Between shared and private mobility

A challenge experience by Volswagen Group

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Introduction

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1. Introduction

The technological advancements of the past century and a half have profoundly influenced nearly every aspect of human life, from the ways we consume and communicate to the ways we move through space.
This thesis focuses specifically on the latter, examining the diverse and complex modes of travel that individuals adopt today. Through this lens, it seeks to investigate the evolving nature of mobility and the design opportunities that arise from these shifting behaviors and expectations. The innovations that drove the development of the project were, on one hand, the autonomous driving, which represents one of the most promising yet radical frontiers of future mobility, and on the other, the users' growing need for customization that is increasingly characterizing every aspect of today's consumption.
Equally fundamental to the process was the awareness of the social and environmental impacts that transportation design has on our cities, acknowledging the flaws of today's paradigm of privately owned mobility and the directions that municipalities are taking nowadays in this regard.

The project described in the thesis in the entirety of its development process originated from the candidates' participation in an international student challenge called IDEEA Project 2025. This marks the fourth edition in which Politecnico di Torino has been involved, with a history of awards and prizes for excellent projects resulting from the rich and meticulous work of engineering students in the past years.
IDEEA (International Design & Engineering Education Association) is a non-profit organization of universities and companies, committed to three main goals:

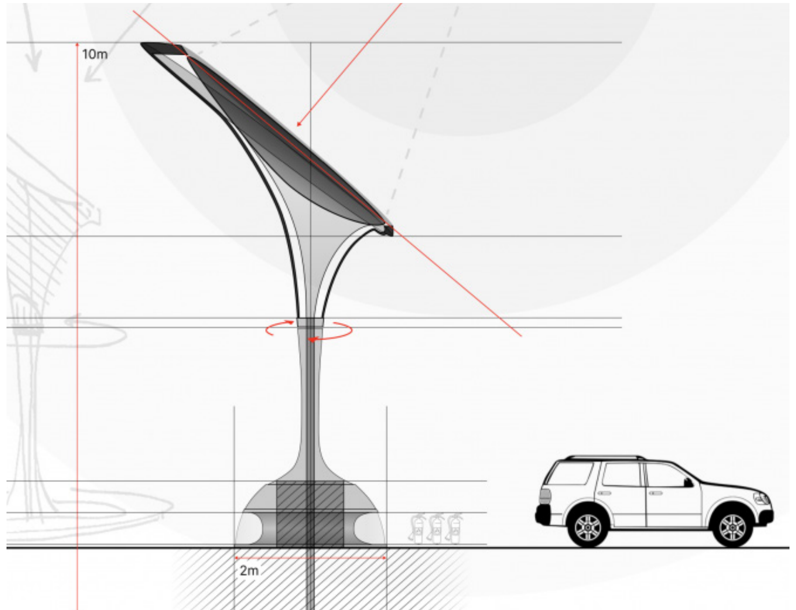
- advancing education and research in emerging technologies in the fields of mobility, product development, and Industry 4.0;
- fostering international and interdisciplinary collaboration between engineering and design students within international teams;
- the creation of a laboratory for testing new design methods and visions of the future.

Since 2019, IDEEA has promoted an annual international competition open to engineering and design students from a growing number of partner universities around the world. These include the Hongik University (Korea), University of Wuppertal (Germany), the Istituto Tecnológico y de Estudios Superiores de Monterrey (Mexico), McMaster University (Canada), Transilvania University (Romania) and many others. The themes addressed relate to contemporary issues in sustainable mobility, urban infrastructure, and innovative product development.

Participants collaborate in international, interdisciplinary teams over several months, conducting in-depth research and developing original and technically sound solutions with the support of nominated academic mentors [1].
The brief for the 2025 edition, titled "Future Mobility Solutions - Featuring Photochromic Technology", challenged students to design the interior of an autonomous vehicle intended for 2030 and beyond, within a clearly defined geographical market, by each participating team. A key requirement was the integration of photochromic materials as a central element of the concept, materials that will be the subject of in-depth research presented in this thesis. These compounds possess the unique ability to change color when exposed to specific wavelengths of light. Additionally, the proposed vehicle must be powered by an electric or hybrid propulsion system, in line with the growing emphasis on sustainable mobility. This year's competition partner is the Volkswagen Group, a leader in the European automotive sector and one of the most influential players globally.

Fig. 1.1 ↙
Drawing from a participating project, 2024 edition [1].

Fig. 1.2 ↓
Hongik University campus, Seoul, South Korea [1].



The birth of this competition stems from the 20-year experience of some of the founding professors within the PACE program, an international academic-industrial organization run by the joint operation of Autodesk, Siemens, HP and other major companies [2], [3].
Although IDEEA no longer collaborates with the same firms and universities, having instead created a new network of relationships, the organisation's founding values remain the same. Among these, one of the competition's cornerstones is its concluding forum, in which all participating students and mentors are invited to take part to present their project results. For the undergraduates, this represents an extremely significant international exchange context and a unique opportunity for professional and personal growth. The importance of this event became particularly evident when it was no longer possible to hold it during the pandemic.
Every year, the IDEEA Global Forum is organised at one of the numerous participating universities, which makes its spaces and resources available for a few days to host the final outputs' presentation. The 2025 edition, the seventh from the birth of the competition, was hosted between the 21th and the 24th of July at the Hongik University in Seoul, recognised as one of the most prestigious South Korean institutes in the fields of design, arts and architecture. The forum days were organized with the aim of both facilitating the conclusion of the final presentation of the projects and, most importantly, enhancing the atmosphere of exchange, mutual recognition and enrichment between students and professors.

The authors of this thesis, had the opportunity and honour of taking part in the forum, presenting the results of the project created in collaboration with mechanical engineering and visual design students from Hongik University. The team received immediate recognition and appreciation from both the professors and the students from other groups, sentiments that were later confirmed at the award ceremony. The conferral of the prizes was a result of the evaluation of the projects by a large pool of professionals, from the academic and industrial fields. Ultimately, the project obtained prestigious prizes in 5 of the 6 present categories, namely:

- Third Place in Best Overall Award
- Second Place in Best Innovation
- Second Place in Best Design
- Third Place in Best Engineering
- Second Place in Best Presentation.

These awards clearly reflect the dedication demonstrated by all the students involved in the project and serve as a strong encouragement for them to continue striving toward their goals with effort and excellence.

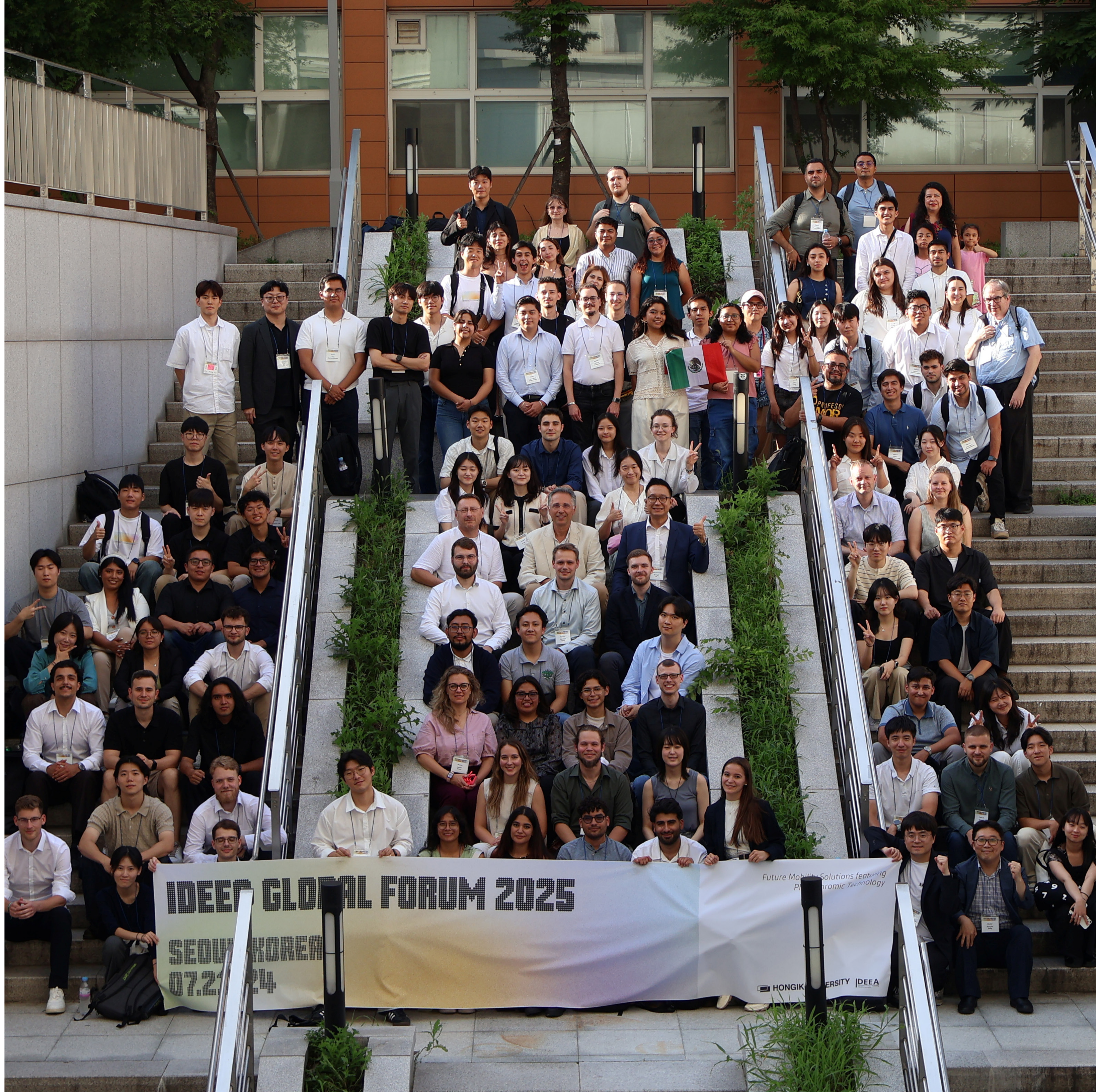


Fig. 1.3→
Group photo of the participants at the IDEEA 2025 Global Forum at Hongik University.

Project scenario

02

2. Project scenario

2.1 The future of mobility

"*Urbanization, the process by which large numbers of people become permanently concentrated in relatively small areas, forming cities*" [4].

This is the definition of one of the most important megatrends of our time, which began with the Industrial Revolution in the 18th century. Today, 57% of the world's population lives in cities, with forecasts suggesting that this figure will reach 70% by 2050. The demographic transformations taking place in cities clearly translate into the need to carefully rethink urban mobility networks, as they are one of the most crucial aspects affecting people's everyday lives. In fact, a city's infrastructure and transport services play a key role in improving, or worsening, everyone's ability to reach their workplace, enjoy their free time, or connect with others, thereby enabling full participation in society. However, urban density is not the only factor that needs to be considered in this matter [5] .

To better understand the complex ecosystem shaping today's and near-future urban mobility, the STEEP model serves as an excellent analytical tool. Used in foresight studies to identify future trends, STEEP analysis is defined as "*a strategic planning tool that assesses external macro-environmental factors affecting an organization. Each component Social, Technological, Economic, Environmental, and Political represents a set of influences that can drive or hinder business performance*" [6].

The components of the STEEP framework in the context of future mobility are outlined as follows:

Social force
Digital connectivity has transformed the daily routine of workers and younger generations, altering their mobility demand throughout the day. While smart working obviously doesn't represent a possibility for every type of occupation, it is shifting people's habits towards a more sedentary lifestyle. This trend co-exist with a growing awareness of the benefits of healthy living, achieved through more physical movement and less polluted air. As a result, commuting by foot or with a personal bike is, in some cases, preferred, but cities must still ensure equal mobility opportunities for citizens with highly diverse necessities.

Technological force
Urban mobility in 2030 and beyond is envisioned to be partially supported by autonomous vehicles, which have the potential to improve urban safety, reduce the need for parking spaces, and enable more efficient driving.
Micro-mobility examples such as e-bikes and e-scooters are evolving in the same direction, allowing to close the gap between private vehicle ownership and local public transportation services. However, this can only work if "*micromobility solutions are carefully managed by the cities*", says mobility expert Dr. Maya Ben Dror, co-founder of the Global New Mobility Coalition at the World Economic Forum. If e-scooters or rental bikes are not thoughtfully integrated into the urban transport system, their uncontrolled spread can result in heightened competition for limited space and conflicts with pedestrians, ultimately reversing the intended benefits of shared mobility. For these reasons, cities such as Paris or Melbourne have banned or strictly limited these kinds of transportation modes.
Data analysis and representation is crucial to the designing of new transport infrastructures, addressing coordination problems between the different means of mobility and visualizing the movements of the users. Mapping and simulation tools such as Modality, developed by Caroline Goulard specifically for major French cities, enable municipalities to understand the impact of transport plans on citizens, ensuring equal access to resources [7].

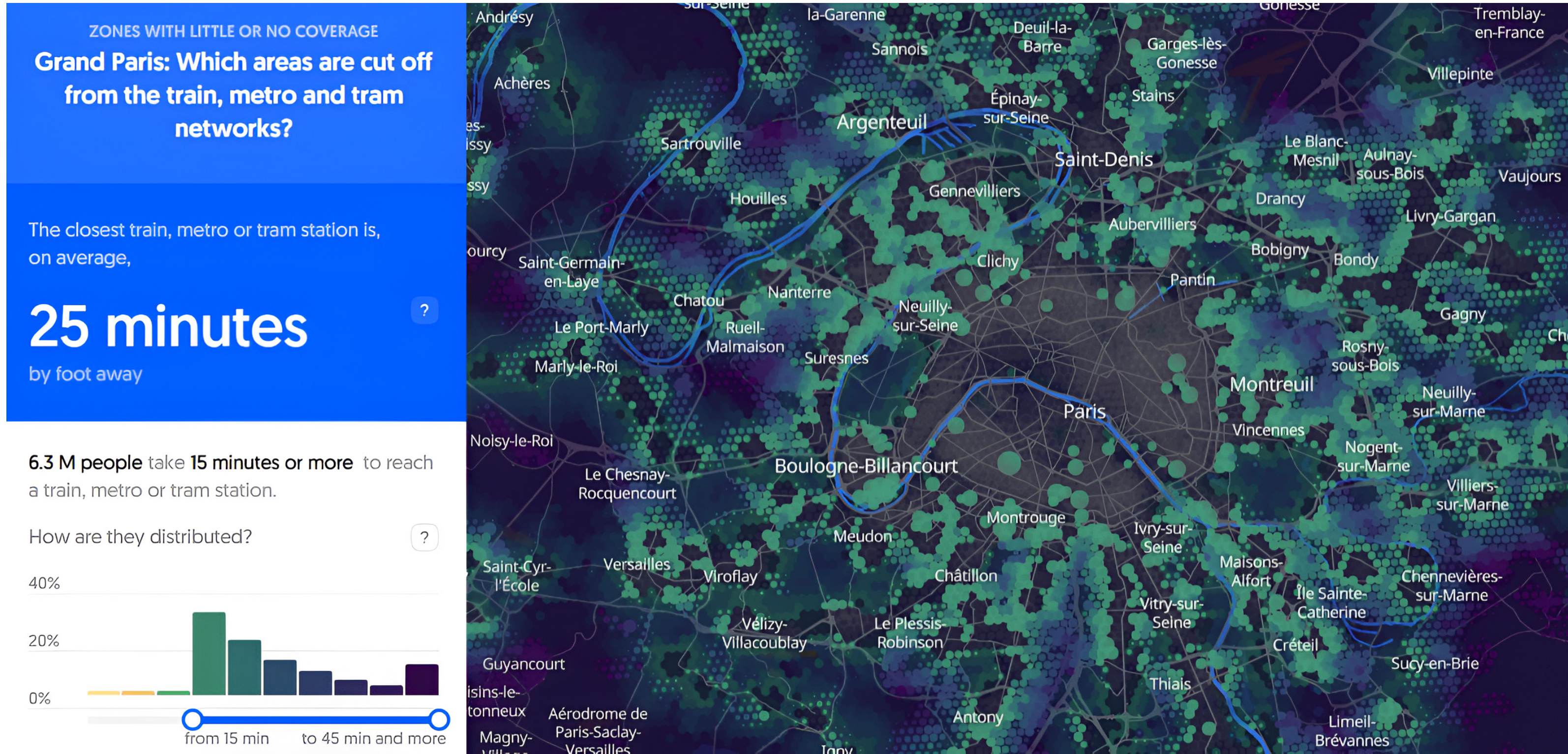


Fig. 2.1 ↓
Example of mobility data representation developed by Modality for the city of Paris [7]..

↖ Fig. 2.2
Example of a carsharing company widespread in Europe and North America [8]..

← Fig. 2.3
Row of electric cars charging in Norway [9]..

Economic force
Consumer desires are shifting from ownership to convenient use without the associated responsibilities, resulting in a growing preference towards sharing and rental solutions. These choices aren't caused only by sustainability concerns but, mostly, by the increasing cost of living, especially for the younger generations, resulting in higher demand for mobility alternatives. Therefore, the transportational model might expand to include services that offer the ability to pay by usage, resulting in a fundamental shift to a "mobility as a service" model, which will be further analysed in chapter 2.2 [10].

Environmental force
One of the most important changes in today's society comes from the necessary shift towards more sustainable energy sources than fossil fuel and carbon. As the transportation sector is one of the biggest causes of CO_2 production and, therefore, a crucial agent in climate change, many governments are taking action to drastically encourage hybrid and electric vehicles adoption. One of the pioneer countries in e-mobility is Norway, with the goal of reaching zero new combustion vehicles registered after 2025. As the demand for lithium-ion batteries increases, as is the quantity of raw materials, which means that recycling is needed in order to grow and promote electromobility in the long term.
Driven by an increased awareness of environmental risks, the aspect of urban spaces and infrastructure is changing as well, with emerging green areas and community-led projects of urban reconfiguration.

Political force
Municipalities and governments, often along with citizens and consumers, are the primary actors in the realization of the described changes. The decisions taken by the public institutions in some of the world's major cities have the goal of reducing car traffic and therefore noise, pollution, accidents and other negative consequences of a high density of privately owned vehicles. Cities like Milan, Amsterdam, London, and Copenhagen are actively advancing mobility reforms that involve congestion charges, parking restrictions or lower speed limits. Singapore set extremely high taxes on new vehicle registrations that discourage car ownership, resulting in only 10% of its citizens possessing a vehicle. Another leader is Paris, which in the past decade has been working on becoming a 15-minute city, a rising and popular model based on allowing residents to reach all the everyday facilities, such as schools, clinics and sports centres, within a quarter of an hour on foot, by bike or using public transportation. The mayor of the French capital, Anne Hidalgo, legitimized every major proposal with public consultation, as the approval and the inclusion of the citizens should represent the ultimate goals of all new transportation concepts.

Ultimately, recent studies and articles affirm that the ideal of new urban mobility is based on two connected transformations: on one hand, the shift between private cars and services, and on the other, the development of intermodal mobility. As cities grow, spaces reduce and life fastens, it's emerging the citizens' necessity of access to efficient and seamlessly interlinked modes of transportation. A straightforward example of an intermodal journey involves traveling by car to a Park-and-Ride facility, continuing by train to the city center, and completing the journey, such as reaching the workplace, using a rental bicycle. To ensure long-term success, it is essential that shared mobility services do not remain isolated solutions requiring separate booking and payment. Rather, to enhance their appeal and convenience, they should be integrated and billed alongside other mobility services [5], [11].

Fig. 2.4→
Two citizens travelling on scooters and bicycles from a well-known sharing services company [12]..

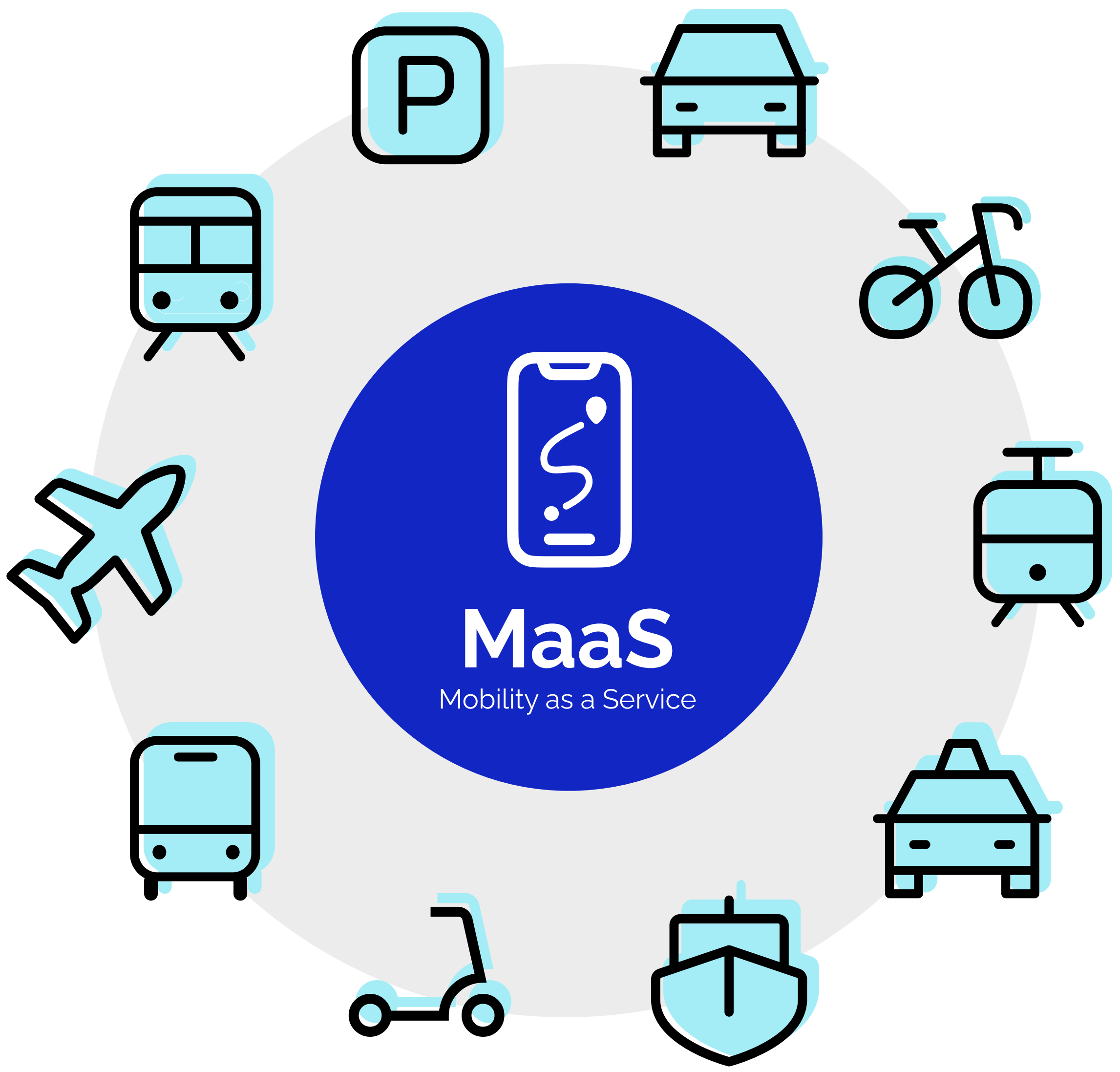
2.2 Mobility as a Service

The concept of intermodal mobility is highly connected to the definition of MaaS, acronym for Mobility as a service. The term was first coined in Finland as "*a system, in which a comprehensive range of mobility services are provided to customers by mobility operators*". It is a model of innovative mobility administration able to integrate diverse public and private transport services into a single digital platform. Using a single app, citizens are allowed to organize, book and pay for services like trains, subways, buses, taxis, car or bike sharing, parking and car recharging, enjoying an integrated, flexible and multimodal travel experience [13].

One of the main characteristics of this model is the offer of mobility bundles that allow customers to pre-purchase a combination of various modes for use for a period of time. This represents a valid alternative to paying per ride on various different platforms, as usually happens when shifting, for example, between public transport and sharing services. The bundles can include different combinations of modes and areas of validity, or even offer non-mobility services in addition to transport options, such as grocery shopping discounts and food delivery. This variation can refer to a different but consequent concept called Mobility as a Feature, a specific form of multiservice in which transport is an addition to the main offer, comprising other essential services.

MaaS has gained growing attention from academics, industry professionals and policymakers at a global level because of its potential to deliver more sustainable mobility in cities. This is based on the expected ability of the model to shift consumer behaviour from private car use towards shared modes, questioning the rooted ownership paradigm that is currently contributing to the climate emergency.
Despite these anticipated effects, detailed market applications of MaaS are still quite rare and difficult to establish in real contexts due to the complexity of its ecosystem. In fact, the MaaS model involves a wide variety of actors with diverse purposes: policy regulators, mobility service providers (MPSs), customers and the Maas Integrator. The interactions among them are driven by different and often competing goals [14], [15].

Fig. 2.5→
Visualization of different services that can be involved in a MaaS system.



2.3 City selection

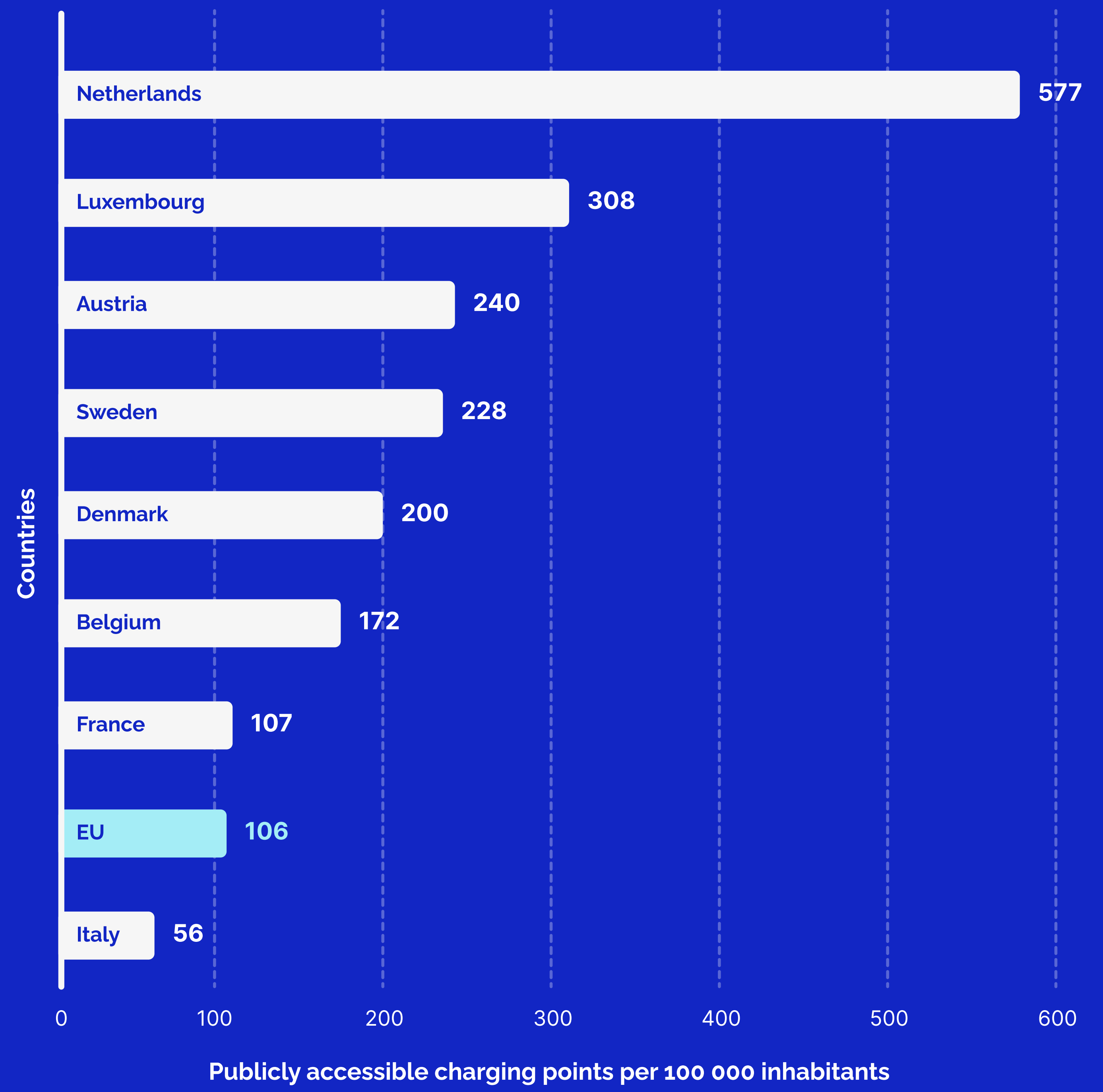
According to the IDEEA competition brief, this phase of the project, focused on scenario and context definition, required an in-depth analysis of the current state of mobility at a geographical level, intending to identify the most suitable location in which to develop the concept. The selection of a specific city and the subsequent research carried out in this regard allowed for a profound understanding of the needs of the chosen context. It provided the background for identifying the users to whom the project is addressed, while defining a scenario that can also be found in other contexts. In fact, the selected location serves as a temporary testing ground for a project outcome that aims to be scalable and adaptable across a variety of different urban contexts. This ambition is projected into a future in which autonomous driving technologies, along with a number of other enabling conditions, will have reached broader validation and implementation.

As the team participating in the project was composed of several students from different continents, the research was divided into geographical areas, with the contribution of the thesis students being focused on the European area.

With the project brief clearly in mind, which expected the vehicle to be autonomous and electric or, at most, hybrid, the city selection criteria were defined accordingly: on one hand, the distribution of recharging infrastructures and the penetration rates of electric cars in the different markets and, on the other, the innovation indices and level of acceptance towards autonomous driving.

The research began with the analysis of the ratio of electric vehicle charging stations to the population in each country. A report from the Organization of Economic Co-operation and Development published in 2022 analysed the accessibility of charging stations, asking respondents if they usually had chargers available within 3 km from their homes. The best outcomes from these studies described that the most favourable country in terms of EV charger availability is the Netherlands [16].

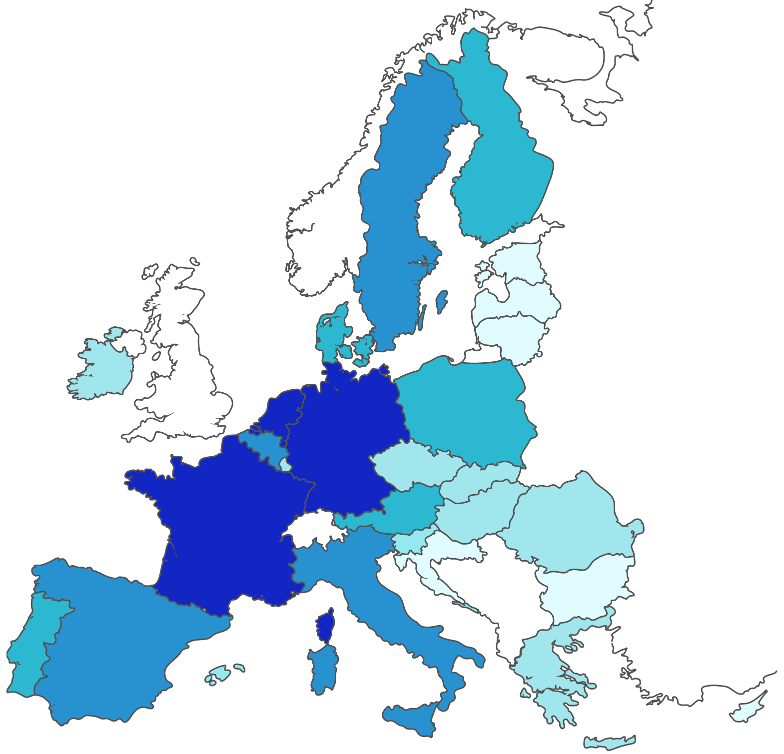
Fig. 2.6→
Diagram of publicly accessible charging points per 100.000 inhabitants in Europe (2022 data) [16].



Distribution of electric car charghing points

Number of charghing points (2023 data)

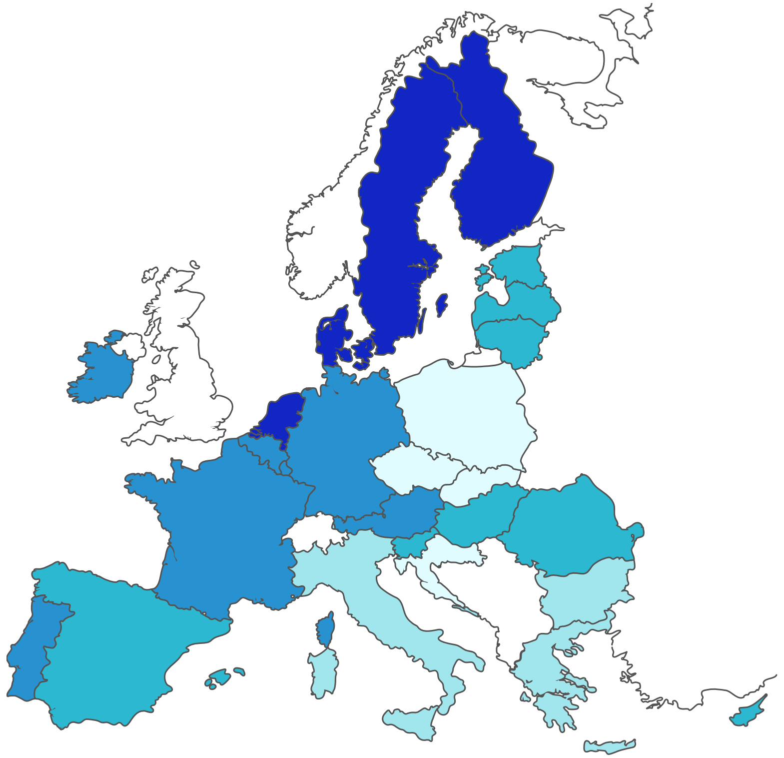
0 | 2000 | 5000 | 25000 | 50000 | 150000



Market share of battery electric cars

% market share (2023 data)

0% | 4% | 5% | 16% | 25% | 40%



↖ **Fig. 2.7**
Distribution of electric car charging points across European contries [18].

← **Fig. 2.8**
Market share of battery electric cars across European contries [18].

Confirming these results, 2023 data revealed that 61% of all charging stations in the European Union are concentrated in only three countries, as follows:

- The Netherlands: 114,453 stations;
- Germany: 120,625 stations;
- France: 119,255 stations.

The Netherlands is the country with the highest share of infrastructure, having on its territory 23% of the total of the EU's EV chargers. The cities with the highest number of stations are Amsterdam, with 15,027 stations, and Rotterdam, with 14,431 stations. The national total, updated to 2025, amounts to 212,274 charging stations [17].
On the other hand, the nations that present the lowest numbers of public charging points in the Union are Croatia, Estonia, Latvia, Cyprus and Malta, which respectively count only a few hundred chargers each [18].
This parameter was frequently found to correlate with the percentage of electric vehicle sales within the respective nation, which comprises a significant factor to consider within the framework of the selection . In the Dutch market, 2024 hybrid electric vehicle registrations reached 159,000 units (41,9% market share), while fully electric vehicle registrations amounted to 132,000 (34,7% market share) [19].

The second criteria considered was the acceptance of autonomous driving, as described both by current legislation in the analysed countries and by reports such as the one conducted by KPMG in 2020. The report, based on four factors (policy and legislation, technology and innovation, infrastructure, and consumer acceptance), ranked Singapore in first place, followed by the Netherlands.
A more in-depth research revealed that, in 2015, the Dutch Ministry of Infrastructure and the Environment opened public roads to large-scale tests with self-driving passenger cars and trucks for industries, developers, and research institutes, enabled by a specific admittance procedure, as "*the Netherlands firmly believes in the potential benefits for significant change in road mobility with the introduction of cooperative ITS systems*" [20], [21].

In conclusion, the country selected as one of the most suitable for the development of the project was the Netherlands. In addition to the already discussed findings, this decision is supported by the fact that Volkswagen is the best selling passenger car brand in the country [22].
In light of the unique urban landscape and road system that characterise the city, Amsterdam was chosen as a challenging yet appropriate project scenario for the IDEEA competition.

2.4 Amsterdam as a pilot scenario

To better understand the needs of potential future users of the service and relative vehicle developed in this project, it was first necessary to carry out a comprehensive analysis of the current state of urban mobility of Amsterdam, the picturesque and cosmopolitan main city of the Netherlands. In doing so, particular attention was paid to the accessibility of the mobility options offered, in accordance with the tenth of the 12 principles of good design, which were kept in mind throughout the entire work process.

Reinforcing the global perception of Amsterdam as the "bicycle capital," a 2022 study reports that 34% of all trips made by residents are by bicycle, followed by 30% on foot and 21% by car. The average number of cars per household in Amsterdam is 0.4, the lowest in the Netherlands, a figure justified by several contributing factors:

- A high percentage of streets have a speed limit of 30 km/h;
- The city center, enclosed by the A10 ring road, is designated as a low-emission zone where diesel vehicles are prohibited and pedestrian and bicycle traffic is extremely dense;
- Parking availability in several areas of the city is being drastically reduced to limit traffic congestion and pollution. This reduction has a direct influence on residents' and visitors' mobility choices. Parking fees are high, enforcement is strict, and obtaining a parking permit requires compliance with stringent criteria. However, the process is facilitated for electric vehicle owners [23], [24], [25].

These factors clearly indicate that Amsterdam is striving to become a "low-car city", where mobility options are shifting away from private vehicle use toward more sustainable modes of transport, such as cycling, public transit, and shared mobility services. It is important to note that the concept of "low-car" does not imply a complete ban on automobile traffic, but rather a careful and gradual reduction, while ensuring that all residents, especially those who require cars, retain adequate access to transportation [26].

Fig. 2.9→
Bicycle parking along a street in the city center of Amsterdam [27].

↖← **Fig. 2.10**
GVB logo [28].

↖ **Fig. 2.11**
Map of Amsterdam's metro lines [29].

← **Fig. 2.12**
Wheelchair user getting on a GVB bus through an access ramp [32].

The city's public transportation system, widely used by both residents and the exceptionally high number of tourists (22.9 million in 2024) which visit the city, is managed by GVB (Gemeentelijk Vervoer Bedrijf). The network includes 16 tram lines, 5 metro lines, 50 autobus lines and 5 ferry routes. They operate regularly from 6:00 a.m. to 12:30 a.m., while, during the night, public transport is limited to 11 bus lines, each running with only one service per hour [30], [31].

The lack of public transport service during nighttime hours is a common feature of many European cities. During these hours, travel becomes slower and more difficult if people decide to rely on public transportation; alternatively the modes of transportation used change. Those who own a car will clearly be more inclined to use it, facing the limitations related to parking and city regulations. Those who do not have a private vehicle will depend on bicycles, taxis, or shared services. These options, which are quite functional for occasional nighttime travel, can become less reliable or practical when it comes to people who commute every day at night for work, especially if they travel long distances or if their profession is particularly tiring. Furthermore, these types of transport are not always accessible to people with physical disabilities who, for example, use a wheelchair.

This, therefore, constitutes a widespread and tangible issue which provides a relevant starting point for the design exploration developed in this thesis.

Nevertheless the services offered by GVB, including both vehicles and stops, are equipped and designed to be accessible to people with physical disabilities, with priority seating, extra space, street-level entrances, elevators, ramps, and helpful staff. Exceptions are made for some older tram models and tram stops where steps and larger gaps compromise adequate accessibility [32].

Research conducted on accessibility in the context of Dutch mobility has brought to light an interesting case study: the **Canta microcar**.

The vehicle, developed by Waaijenberg Mobility in collaboration with Delft University of Technology, was launched on the market in 1995. This compact car was designed primarily for people with disabilities, but its actual users are not limited to this demographic: its small size, particularly its width of only 1.1 meters, and its classification as a "mobility aid" allow it to be driven on bike paths, sidewalks, and pedestrian areas without the need for a driver's license. Speeds are limited (approximately 45 km/h), and driving is prohibited on expressways or highways.

The initial models were gasoline-powered, but elec-tric versions are now also available, such as the Canta 2. Each model can be adapted to its driver in a number of ways: the position of controls such as the brake and accelerator can be modified and even integrated directly into the steering wheel; the seat is highly adjustable and swivels to facilitate access to the driver's seat. In one particular version, the user can access the passenger compartment directly from their wheelchair, due to a ramp located at the rear of the vehicle. This model lowers automatically to ground level when parked and raises pneumatically when started.

Thanks to the described features, Canta represents an important innovation as it has provided a means of personal transportation for those who have great difficulty obtaining a driver's license due to disability, injury, or advanced age [33], [34].

Fig. 2.13 ↗
Canta 2 Waijenbenrg Mobility microcar [34].

Fig. 2.14 →
Canta 2 Waijenbenrg Mobility microcar, interior [34].

Finally, a territorial overview of Amsterdam's neighborhoods was conducted in order to better understand the characteristics of the context in which the project is being implemented [35], [36].

1 Schiphol Airport

Area frequented by airport staff, travelers, and employees. It is a suburban area with poor transport links at night.

2 Westpoort

Industrial and port area with a small number of residents. Many commuters work here, often with non-standard working hours.

3 Nieuw-west

Large low-income residential area with families and students where transport services are not capillary.

4 West

Dense middle-class residential district. Area characterized by intense mobility toward the city center.

5 Centrum

The tourist and commercial heart of the city, densely populated, with high daily and nighttime traffic.

6 Zuid

Home to major offices, universities, and museums, with heavy traffic during working hours, less so in the evening.

7 Amsterdam-Noord

Former industrial area undergoing significant change, connected by ferries and metro, but in an uneven pattern.

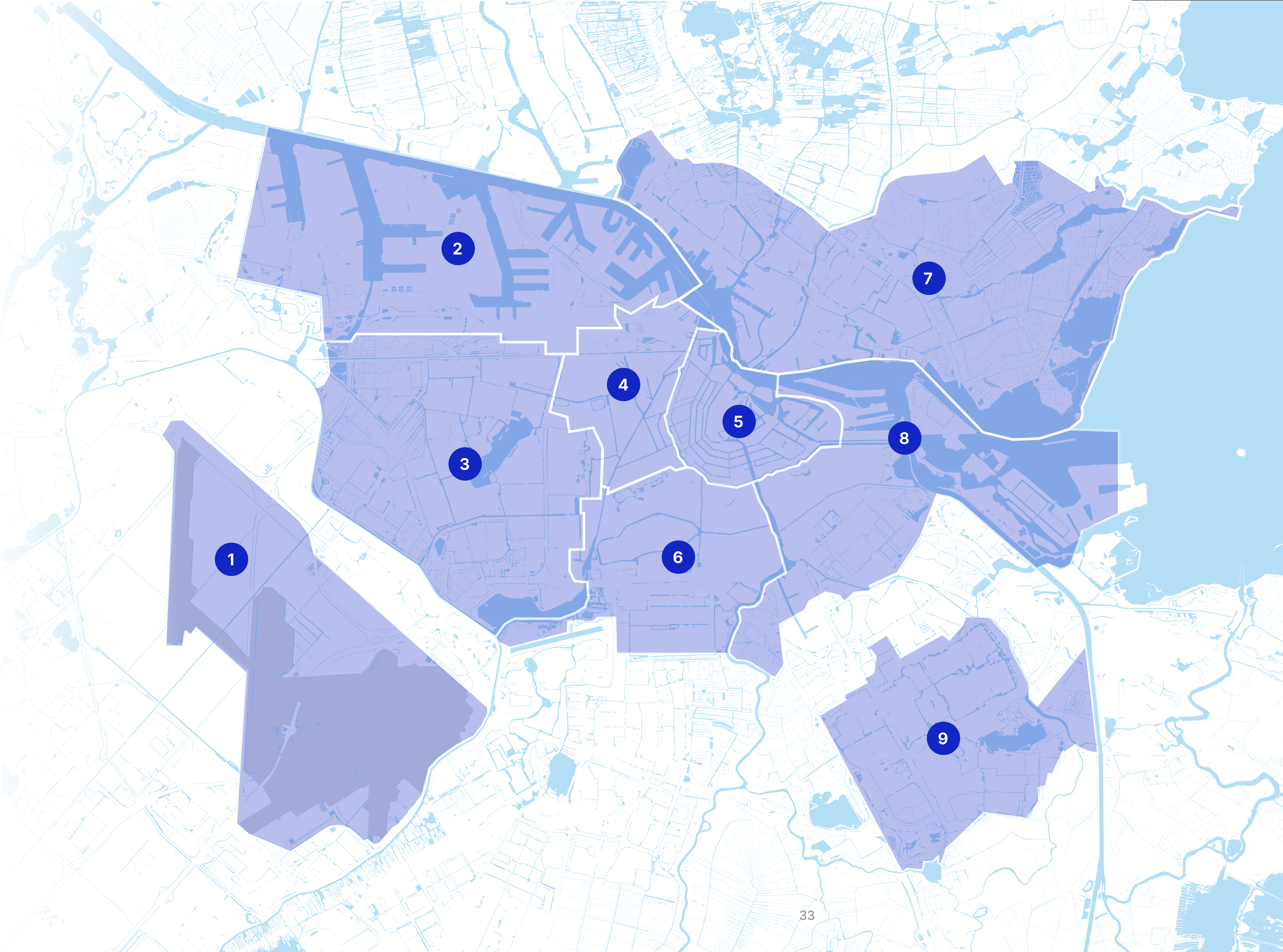
8 Oost

A dynamic district of residential areas and universities, with a high number of cyclists and local transport.

9 Zuidoost

Suburban area with residential complexes, offices, and sports facilities. Many commuters but limited nighttime services.

Fig. 2.15→
Map of Amsterdam's neighborhoods.



Autonomous driving

03

3. Autonomous driving

3.1 Current state

To better comprehend what autonomous driving will enable in a not too distant future, it's necessary to understand how this technology is being integrated and accepted in our society.

"A self-driving car, or autonomous vehicle, is a type of vehicle that can operate with little or no direct input from humans"

This is how management and strategy consulting firm McKinsey & Company defines an autonomous vehicle. It's important to note how, in this definition, human input can remain a relevant factor [37]. For that reason, automated driving is commonly measured on 6 different levels, from 0 (no driving automation) to 5 (full driving automation), defined by the Society of Automotive Engineers (SAE). The SAE J3016 levels of driving automation describe the extent to which a vehicle's driving functions are performed by automation rather than a human driver and are defined as follows:

- **SAE Level 0**:
The driver is in full control of the vehicle and all driving tasks.

- **SAE Level 1**
The vehicle provides assistance with either steering or brake/acceleration, while the driver remains fully engaged & in control.

- **SAE Level 2**
The vehicle can assist with both steering and brake/acceleration simultaneously, while the driver monitors the system at all times and must be ready to control the vehicle.

- **SAE Level 3**
The vehicle can operate independently in certain driving situations if all requirements are met, but the driver must potentially be able to take control if requested.

- **SAE Level 4**
The vehicle can handle all driving tasks in specific environments and conditions. In some use cases the presence of a driver who is ready to take over is not required and the installation of pedals and a steering wheel is not mandatory.

- **SAE Level 5**
The vehicle is fully autonomous and can operate in any environment and under all conditions without a human driver being present at any point of the ride [38], [39].

The EU marked the beginning of its journey towards autonomous driving systems with Regulation (EU) 2019/2144, which overhauled vehicle safety requirements and, for the first time, created the legal basis for approving vehicles equipped with advanced automated driving features. This paved the way for Implementing Regulation (EU) 2022/1426, which set the detailed technical procedures and safety criteria for type-approving Automated Driving Systems, making it possible for manufacturers to bring such vehicles to market under harmonised EU rules. Building on this, the adoption of the amended UN Regulation No. 157 in January 2023 unlocked a major step forward: authorised Level 3 automated lane keeping systems can now operate at speeds of up to 130 km/h on motorways and perform automated lane changes under defined conditions [40], [41].

Today, SAE Level 2 driver assistance is common across the European market, while Level 3 is permitted in specific, pre-approved scenarios such as highway driving within the limits set by UN R157. Level 4 operation is generally restricted to controlled trials or limited operational areas, subject to strict safety and monitoring requirements. Some national pilot projects and exemptions allow more advanced use cases, but widespread deployment remains governed by the EU's gradual, safety-focused approach [42]. Until now the EU's approach towards the introduction of autonomous vehicles has been cautious and safety-oriented, by progressively introducing them through regulations and strict safety standards. However, innovation oriented countries, such as the Netherlands that have been selected for this project, are given the possibility to experiment and test more advanced autonomous driving systems.

3.2 Opportunities in autonomous vehicle interiors

Almost every major interior element in a conventional car interior is designed to concentrate all vital information and controls toward the driver, thereby minimising distractions during the journey. Features such as mirrors, pedals and the steering wheel are only required if an individual is actively maneuvering the vehicle, while the dashboard is densely packed with information relevant primarily to the driver. This configuration establishes a clear hierarchy between passengers and driver, with the latter as the primary operator interacting with the vehicle.
The introduction of SAE Level 4 or higher automation fundamentally shifts this focus from the driver to all passengers, with profound implications for both interior organisation and the overall user experience. Removing the need for a driver-centred layout frees the interior from elements such as the steering wheel, pedals, mirrors, and numerous dashboard controls. Furthermore once a driver is released from the responsibility of constantly paying attention to the road, he is not bound to be seated facing the road and can rather position himself according to personal preferences.
This technological shift removes long-standing constraints in vehicle interior design, enabling configurations that were previously impractical or impossible. Without the fixed position of the driver's seat and traditional driving controls, the space can be optimised for comfort, accessibility, and functional versatility. This opens the way for modular seating arrangements, immersive environments, and highly adaptive layouts that respond to the specific requirements of different journeys and passenger profiles [43].

↙ Fig. 3.1
Renault Morphoz concept car interior, first seat position [44]

↓ Fig. 3.2
Renault Morphoz concept car interior, second seat position [44]

3.3 Case studies & multi-criteria benchmarking

Observing existing projects within a specific operating field is a crucial step to gain understanding of what market-leading competitors offer. The multi-criteria benchmarking is a strategic tool that allows these case studies to be systematically evaluated across multiple performance dimensions, enabling structured comparisons rather than subjective judgments. Ultimately, this approach provides a clear overview of best practices, unique selling points, and market gaps, thereby supporting informed design decisions and guiding the strategic direction of a project.

For this particular case, the analyzed commercial projects provide an autonomous "robotaxi" service and are not intended for private ownership. As this aligns with the focus of the thesis research, such use cases offer the most relevant insights to inform the design investigation. While numerous other active projects exist worldwide, the selected examples offer a complete and representative overview, encompassing all relevant vehicle types and effectively summarizing the current state of this category.

Finally, the evaluation criteria applied in this analysis, which do not have a comparative function between the case studies, consider multiple aspects, with the primary focus on:

- Accessibility and Safety
- Comfort and User Experience
- Service Experience

Table 3.1 illustrates the specific criteria within these topics that served as the basis for the evaluations conducted.

Tab. 3.1→
Choosen evaluation topics and criteria utilized for the benchmarking

Topic	Criteria
01 Accessibility & safety	**Wheelchair accessibility** Does the vehicle consider the needs of wheelchair users regarding access, safe locking, and sufficient interior space? **Entrance from both sides of the vehicle** Can the vehicle be accessed from the left as well as from the right side of the vehicle? **Audio announcements** Does the vehicle accommodate visually impaired or otherwise distracted users by providing both acoustic and visual announcements? **Wide door opening for easy access** Does the vehicle's door design and opening mechanism facilitate quick and easy access, suitable for roadside pickups? **Emergency assistance button (in- vehicle or app)** Can users easily stop the ride or ask for assistance from the inside of the vehicle if needed?
02 Cofort & User experience	**Choice of facing direction** Can passengers choose to sit facing any other direction than the one suggested from conventional vehicles? **Vehicle control for every passenger (climate, lighting, start/stop)** Does the vehicle move beyond a driver-centered interior by providing each passenger with individual control over vehicle functions? **Vehicle designed for autonomy (no steering wheel etc)** Is the vehicle purpose-built for autonomous operation, or is it a conventional vehicle adapted for autonomous driving? **On board entertainment system** Being alone in the car, can the passenger access an entertainment system to use the commute as a moment of relaxation?
03 Service experience	**Customizable passenger experience (colors, smells, etc.)** Does the vehicle allow passengers to customize their in-vehicle experience by modifying sensory aspects, such as scents, interior lighting or colors? **Supports shared rides (multi passenger-pooling)** Can the vehicle be shared not only with friends and family, but also with strangers heading in the same direction? **Coverage extends to suburban/extraurban areas** Does the vehicle's operating range extend beyond urban and suburban areas, allowing for extra-urban trips? **24/7 availability** Can the service be booked at any time, regardless of working hours or public holidays?

Wymo One

Case study 1

Waymo is a pioneer in autonomous mobility, widely regarded as a trailblazer and industry benchmark for safety innovation. Its mission is to transform modern transportation by creating a service that is safer, more sustainable, and inclusive for everyone.

Through a fusion of advanced AI, a robust sensor suite and extensive real-world and simulated testing, Waymo has developed a fully autonomous robotaxi system that integrated with commercial vehicles.

By significantly reducing collisions and easing traffic congestion, Waymo aims to set new standards for urban mobility and establish self-driving technology as a trusted, everyday solution

Company: Waymo LLC
Nation: USA
Year: 2018
SAE lv.: 4
Max passengers: 4
Availability: Phoenix, San francisco, Los angeles, Austin, Atlanta

Accessibility & Safety

Wheelchair accessibility	✗
Entrance from both sides of the vehicle	✓
Audio announcements	✓
Wide door opening for easy access	✗
Emergency assistance button	✓

Comfort & User experience

Choice of facing direction	✗
Vehicle control for every passenger	✓
Vehicle designed for autonomy	✗
On board entertainment system	✗

Service experience

Customizable passenger experience	✗
Supports shared rides (multi passenger-pooling)	✗
Coverage extends to suburban/extraurban areas	✓
24/7 availability	✓

Verne

Case study 2

Verne is a new venture in autonomous mobility, founded by Bugatti and Rimac Automobili CEO Mate Rimac and conceived as a project entirely built around self-driving technology.

Its mission is to transform urban journeys by delivering a premium robotaxi service where comfort, and luxury are placed at the center. Unlike cars converted for autonomy, Verne has no steering wheel or pedals, making it purpose-built for SAE Level 4 & 5 driving.

With a tailored ecosystem and a a well executed deisgn and personal branding supporting the idea, it seeks to redefine urban mobility beyond ownership.

Company: Project 3 Mobility
Nation: Croatia
Year: 2026
SAE lv.: 4
Max passengers: 2
Availability: Zagreb

Accessibility & Safety

Wheelchair accessibility	✗
Entrance from both sides of the vehicle	✓
Audio announcements	—
Wide door opening for easy access	✓
Emergency assistance button	✓

Comfort & User experience

Choice of facing direction	✗
Vehicle control for every passenger	✓
Vehicle designed for autonomy	✓
On board entertainment system	✓

Service experience

Customizable passenger experience	✓
Supports shared rides (multi passenger-pooling)	✗
Coverage extends to suburban/extraurban areas	✗
24/7 availability	✓

Zoox

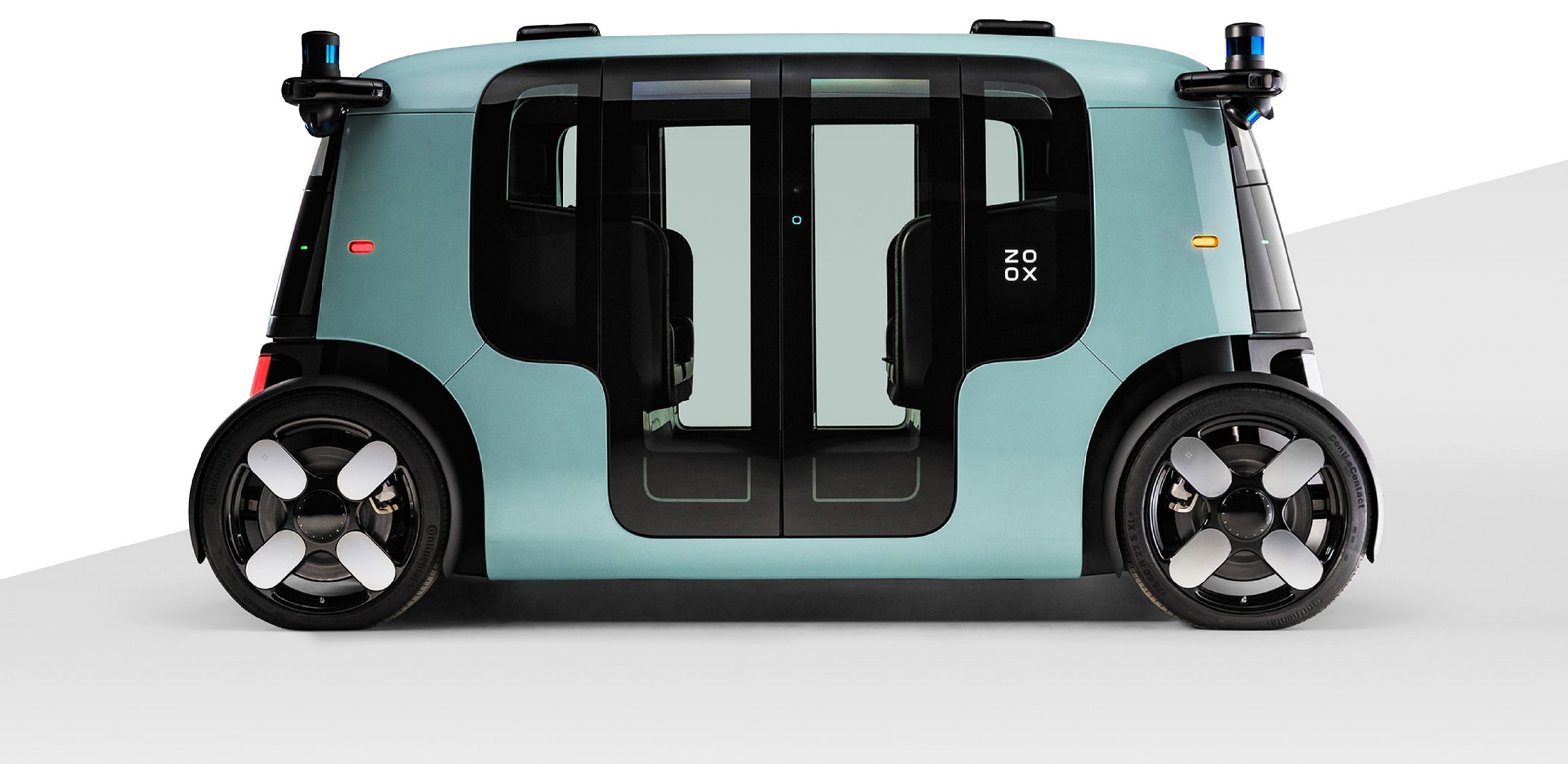
Case study 3

Zoox is an established player in autonomous mobility, active since 2014 and now part of Amazon.

Their approach is to create a purpouse built robotaxi for general passenger transport, functioning as a privat multifunctional cabin.

Zoox has the courage to reinvent and change established aspect of traditional mobility, offering something truly innovartive and projected towards the future of mobility.

Company: Zoox Inc.
Nation: USA
Year: 2026
SAE lv.: 4
Max passengers: 4
Availability: Las Vegas



Accessibility & Safety

Wheelchair accessibility	✗
Entrance from both sides of the vehicle	✗
Audio announcements	✓
Wide door opening for easy access	✓
Emergency assistance button	✓

Comfort & User experience

Choice of facing direction	✓
Vehicle control for every passenger	✓
Vehicle designed for autonomy	✓
On board entertainment system	✗

Service experience

Customizable passenger experience	✗
Supports shared rides (multi passenger-pooling)	✓
Coverage extends to suburban/extraurban areas	✗
24/7 availability	✓

Cybercab

Case study 4

Tesla's Cybercab project is spearheaded by CEO Elon Musk, representing the company's vision for a fully autonomous future, with a new approach to privately owned mobility.

It introduces a two-seater, electric robotaxi prototype, completely reimagined for autonomy, featuring no steering wheel or pedals, gull-wing doors, and wireless inductive charging.

The goal is to offer a high-volume, low-cost urban transport option under $30,000, starting around 2026. Positioned as a multifunctional vehicle, the Cybercab may both work as a personal vehicle as well as a robotaxi. This shows a strong ambition to shift from car ownership to seamless, on-demand mobility.

Company: Tesla Inc.
Nation: USA
Year: 2026
SAE lv.: 4
Max passengers: 2
Availability: Austin

Accessibility & Safety

Wheelchair accessibility	✗
Entrance from both sides of the vehicle	✓
Audio announcements	—
Wide door opening for easy access	✓
Emergency assistance button	✓

Comfort & User experience

Choice of facing direction	✗
Vehicle control for every passenger	✓
Vehicle designed for autonomy	✓
On board entertainment system	✓

Service experience

Customizable passenger experience	—
Supports shared rides (multi passenger-pooling)	✗
Coverage extends to suburban/extraurban areas	✓
24/7 availability	✓

Service concept

04

4. Service Concept

4.1 Service definition

Having examined both the broader scenario and the state of the art in autonomous driving, the work now turns towards the practical development of the service, designed to address the needs of the selected pilot context, the city of Amsterdam, while retaining the potential for application in many comparable urban settings.

The response to Amsterdam's progressive policy of reducing parking availability and raising the costs associated with privately owned vehicles, is a service designed to provide citizens with reliable mobility without the necessity of individual ownership. Instead of being tied to a personal car, users gain access to a vehicle that relieves them of the constant responsibilities connected to maintenance, cleaning, insurance, parking, and even the act of driving itself. By shifting the focus from possession to usage, the service not only addresses practical transport needs but also aligns with broader urban goals of reclaiming space and reducing congestion. Ultimately, the vehicle becomes a facilitator of seamless mobility, enabling users to concentrate entirely on their journey and destination rather than on the burdens of car ownership.
To tackle the issues of traffic congestion, emissions, and the excessive number of vehicles circulating simultaneously in urban areas, the instinctive approach is to design cars capable of transporting as many passengers as possible, encouraging shared rides. Yet, this approach does not truly reflect the way people move in cities. Many individuals who use their personal car on a daily basis value the independence it provides as well as the privacy of having their own space during a journey, something that a large shared vehicle cannot offer. This is also supported by European mobility statistics: for the population aged 15 to 84, the average car occupancy during urban trips ranges from a minimum of 1.17 passengers in Italy to a maximum of 1.87 in Romania. These numbers highlight that cars in cities are often used by a single person or, at best, two. For this reason, when designing a vehicle specifically for urban mobility, there is no need to plan for more than two seats to meet the actual demand. Moreover, considering the structural characteristics of various European cities such as Amsterdam, which developed on a historical and compact urban fabric, a small and highly maneuverable vehicle proves to be the most appropriate solution. A compact dimension not only makes navigation easier in the city's narrow and congested roads, but also simplifies parking and integration into the existing mobility infrastructure.

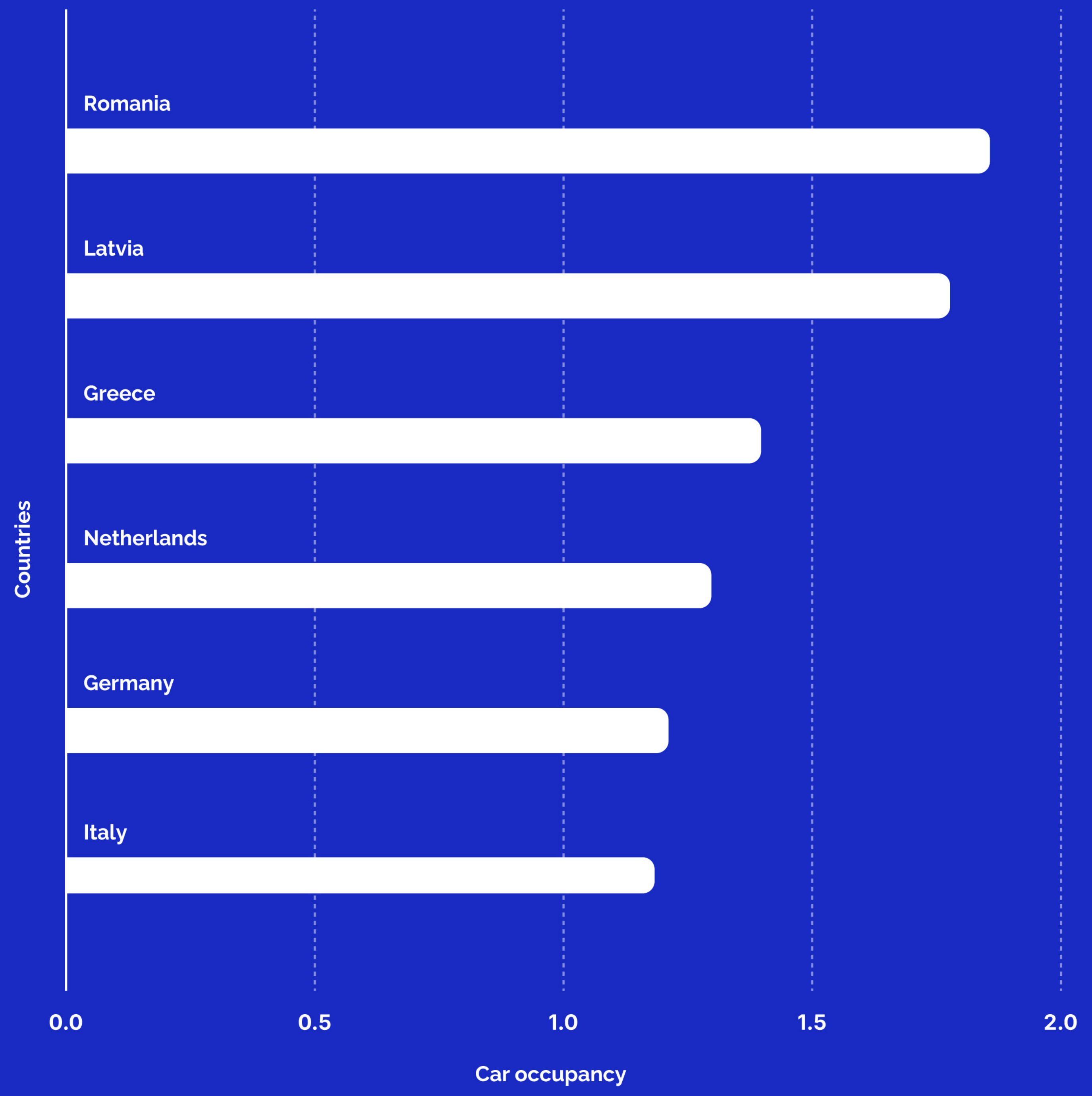


Fig. 4.1→
Car occupancy in European contries [45]

At the same time, reducing the number of active vehicles on the road remains a shared interest of the service providers, the public administrations, and the citizens themselves, since fewer cars mean less congestion, lower pollution, and a more livable urban environment. To respond to this challenge, the service will integrate an individual ride sharing option directly into the booking process. Passengers will be able to decide whether they prefer to travel alone or if they are willing to share their trip with another person moving in the same direction. If the second option is selected, the system will identify a suitable match among nearby users, pairing together those with overlapping or compatible routes. The pairing process is designed to ensure that both passengers will reach their destinations without being forced to deviate significantly or waste additional time on their journey.

The introduction of a new mobility service within the already stable and complex transport infrastructure of a city can easily generate disruption if not properly managed. To avoid creating competition with public transport, the service is not conceived as an alternative that citizens must choose over existing systems, but rather as an integrative option that complements them. Its role is to fill the gaps where traditional means are less efficient or not available, while ensuring continuity and coherence with the established urban mobility network. In this framework, cooperation with local public institutions and transport organisations becomes a central aspect. These actors contribute by facilitating circulation within restricted mobility zones, integrating the new service into their official mobility plans, and promoting it through their communication channels such as websites and information platforms.

On the other side, the designed service generates clear benefits for the city by acting on two complementary levels. First, it systematically collects and shares anonymised data on citizens' mobility patterns, offering municipalities valuable insights to monitor travel flows, evaluate policy effectiveness, and plan targeted infrastructure improvements. At the same time, the service itself contributes to achieving long-term sustainability objectives, by reducing the number of active vehicles on the streets, cutting emissions, and making better use of the existing urban infrastructure. This reciprocal exchange of resources and information ensures that the service strengthens the public system rather than competing with it [45].

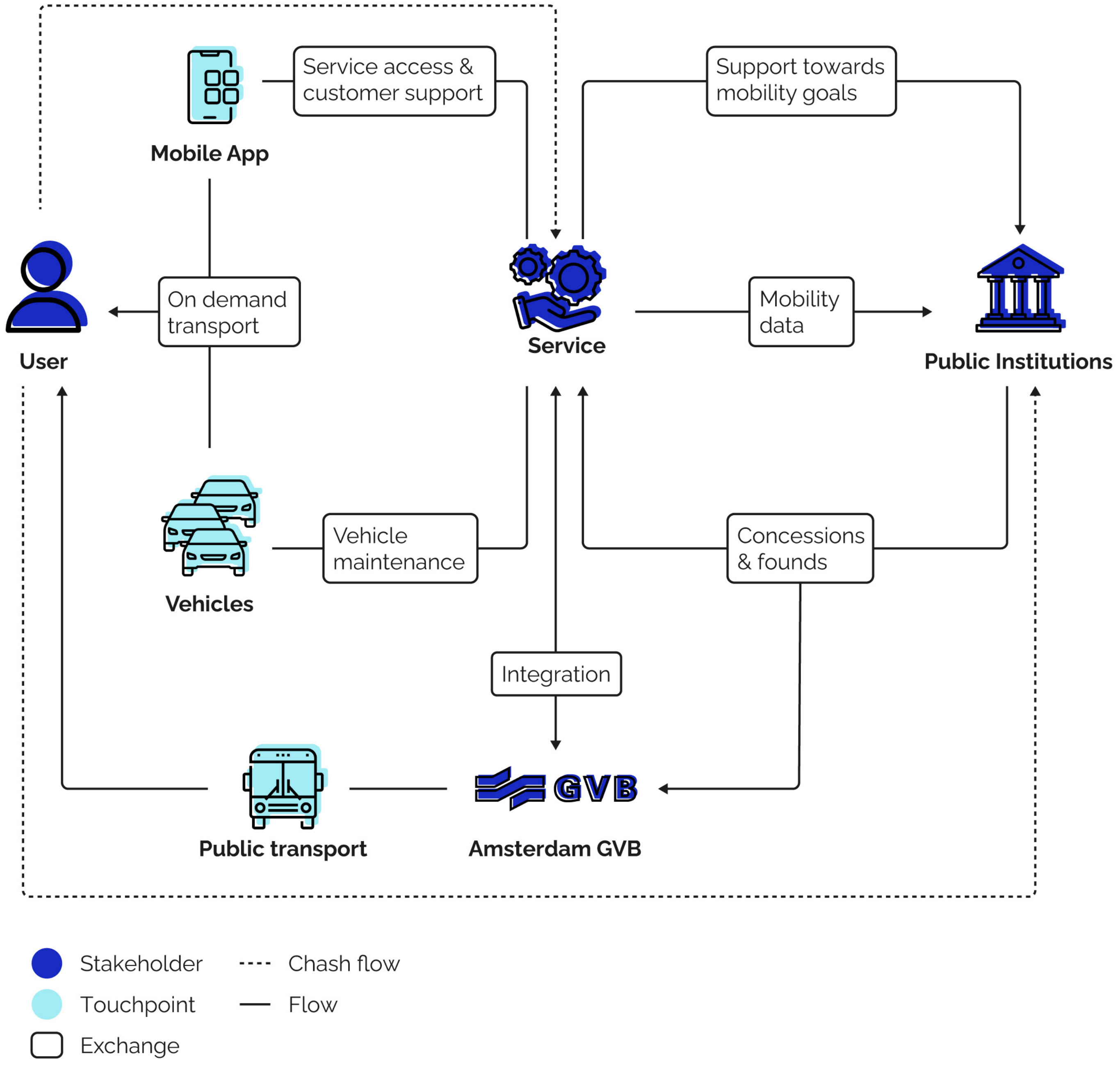


Fig. 4.2→
Visualization of the service ecosystem map, highligting the stakeholders and the flows involved in the service

← **Fig. 4.3**
Electric car charging operation, representative of one of the main purposes of the service's CareHubs [27].

When managing a complex mobility system, the product itself is equally as important as the broader ecosystem that enables the service to function reliably and seamlessly. Vehicles themselves are not sufficient to ensure consistent quality or safety standards, as they must be supported by a network of dedicated facilities where they can regularly undergo inspection, maintenance, cleaning, and charging. To meet this need, the system relies on dedicated "**CareHubs**". These are centralized operational centers designed specifically for vehicle upkeep and management. Within these hubs, every aspect of fleet maintenance is monitored and executed, from technical checks to interior sanitization, ensuring that the vehicles remain in optimal condition for daily use. This ecosystem approach guarantees that every user, at any time of the day, can access a vehicle that is functional, clean, and fully charged. Beyond serving a practical role, CareHubs represent a crucial backbone of the mobility service, providing the organizational structure that allows the fleet to operate at scale, adapt to demand fluctuations by storing inactive vehicles, and integrate efficiently within the wider urban transport system.

The strategic placement of the CareHubs within a city requires careful attention to both operational efficiency and urban integration. Hubs should be located in areas with sufficient land availability, allowing for vehicle storage, charging, maintenance, and potential future expansion. Reliable access to energy infrastructure is essential to support continuous charging and operational readiness. While well connected to the city's main road network to minimize transit times, hubs should remain outside highly congested areas to avoid contributing to traffic delays. Proximity to major employment nodes and transport interchanges enhances responsiveness during peak demand periods. Finally, environmental and social impacts must be considered, ensuring that noise, safety, and compatibility with surrounding neighborhoods are properly managed.

When taking these aspects into consideration, suburban districts and industrial areas, as well as locations close to major transport hubs such as airports or railway stations, qualify as the most suitable sites for CareHubs. In Amsterdam, the following areas best represent the urban contexts where such facilities can be effectively placed.

1 Westport, Sloterdijk Station

Westpoort represents one of Amsterdam's largest industrial districts, hosting thousands of work commuters daily and hosting major industrial facilities as well as the Amsterdam harbour, which ranks among the biggest and the 4th busiest seaport in Europe. Unlike other boroughs, this area is almost entirely non residential and instead strongly oriented toward logistics, large scale production, and heavy industry. A CareHub facility located here, especially in proximity to the Sloterdijk Station, would benefit from direct access to the A10 and A5 highways, ensuring efficient connections to other boroughs of Amsterdam and to the wider metropolitan region. Furthermore, the already industrial and night-active character of Westpoort reduces potential conflicts with residential uses, making the presence of a 24/7 operational facility more compatible with the local context [46], [47].

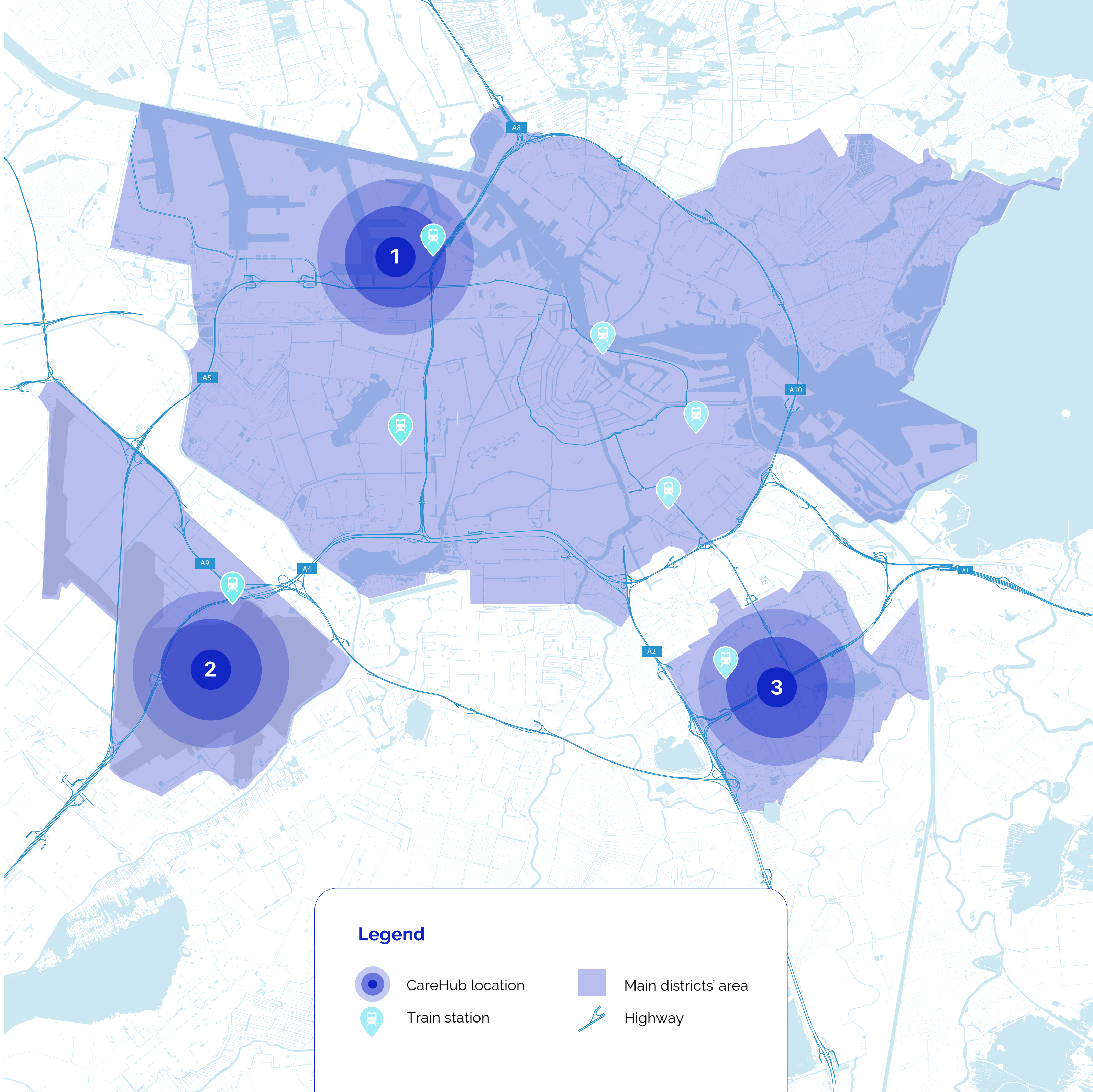
2 Schiphol Airport

As one of Europe's busiest airports, Schiphol generates a significant flow of passengers and employees on a daily basis, making it a major node in the regional and international mobility network. Placing a CareHub adjacent to such a large employment and logistics hub allows the service to directly serve a substantial working population while remaining outside the highly congested city center. The location also benefits from excellent road connectivity, with rapid access to the A4 and A9 highways, facilitating efficient vehicle circulation and redistribution throughout the Amsterdam metropolitan area. Beyond the core operational functions of inspection, cleaning, and charging, a CareHub in this zone can also play a complementary role as a base for "last-mile" services, providing short-distance trips to and from the airport or nearby business and residential areas [48], [49].

3 Zuidoost, Bijlmer Arena station

Zuidoost can be seen as one of Amsterdam's most dynamic and multicultural districts, markedly different from Westpoort and other peripheral areas. In addition to its residential neighborhoods, which were home to approximately 88,000 inhabitants as of 2018, the district also acts as a major hub of entertainment and nightlife, thanks to the presence of the Johan Cruijff Arena, large shopping malls, and event venues. Although located outside the historic city center, Zuidoost is well connected to the rest of Amsterdam. The area around Bijlmer Arena station serves as a key interchange, linking regional and national rail services with multiple metro lines, while also being close to the junctions of the A2, A9, and the southeastern section of the A10 ring road. The multifunctional and high-traffic nature of the district makes it well suited for facilities that operate around the clock, as their presence can be seamlessly integrated into the urban fabric [50], [51].

Fig. 4.4→
CareHubs map



4.2 Customization

In today's competitive landscape, users increasingly expect services to adapt to their individual needs rather than the other way around. Product customization not only shapes customer satisfaction, but also plays a decisive role in fostering loyalty and long term engagement. This becomes particularly significant in services such as shared mobility, where the car is no longer owned and the service might be experienced as generic or detached. By offering meaningful forms of personalization, such services can reintroduce a sense of connection and relevance, even in the absence of ownership [52], [53].

A truly seamless experience in shared mobility can only be ensured if the service remains consistent each time, regardless of the specific vehicle assigned. To achieve this, users can define their preferences through an application, which are then automatically implemented for the trip assigned at the time of booking.
In the short commute between the booking and the user getting on board, the interior adjusts to the individual profile, allowing users to experience a familiar and coherent setting. This approach guarantees continuity across journeys, recreating the sense of comfort and ownership typically associated with a private vehicle.

Specifically, the user can customize the following aspects of the vehicle interior:

Travel modes
This setting specifically concerns the seating arrangement of the passengers during the ride. Two travel modes are available: "Cruise", in which both passengers sit side by side facing the same direction, and "Conversation", in which they sit facing each other, simulating a more social environment.

Interior colours
The user can control the behaviour of several panels integrated into the interior, allowing customization of colors and overall visual atmosphere. This option directly responds to the IDEEA 2025 challenge brief, which emphasizes exploring applications of photochromic technology. Further sections of this research will provide a detailed explanation of this technology and its specific implementation.

Window tint
The cabin is a fundamental aspect in enabling users to shape the environment according to their needs, whether that means creating a relaxing atmosphere or enjoying the surrounding cityscape. To achieve this, the transparency of the windows can be adjusted directly by the passenger.
The underlying intent is to provide passengers with a level of customization comparable to that of a personal living space, where one can decide the placement of furniture, select its colors, or adjust window blinds. In the same way, the vehicle seeks to replicate this sense of personal control and comfort within a mobility context.

4.3 Accessibility

Mobility is more than the act of moving from one place to another; it is the enabler of opportunities, connections, and independence. Yet, not everyone experiences this freedom equally. For many, barriers in transportation translate into barriers in life. As technologies and products evolve, the challenge is no longer only about efficiency or productivity, but also about inclusivity. In this sense, the principles of Design for All become essential: designing products and services so that they are inherently accessible, without discriminating among different user groups. Within this framework, autonomous driving represents a paradigm shift, offering the possibility to rethink vehicle access and usability in ways that can remove long standing barriers and extend true access also to users with motor disabilities.

Following these considerations, the developed service needs to have flexible interior elements, to guarantee every action and option to be available to a wide and diverse user base, with particular attention to individuals using a wheelchair.

4.4 User workflow

When accessing the service for the first time, each user is asked to download the dedicated app, complete their personal profile, and set their travel preferences. This initial setup is essential to ensure that every assigned vehicle is automatically adapted to the user's customization choices, without requiring adjustments at each ride.
The service is primarily designed to function as a long-term subscription, allowing users to experience it as they would with a privately owned vehicle. Nevertheless, more flexible options are also available, such as monthly mileage packages or a pay-per-use plan.
After setting up the account, users can manage frequently travelled routes to streamline the process, while new trips can be configured by specifying pick-up and drop-off locations, number of passengers and even the willingness to share the ride with another traveler heading in the same direction. Upon booking confirmation, users can board the assigned vehicle via in app verification.

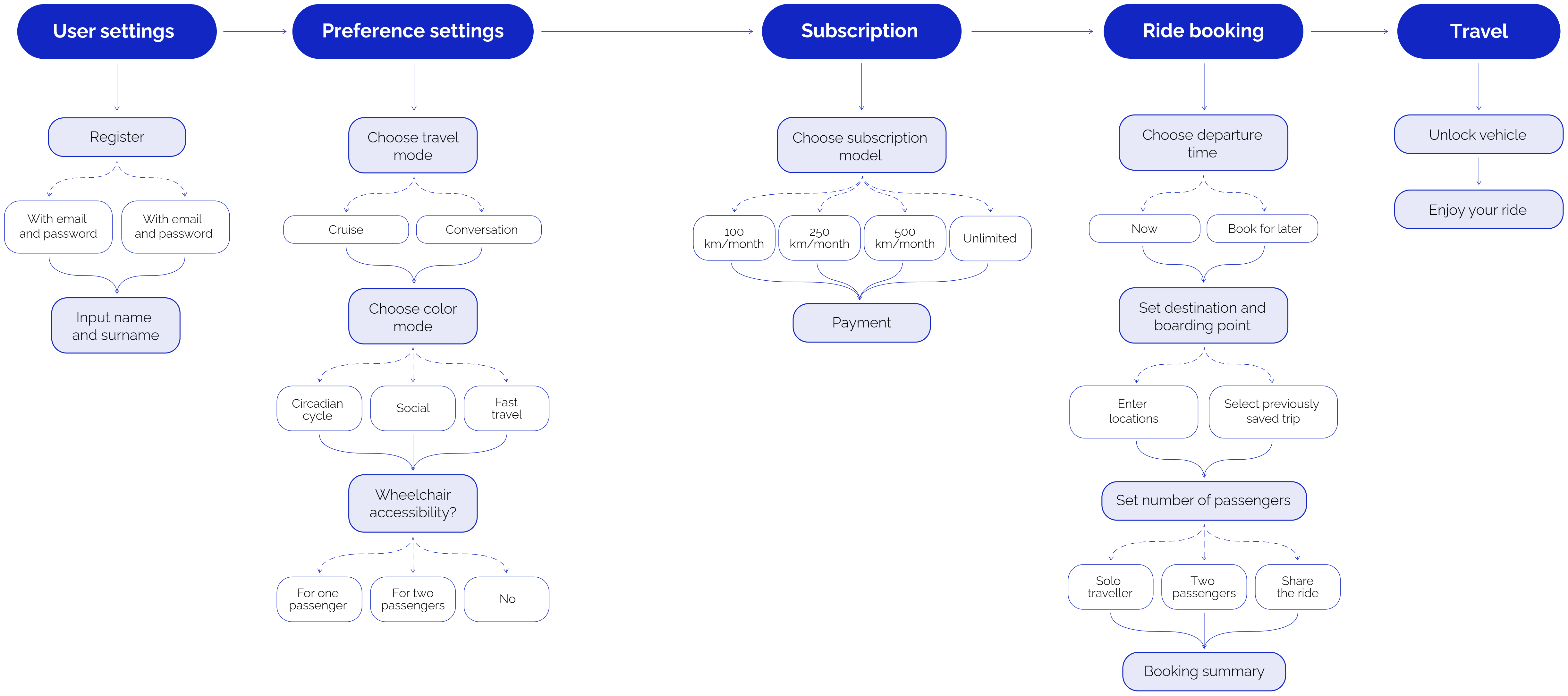


Fig. 4.5 →
Visualization of the user workflow

4.5 Target segments

When identifying a potential automotive target group, audiences can commonly be segmented based on demographical, behavioural, geographical and psychographical criteria. However, when shifting the perspective from private car ownership to autonomous mobility services such as robotaxis, the notion of a "target group" inevitably changes. Instead of appealing to individuals as potential buyers of a product they can proudly display, the focus moves to a much broader and heterogeneous set of users, who access the service according to situational needs rather than long-term ownership. In this context, segmentation is less about lifestyle branding and more about different user groups who need flexible on demand transport [54].

From this perspective, several potential user groups can be identified as primary beneficiaries of a robotaxi service. Urban commuters may value the convenience of seamless travel without the burden of parking and paving the way in a chaotic bicycle-dominant city center, while residents in poorly connected areas would gain access to reliable mobility otherwise unavailable. Another significant segment includes nightlife customers leaving pubs, bars, or clubs, who often need a safe and private way home at times when driving themselves would not be responsible.Yet perhaps one of the most critical groups are night shift workers. For those employed in sectors such as healthcare or logistics, mobility during the night remains scarce and unreliable. Hospital staff, for instance, deserve access to a transportation option that not only guarantees availability but also provides a space where they can rest and unwind after demanding hours of work.

Finally, as previously noted, individuals with limited mobility who rely on wheelchairs often face significant barriers to mobility. Even when accessible options are available, they are frequently accompanied by disadvantages such as higher efforts, higher costs, or a generally unsatisfactory user experience. This makes wheelchair users one of the groups most in need of inclusive and accessible mobility solutions that can offer them greater independence and autonomy.

Fig. 4.6→
Nightshift worker identified as one of the possible target users of the service [27]

Vehicle concept

05

5. Vehicle concept

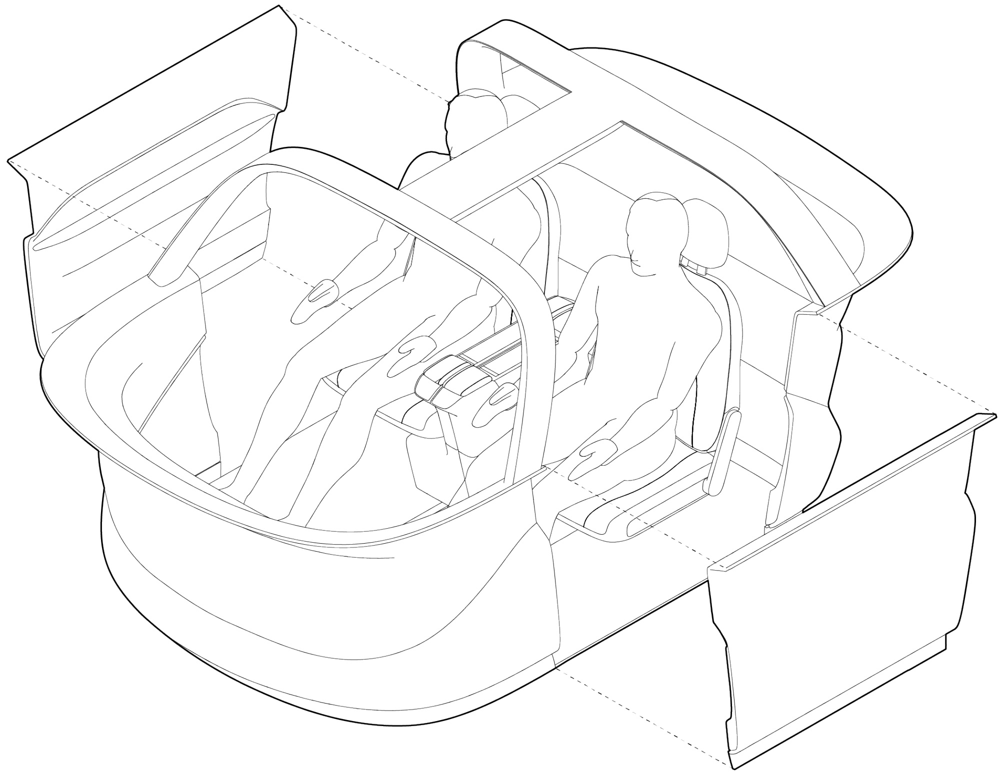
5.1 Concept intruduction

The vehicle concept represents the stage in which all the research, analyses, and reflections presented throughout the project are translated into a tangible design proposal. In alignment with the IDEEA 2025 challenge brief, the focus has been deliberately narrowed to the development of the vehicle interior. This decision stems from the understanding that, in the context of autonomous mobility, the interior is the dominant environment of interaction, as it is the space where users spend the entirety of their journey, and therefore the dimension that most directly shapes their comfort, safety, and overall experience.
Designing the interior in isolation does not imply neglecting aspects of the vehicle's exterior. On the contrary, every choice regarding spatial layout and accessibility has been conceived with awareness of the repercussions on exterior features such as window placement, door shapes and movements, and the overall proportions of width and length. What distinguishes this concept, however, is the conviction that in a vehicle where driving functions are fully automated, the interior no longer plays a supporting role but becomes the very core of design innovation. For this reason, this thesis prioritizes the passenger space as the primary field of experimentation, seeking to re-define how future users will live, rest, or work during their journeys.

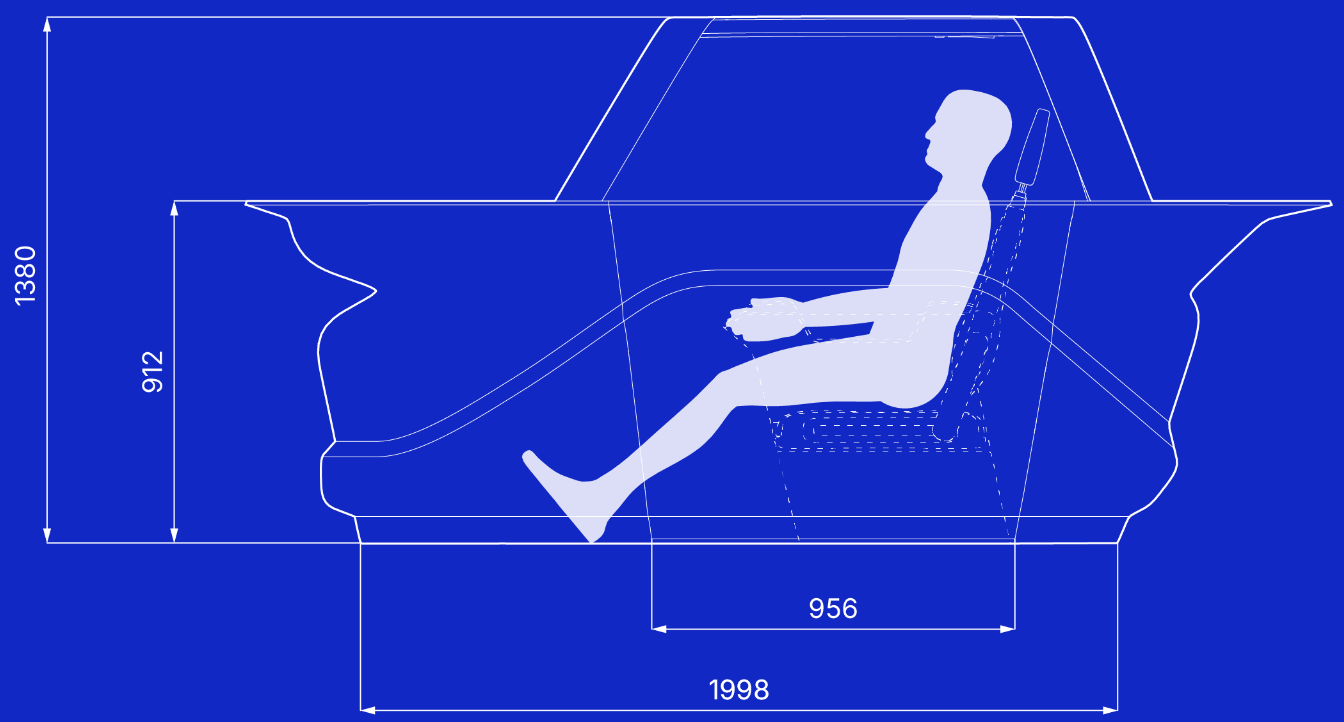
5.2 Dimensions

Establishing a vehicle's dimensions is a decisive step in the design process, as it determines not only the overall proportions but also the usability and adaptability of the concept. Dimensions must be defined in response to multiple factors, including passenger capacity, accessibility requirements, and the level of interior comfort that the vehicle aims to provide. At the same time, the vehicle's footprint has to be tailored to its intended function and the specific urban environments in which it will operate. A compact layout improves manoeuvrability in dense cityscapes, facilitates parking opportunities, and contributes to greater safety both for passengers and for surrounding traffic.
As was mentioned earlier in the document, the vehicle concept has been developed for two passengers seated side by side, with the possibility to reorganize the space according to different needs. The interior can shift between alternative seating configurations or allow the seats to be fully retracted in order to make room for wheelchair users. While the overall footprint aims to remain as reduced as possible, the vehicle floor needs to be lengthened to ensure a more comfortable user experience and, above all, to allow sufficient manoeuvrability for wheelchairs within the cabin. Furthermore, the absence of a steering wheel and traditional dashboard controls, made redundant by full vehicle autonomy, enables passengers to be positioned further back than in a conventional car. This choice provides additional legroom, allowing for a more open and spacious vehicle perception.
As a practical guideline, and to avoid potential complications with vehicle homologation and registration processes, the definition of the proportions was based on an existing compact urban vehicle. For the purposes of this research, the Fiat Panda 2012 was selected as a dimensional benchmark, offering a realistic reference while leaving space for innovation within the parameters of current regulatory and functional standards.

Fig. 5.1 ↓
Axonometry of the main vehicle interior shell, with proportioned human figures for antropometric reference.

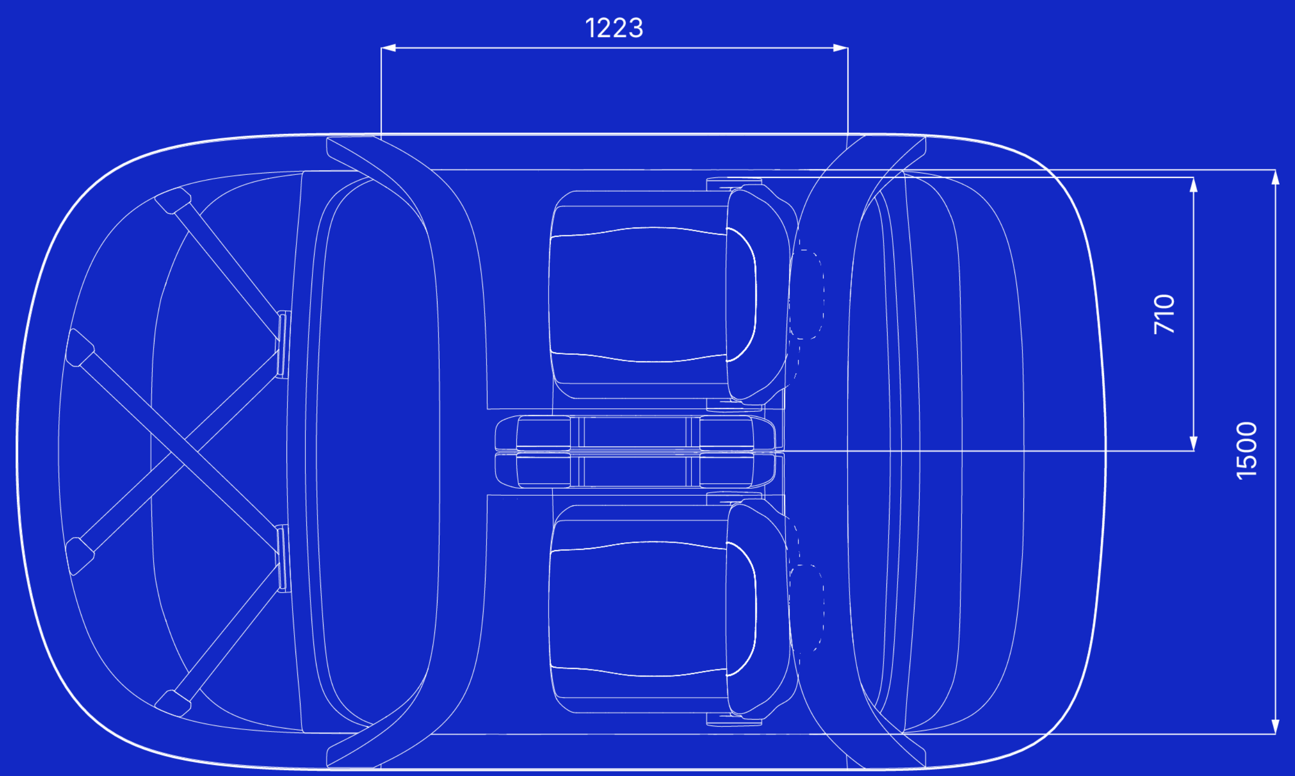


Side view of the interior cabin



The cabin length is kept shorter, compared to conventional two-row vehicles, resulting conse quently in a reduced wheelbase. This configuration provides plenty of comfort and space for only two passengers, without adding excess volume. The cabin hight. takes the hight of the potential tollest passenger into consideration, to ensure sufficient headroom in all cases.

Top view of the interior cabin



The cabin has been designed with a width slightly greater than that of compact vehicles, including the chosen reference model. This adjustment is a deliberate choice to ensure passenger comfort while allowing sufficient space for wheelchair users. To support accessibility, the door openings on both passenger sides are far wider than average compact cars, facilitating unobstructed entry and exit.

Units in mm
Scale 1:20

5.3 Layout configurations

The design of a ride-hailing service that makes flexibility and customization its hallmarks translates, when it comes to the interior design of its fleet of vehicles, into a series of constraints and critical issues. These clearly stem from the differences between the needs and preferences of the large pool of users to whom the service is aimed. One of the challenges, unlike what might happen in the design of a privately owned vehicle, where customization often takes place at the time of purchase by selecting from a range of options and features, is to make the car adaptable to different requests at any time.

The first requirement is expressed in the multiple seating configuration of the interior, designed to be mobile and flexible in response to different user profiles and their varying preferences. This approach was chosen by taking full advantage of the possibilities offered by autonomous vehicles, as discussed in chapter 3.2. Freed from the need for a driver, the interior design can imagine a layout in which the two passengers aren't always both facing the direction of travel but are seated facing each other. This change creates a more intimate and cozy space, typical of any moment of conversation and interpersonal relationship, in which proximity and body language play a fundamental role.

Historically, these themes have been reflected, for example, in what are known as "love seats", small-sized double seats designed to accommodate a private conversation between two people. While in the 17th century these were understood as armchairs designed to accommodate a couple sitting side by side, later, around the mid-19th century, interesting examples of seats characterized by an S-shaped structure emerged, in which two people could sit facing each other, in what was called at the time a "social seat." A similar example of this type of chair was also created by Antoni Gaudí for the dining room of his Batllò House in 1904 and was named Confidant. Although the style and ergonomics change, the shared armrest and focus on the intimacy of conversation remain [55], [56].

Fig. 5.2 ↗
Charles II oak panel-back double armchair, 17th century [55].

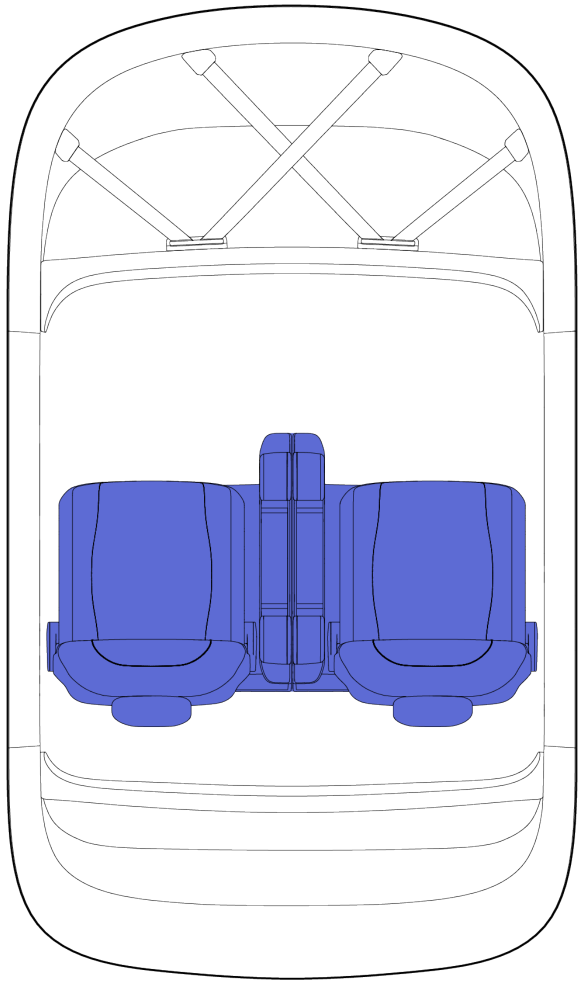
Fig. 5.3 ↗→
Victorian rosewood-framed love seat, 19th century [55].

Fig. 5.4→
Confindant, Antoni Gaudi. Designed in the 20th century for Casa Batllò [56].

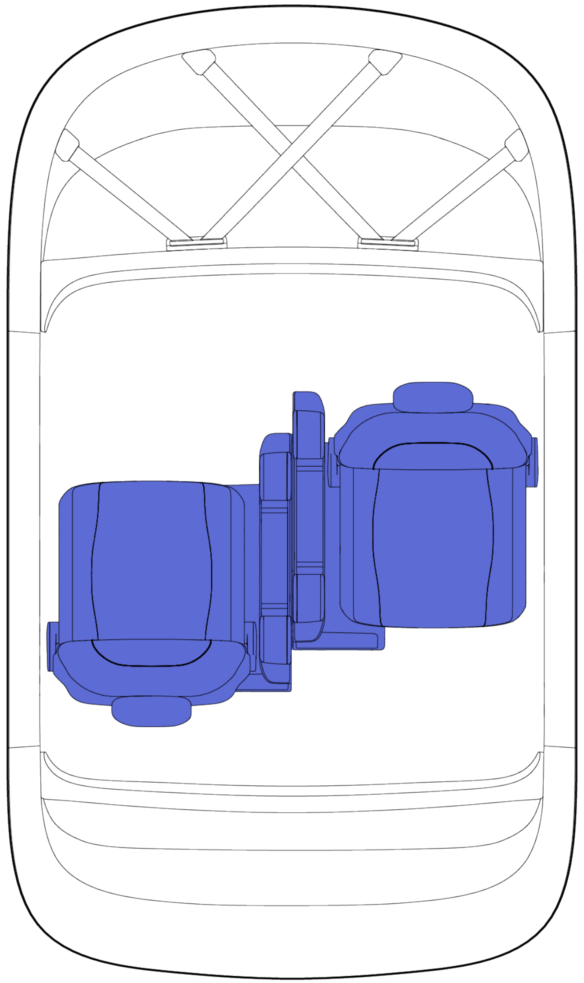
The vehicle's interior therefore had to accommodate passengers in the traditional mode, called "Cruise", and in the mode just described, which is named "Conversation."

The second challenge is accessibility, understood as a fundamental requirement that a service of this type does not want to avoid, but rather intends to make a point of strength. Focusing on finding a solution, in particular, to the difficulties of urban mobility for wheelchair users, it is necessary to rethink the interior of the car.
Consequently, there were two possible approaches in this regard:
ensure that there was space inside the passenger cabin for one or more wheelchairs to be stored while their owners enjoyed the journey;
ensure that wheelchair users could remain in their wheelchairs and access the car with them, traveling safely without having to shift to the seat.
Guided by the dimensional limitations of the overall vehicle and the desired level of travel comfort, the second option was identified as the most viable, even though it posed a new design challenge: to free up space in the passenger compartment, if necessary, to accommodate one or two wheelchairs. This was made possible thanks to the solutions adopted in the design of the seats.

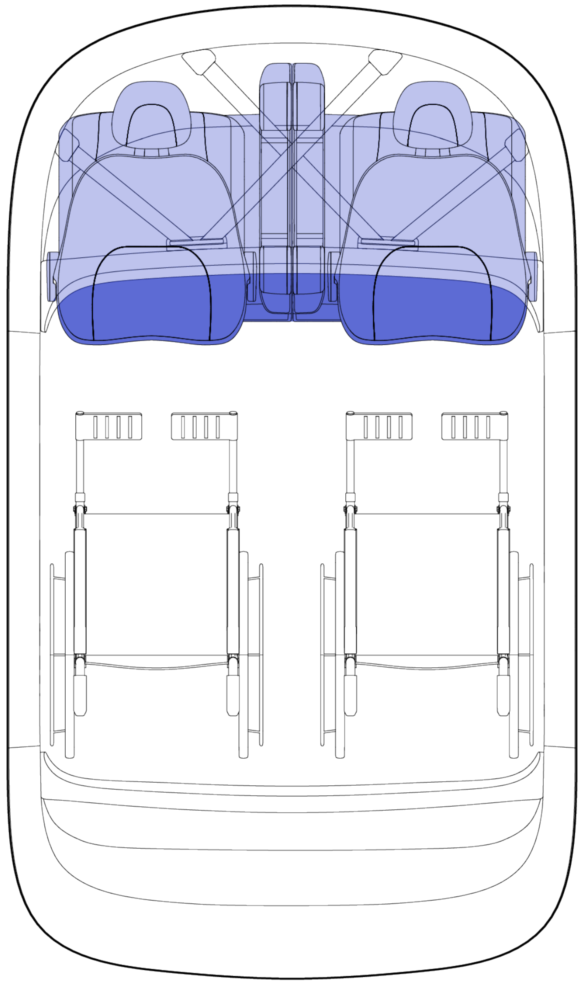
1. Cruise Mode



2. Conversation Mode



3. Accessibility



5.4 Seats

At this point, the design process moved on to one of the fundamental elements of any car interior, which, in light of the described needs, takes on even greater importance: the seat.
It is the most direct interface between the user and the vehicle, having a decisive impact on the safety and comfort of the travel experience. Its positioning, size and design are the main factors that define the perception of the car's interior space, especially in a scenario where other key elements of traditional driving, such as the steering wheel, are not present. Therefore, by placing the user experience at the center of the concept, the correct and conscious design of the seats was fundamental.

First, it was necessary to define the approximate dimensions of the seat in relation to the identified market. To do this in accordance with the anthropometric values of the target population, the DINED database was used, a highly relevant and accurate tool developed by the TU Delft University in the Netherlands. By accessing data from various studies, the resource allows users to view and compare measurements differentiated by nationality, gender and age. Tools also enable users to view the correlation between two measurements or generate a three-dimensional mannequin with the desired anthropometric measurements.
The measurements shown in Tab. 5.1 are based on data from the Dutch adult population (statistically, the tallest in the world), both male and female, aged between 20 and 60. Different percentiles were considered for each measurement in order to ensure comfort for the widest possible range of users [57], [58].

Component	Percentile	Human dimension	Notes
Seat width	95th	447mm	Based on hip breadth in seated posture; Ensures comfort for wider users.
Seat depth	50th	445mm	Based on buttock popliteal length; Prevents leg pressure or lack of support.
Seat hight from floor	5th	397mm	Based on popliteal height; Allows shorter users to place feet flat.
Backrest hight	50th	445mm	Based on shoulder height while sitting; Prevents lack of back support or comfort.
Backrest width	95th	447mm	Based on shoulder breadth; Ensures comfort for wider users.

Tab. 5.1 ↗
Measurements for specific percentiles, obtained from the DINED databased and used for the seat design [57].

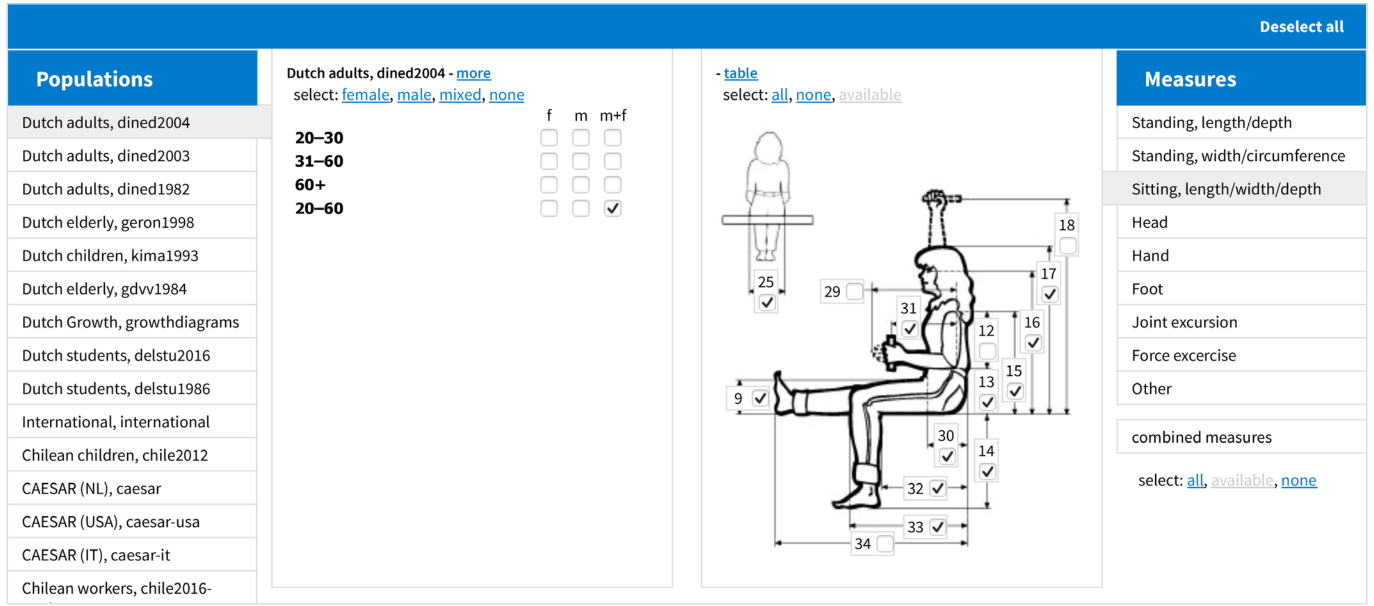


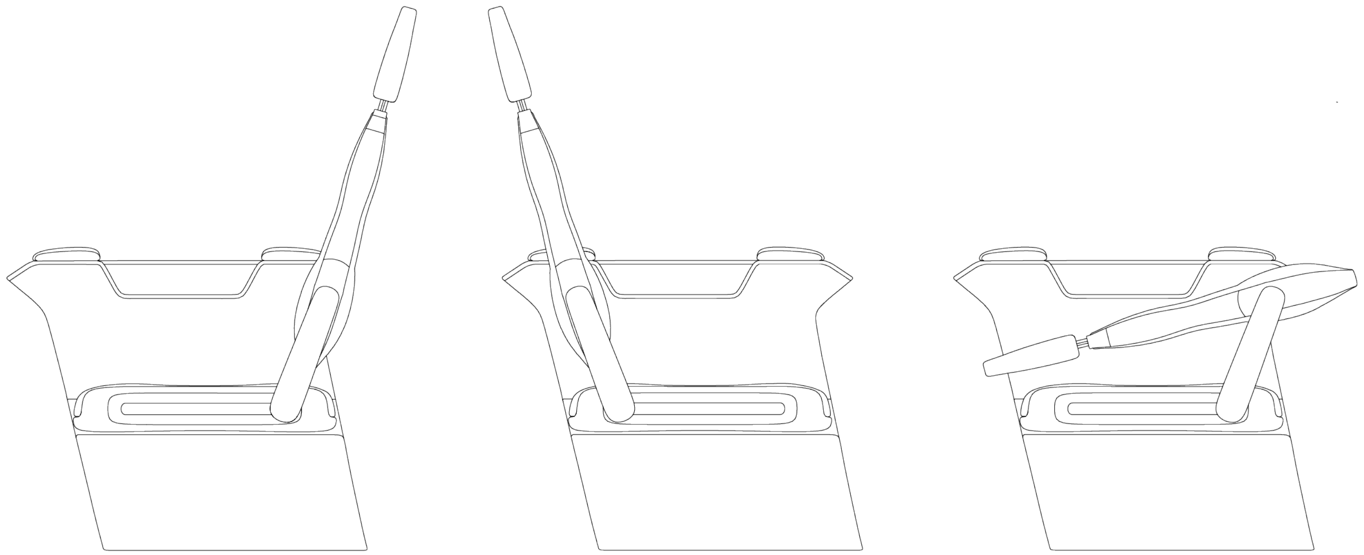
Fig. 5.5 →
DINED database showing specific measurements for feamale and male dutch adults, aged between 20 and 60 years [57].

Subsequently, research was conducted into how to ensure that the seats would allow for different configurations of the car's interior layout and access for a person in a wheelchair, while saving as much space as possible. Following the initial development of numerous solutions, some of which involved rotating the entire seat, the one finally adopted is based on the mobility of the backrest in relation to the seat bottom. In fact, to enable the transition from Cruise to Conversation mode, it is sufficient to ensure that the backrest, which is integral with the headrest, is able to move from one end of the seat to the other. This transition is made possible by two automated tracks located on the sides of the seat cushion, along which two arms connected to the backrest slide. Clearly, a few other precautions must be taken to ensure that this solution is functional:
the seat must be symmetrical and parallel to the ground, unlike most car seats, which are tilted upward;
the backrest and headrest must have symmetrical padding on both sides of the structure, ensuring comfortable use in both travel modes.

However, the degrees of mobility of the backrest cannot be limited to translation from one end of the track to the other. In fact, in order to allow a wheelchair to access the vehicle, it is essential to provide the necessary space, which is clearly not available if the seat remains in the standard position. This gives rise to the second major functional requirement of the seat, namely the ability to compact.
This is achieved by rotating the backrest towards the seat, at the joints between the backrest and the arms connected to the side tracks. In the compact position, the seat is low enough to fit under the dashboard, an area that is more spacious when an electric motor is present. This movement is made possible by the presence of a rail positioned on the floor, one for each seat.

Fig. 5.6 ↓
Seat limit positions.

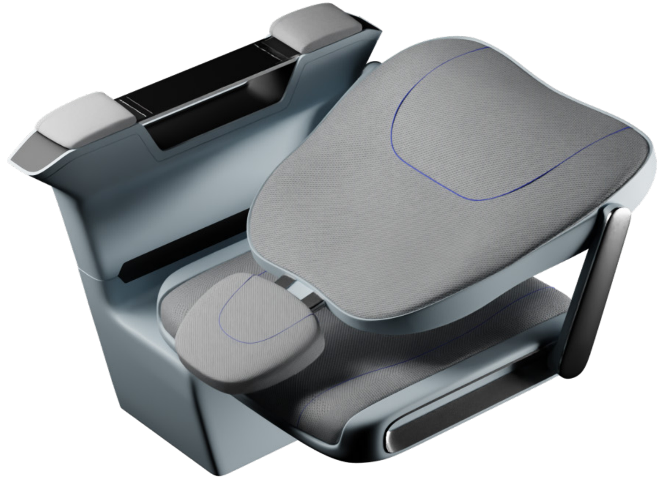
1. Cruise Mode **2.** Conversation Mode **3.** Accessibility

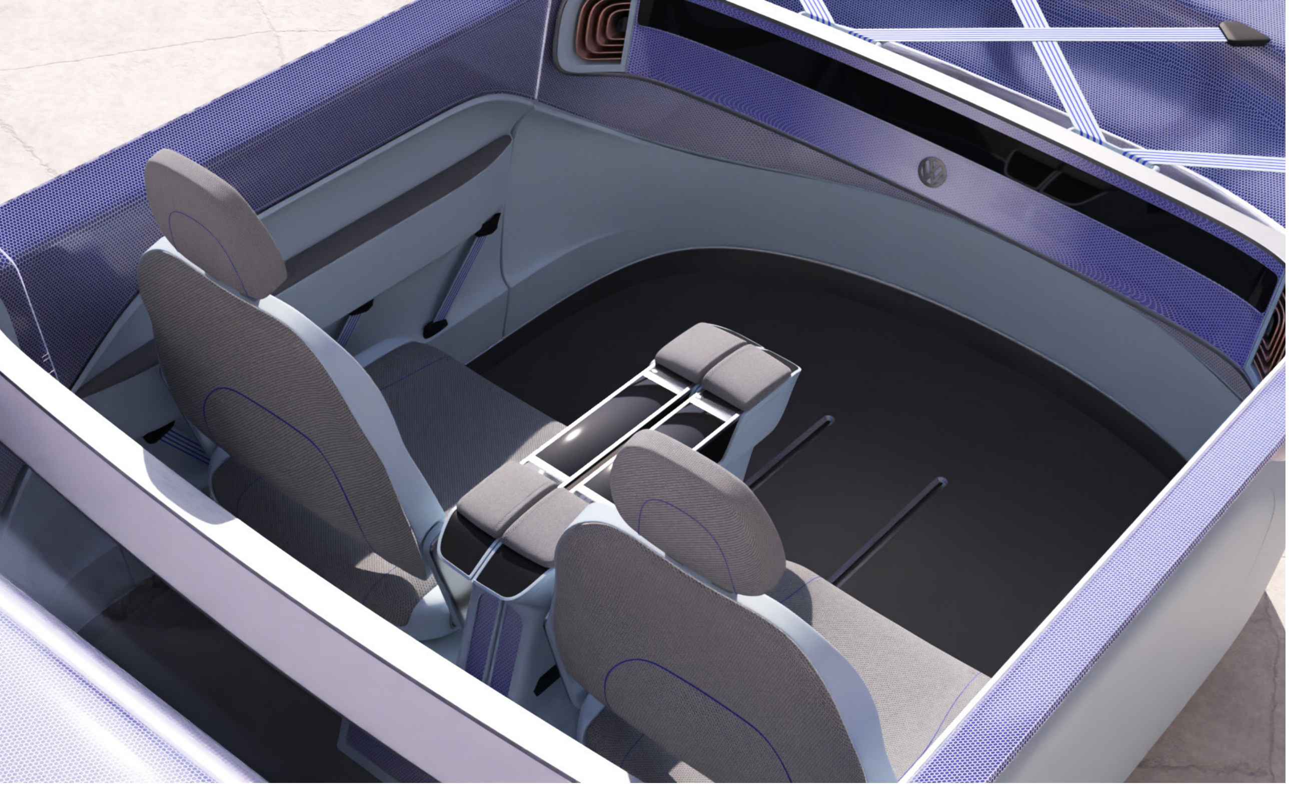


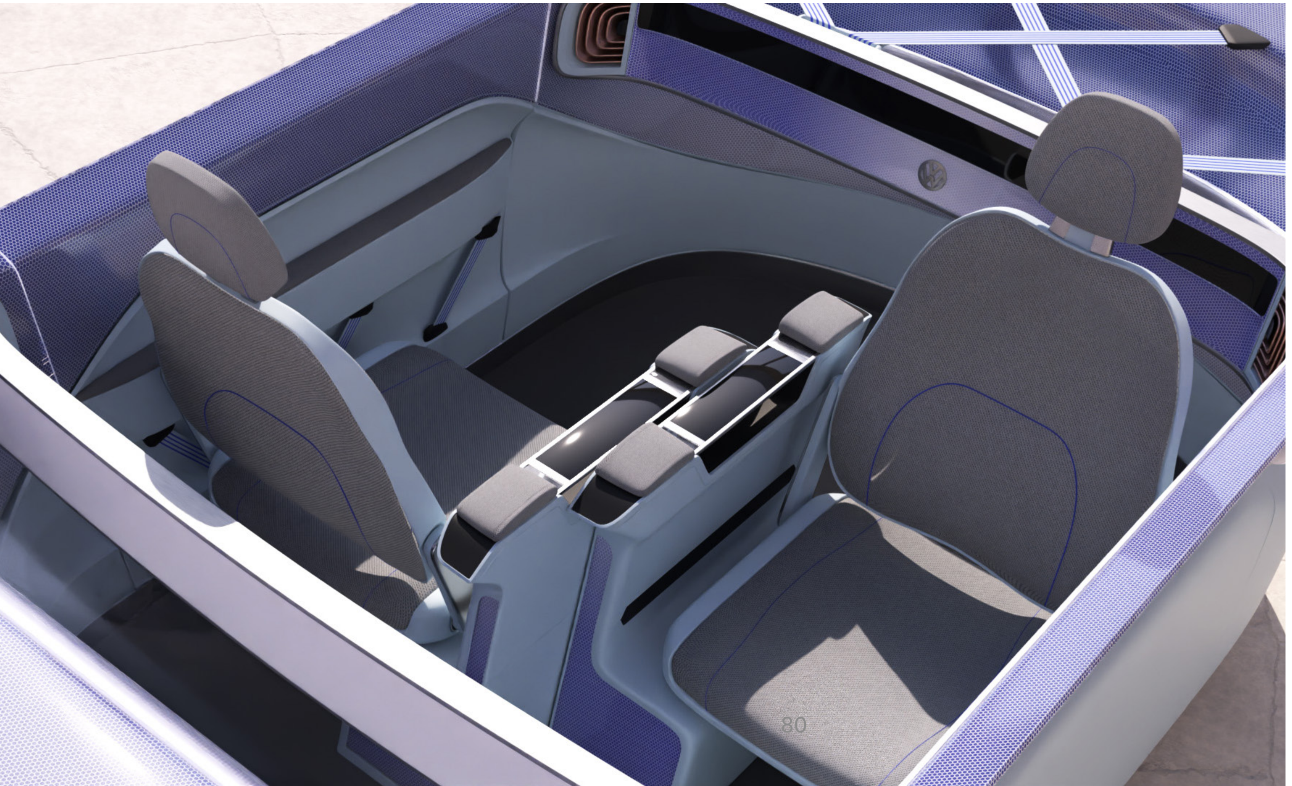
In a classic passenger compartment, the two front seats are divided by a central tunnel in which the gearbox, if present, storage compartments, and other minor functions are generally located. Since this is an autonomous car and not privately owned, it was considered advantageous to eliminate the single central tunnel and redesign it as two separate components, each of which is an integral part of the seat. This fundamental element forms the connection between the seat and the floor, as well as the component that directly slides along the track on the ground. The upper part of it, in addition to providing support for the passenger's arm, features a screen on which each user can view key travel information and interact with some basic controls.
The seat and tunnels therefore have two key features:
flexibility, defined as the ability to be configured as desired or positioned in order to accommodate one or two wheelchairs;
independence between the two seats, in respect of the shared nature of the service for which the vehicle is the main touchpoint.

Fig. 5.7 ↗
Seat, open position.

Fig. 5.8 →
Seat, folded position..







←← Fig. 5.9
"Cruise mode": both seat in default pisitions, facing the same direction.

← Fig. 5.10
Accessibility for 1 wheelchair: one of the seats is folded under the dashboard leaving space for a wheelchair user.

←← Fig. 5.11
"Conversation mode": one of the seats remains in its dfault position, while te other has shifted forward and faces in the opposite direction.

← Fig. 5.12
Accessibility for 2 wheelchair: both of the seats are folded away and leave space for two wheelchair users.

5.5 Accessibility

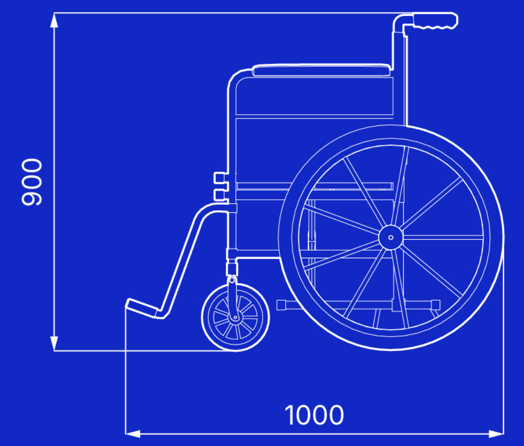
The accessibility requirement, addressed through the design of the seat and its movements, is also met through a few other important measures.
Although the design process discussed in this thesis is limited to the definition of the service and the interior of the passenger compartment, it is essential to consider that in a real-world context, a wheelchair user will need an access ramp. The lateral positioning of the ramp, at the side access doors in the standard configuration of cars, requires the wheelchair user to rotate 90 degrees when entering in order to move into cruise or conversation mode, which is obviously not ideal. However, the reasons behind this decision are linked to the fact that this solution is much more compatible with the characteristics of road infrastructure and urban sidewalks, unlike what often happens in the design of vehicles specialized in transporting passengers with disabilities, such as Canta, where access is through the rear door. To support this decision, the access doors will be sliding and as wide as possible, so that wheelchair access is as easy as could be.

Furthermore, considering that users with disabilities will remain in their wheelchairs during the journey, it is essential to have ground locking devices to ensure safe travel. This can be easily achieved through a docking system positioned on the floor, in which metal platforms lock the wheelchair in place using bolts or screws previously mounted on the underside of the wheelchair. This is a reliable safety system which, thanks to automation, allows the wheelchair to be locked and unlocked without the need for assistance from another person [59].

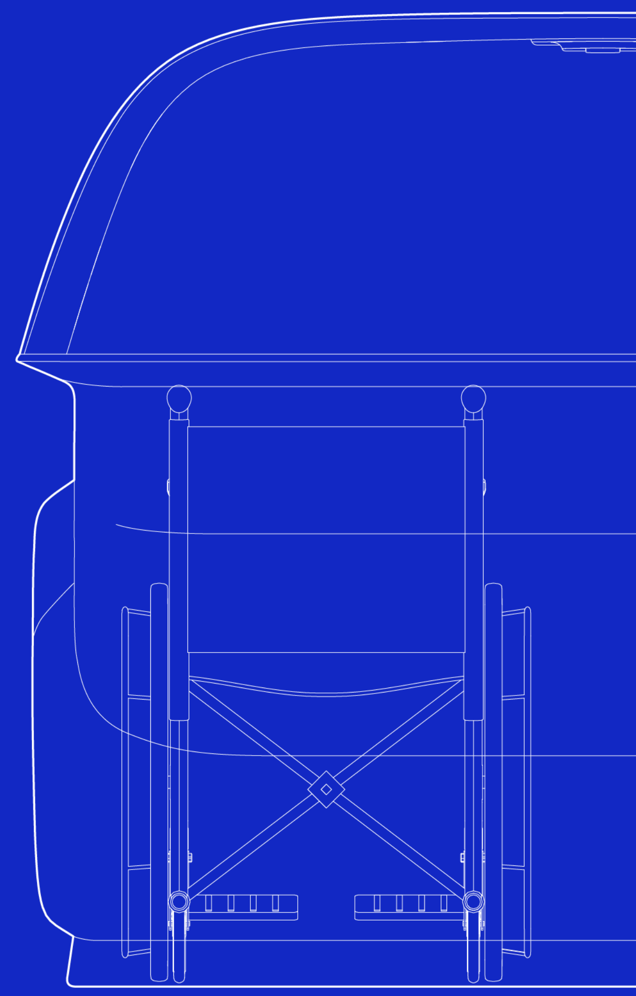
In order to comply with the vehicle's design, which provides for two modes of travel, there must be four docking systems, two on each side, one facing the direction of travel and the other facing in the opposite direction.

Fig. 5.13→
Dimensions and placement of a standard wheelchair inside the cabin

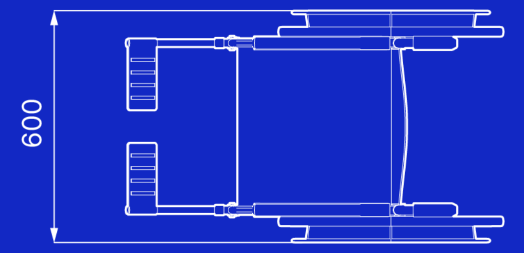
Side view of a standard wheelchair



Wheelchair placed inside the cabin



Top view of a standard wheelchair



Units in mm
Scale 1:20

5.6 Photochromic and electrochromic technology

As already introduced, the use of photochromic technology was a central point of the IDEEA 2025 project's brief that challenged the participants to find an application for them to the vehicle interior.

For better understanding, photochromic materials are compounds whose coloration is modified under the effect of an excitation following the conversion of ground state into a metastable excited level. The transition from energetic level A (ground state) to energetic level B (metastable), is accomplished by excitation at a certain wavelength la, corresponding to an absorption spectra of the material in energetic lv A. The opposite transition is obtained by irradiation at a wavelength lb, in the absorption spectra of the material in the B photostationary state (metastable or stable).
The activation of the photostationary state for most compounds requires UV light, at different wavelengths for the activation of different pigments. The lifetime of this excited state strongly depends on the outside circumstances and from the nature of the chosen material. And finally the return to the original colour can happen through light irradiation for organic Type-P compounds, and also through thermal excitation for organic Type-T materials.

Photochromic materials belong to the larger family of chromogenic materials, which are described as "chameleonic" due to their reversible color change as a response to changes in environmental conditions. The following are additional chromogenic materials, with the condition that triggers their color changing mechanism:

- photochromics: light
- thermochromics: temperature
- mechanochromics: mechanical stress
- chemochromics: specific chemical environments (gas, pH, water etc)
- electrochromics: voltage
- biochromics: pathogens

Materials with such properties hold great potential in the context of autonomous mobility, where passengers no longer focus on driving tasks and the interior space becomes the true center of attention. Each ride brings different users, each with their own needs, preferences. Photochromic surfaces are able to respond to this variability by adapting almost instantaneously to these specific needs, without having to undergo material treatments that change their appearance irreversibly. In addition, the ability to customize the interior environment fosters a stronger sense of ownership and control, supporting the very concept of shifting mobility away from private ownership and towards a use based model.

To effectively showcase the potential of photochromic materials, they have been applied to almost every non-functional surface of the vehicle's cabin. In this way, regardless of the passengers' seating orientation, a portion of the photochromic surface remains visible and contributes to the overall spatial experience. More importantly, their application has been considered not only for aesthetic customization, which on its own may quickly lose novelty and does not substantially enhance user comfort, but also from a functional perspective, by exploring how color variations can actively influence passenger perception and wellbeing. Based on this rationale, three different settings for the photochromic panels have been designed, as outlined below.

Fig. 5.14→
Anrealage's presentation of phtochromic clothing collection at the 2023 Paris Fashion Week.

Circadian cycle mode

The circadian cycle is the body's inherent, 24 hour rhythm that governs sleep/wake patterns and various physiological processes, responding primarily to environmental cues such as light and darkness. Aligning the interior environment of the vehicle with this cycle can subtly enhance passenger well-being, even during relatively short journeys. In this concept, the color gently shifts throughout the day to mimic the natural progression of sunlight. Starting with soft, warm hues at dawn, the colors gradually brighten and cool during the morning and midday, then warm up again toward the evening, finally settling into deep, calming shades at night. Although these changes may be perceived only subconsciously or even remain imperceptible to the user, they contribute to creating a more balanced and restorative environment that supports comfort and overall wellbeing.

Fig. 5.15→
Interior at 06:00 AM. Soft warmin hues reflect colors and light at dawn.

Fig. 5.16→→
Interior at 10:00 AM. The colors gradually brighten and gool approaching midday.

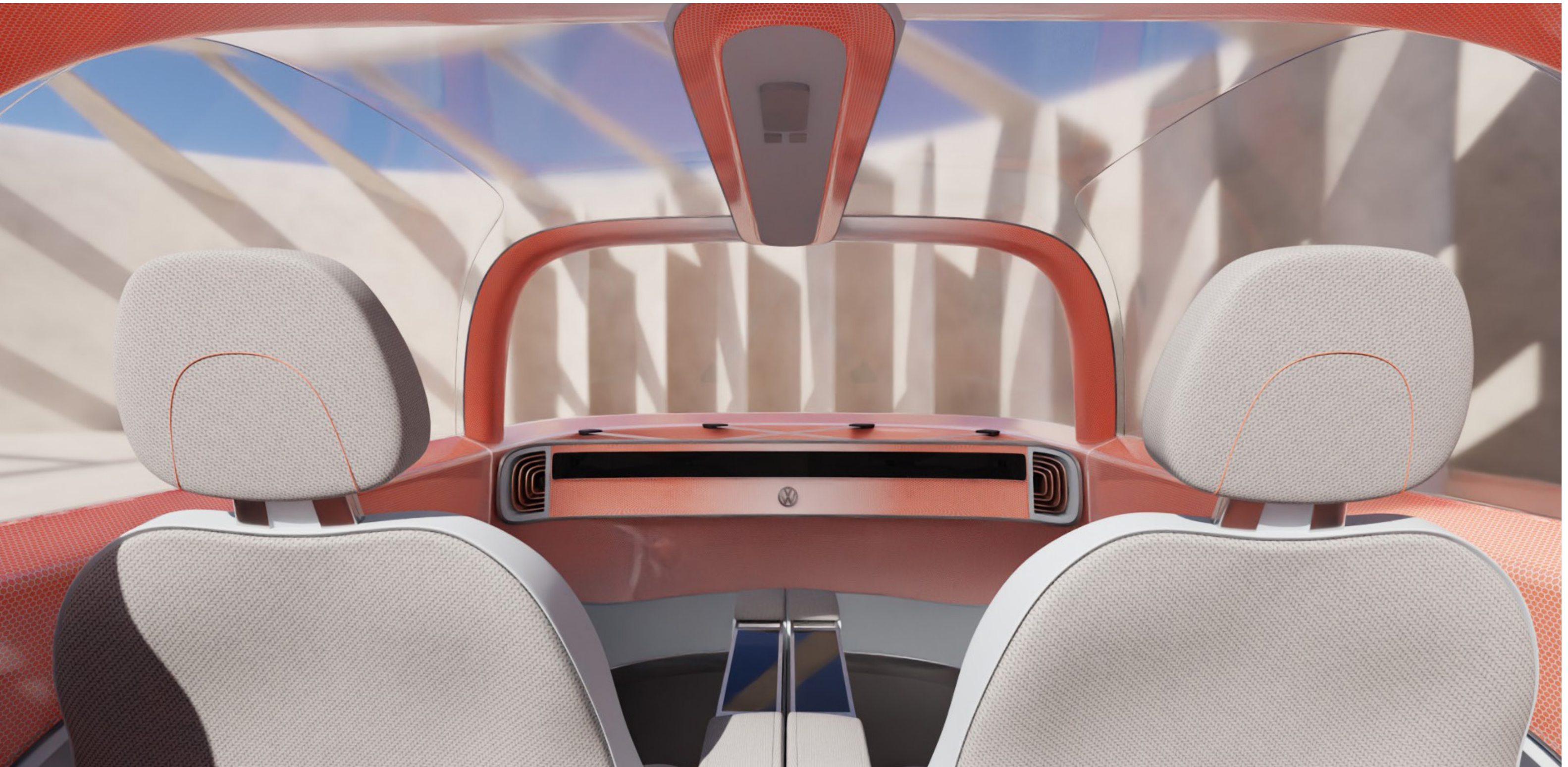
Fig. 5.17→
Interior at 03:00 PM. Colors warming up again in the afternoon.

Fig. 5.18→→
Interior at 09:00 PM. Mood setling into deep and calming shades after sunset.

Social mode

In a vehicle designed for only two passengers, creating a social and conversational environment can significantly enhance the user experience and make the ride more enjoyable. The way humans are influenced by warm red and orange hues, their social activity can be positively influenced, thereby increasing sociability and encouraging interaction. This feature can be beneficial both for two passengers who already know each other and for two strangers who may wish to engage in brief conversation, to enjoy the ride more than in silence.

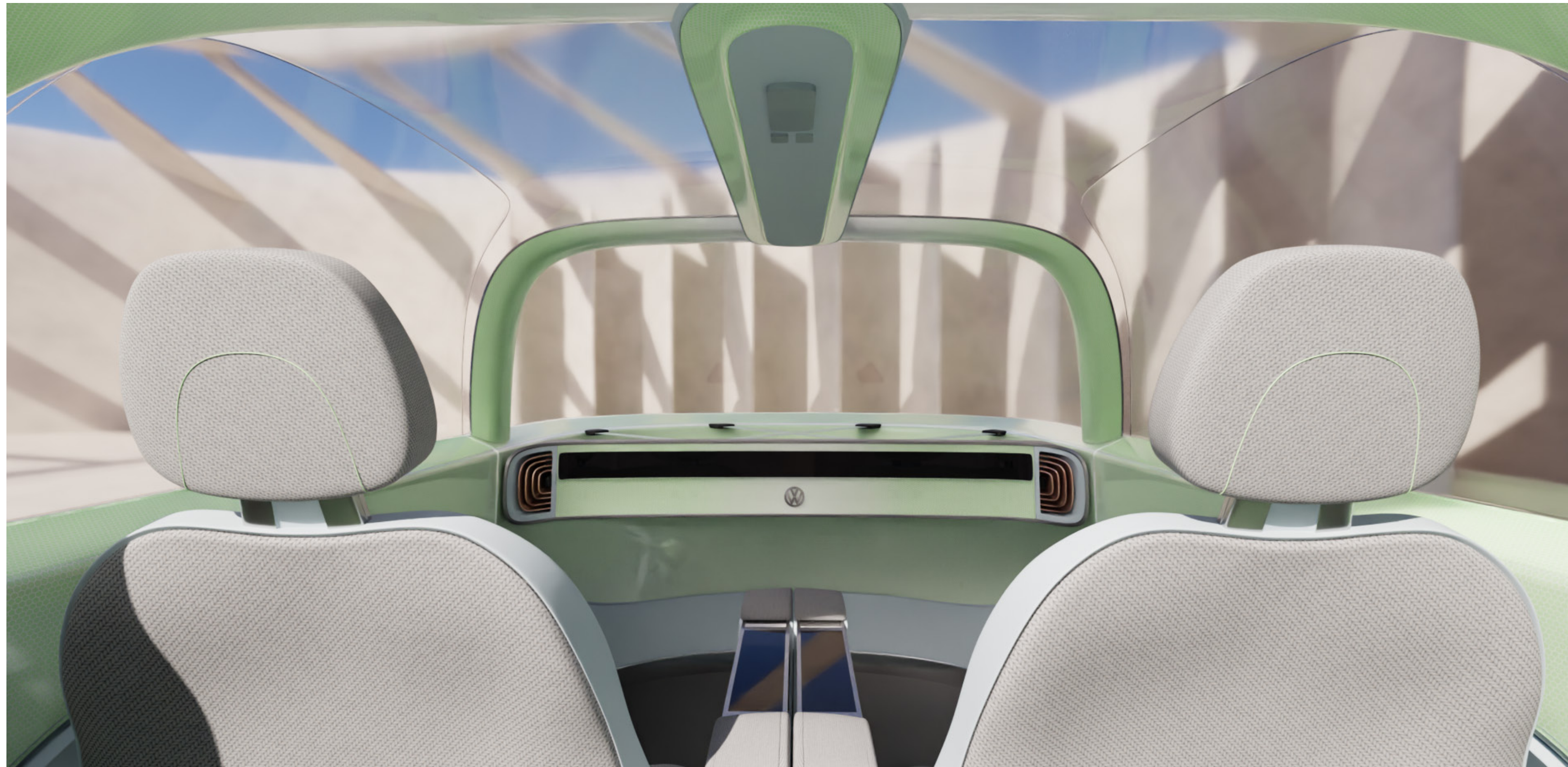
↓ **Fig. 5.19**
Interior colors set to Social mode displaying warm red hues.



Fast travel mode

As much as a commute can be made more comfortable, it ultimately remains a necessary consequence of moving from one place to another, rather than an activity that passengers actively wish for or enjoy. While every mode of transport aspires to minimize travel time, approaches like, increasing speed, may not always be the most effective ones. An alternative strategy is to influence passengers' perception of time itself. For example, the use of green hues, evoking calmness and relaxation, can create a more soothing atmosphere that makes the journey feel shorter, not by reducing its actual duration, but by shaping the way it is experienced.

↓ **Fig. 5.20**
Interior colors set to Fast travel mode displaying green hues.



Even though photochromic materials hold great potential, they cannot operate without a dedicated technological system to unlock their full capabilities. For this reason, the photochromic panel has been conceived as a multilayered, sandwich structure designed to integrate the functional elements in an optimal manner. The panel is composed of the following layers:

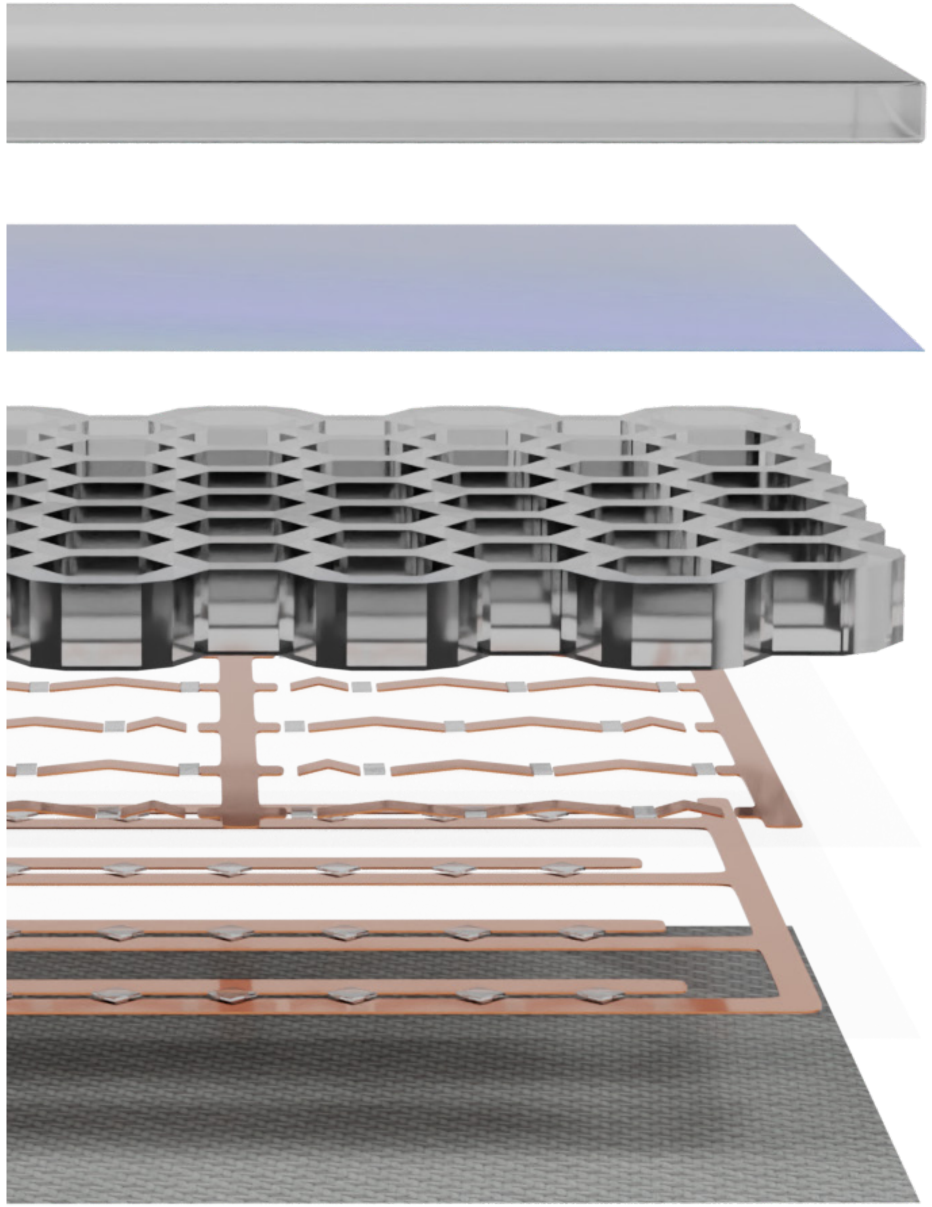
- Transparent PMMA support panel
- Photochromic film
- Silicone honeycomb diffuser
- Printed circuit board with RGB LEDs
- Printed circuit board with UV LEDs
- UV-blocking protective layer

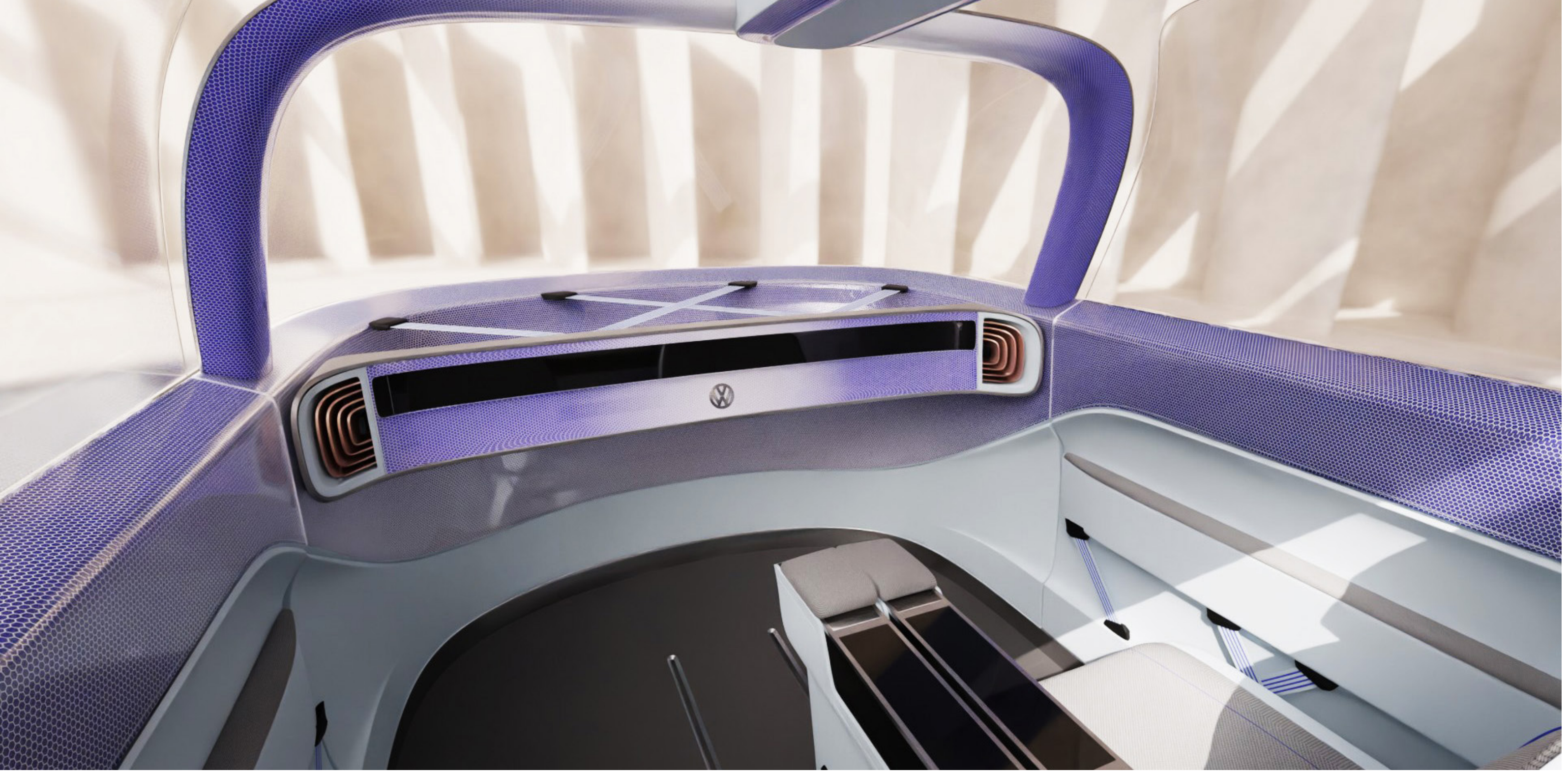
Among these, three elements can be considered essential to the panel's functionality: the photochromic film, the transparent supporting substrate, and the light source. The photochromic film is laminated onto the PMMA panel, which provides mechanical stability and extends its operational lifespan, while at the same time ensuring optical transparency that allows the photochromic reactions to be visible from the outside. The film itself consists of three primary components: an organic photochromic dye, a solvent medium, and a flexible transparent substrate. In order to cover the full color spectrum, the system adopts a CMY pigment composition. The development of this layer references the PhotoChromeleon project conducted at MIT CSAIL (HCI Engineering Group), which introduced an optimized CMY dye combination specifically designed to minimize spectral overlap between channels. Following this reference, the selected dyes are bi-stable P-type derivatives provided by Yamada Chemical Co.: DAE-0001 for cyan, DAE-0012 for magenta, and DAE-0068 for yellow.

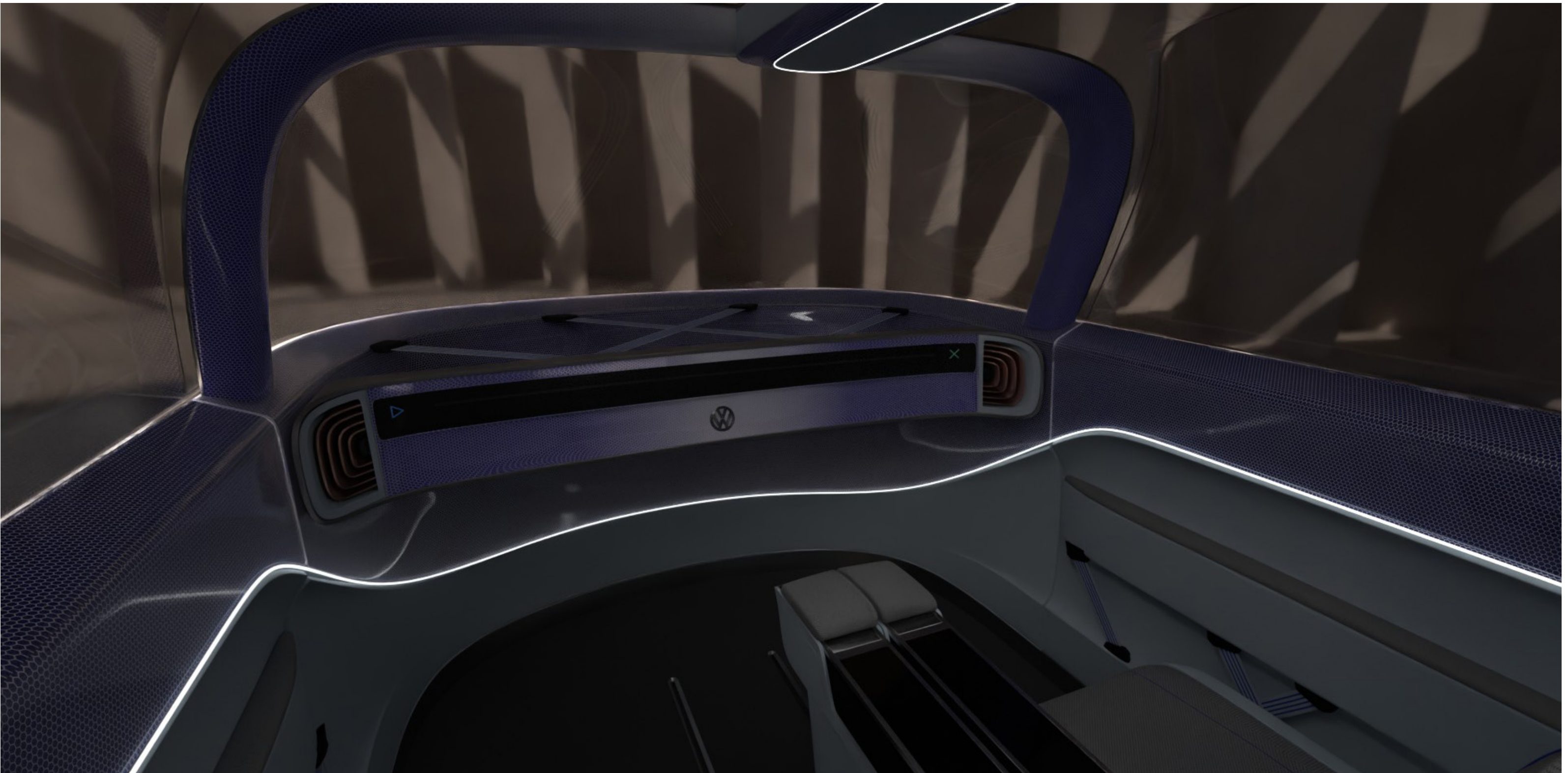
To actively control the film's color response, the light source combines both UV and RGB LEDs. The absorption spectra of the selected dyes were analyzed in order to enable wavelength-specific activation. In this configuration, the UV LEDs are responsible for saturating the CMY pigments by irradiating them with the required activation wavelengths, thus driving the film into its fully colored state. Subsequently, the RGB LEDs are employed to exploit the reversible nature of P-type photochromic dyes. By emitting light at specific wavelengths, they selectively deactivate individual pigments, allowing for fine control of color composition. Through this approach, the system is capable of reproducing virtually the entire visible spectrum by modulating the relative contributions of cyan, magenta, and yellow.

To improve optical uniformity, a silicone honeycomb diffuser is placed between the LEDs and the film. While not strictly indispensable to the panel's operation, this layer distributes the incoming light evenly, preventing localized color spots, created by individual LEDs shining directly onto the film. Finally, the inclusion of a UV-blocking layer is considered beneficial to absorb any excess ultraviolet radiation, protecting the system's internal components and ensuring more consistent long-term performance. Considering passenger safety, any unnecessary exposure to UV radiation must naturally be avoided. For this reason, the programming of the panels takes place before the passengers enter the vehicle. Alongside other interior customizations, this process is carried out during the short commute between the ride being ordered and the vehicle's arrival at the user's location [60], [61].

Fig. 5.21→
Exploded view of the design photochromic panel and its components.







↖ **Fig. 5.22**
Electrochromic glasses in a transparent state due to no applied voltage.

← **Fig. 5.23**
Electrochromic glasses in a fully opaque state following a voltage application.

Under visible light, the photochromic coloration achieved through this technology remains consistent only for limited periods of time. Over the course of minutes and hours, the induced color naturally begins to fade, progressively returning to the material's ground state. With appropriate calibration, this behavior does not pose a critical issue, since the duration of most urban commutes remains compatible with the material's temporal response. Nonetheless, external light entering the vehicle poses a challenge to the color programming process of the panels while the vehicle is en route to pick up passengers. In such situations, the process may be slowed down or even partially hindered, preventing the precise activation and deactivation of the pigments.

To address this limitation, another class of chromogenic materials proves valuable: electrochromics. Unlike photochromic systems, which rely on reversible chemical reactions triggered by light exposure, electrochromic materials operate through the application of an electrical voltage that induces a controlled change in their optical properties, most notably their level of transparency or opacity. This mechanism allows electrochromics to switch between clear and darkened states in a highly reliable and reversible manner, while also offering precise control over the degree of light transmission.
When integrated into the vehicle's transparent surfaces, such as the windshield, side windows, and panoramic roof, electrochromic layers provide a dual function. During the photochromic programming phase, they can significantly reduce incoming light, effectively shielding the interior and ensuring that the panels are programmed without external interference. Once the process is complete, however, electrochromics transition into a complementary feature that enhances the overall user experience. Passengers are able to customize the tint level of their windows according to their individual preferences, adjusting brightness, glare, and privacy in real time throughout the journey.
In this way, electrochromics not only compensate for one of the inherent limitations of photochromic systems, but also contribute to a more adaptive and user-centered mobility experience [62].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6. Bibliography

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The technological advancements of the past century and a half have profoundly influenced nearly every aspect of human life, from the ways we consume and communicate to the ways we move through space. This thesis focuses specifically on the latter, examining the diverse and complex modes of travel that individuals adopt today. Through this lens, it seeks to investigate the evolving nature of mobility and the design opportunities that arise from these shifting behaviors and expectations. The innovations that drove the development of the project were, on one hand, the autonomous driving, which represents one of the most promising yet radical frontiers of future mobility, and on the other, the users' growing need for customization that is increasingly characterizing every aspect of today's consumption. Equally fundamental to the process was the awareness of the social and environmental impacts that transportation design has on our cities, acknowledging the flaws of today's paradigm of privately owned mobility and the directions that municipalities are taking nowadays in this regard. The answer to these studies and reflections lies in the design of an urban mobility service and the interior concept of an autonomous vehicle, which leverages the characteristics of a particular type of material - the photochromic compounds - emphasizing the flexibility and customization options offered by the service. The thesis was developed as part of an international student challenge called IDEEA Project 2025, offering a speculative but concrete vision for the future of shared, adaptive, and sustainable mobility.

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