_2 per kilometre typical in normal quadricycles, the weight reductions introduced by the µcar (greater than 20% of total weight) contribute to further emission reductions. Moreover, because it has fewer components and it is easier to dismantle, the life cycle assessment of the whole vehicle is also reduced.

Traffic flow is another aspect where the µcar typology introduces further improvements. Its electric powertrain and low weight allow to keep up with normal traffic conditions, while the small footprint and tight turning circle favour low-speed traffic conditions. Ultimately, a total length of 2.2 meters allows perpendicular parking, saving on urban space that could be complemented with local car club schemes.

With respect to safety, the µcar offers an improved body layout for impacts against pedestrian while it still offers enough strength to withstand impacts against heavier vehicles. Moreover, the particular layout of the µcar introduces crumple zones at the lateral sections, and its single-door configuration further reinforces body stiffness.

Ultimately, such an apparently academic study has become particularly timely, after the recent interest of the automotive industry (since 2009) in electric quadricycles as alternatives to city cars (Shankar, 2011), not only for favourable tax policies and insurance costs, but also as overall urban runabouts. Hence, as the critical assessment proved in Chapter 8, this design strategy appears as the first systemic definition of a valid route map to propose vehicles that, not only address urban mobility concerns, but also incorporate the human element that both vehicles and our cities need.

While some conceptual quadricycles may have followed similar sources of inspiration to those initially proposed in this research, they have also shown the limitations of unidirectional design processes. As this research (and others before it) has shown, multidisciplinary methods are fundamental in the development of sustainable ways of living. Design, engineering, sociology, urbanism or semantics are important elements, inasmuch they constitute collaborative tools of the process. Furthermore, we can obtain significant improvements on the efficient use of resources when we understand how to integrate those heterogeneous tools within holistic approaches. In that sense, the contribution of this research can transcend vehicle design, and extend to other design problems where technical factors are interlinked with economic, social and emotional considerations.

8.1 Recommendations

8.1.1 Industry

From the second decade of the 21st Century, the automotive industry must embrace the complexity of their new social and industrial scenario. In a world where car use is a direct source of environmental, economical and social burden, uni-dimensional design processes are unable to define the holistic dimension of their implications (Especially when such implications are greatly stigmatising their business). This consideration is particularly important attending to the limited viability of their current business model per se. The common argument that the automotive industry produces the highest value per money of any other industry must to be revised from their concept of value itself. Speed, freedom and comfort for the individual is increasingly neutralised at a macro scale. And the burden that loans, taxes and insurance currently infer in buyers further worsen the picture.

The above is particularly relevant within mega-cities, growing contexts where the effects of car use are manifest. The inability to keep up with urban vibes, surpassed by other industries such as consumer electronics or retail fashion, is also relegating cars to a secondary role in cultural terms. Moreover, in cities, users have more possibilities to avoid the ownership of cars all together or to look at alternatives such as car club schemes.

This research proposes an urban typology as a result of a process that breaks the boundaries of design and engineering to give an answer both adequate and human. It is a dialogue between what is possible and what is not there yet. Instead of technical readiness, such a simple package requires taking risks to propose an integral solution, leaving the comfort zone and addressing the problem from currently existing set of tools. This research shows that in order to obtain substantial gains in efficiency, maintaining user acceptance and economic feasibility, the design process must abandon the traditional over-the-wall process and interlink design and engineering with an understanding of current legislative framework.

Such a process, while original, is not completely alien to the automotive industry. The Austin 7 appeared from an understanding of the cyclecar success translated into the quality and reliability only the automotive industry could give. The original Mini was a breakthrough possible thanks to a clever relation between packaging and design. The 2CV was 'the most successful example of minimalism applied to car design' in response to a particular need of mobility.

The automotive industry must recuperate that maverick spirit and this research shows an original and feasible strategy to do it, both in the typology and design method.

8.1.2 Academia

In such a problematic scenario, the role of academia should be double: to propose short-term design strategies able to aim us towards sustainable and human futures; and to explore long-term directions, out the scope of modern industries.

In terms of short-term design strategies, the needs of our world today are demanding an implementation of the concepts of efficiency and sustainability to the design and engineering practices themselves. The traditional car architecture is clearly reaching its plateau, while concerns such as pollution or traffic flow require a fundamental rethinking of both requirements and the technologies involved. As this research proved, technology and design thinking are already developed to a level that allows further integration. What the situation requires is a departure from those conventional methods that have become outdated.

In that sense, this research represents a starting point. It intentionally uses a 'low-tech' approach as both an answer to current complex urban vehicle architectures and a way to increase feasibility. It is also flexible in its definition, representing a starting point for future detailed design and technical embodiments. But apart from this typology, the 'low-tech' approach also shows the possibilities of combining engineering and design towards a better future.

Without the boundaries of short-term industrial strategies, universities should, not only implement existing disciplines within a common framework, but also test the limits of both disciplines and the tools involved. Tools such as the virtual reality environment are existing solutions that can contribute to fast iterative processes combining both objective and subjective parameters.

The ultimate role of Academia is to define a new and meaningful future. What is a vehicle? What do I need to go from home to my workplace? The answer provided by conventional cars, despite its historical importance in the 20th Century, appears clearly unidimensional for current contexts. And unless these innovation centres form a better answer, the contexts themselves will impose undesired solutions.

8.2 Further research

This work do not aim to be a finished process, but a kick-start to both a new urban vehicle typology able to address current problems and a new approach to the relationship between design and engineering.

After this research, refining the design embodiment that supported this PhD seems the immediate next step. The µcar appeared as a research resource to deal with the theoretical necessities of this research. This generated an embodiment that, while it perfectly accomplished its purpose, would not constitute a finished design proposal. Thus, the conceptualisation would need further refinement to continue a process supported by users' feedback to produce a road-ready proposal.

Similarly, the multidisciplinary approach followed along this research started a process that should be continued beyond the technical considerations included in Chapter 6. A systematisation to typical industry standards of the conceptual development would help optimise parameters such as electric powertrain performance, total costs or life cycle efficiency.

Furthermore, the proposed modular architecture should be further explored to test the capability of incorporating a family of different vehicles within a common exposed core. This point would be particularly interesting, for it reinterprets a concept familiar to automotive industry (platform strategies) from a different perspective where the core becomes an identifiable design resource rather than a technical element in need of concealing differentiation.

In conclusion, further research on urban vehicle could find a useful resource in this work as a starting point to define detailed integration of particular proposals within specific contexts comprising specific urban scenarios, industrial strategies, use modes and type of users.

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