# Plastic intensive, purpose-built car

*Autonomous urban transport in 2029*

*Master graduation thesis*

**Tim Schutte | 12/07/2019**

TU Delft | سابك sabic

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12 July 2019

# Colophon

Master thesis
*Plastic intensive, purpose-built car:*
*Autonomous urban transport in 2029*

Tim Schutte

TU Delft, Faculty of Industrial Design Engineering
*Integrated Product design*

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# Acknowledgement

As the chair of the supervisory team, Peter assisted me with finding the relevant information needed to execute this project. His expertise and involvement in projects concerning ergonomics and autonomous transportation helped me to define my project.

Wouter supported me and helped me in choosing the right steps and methods throughout the project as the mentor for my project. His advice is very valuable to me, as he has experience in design and processes within the automotive industry and the methodological approach of the university.

Within SABIC, Geert Jan has been supporting me with my project. His expertise as an automotive designer and shared passion for cars makes for interesting conversations and valuable feedback. His knowledge on cars, designs and how they are conceived is very inspiring.

During the project, but also during the several months of intership prior to the graduation project, I consulted with several colleagues, which was very helpful. The feedback on the content of the project, the choices that I made and also the way I presented it, helped me progressing.

My family and friends were always there for me. They supported me throughout my studies and I could always count on them.

# PREFACE

This is my final project for the master Integrated Product Design at the TU Delft. After this I will start working as a design engineer implementing everything I learned and keep on learning and specializing throughout the years to come.

As I always have been very interested in developments in the automotive industry and have specialized over the years in this field by taking automotive electives and projects, I was really excited to do a graduation project focused on this. Especially at this interesting point in time, with the upcoming autonomy enabling technologies.

Combining this potentially disruptive change in the automotive industry and SABIC's material portfolio, made it to be a challenging and interesting project, as I had to rethink they way I used to design cars.

Working in the office for the duration of this project made me recognize the value of the Integrated Design Engeneering master, combined with the more hands-on Industrial Desgin Engineering bachelor at the The Hague University of Applied Sciences that I did prior to the master: the great diversity of subjects that I gained knowledge of, allows me to bring ideas to the table that combine an array of subjects and discipline into one integrated idea.

It also showed that there are great differences with university projects and actual projects for clients: with projects at the faculty, you are required to combine different aspects, whereas in the industry you are often focusing and specializing on a particular apsect, especially in larger companies, where everyone has their own expertise. The differences in result also become apparent to me. In the industry, the outcome and final result is the a very important aspect of a project and that makes projects rather result-focused, whereas at the university the process to get to a certain result and the documentation of this process is also very important.
Generally, I would describe myself as pragmatic and being fond of good and well-balanced design. That is why I combined these aspects in this project and tried to create a desirable, integrated design, with proper substantiation. Going from a lot of hands-on and pragmatic projects, this more visionary and conceptual project was a nice challenge.

# CLAVIS

| | |
|---|---|
| ACES | Autonomous, connected, electric, shared |
| Active safety | Systems that avoid accidents |
| ADS(-DV) | Automated driving system (dedicated vehicle) |
| AV | Autonomous Vehicle |
| DfD | Design for disassembly |
| DLO | Day light opening (side windows of a car) |
| EoL | End of life |
| (B)EV | (Battery) electric vehicle |
| Greenhouse | All windows of a car |
| ICE | Internal combustion engine |
| ITS | Intelligent Transport Systems |
| Means of transport | the carriers used for the different modes of transport |
| Modes of transport | transport through air, water, land, space, pipeline, cable |
| OEM | Original equipment manufacturer (herein referring to car manufacturers) |
| Passive safety | Systems that reduce the effects of an accident |
| PC | Polycarbonate |
| PP | Polypropylene |
| TNC | Transportation network company |
| V2X | Vehicle to everything (V2V (vehicle) V2I (infrastructure) V2N (network) V2P (pedestrian)) |

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# EXECUTIVE SUMMARY

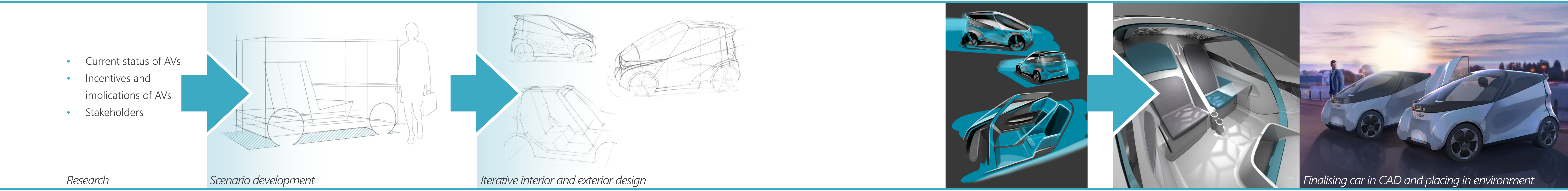

It is expected that the automotive industry will be facing a radical shift, going from human driven cars to cars that are driving autonomously. In this project I started out with performing an in depth literature research to get a good understanding on what is expected to change. My expectations that the design and solutions for a self-driving car can be motivated by other factors than human controlled cars is confirmed by this research. These incentives of autonomous transportation and the implications are used as input for the development of a vision for a shared autonomous car for the city in ten years.

Scenarios that show different possible types of vehicle with different function were created and a twoseater urban commuter vehicle was chosen to develop further. The different functions of the interior, such as doing work or relaxing instead of driving, but also the wish to sit facing forward and looking outside and the need for a sense of dependability and trust because you are not in charge of the car's movement are integrated in the final design. Considering the small footprint combined with a desired seating layout and ergonomic seating position, affects the exterior and makes for challenging design boundaries in terms of volume.

This project is a collaboration with raw material supplier SABIC and therefore another consideration is how this changing system affects the plastic material business and how SABIC can influence this change in the future automotive development. The car is being used for the daily commute, but during off-peak hours it can be hailed by other users with similar needs (urban travel with one or two persons and some room for storage). The shared character of the car makes that it is going to be used more intensively than a privately owned car and therefore the material requirements are different.

I decided upon a car that uses polycarbonate for the greenhouse and different grades of polypropylene compounds for panels and glass fiber reinforced polypropylene for structural parts. Additionally, the car operates in a system where the fleetowner that deploys the cars and brings the car in for service, can repair worn out or damaged parts by replacing them with new components. With plastics this is more convenient than with metal panels and the replaced parts are recycled and brought back into the system as building blocks for newly manufactured parts.
The opportunities and challenges of designing with thermoplastics are identified and accounted for in both the design of the interior and the exterior.
Places where different parts meet in the exterior design are showing deliberate transitions, masking the thermal expansion of the plastic components and hiding misalignments when parts are replaced over time. Also the potential of the integration of visual sensors needed for autonomous handling in polycarbonate greenhouse parts is highlighted.
In the interior the working and relaxing functions are implemented by showing a clear division between the working side and relaxing side of the car.


*figure 1: depiction of the project process steps*



# 1

# Introduction

*Being walking, rolling, floating, flying, driving or anything else, we get ourselves and (our) products from A to B from time immemorial. Ever since the introduction of the first car, drivers are expected to operate the vehicle, but that might be bound to change now with the introduction of the autonomous vehicle (AV), where the driver becomes a passenger.*
*How will this change the way people use road transportation and what could such a vehicle look like?*

# Introduction

## Automotive transportation

Over the years, several inventions radically influenced the automotive industry. For example the development of the internal combustion engine, the adoption of the steering wheel as opposed to the tiller as means to change direction, the introduction of the fully closed and pontoon type body, the two-box and three-box vehicle lay-out, and some safety features such as the (three-point) seatbelt and airbags.

Yet the main function of any mode of transport is to get people and goods to a destination (either as efficient as possible for the sole purpose of getting to another place or the goal not only being the destination, but also, or exclusively, the journey) with whatever means of transport. With cars becoming used more widespread, the dependency on these cars became greater as well. When people are able to afford to own a car, it is most often seen as a convenience.

The most recent developments that are affecting cars and will increasingly exert influence, are related to the powertrain, digitalization and connectedness, which are all deployed to some degree already, but have the potential to come all together in the autonomous vehicle:

- The development of the alternative electric powertrain technology opposed to the internal combustion engine (ICE), mostly driven by environmental reasons for some decades now (Shaheen, Wright & Sperling, 2002, Chan & Chau, 2001), allows for a different (more compact) flat-floor platform design. Besides affecting the infrastructure (for example with charging points) it also opens up possibilities for a different vehicle layout, which could be an asset for autonomous vehicles, in which the users are not obliged to drive and can involve in different tasks.

- With the digitalization of societies allowed by technical development, people and things become more connected. Cars can become more connected with other cars (vehicle to vehicle, V2V) and with the infrastructure (vehicle to infrastructure V2I) and users can be connected digitally with the vehicle as well. This trend of digitalization is in line with the expected development towards a more usership oriented society (Pakusch, Bossauer, Shakoor & Stevens, 2016).

*figure 2: SABIC plant in Limburg (courtesy of SABIC)*

## Autonomous transportation

Looking at the seriousness and the amount of companies working on deploying AVs in the coming years (CBinsights, 2018), it seems that a paradigm shift in the automotive industry -transitioning from driver controlled to system controlled- is imminent and will have implications for the car as we know it. With the electric motor there is no more need for a two or three-box lay-out, as the body's silhouette is no longer subjected to a large engine compartment. Additionally, the interior of an autonomous vehicle (AV) may have a different lay-out as there might be no need for a driver's position: all users can be passengers.

Additionally, other features and regulations (for example anything driver-related) might be rendered obsolete but undoubtedly will be replaced by others, for example by detecting devices on the exterior that enables the car to navigate (cameras, LiDARs, and radars).

## SABIC interest

This thesis is supported by SABIC, the fourth largest global chemical company, active in the (petro)chemical industry and among other things manufacturing polymers. SABIC is a supplier of raw materials, to any company among which automotive OEMs and tiers. SABIC is working on innovative applications for the automotive industry by showing the advantages of their material over conventional materials used for interior, exterior and structural applications. Combining mechanical performance, lightness and design freedom, thermoplastic polymers show their value in automotive use.

The incentive of this project is for SABIC to get more details and ideas on the possible future of mobility in order to recognize the changing market and to keep up with the development as a supplier of raw materials for innovative applications when demands are changing.

# Project focus

The aim of this project is to come up with an integrated conceptual design of an autonomous vehicle for the year 2029 that answers to certain needs of the users/passengers -based on a extensive (literature) research- and explore possible new areas of interest for SABIC. The exterior design will be driven by the function and design of the interior, but also by the requirements on the placement and integration of visual detection devices. Therefore attention is also payed to how these devices could be implemented in the exterior design.

Considering SABICs interests and the intended final result the project can approach is twofold:

- The material driven aspect:
  The material portfolio of SABIC is used as input for the design development. Polycarbonate and polypropylene is used to focus design decision around. Their respective properties, opportunities and challenges are used for the design and also the repairability of worn out or damaged parts by replacing them is considered.

- The vehicle driven aspect:
  The envisioned autonomous vehicle for a future scenario is driven by the transportation needs of the users. Different aspect in terms of interior functions, layout and ergonomics affects the design of both the interior and exterior.

The shift towards more vehicle autonomy is already initiated, but the reasons, driving forces and (system-wide) implications are not that unambiguous. That is why first an analysis is conducted, where the incentives and implications of the AV are compared deliberately by consulting multiple researches and sources. From this research practical starting points are derived for creating the future vision and scenario.

***To recognize the full potential of the paradigm shift, an approach is implemented, where all the incentives and implications are reviewed, providing useful and different starting points for the NPD.***

Also the current visions of the OEMs are studied, in order to get a good view on where new opportunities arise and how this trend will develop.

These insights of the research provided the outline for the future scenarios proposal and justified the raison d'être of the drafted autonomous vehicle scenarios. The scenarios reflect the potential for SABIC as a raw material supplier. The chosen scenario is translated into an integrated design for a purpose-built automated driving system dedicated vehicle (ADS-DV) for transportation of people within cities for the year 2029.

***This project is aiming on creating a profound understanding of the future of autonomous vehicles and transportation of people, with as an end result a visionary proposal of a purpose-built AV, highlighting the future potential for SABIC as a raw material supplier.***

*Figure: Intel, 2016*

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# Analysis

*The potential of AVs is expected to affect transportation as we know it on different aspects and levels: the incentives are rooted in the expected benefit of safety, traffic flow, comfort, convenience, pollution, and mobility for all society members. It is also important to look at the implications of this paradigm shift in terms of these aspects and on health, ethics, policy, and car-ownership (Haboucha, Ishaq & Shiftan, 2017, Chan, 2017, Gruel & Stanford, 2016, Fagnant & Kockelman, 2015). As this is a completely new development like nothing before, there might be new potential solution spaces, which can only be discerned by analysing the this change in a holistic manner.*

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# Context

## SABIC

SABIC states the following general description on their website:

> *"SABIC is a global leader in diversified chemicals headquartered in Riyadh, Saudi Arabia. It manufactures on a global scale in the Americas, Europe, Middle East and Asia Pacific, making distinctly different kinds of products: chemicals, commodity and high performance plastics, agri-nutrients and metals. The company has more than 35,000 employees worldwide and operates in more than 50 countries, with innovation hubs in five key geographies – USA, Europe, Middle East, South East Asia and North East Asia."*

This sums up quite well what SABIC is doing in general. The main objective of SABIC's plastics business unit is the production of commodity and high performance thermoplastics. Looking at SABIC's automotive business, the company has continuously developed and improved resins, compounds and processes considering the following application areas:

- Interior applications (low weight, heat and scratch resistance, weathering performance (UV stability) and in-mold coloring)
- Chassis applications (structural rigidity, impact performance, weight reduction, part integration and passenger and pedestrian safety)
- Glazing applications (weight reduction, abrasion resistance, weathering performance (UV stability), optical quality (light transmission and image deformation) and functional integration and design freedom)
- Exterior applications (high impact resistance, stiffness, and flow, high gloss aesthetics (non-painted), weight reduction, design freedom and part integration)
- Lighting applications (heat resistance, optical performance, enhanced material flow and design freedom)

*Figure 3: LEXAN™ polycarbonate glazing (Hyundai Qarmaq) (Courtesy of SABIC)*

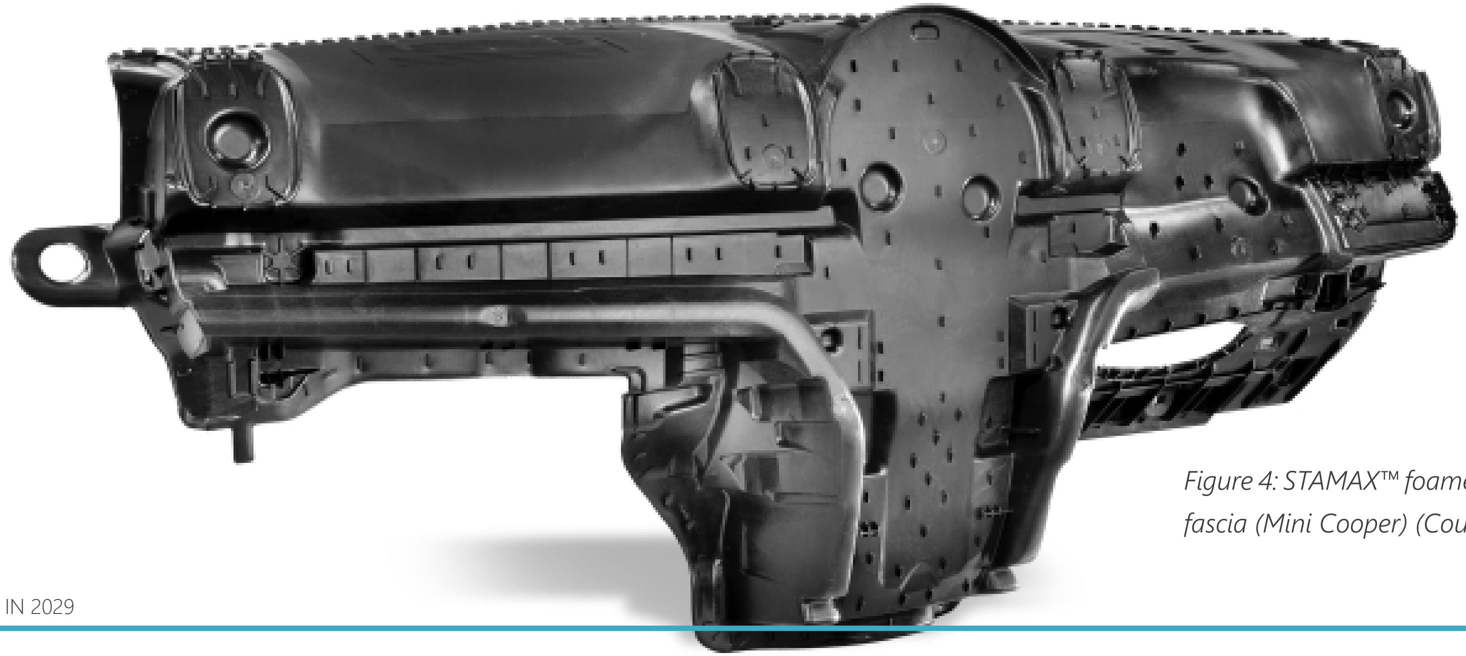


*Figure 4: STAMAX™ foamed LGFPP dashboard fascia (Mini Cooper) (Courtesy of SABIC)*

Besides thermoplastic polymers such as PP, ABS, PMMA, PBT and some blends (for example PC/ABS and PC/PBT) SABICs automotive material and application portfolio includes LEXAN™, which is a polycarbonate that can be used for different applications, such as glazing (figure 3) and lighting lenses. STAMAX long glass fibre polypropylene (LGFPP) is used for e.g. structural interior parts such as instrument panel carriers (figure 4) and can be processed as a solid material or as a lower weight alternative with a core that is foamed.

# Levels of Autonomy

*The identification of vehicle autonomy is more complex than just autonomous and non-autonomous. In order to understand what is meant when talking about autonomous vehicles, the most used system is that the Society of Automotive Engineers (SAE) (SAE International, 2018). This document indicates how much of a vehicle's tasks are system controlled.*

Understanding these levels and how they are used, clarifies how system autonomy is intended and how it should be referred to. The following levels are discerned:

| | |
|---|---|
| Level 0: | No driving automation |
| Level 1: | Driver assistance |
| Level 2: | Partial driving automation |
| Level 3: | Conditional driving automation |
| Level 4: | High driving automation |
| Level 5: | Full driving automation |

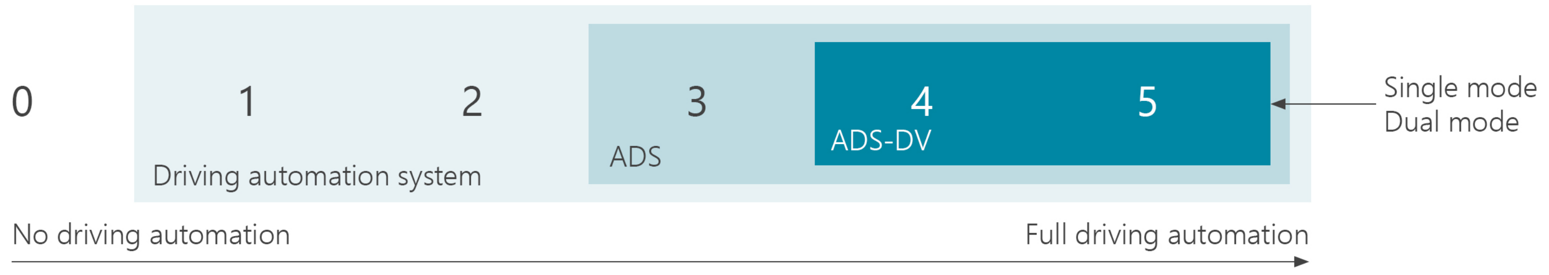



*Figure 5: driving automation levels*

The level of the features of driving automations systems in vehicles are grouped as shown in figure 5, where five levels are considered a driver automation system (level 1 to 5) and level 3 to 5 are labelled as automated driver systems (ADS). Features or systems at ADS levels are capable to take over all of the dynamic driving tasks whether or not at a specific operational condition.

Where these levels indicate the functional autonomy of systems or features rather than the autonomy of the actual vehicles, at level 4 and 5 the ADS-dedicated vehicle (DV) is considered to be effectively similar to the functional autonomy of the vehicle. A vehicle that is labelled as ADS-DV might still be equipped with features that enable the user to act as the driver (dual-mode vehicle), but due to the fact that there is no need for a fallback-ready user for any driver task (compared to a level 3 ADS), it is considered to be a truly driverless vehicle. Within this thesis the indicators 'driverless vehicle' and 'autonomous vehicle' will refer to this fully ADS-DV (level 4 and 5). The only difference between level 4 and 5 driving automation levels is the fact a level 4 ADS-DV is limited to a specific (set of) so-called operational design domains (ODD), whereas a level 5 ADS-DV is not. These operating conditions could be related to for example geography, environment, time, speed, road and/or traffic.

Already widely available active safety and driver assistance systems (level 1, 2 and 3) ("Cars With Advanced Safety Systems", 2019, Chan, 2017):

- Automatic emergency braking
- Forward-collision warning
- Blind-spot warning
- Rear cross-traffic warning
- Rear automatic emergency braking
- Lane-departure warning
- Lane-keeping assist
- Lane-centering assist
- Adaptive cruise control
- Parking assist

Two potential types of general development of ADSs towards full driving automation are recognized: an evolutionary and a revolutionary path, which are respectively referring to a current status of 'something everywhere' (some of the level 1 and 2 ADSs) and 'everything somewhere' (where the car is fully equipped with level 4 features) (Chan, 2017). This is graphic representation indicating the amount of autonomous features (ADS) and the operational domains they are deployed in and how they are expected to develop towards full automation.

A relatively affordable way (for OEMs) to make an autonomous vehicle would be to equip an already available car with the necessary ADSs. Then there are no developing costs involved in making the basis vehicle. This, however, does not take full advantage of the potential of a driverless vehicle, especially a single mode level 4 or 5 ADS-DV: with dual mode AV, features of the car related to handling and a safe operation are still needed (not so much during autonomous mode, as during manual mode), including traditional seating layout (at least a forward facing driver's seat), windows and wipers, headlights to see and all steering and handling equipment (such as the steering wheel and pedals).
With a single mode AV some of these features become obsolete, as there is no (human) driver anymore: there is no more need for a traditional seating layout, windows are not necessary anymore, headlights are only there to communicate your presence to other road users (to be seen) but don't need to have the function for the passengers to see their environment. Additionally, all the steering and handling related equipment is rendered obsolete. Combined with the flat-floor layout of electric vehicles, this opens up lots of opportunities and is much less restricting than dual mode AVs.

## AV DEVELOPENT PREDICITION

Being a quite recent and also potential game-changing development, the (rate of) implementation of autonomous vehicles in the future is not that clear and predictions are difficult to make as they are dependent on a multitude of factors. Gao et al. (2016) shows different scenarios with high diruption and low disruption. Several OEMs are already announcing to introduce  partial AVs in 2021/2022 and this could be the start of the implementation of the system. Some fully AVs (level 4) are already in use on restrectid areas and the ramp up is expected to be gradual and driven by the technology advancements. Regulatory challenges, reliability and consumer acceptance are factors that might influence the implementation rate. Technical or regulatory unforeseen barriers might be a cause for a low disruption scenario, as depicted in figure 6. But in a positive and high disruption situation, up to 15 per cent of the sold vehicles could be level 4 and up autonomous.

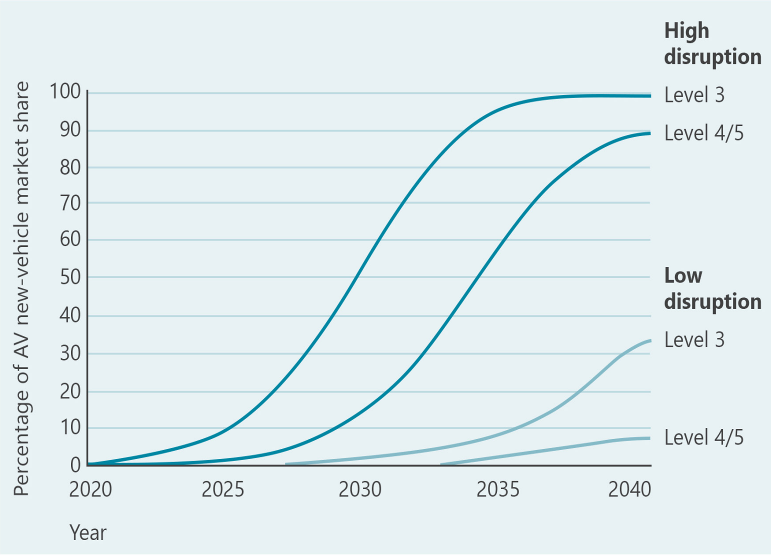



*Figure 6: prediction of AV implementation (Gao et al., 2016)*

Waymo (started out as the Google car project) is currently by far the best performing autonomous test vehicle, with the least amount of human interventions per distance (an avarage of 18.000 kilometers driven per human intervention, (Waters & Burn-Murdoch, 2019). Lots of other companies (OEMs, technology companies, and joint ventures between them) are extensively testing AV technology as well, showing that there is an eagerness to implement this.

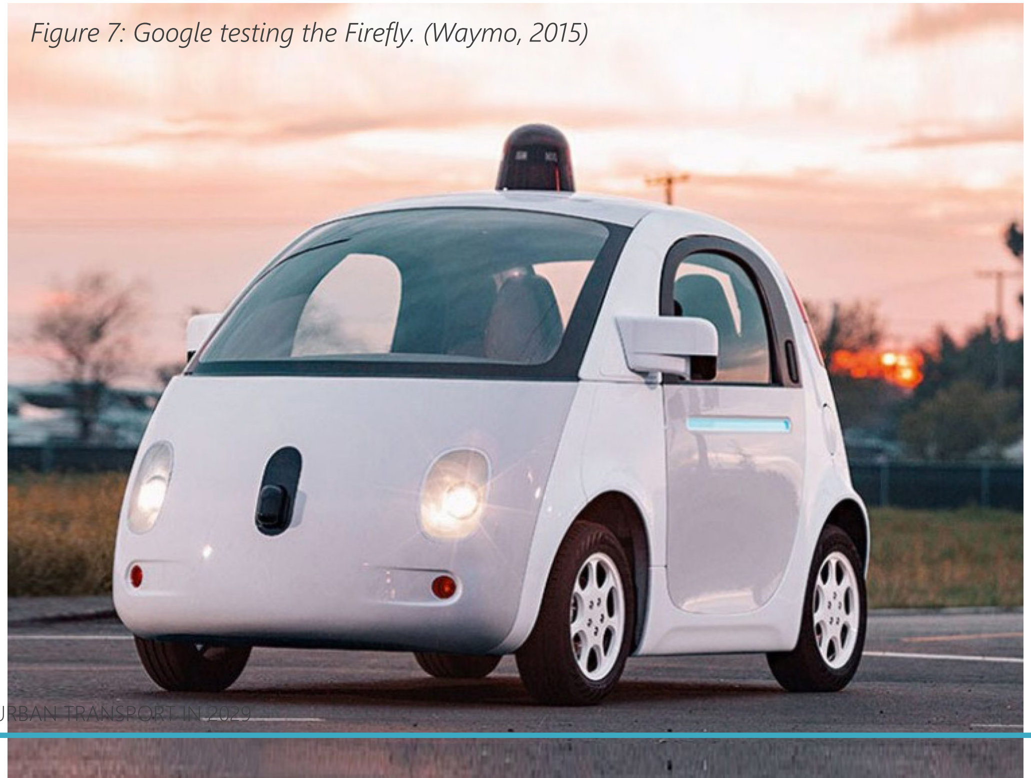


*Figure 7: Google testing the Firefly. (Waymo, 2015)*

## EV DEVELOPMENT

The recent reinvention of the electric vehicle (EV), combined with a growing concern for the effect of pollution on the environment and global warming, results in a rapid increase and almost exponential-like growth of the share of the EV as part of the total global car sells. At the end of 2018, the global share of newly sold EVs was still only 2,2%, with more than half of the cars being sold in China alone, but due to progressive politics some countries have a share that goes up to 40 per cent (Norway) (Irle, Pontes, & Irle, 2019). Looking at this trend and the realisation that almost all of the OEMs have plans to (further develop) their EV supply, makes it reasonable to assume that this technique can be the basis for future drive trains of vehicles.

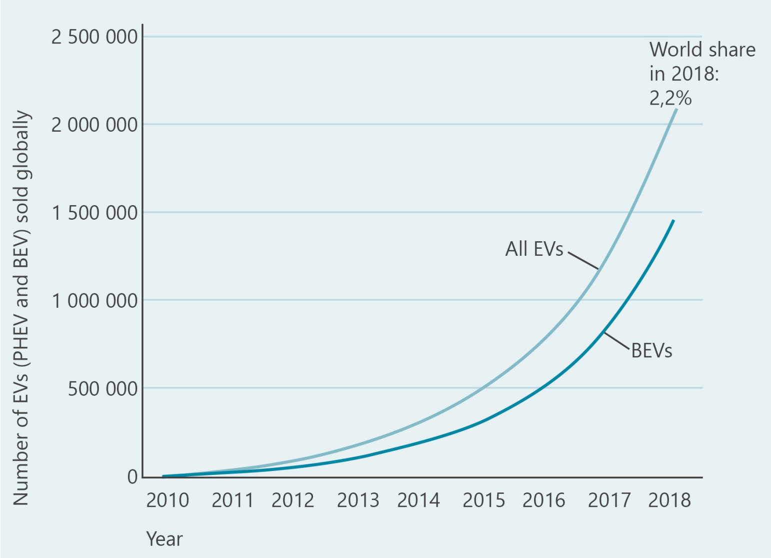



*Figure 8: global EV sells over the years (Irle, Pontes & Irle, 2019)*

# Incentives and implications

*An extensive (literature) research has been conducted with the main reason to enable myself to distantiate from the traditional development process of vehicle design and have different starting points and input for the development of a relevant AV. This will help creating a design that take account of lots of aspects. The conclusions of the different aspects are discussed in this chapter and the full reasearch can be found in Appendix C. These conclusions are used as desiscion factors to determine what tpye of AV has potential and provides intersting challenges for SABIC to think about.*

## Safety

Annually there are a lot of casualties because of car accidents and most are traced back to human error (European Commission, 2018; NHTSA, 2018; WHO, 2108). During the transition period if AVs are sharing the same roads with non-AVs, they should still be equipped with similar passive safety features in order to ensure a comparable level of safety and account for the sometimes unpredictable and impulsive handling of human drivers, which indicates that it might not benefit the overall safety (Litman, 2018; Sivak & Schoettle, 2015a). In a later stage of full market penetration (or AV-exclusive operational domains), the necessity of these features can be reconsidered. In this respect it can be imagined that the everything somewhere development is the most likely implementation option, as the something everywhere development poses more potential hazards (Saffarian, de Winter & Happee, 2012; Llaneras, 2006; Solís-Marcos, Galvao-Carmona & Kircher, 2017; Banks, Eriksson, O'Donoghue & Stanton, 2018). This is most likely to happen in a (local) controlled and AV-exclusive environment (in terms of motorized vehicles).
People are initially inclined to be uncomfortable with the idea of AVs (Hudson, Orviska &Hunady, 2018; König & Neumayr, 2017), but to increase trustworthiness and perceived safety, characteristics of the car can be used to generate trust (Waytz Haefner & Epley, 2014; Verberne, Ham & Midden, 2012).

## Traffic flow

In the scenario where only AVs are allowed to drive at a certain operational domain, this might affect the traffic flow positively at the area, as the potential hazard of interference with other non-AV drivers is omitted (Fagnant & Kockelman, 2015). This effect could be partially cancelled out without further measures, as AVs might induce more trip making.
It is be desirable that AVs act predictable, which in this context means human-like, as the human mental model of how drivers handle certain situations might still be applied to the expected behaviour of AVs (Sivak & Schoettle, 2015a). Also the technology allows AVs to communicate with other road users (both vehicle drivers and for example pedestrians) in the sense that it can indicate what it will do or what the other road user could do (this interaction is currently used by for example making eye contact between the driver of a vehicle and another road user, or other ways of body language).

## Convenience

With the (shared mobility focused) AV the users are expected to have the convenience and flexibility to choose whatever vehicle fits their needs best for a certain trip. Per trip payments or subscriptions in this scenario are beneficial (especially for them that do not travel too much) as there are no high (initial) costs involved for purchasing and servicing the vehicle. There are several type of trips discerned to travel by car:
Work related, going on a day out, shopping for goods, going on holidays, for emergencies and going to other activities (like school, or sport clubs or visiting people etc.)

When looking at the trip itself, with any AV there is no need to drive the vehicle and therefore time can be spent differently, which could have a great impact on the car interior (Kinicsoy, 2018). People often indicate that when they are relieved from the driving and monitoring tasks, they might involve in the following activities (Schoettle & Sivak, 2014; Kilinscoy, 2018; Kyriakidis, Happee & de Winter, 2015):

- watching the road,
- reading,
- socializing with others in the vehicle,
- listening to music,
- sleeping,
- using the smartphone,
- working, watching movies,
- playing game,
- resting/doing nothing.

As there are lots of different reasons to use a car, lots of different types of vehicles, catering for the respective needs, could be thought of: commuters are most often the only occupants of their vehicle, whereas with holidays and days out there are typically more passengers. Also luggage space is more important with the latter and when going for grocery shopping and a working space might be preferred by the commuter.
Some issues regarding transportation can be resolved by advancements on technological level and progressive politics, yet one of the main drivers for the success of autonomous transportation and also carrying most of the uncertainties for making predictions at this moment, is the acceptance by society and potential behavioral changes.

## Comfort

Within the context of AVs, personalization can still be achieved considering privately owned vehicles, but with the expected increase in car- and ride-sharing services (where the user does not own the vehicle), personalization might be achieved by the means of the

hailing software, communication with the users personal smart-device and subsequent changes induced by the vehicles software and adaptive hardware systems, such as lights, temperature regulation and sound.
The function of the requested AV -which is likely to fit the needs of the user well- will add to the comfort as well.
Additionally, material use and anthropometric fit will enhance the perceived comfort.

## Ethics

Vehicle automation is expected to introduce extra liability to vehicle manufacturers and system suppliers. Most of these ethical aspects have cannot be addressed in this project, as they are mainly related to software.

## Health

In order to reduce the change of motion sickness in vehicles, it seems sensible to address the culprits (conflicting sensory inputs (Murdin, Golding & Bronstein, 2011)), or at least not ignore them.
This can be achieved by for example implement sufficient possibilities to look outside (Turner, 1999), to ensure that the visual input of movement is consistent with the actual movement of the vehicle. Sitting in a forward-facing position and lying down in a supine position (lying down on the back) is preferred in terms of experienced motion sickness. Additionally sleeping or having the eyes closed can also help (Sivak & Schoettle, 2015b).
Giving up control of the vehicle (going from driver to passenger) will increase the chance of experiencing motion sickness (Diels & Bos, 2016), but there is no way of giving every passenger the possibility to influence the motion of the vehicle.

## Ownership

Some reasons for the choice of ownership are likely to be based on price (and related frequency of use), functionality, and convenience. Nowadays, people that do own a vehicle still consider taking public transport within urban areas where the public transportation systems are well developed and accessible and car use is less convenient (due to city's measures to reduce cars like high parking prices, or the long time it takes to get there due to traffic). But with the AV these problems seem to diminish, as the passenger(s) can be dropped off and does not need to think about what to do with the car (Litman, 2018). The problem of long trip duration might still be apparent, but as time can be spend differently within the AV, it is not just wasted time.
With the envisioned introduction of AVs the ownership models might change into less personally owned vehicles and more shared mobility.
Most current shared mobility types are realized within the contours of higher density (urban) areas, as the potential demand and supply is higher in these areas. With AVs and ride-hailing services, it can be imagined that the proximity parking demand decreases in comparison with the current situation, whereas with ADS-DVs - where the AV only needs to drop off the passenger- peripheral parking might be beneficial for the amount of vehicles parking in city centers, relieving the car density (Anderson et al., 2016). It is also preferable that the waiting time for your hailed vehicle is not too long, however, the expected side effect of peripheral parking is that it takes more time for a vehicle to reach its user. Additionally, this might increase the traveled distance of AVs.
These assumptions are all based on current situations and policies on car use in urbanized areas, but recent developments in policy-making, shows there is a movement towards developing car-free zones (Nieuwenhuijsen & Khreis, 2016), which then might reduce the convenience aspect of the AV of getting you to the exact place you need to be.

## Pollution

The decrease of pollution associated with electric autonomous vehicles is difficult to predict, as it is not only quantifiable by efficiency, but also by side effects such as changes in user behavior (Gruel & Stanford, 2016; Pakush, Stevens, Boden & Bossauer, 2018). However, the general consensus is that there is still a reason to assume that it will lower the overall energy consumption.
The vehicle exterior could account for that in the sense that not only the drivetrain can be optimized, but also the aerodynamics, weight and use materials of the vehicle (Cerdas, Egede & Herrmann, 2018).
In terms of material use and the costs of manufacturing and using virgin material, there is room for improvement in general, especially with waste disposal and recyclability and repairability of parts.
The effect of traffic flow on pollution can be ensured mainly with higher shares of AV, due to platooning, inter-car and infrastructure communication and the related anticipation on situations far up front.
The production of the base vehicle (without drivetrain and battery) for EVs and ICEVs is assumed to be the same within LCAs where human-driven cars are compared.

## Equal mobility

When being able to dive a car is not a requisite anymore, anyone should be enabled to make use of a car. Societal groups that might not have been able to drive themselves, but can use an AV on their own include people that don't have a driver's license, children that are too young to drive, people that are disabled to drive due to physical or mental reasons and elderly who don't have the motor skills it takes to drive (anymore). People that are unfit to drive are also enabled to use a vehicle themselves (think of people that are under the influence of alcohol, drugs or medicines or too tired to drive). The only aspect that might be of influence of equality is accessibility, in terms of affordability, but moreover physical accessibility (think about people that have difficulties getting in a car, due to physical limitations).

# CURRENT STATUS

## INTEGRATED CONCEPTS

*When looking at the most recent integrated AV concept and attempts of companies, clear directions and approaches can be discerned between them. Only level 4 and 5 passenger vehicles are considered in this overview in order to comply with the approach of this project. The more detailed (company) information of these concepts on which the following information is based, can be found in Appendix D.*

There are a lot of differences between all of these concepts, but simultaneously several common denominators can be discerned between some of them:

- Degree of autonomy
- Shared (ride-sharing, car sharing)/privately owned
- Functionality (for transporting goods or persons or service)
- Uniqueness
- Luxury
- Single mode/dual mode
- Driver focus/passenger focus
- Practicality
- Versatility
- Urban use
- Travel distance
- Modularity
- Comfort

Some of the aforementioned functions are exclusive for certain other functions and can therefore be used interchangeably when trying to map them on a single axis. At level 4 and 5 the degree of autonomy is only implying a difference in domains in which the vehicle can operate, but as vehicles at either of these levels can be both single and dual mode, it is not a very useful mapping criteria. Looking at the single and dual mode functions, it is always linked to driver engagement and driver or passenger focus: a dual mode level 4 or 5 AV is always described as (or in synonyms of) engaging, driver-oriented, and dynamic. Therefore a difference in driver or passenger orientation can be found.

Luxury on the other hand is often used as USP for a single mode AV, however it is not mutually exclusive for single or dual mode vehicles (compare the Mercedes F015 and the Lagonda Vision Concept to the Audi Aicon, Rolls Royce 103EX and the Renault EZ-ULTIMO).

A privately owned AV is often focused on driving experience and/or luxury for the reason that shared driverless vehicles are among other things meant to relieve the user from the burden of driving, whereas it is assumed that persons that do enjoy driving are more likely to own a vehicle that enables them to drive the car themselves and see the car as more than just a means of transport. When companies throw in descriptive terms such as 'luxury' and 'premium', they tend to refer to a subjective feeling of being served with more, different, more comfortable, and more expensive features rather than using the economic explanation of a luxury good (for which the demand will increase when the price of the product increases).

As there is already a multitude of concepts developed where different functional areas are explored, some approaches or visions are much alike and become common in this field, whereas others are more unique.

From these observations, two functional mapping axes are derived and used for mapping the listed concepts in figure 9:

- Driver focused – passenger focused
- Ordinary – unique

Besides this, the concepts can be grouped very well by determining their functions, focus point or USPs. These can be luxury, functionality (transport of goods or people, mobile catering or multi-functionality), shared use or private use.

**Conclusions**

A digital assistant, learning from your preferences (sometimes materialized as an eye-catching piece in the interior and anthropomorphized by giving it a human voice and name) is used by several brands.

Some concepts are designed with a monolithic approach, enabled by the electric drive train and different layout demands.

Dual mode seems to limit function and design freedom, as the vehicle is still subjected to requirements set to ensure a safe operation by the driver. Therefore, the more unique and out-of-the-box ideas can be found within the single mode AVs.

Inside-out design approach is often used because of the multitude of possibilities for interior functions with different demands.

In these prospects, visions and concepts, AVs for person transport are envisioned to be shared (and ride-hailing based), privately owned luxurious vehicles or (fixed route) shuttle services. However, there are some modular systems that are focused on transportation of goods or allow to change between transportation of persons and goods.

The most commonly used identifiers are comfort and similarities with living rooms and lounge areas are pointed out.

Large DLOs and sunroofs are implemented liberally to enhance and emphasize the spaciousness of the interiors.

More often than not the system in which the vehicle will operate is not or rather briefly described, showing that either the system aspect is being disregarded, or no change in system is assumed.

In the next chapter, possible scenarios are explored and visualized in order to be validated based on their respective value and potential for SABIC. Their envisioned position in the mapping would be in the top right corner.


*Figure 9: map of the most recent concepts of autonomous vehicles*

1. Adient AI18 — CS, RS
2. Aston Martin Lagonda Vision — O
3. Audi Aicon — O
4. BMW next 100 — O
5. BMW i-next — O
6. Chrysler Portal — O, CS
7. Honda NeuV — CS
8. Icona Nucleus — CS
9. Mercedes Benz Urbanetic — RS
10. Mercedes Benz F015 — O
11. Mini Cooper Vision 100 — CS
12. Nio Eve — O
13. Nissan IMX Kuro — O
14. Peugeot e-legend — O
15. Renault Symbioz — O
16. Renault EZ GO — RS
17. Renault EZ Ultimo — CS
18. Rinspeed Micro Snap — RS
19. Rolls Royce 103EX — O
20. Smart EQ — CS
21. Toyota I-ride — O
22. Volkswagen I.D. BUZZ — O
23. Volkswagen Sedric — CS, RS
24. Volvo 360C — CS

CS: car sharing, RS: ride-sharing, O: Ownership

# ADS Technology

For any motorized vehicle to function, a combination of hardware and software products is needed nowadays. For autonomous vehicles new ADSs are introduced and already available techniques, sensors and systems are optimized as the operational safety is dependent on them. The ADSs are generally reliant on the following sensors: LiDARs, radars, cameras and ultrasonic sensors, generally layed out as depicted in figure 10:

- LiDAR (light detection and ranging): the distance velocity and shape of objects in its surrounding is determined by sending out pulsed laser light and measuring the reflected pulses by the object. By transmitting a numerous amount of pulses, it can map the environment accurately, even at higher speeds. With the commonly used 900-1550 nm lasers (invisible to the eye), it is ideal for short to medium distance ranging (up to approximately 200 meters) and can be used in the dark as well. With the development for more automation in cars, the demand for LiDARs increased rapidly over the last years. Brands to offer detection and ranging systems include Velodyne, Valeo and Luminar and more.

- Radar: determines velocity and range of objects by emitting radio waves. Radars can be short range (SRR, 0,2-30 meter), medium range (MRR, 30-80 meter) and long range (LRR, 80- over 200 meter). SRRs are among other things used for collision warning, blind spot monitoring and lane change assistant, whereas the LRR is used in front of vehicles in order to detect changes in traffic furter ahead and provide information for anticipation (such as braking).

- Camera: the camera is the only passive sensor in this list, in the sense that it only collects reflected light and doesn't emit anything. Depending on the light that is seen by the human eye as well, this sensor is susceptible to the environment situation: low visibility is negatively influencing the camera's sensing ability. But when visibility is good, camera's have a very high resolution output.

- Ultrasonic sensor: they are mostly used as a cheap and effective sensor for park assist in the front and rear bumper. They can detect obstacles at low speed by calculating the difference between the time of sending out ultrasonic waves and receiving it after it bounces off an object.

Implementation requirements:

- LiDARs needs to have a visor suited to its IR wavelength in order to properly detect its surroundings. Therefore it is important that an unobstructed view is warranted.
- Radar systems on the other hand can still be functional when placed behind panels and are weather independent.
- Cameras have similar requirements as LiDARs; an onubstructed view is needed as it is a vision based system. The only difference is that it should be have a certain degree of transparancy and not to much reflection.
- Just as radar, ultrasonic sensors are also not affected by dirt attached to its surface and weather conditions.

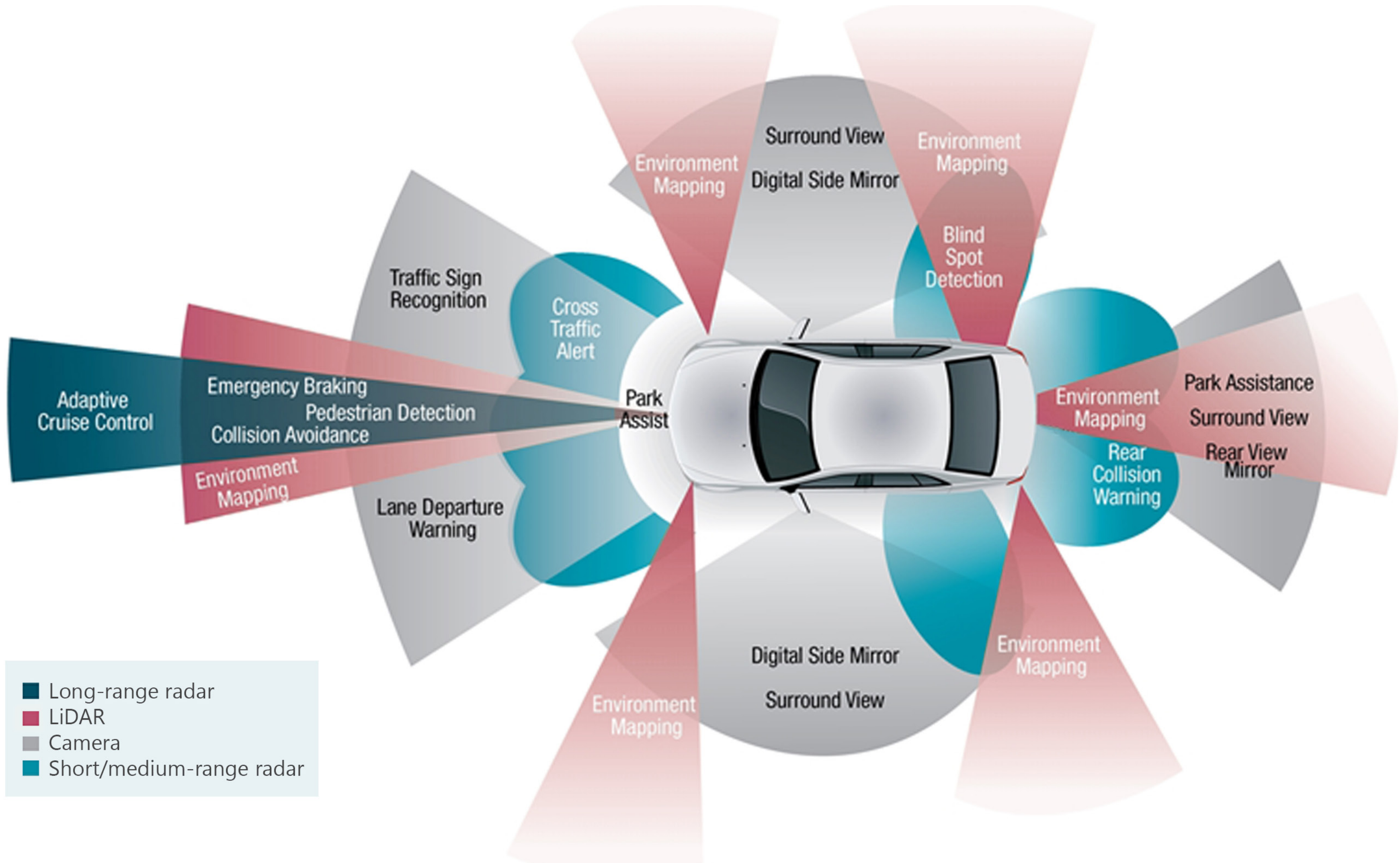
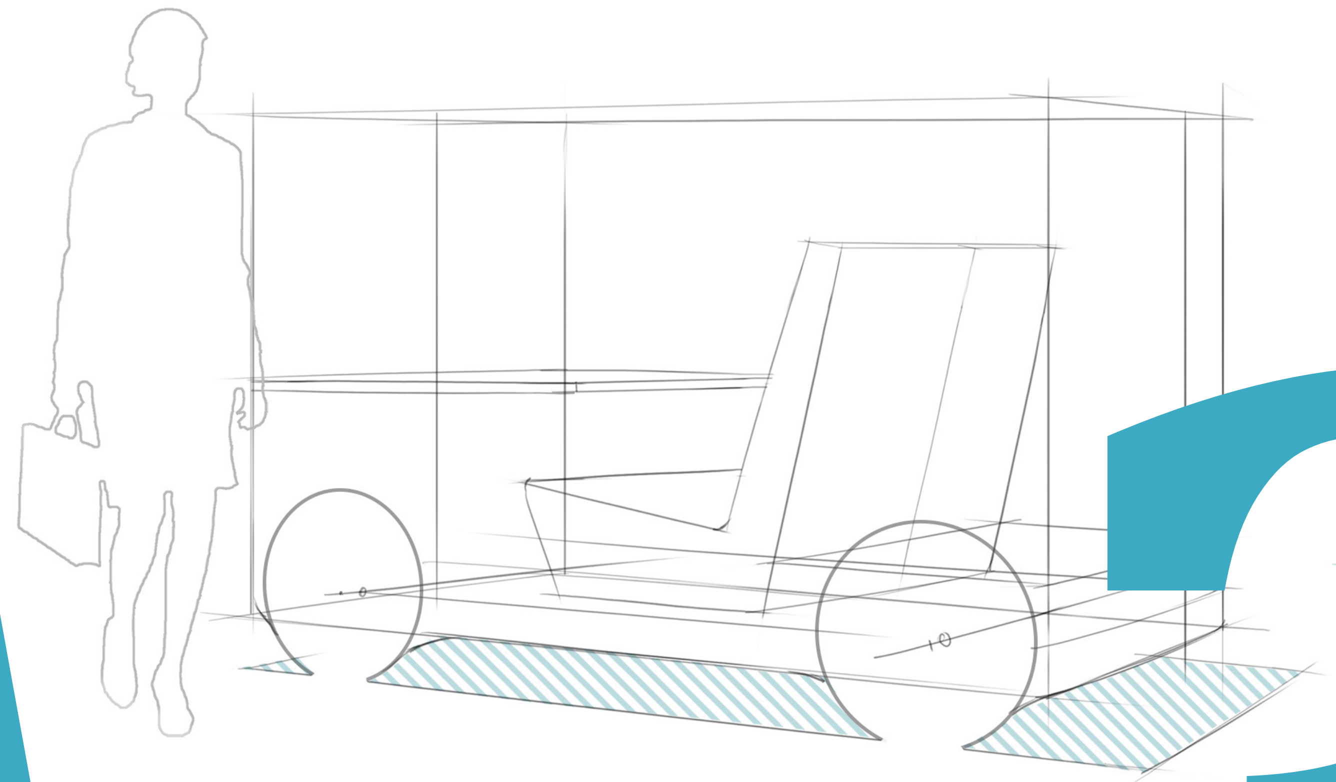



*Figure 10: typical function and position of sensors (SAE International, 2019)*

# 3

# FUTURE SCENARIO

*In this chapter the prior research is translated into potential scenarios for purpose-built AVs. The research provided the argumentation for the outline for the scenarios and the scenarios themselves show the potential viability of the demands for purpose-built shared AVs. The final choice of scenario reflects what SABICs input can be.*



# Stakeholders

*In this section the main stakeholders are highlighted and mapped according to their respective influence and interest in the development of automobiles. Stakeholders related to car mobility in the current situation are defined by Jeekel (2013) as follows: Commercial stakeholders (including car dealers, garage owners, car industry, insurance companies, oil companies, petrol station managers, driving schools, lease companies, service providers, travel information providers), governmental stakeholders (including road authorities, legal services, enforcing institutions, policy makers, financial institutions, tax organizations, emergency institutions, regional governments) and societal stakeholders (including employers, road user (organizations), environmental organizations, academic world). The main stakeholders closest related to the (new) development of vehicles are derived and explained. Additionally, the car industry value chain is divided into OEMs (referring to the car manufacturers) and tier 1, 2 and 3 suppliers.*

- *OEM, car manufacturers*

The car manufacturers (for recognizability referred to as OEMs) have always been the core of the automobile development process. Together with the tiers, they can manufacture and assemble cars. Their demands for certain products and materials is forwarded to these tiers, who will supply it to them. The OEMs are influenced by the legislation made by the policy makers and also by the wishes of the users. In the future scenario, the OEMs will lose some of its influence as the market for shared mobility and autonomous transportation increases. The mobility service provider might become a significant influencer for the OEMs. But the OEMs will also change their focus towards a provider of cars as well as mobility services.

- *Tier 1, suppliers of (sub)assemblies*

Typically, tier 1 suppliers' only clients are OEMs and therefore their interest is high. They are mainly driven by the demand of the OEMs, but can also show potential of their own innovation towards their clients and create demand and positioning themselves as the preferred supplier. The first tiers are supplied with components and materials by respectively the tier 2 and tier 3 suppliers. In the new scenario this dependency and influences sill remain the same.

- *Tier 2, suppliers of components*

They supply components to tier 1 companies, but also to other markets. Due to this, their interest is lower as well as their influence. Inside the automotive market they are influenced by the demand of the tier 1 suppliers and in their turn exert influence on the tier 3 supplier. This influence is expected to remain in the future.

- *Tier 3, suppliers of raw materials (SABIC)*

Generally, a tier 3 supplier is a supplier of raw materials, such as plastics (SABIC) and metals. Some material grades are produced specifically for the automotive industry, but overall the automotive sector is only a part of the business of the raw material supplier industry and therefore their interest is a bit lower as well as their influence. They are, however, supplying to OEMs, first and second tiers, which shows that they are directly involved with a larger variety of clients.

- *Insurance companies*

In general insurance companies are reacting to the developments in the automotive industry by adjusting their rates accordingly. This means that both their influence and interest is relatively low. The largest insurance company (Allianz) initiated to conduct some tests of their own in order to rank vehicles on reparability and consequently determine vehicle's insurance rates ("Aufgabengebiete - Allianz Zentrum für Technik", 2019).

- *Oil companies*

At the moment the car market is dominated by cars equipped with ICEs and considering that the majority of oil is used for propulsion of vehicles (about two-third of the petroleum products in the United States are gasoline and distillate fuel oil, mainly diesel ("Oil: Crude and Petroleum Products Explained. Use of Oil", 2018)), the interest of these companies is rather high. But recently the EV in all its variations gained market share. Combined with policy changes towards a more sustainable future, for the autonomous vehicle the electric drivetrain seems the most practical option and will therefore increase the EVs market share at the expense of the ICE vehicles, resulting in decreasing sales for the oil companies. The EVs, however, do require energy that is supplied by energy companies. This will means that the electric energy market will experience an increase in demand for energy.

- *Lease companies*

In the early years of the availability of AVs when the prices of these vehicles will be significantly higher than conventional vehicles, due to the not yet available economies of scale, leasing might be the more attractive alternative when ownership is preferred. This has been seen in the rise of (battery) electric vehicles ((B)EV) as well, where most of the vehicles are being leased as well, due to the higher prices than comparable vehicles with ICEs but also because of the long term risks (battery degradation and vehicles with better range developing rapidly). Therefore it is expected that if there is a demand for personally owned AVs, they will be leased predominantly.

- *Mobility service providers*

Mobility service providers (such as rental companies, taxi companies, and transportation network companies (TNC's), such as Uber and Lyft) have currently not much to say when it comes to manufacturing vehicles. They make a decision for what cars to use for their service and offer the service to the vehicle user and customer. A different insurance policy is applicable for this difference in ownership. When autonomous vehicular transportation becomes more common, the demand for shared mobility services is expected to increase as well. Therefore the position of the mobility service provider changes in the new scenario: they will gain influence and get closer to the position of the OEMs. With large market shares the possibility arises to exert influence on the OEMs. With this change in position, it is likely that policy makers have to adapt to this situation and make regulations applicable to this upcoming influential party.

- *Policy makers*

(Governmental) policy makers make legislation and assign governmental institutions to enforce it to OEMs and other manufacturing companies by regulations. As any company has to conform to those rules, the governmental policy makers have significant influence on how the automobile industry evolves. With the upcoming autonomy enabling technology -which is not accounted for in some of the current regulations- the policies might change, consulted and advised by advisory groups, manufacturing and mobility companies, and environmental organizations. With the increasing influence and interest of service providers and (shared) mobility companies, there is reason to believe that more regulation on mobility systems is needed to account for this increasing share of the market.

- *Tax organizations*

Similar to other products and services, cars and the use of cars is taxed by governments in order to cover public expenses related to the use of these vehicles. It is also used as a means to motivate or demotivate certain choices. This is mainly done to encourage the use of less polluting vehicles. Affected by policy makers, decisions on higher or lower taxes might affect the choice the consumer makes.

- *Vehicle users*

The main users -in this document referred to as passengers- of vehicles are important stakeholders, as they will be interacting with the AV the most. Comfort, convenience, intuitiveness and functionality, among others, are important attributes within this context. At this moment car ownership is very common, and rises with higher GDP per capita (Ritchie & Roser, 2019). For some it is merely a means of transport as for others it is also a way of expressing themselves. Currently, vehicle users are have quite some interest in the development of cars, but their influence is limited: the users are the target groups for OEMs and are influencing them in the sense that cars are developed to be sold or leased to the user and should therefore conform to some of their demands. As a function the AV may either be continued to be used as a car is used now or complementary to other means of transport (e.g. the train or airplane as last mile transportation) which can be supported by the shared and ride-hailing potential of the AV. Therefore it is expected that with this shift in the mobility system, the users are being considered more in order to find out how their needs can be met by the OEMs and the service providers.

- *Interest group*

Interest groups are organizations that have the objective to change public opinion and policy. Their motivations can be diverse, but for the automotive industry the ones advocating a cleaner environment, safer roads and business associations lobbying are most influential, but their influence and interest is expected to remain similar.

Additionally, parties with little or none influence are affected as well, such as fuel stations, garage owners driving schools, which are expected to see their businesses decrease. And some parties which gain more relevance in the development, such as road authorities (which are expected to work on the infrastructural part of the vehicle to infrastructure (V2I) communicational systems) but also energy producers and suppliers will see their market expand.

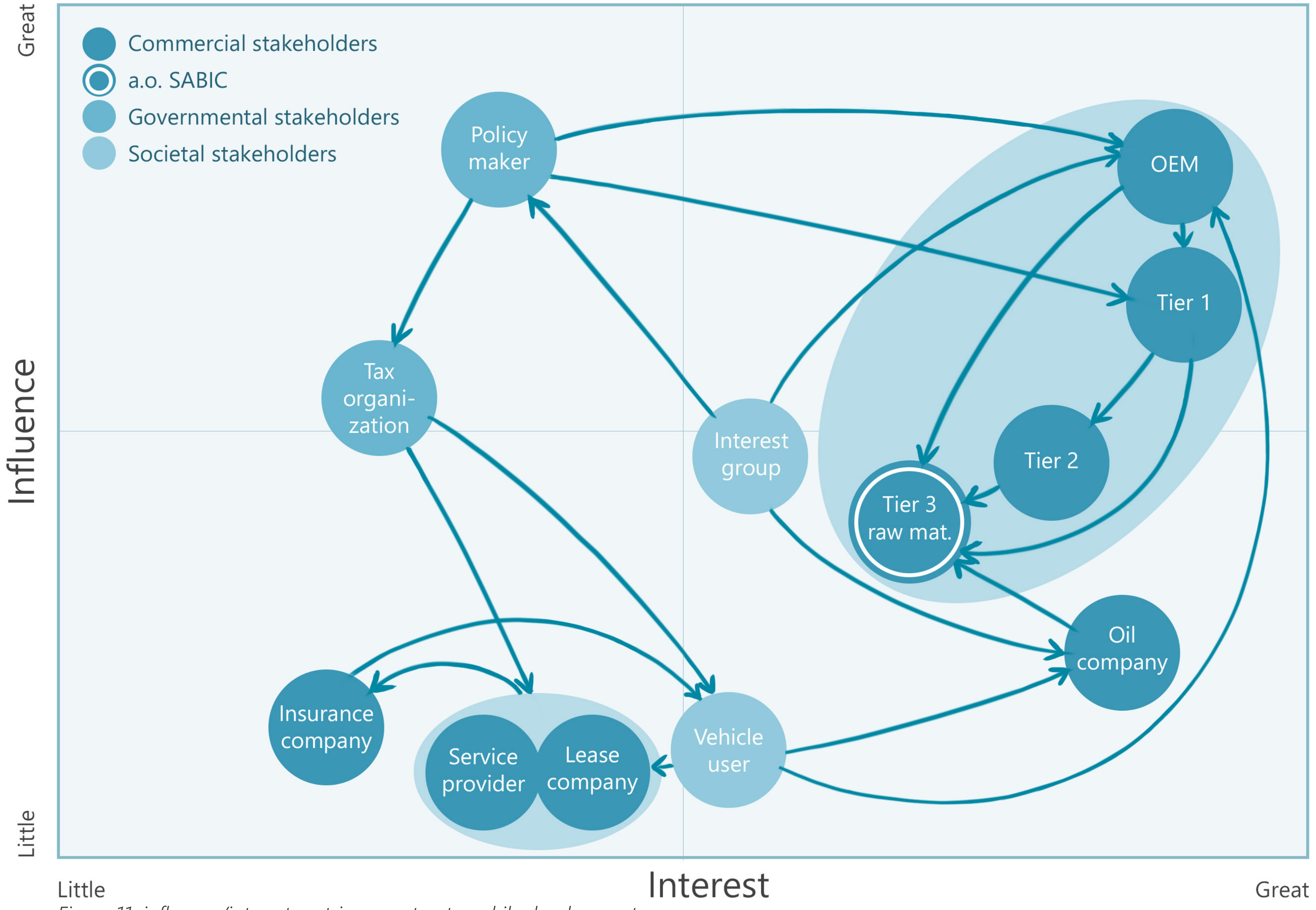



Figure 11: *influence/interest matrix current automobile development*

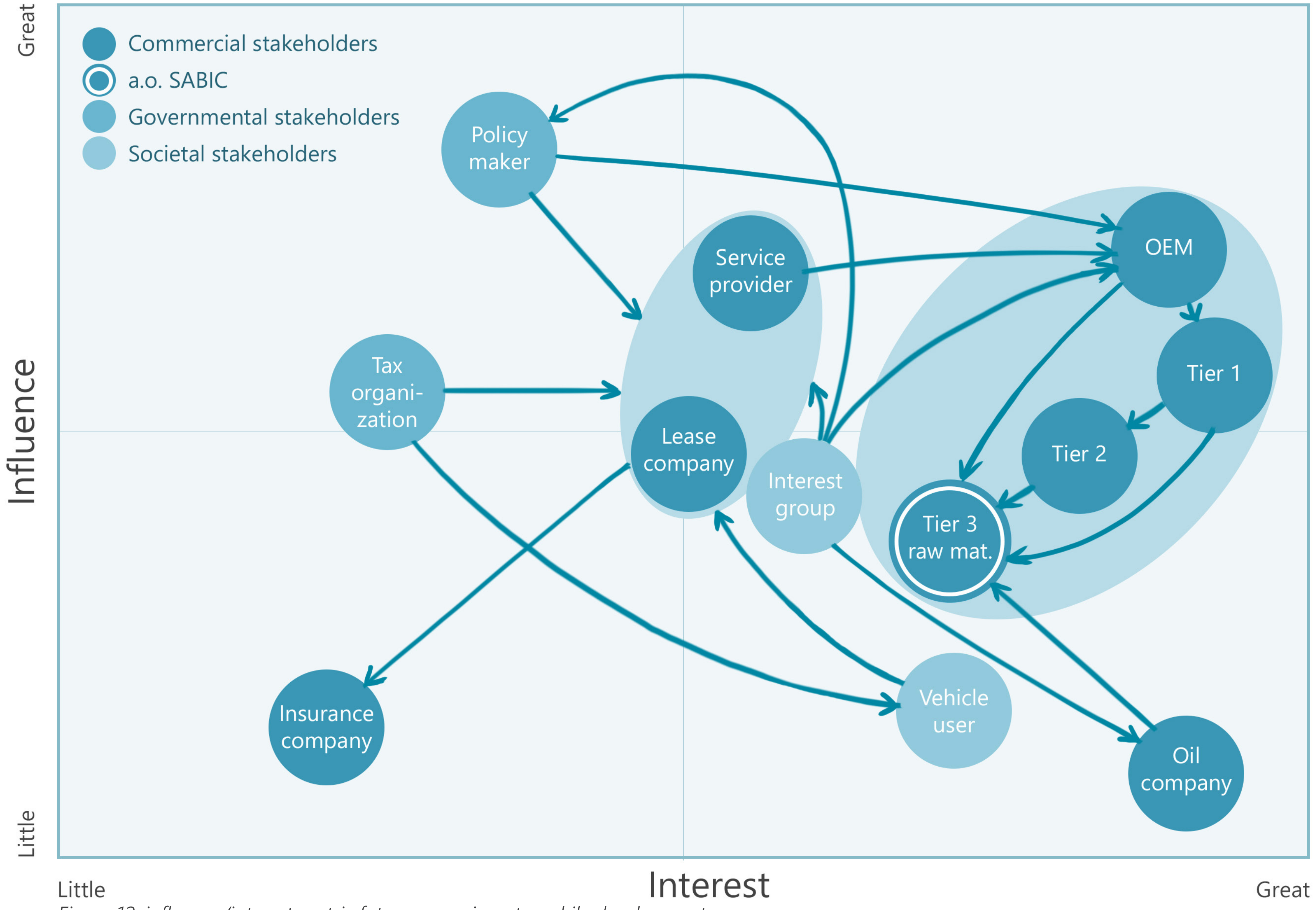



Figure 12: *influence/interest matrix future scenario automobile development*

# Scenarios

*People that own a car, often make a decision of what car to get based on the expected most demanding need (in terms of for example amount of seats or storage capacity). This results in the ownership of a vehicle that might be overqualified for some of the trips.*

Purpose-built vehicles have the potential to remedy this overqualification for the consumer, but they are less inclined to own such a purpose-built vehicle because generally it is less fit for other demands. That is why I think that AVs with a specific purpose are likely to be part of a car sharing and/or ride-hailing service, revealing the most potential.
Vehicles addressing a particular type of function that is not in demand regularly, can be based on a skateboard type of modular platform (as recently seen at Mercedes Benz, Rinspeed and AEV Robotics), allowing the drive train to be used for a different type of vehicle for which the demand is higher.
Additionally, more intense use during a shorter period of time, makes that the degradation of parts that is dependent on the amount of use accelerates, but the wear related to the time of exposure to the elements reduces. Therefore the resistance for aging could be lower.

Based on all of the prior research, the following general aspects are shaping the periphery for this project for the development of an autonomous vehicle for the year 2029:

- It will be operating in an environment where the interaction with other motorized vehicles is autonomous
- Therefore, the demands for passive safety systems are less stringent
- The vehicle is a single-mode AV and therefore can be operated exclusively by the ADSs
- The vehicle design will be based on an electric drivetrain
- The scenario proposals revolve around purpose-built vehicles that are suited for a more specific (range of) trips

With this and the prior research in mind, configurations of different purposes are composed as showed in Appendix E. The four variables were the function of the trip, the type of user (life stage), the amount of users (and their relation) and the operational environment.
As the focus is on purpose-built vehicles, starting point for making configurations was the function of the trip. A selection of frequently occuring functions has been discerned: school, tertiary education, work (commute), work (other), shopping (supermarket), shopping (mall/city), sport/clubs, holidays (close by), holidays (further away), day out (country side, woods, beach, mountains), day out (activity, museum, festival, park, game), day out (food/drinks, party, sightseeing), visit family/friends and generic appointments and errands.
Next combinations with the other three variables were drafted:
Type of user: child, teenager, adult (younger), adult (older), elderly, composed group (family)).
Operational environment: rural, campus, urban/city, suburb, intercity (small distance/satellite city), intercity (long distance).
Amount of users: alone, 2 persons (strangers), 2 persons (family/ friend/ acquintance), more persons (strangers), more persons (family/friends/acquintances).

By mapping these combinations on the aspects of envisioned trip frequency, trip lenght/speed, storage space, amount of people and cabin space, I was able to find similarities between sets of type and amount of users an operational environments with different functions.

***The paradox of purpose-built vehicles for shared use can be adressed by finding similar vehicular needs for different functions***

I found this to be relevant as I realised there is paradox when it comes to purpose-built vehicles in a car sharing system; usership in general is seen as an on-demand alternative to ownership, where you use a (shared) car just for a certain purpose and ideally only pay for the time thst you usee the vehicle. Therefore it is imaginable that the car that you want to use is well equipped for the job (and not over- or underqualified), an argument advocating for purpose-built vehicles. Additionally, someone else using the vehicle when you don't is in the interest of the service provider, as they make money by providing the vehicle to users.
The drawback here is that when the demand for a certain purpose is concentrated or peaking on a certain time frame and low in demand on other time frames, the purpose of sharing (for the service providing company) is loosing its potential unless it is broader applicable, without compromising on the primary function.

# Scenario 1: the urbantrip

*This scenario is focused on the daily commute in the city, suburb, or between city and satellite city: about 20 per cent of the daily trips made and distance traveled, are commuting trips to and from work. The car is mostly occupied by just one person and the time that this trip is conducted is often concentrated at specific times of the day (between 6 and 9 in the morning and 4 and 6 in the afternoon). Also this type of trip is made rather frequently (mostly during weekdays).*

Looking at the space needed and the space used, it can be assumed that the commuting car can be reduced in size, in a usership based system (as opposed to ownership).
To take full advantage of the car sharing potential during the day, the car can be hailed by users with similar needs in between the peak hours of commute travel which are likely to be shopping, getting to certain appointments and going to do other activities (McGuckin & Fucci, 2018). These secundary functions require less comfort, as their trips are shorter, and more storage capacity. Also the likilehood of the car being used with two persons in stead of one rises with these functions.

- The function of the AV will be focused on commuting (which use is very often concentrated on certain hours in the morning and afternoon) and a door-to-door type of travel
- The secondary function for which the car can be hailed during the day is shopping and other activities (which is peaking more in between the commuting peaks and in the weekends)
- The vehicle seats up to two passengers and has some storage space that accounts for the typical shopping demands.
- The car allows the commuter to work during the trip
- Being used more intensively, the car should account for that.

Possible solution areas to cater for certain demands:

- Forward facing seats, with a comfortable seating position
- Ease of getting in and out of the car, considering that it might be used by a broad spectrum of people
- High demand for this type of vehicle can mean that there is an interesting business case for part changes over time due to material wear

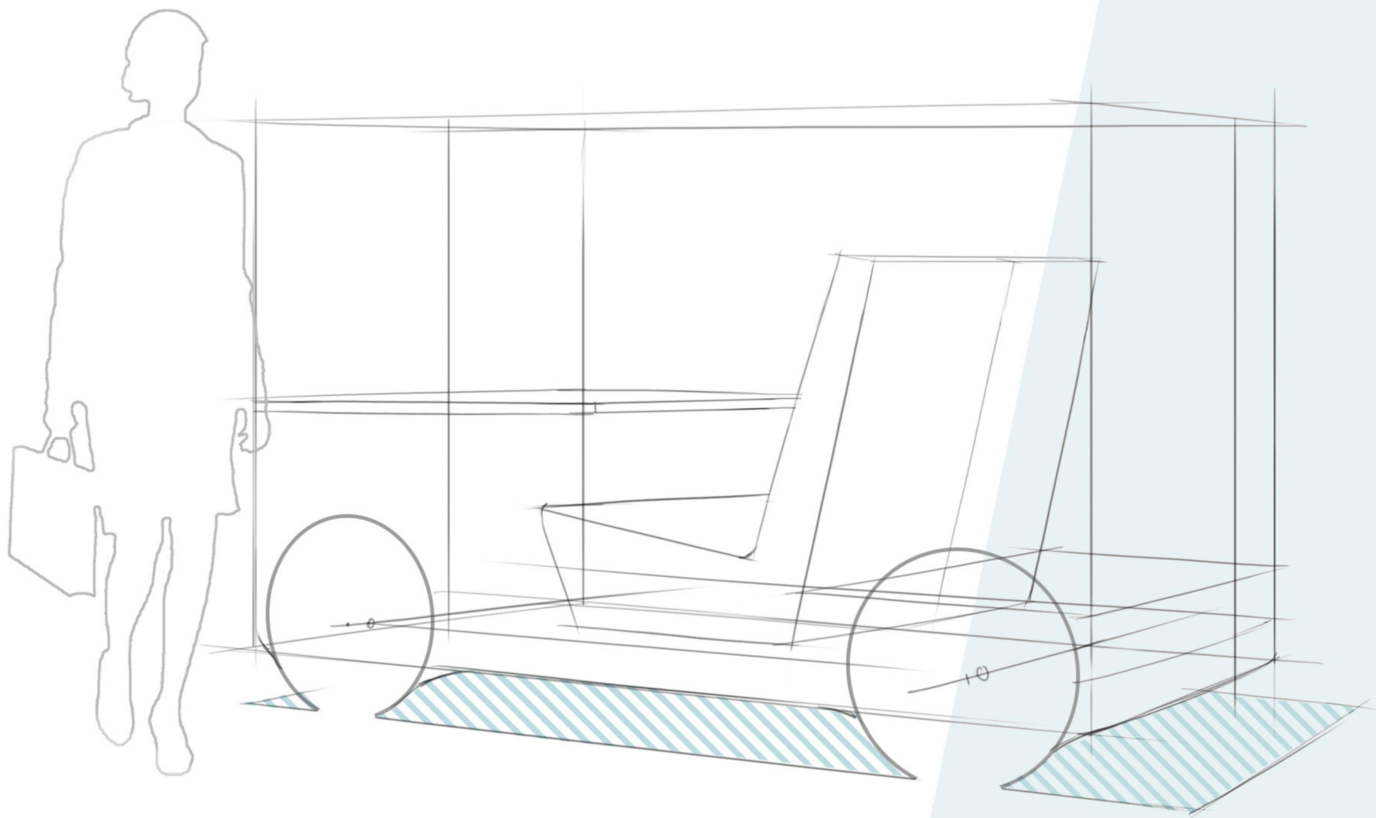


*Figure 13: general package for the urbantrip vehicle*

# Scenario 2: the schoolbox

*This scenario shows the function of daily school travel. Children typically go to school every weekday and therefore have a frequent and recurring travel behavior, just as the commuter. However, their avarage trip lenght is smaller.*

Children get to school carrying their backpack and need seeting for just a short period of time. As it is a short trip within the perphery of the suburban or urban area, physical discomfort is not likely to appear and therefore the seats can account for that. Similar to the daily commuter, the school transport vehicle is doomed to not be used outside the school travel hours. This shared-ride vehicle has the potential to be used for other irregularly timed trips with similar needs as well, such as going to sport clubs (needing similar storage space for sporting goods), short trips in cities or as first and last mile transport for multimodal trips.
Being generally smaller than adults, children need smaller seats and less space for the same level of comfort. But to cater for these trips outside school as well, the vehicle should have seats that can be used by adults as well.

- The function of the AV will be focused on school ride-sharing trips (which use is very often concentrated on certain hours in the morning and afternoon)
- The secondary function for which the car can be used during the day is going to sport clubs, short city trips and multimodal trips (which can be used outside the school travel peaks and in the weekends)
- The vehicle seats up to eleven passengers and has some storage space that can be used for the backpacks of the children
- The vehicle should have good transparency, in order to make it accessible and safe (as it is used mainly for a vulnerable societal group)

Possible solution areas to cater for certain demands:

- As children are extra susceptible for motion sickness, the DLO should also allow children from all sizes to look outside
- This vehicle is used by both children and adults, but during the schooltrips the seats might be optimized for the childrens' anthropometrics
- Ride-sharing and order of picking up the children asks for an easy accesibility system
- Due to the short trip distance and time, the seats can be fixed
- As this is a vehicle that has the largest surface areas, spanning distances of surfaces and part stiffness should be accounted for

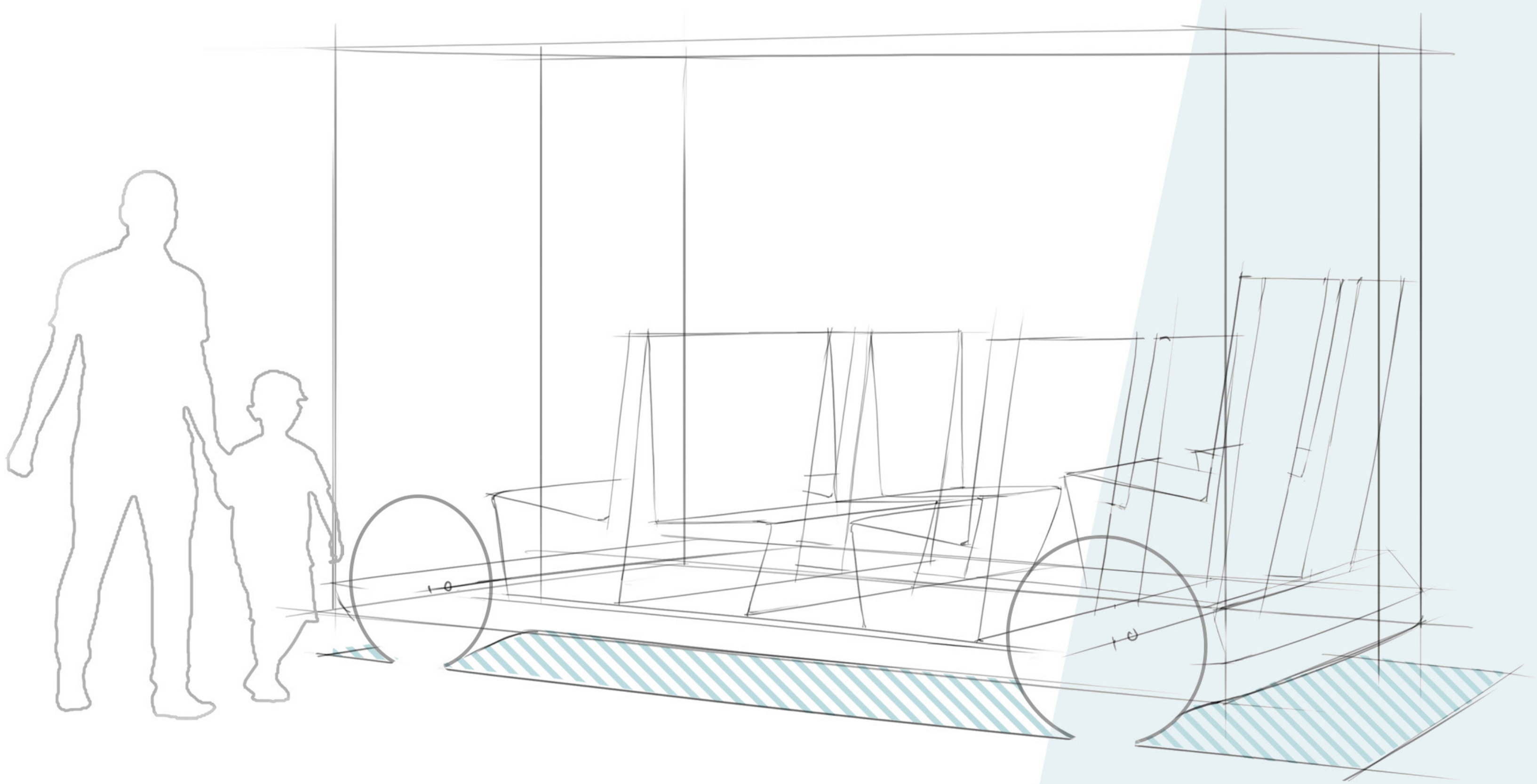


*Figure 14: general package for the schoobox*

# Scenario 3: the leisure

*This scenario is aiming at providing transportation for a family vacation. This type of vehicle is only needed maybe one or a few times a year for a particular person and is therefore rather infrequently occuring. But due to a specific set of preferences, it can be rather different from other type of vehicles.*

When going on vacation with family or friends, you need to bring your luggage and maybe some additional materials as well (depending on the needs at the place of stay), which means that there is a need for sufficient storage capacity. Also the level of comfort should be high and discomfort low, as the trip is often quite long. And due to this trip lenght, it can be imagined that there are different activities in which the users can get involved, including eating, resting/sleeping, talking, playing games and using electronic devices.
Comparing the trip lenght of this with other trips, it can be seen that other family/group trips of longer distances can have similar requirements in terms of cabin space, comfort level and interior tasks.

- The AV will be specifically focused on group vacations
- The secondary function for which the car can be used is going out for the day or visiting family or friends.
- The vehicle seats up to five passengers and has significant storage space that fits the typical amount of luggage for a vacation with up to five persons
- Privacy from the outside environment might be of added value, especially when one decides to sleep

Possible solution areas to cater for certain demands:

- During longer trips it can be desired to involve in different tasks over the duration of the trip. And therefore it might be desirable to be able to sit facing eachother, but also turning away.
- There is a need for some storage space in the cabin as well for example for food and drinks, games, devices and more.
- One side could be without a door, to attach e.g. a table or other things
- Looking outside is valued for vacation trips, as the trip is part of the vacation experience, besides the destination
- Modularity and flexibility is desirable for this type of use

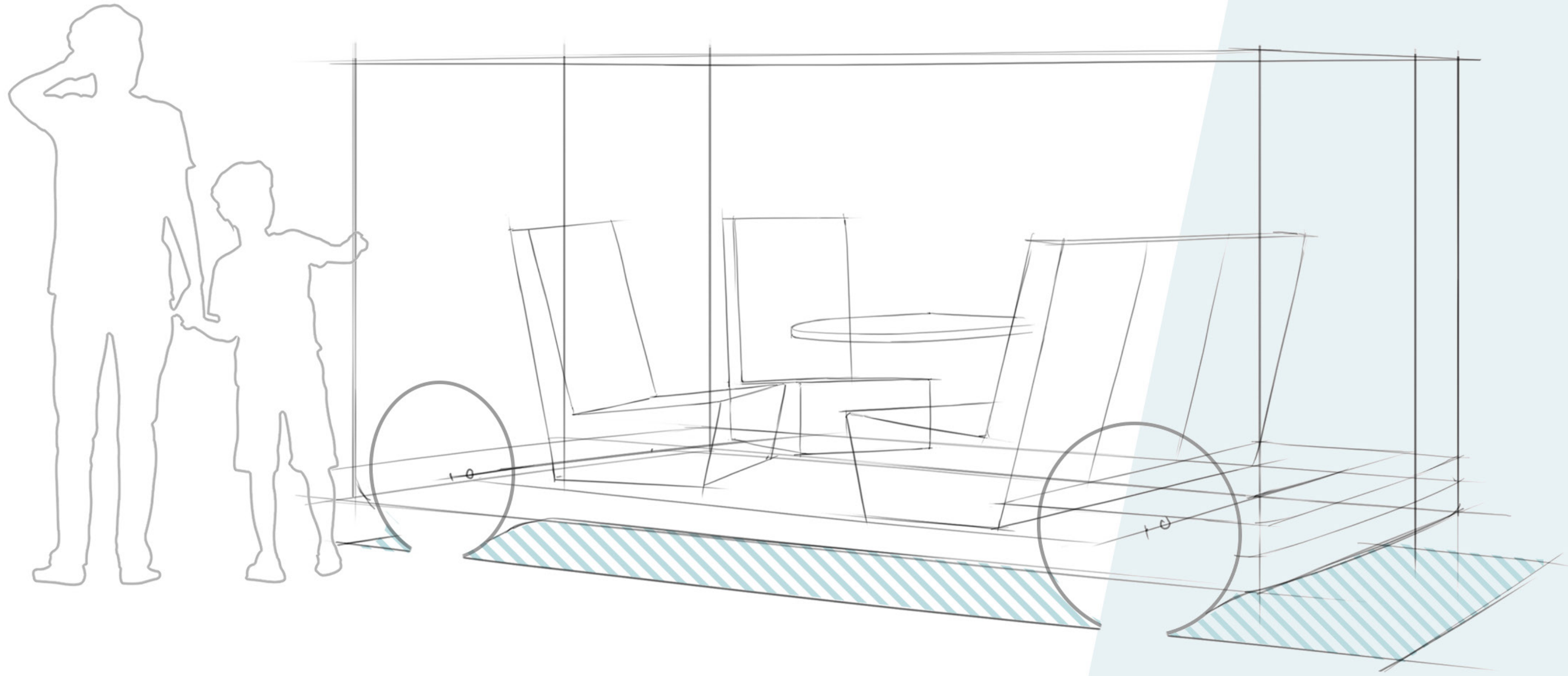


*Figure 15: general package for the leisure vehicle*

# Vision: the urbantrip

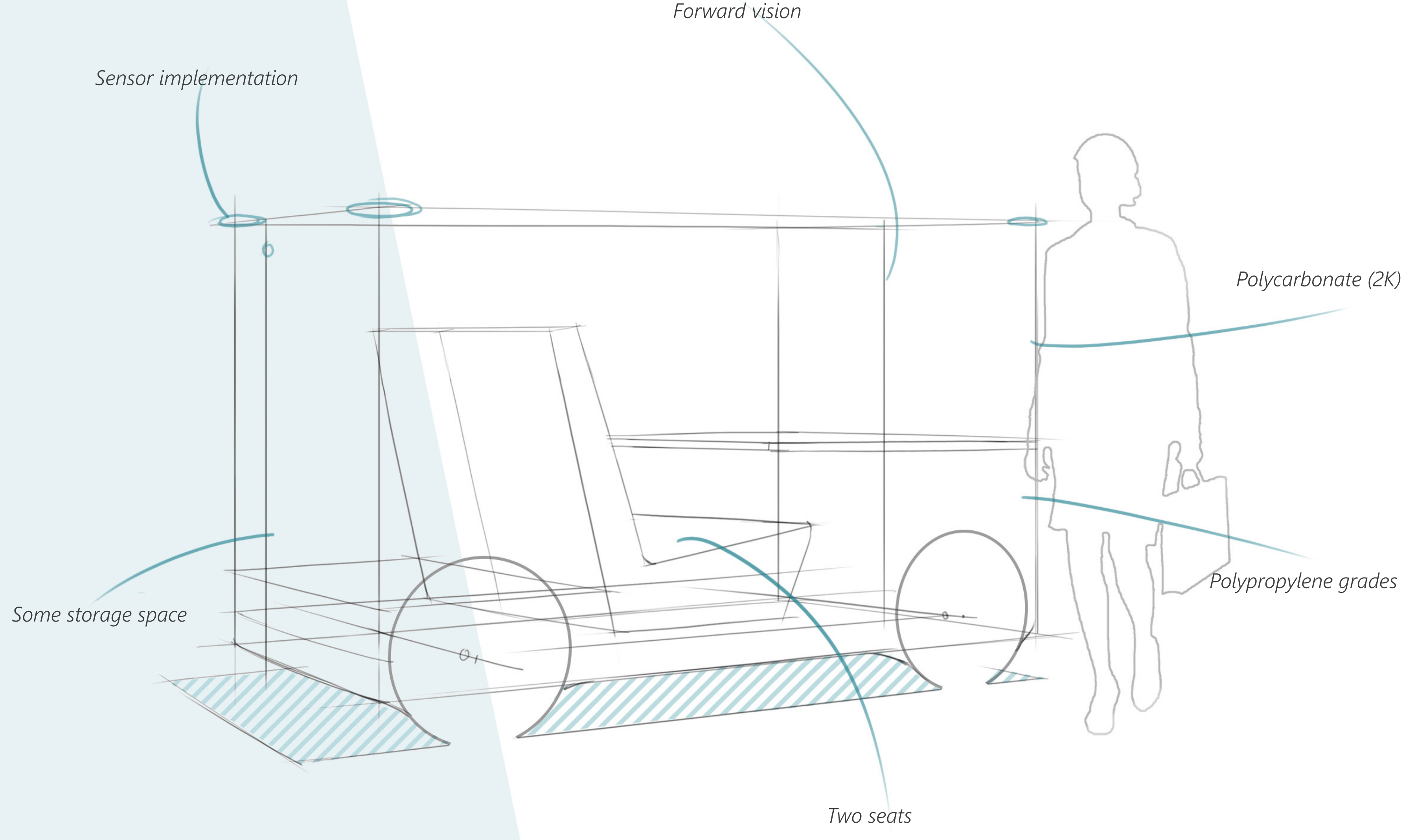



*Figure 16: package for the chosen urbantrip scenario*

During an internal session with colleagues of different disciplines and expertise, I proposed these three scenarios and walked them through the packages and the general considerations. The goal was to get feedback on what they thought of having most potential as an autonomous vehicle in the shared system from a material perspective. This lead to the following considerations:

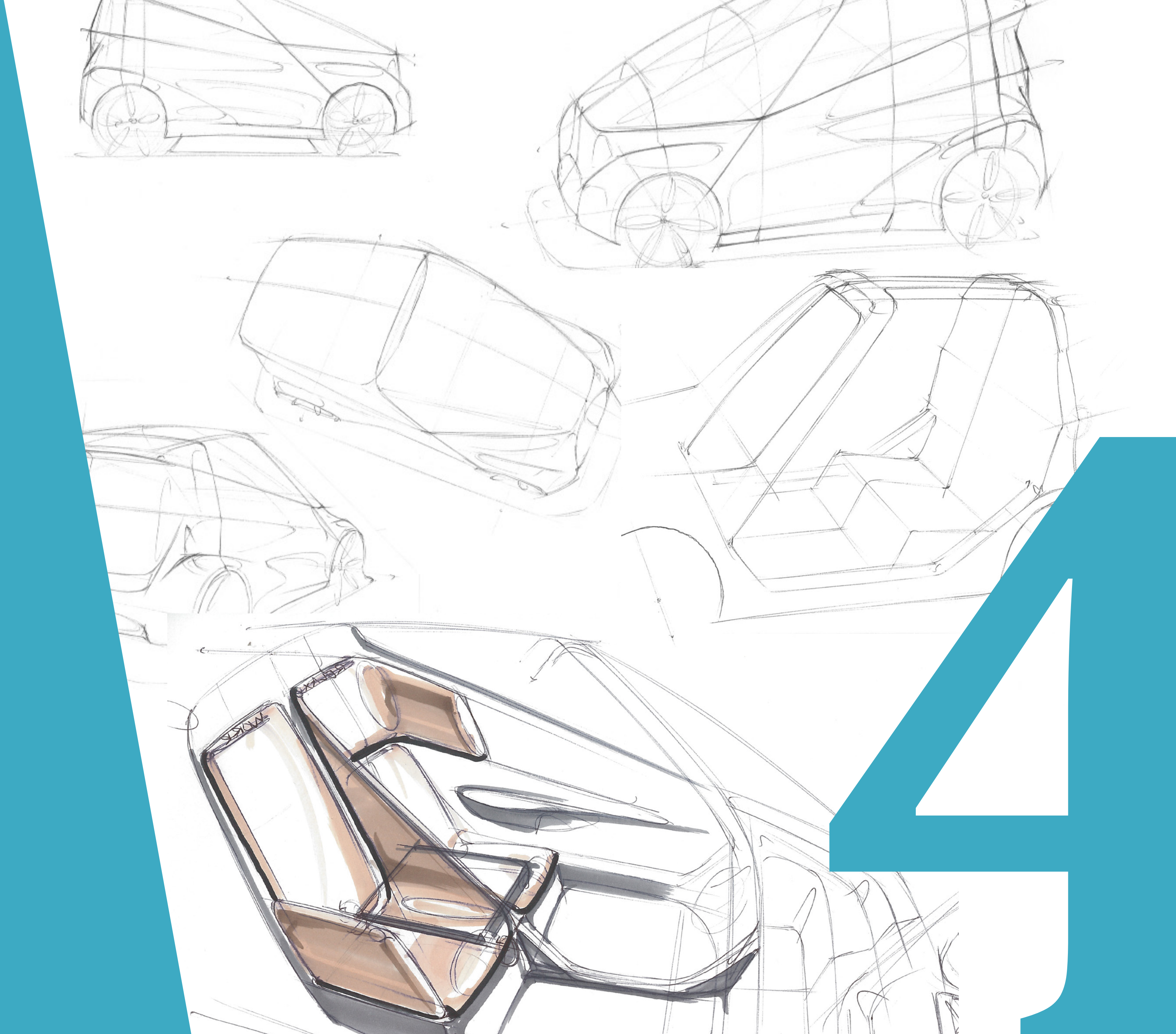
- The ride-sharing option of the second scenario is expected to be most prone to abuse, which is challenging from materal point of view (material wear and representativity)
- With more on-demand transportation the line between ride-sharing (commercial vehicles) and private transport is blurring. This is important to realise, but at this moment the focus is prioritized to be on the less commercial-like vehicles. Additionally, it was mentioned that it is difficult to make proper use of all the potential outside the primary function's time slots of the school scenario.
- Regardless of the fact that the main purpose of the leisure scenario combined with the car sharing service has not been addressed by other companies as such, it was recognized to have similar needs for the interior function as already proposed concepts by OEMs and therefore the result might be less unique than expected.
- The long distance autonomous vacation travel might be difficult to imagine to happen in 10 years, considering the vehicle operation would be in an autonomous-exclusive environment in my vision.
- There is a lot of potential for sustainability improvements in a shared AV system with fleet ownership. Separating and collecting different materials in the current personal ownership based system is difficult (due to different owners and complex multi-material assemblies), but with fleet owners gaining a larger market share, collecting vehicles or parts for recycling can be better regulated and the change in structural demands of the vehicle opens up opportunities for less differentiation in material use.
- The urban trip scenario was recognized to have the most potential due to the possibility for uniform material use and related recyclability potential. But also the secondary functions that are complementary to the main function, makes for more intensive and broad use, supports this decision.

***The electric 2-seat AV brings the users to and from work in an all-autonomous environment. The car can be hailed for other trips with similar needs (up to 2 persons, some storage space and (sub)urban travel (30min)). Fleet ownership allows for better regulation of collection and separation of materials at the EoL. DfD and repairability elongates the life cycle, adding to a more sustainable concept.***

# 4

# FURTHER DESIGN DEVELOPMENT

*Now the desicion for a scenario is made, relevant aspects and conditions for this particular scenario is collected. The vehicle functions are affecting the interior and these interior functions are affecting the exterior. Also the material choices are driving the way that parts connected and how the panel ga can look. Additionally, moodboards are made as a reference for the design and styling of the car and these collages are reflecting the aspects that are found to be important in a autonomous car.*



# Design boundaries

*The extensive research on the developments of autonomous transportation and the development of the scenario leaves me with several valuable design boundaries and changes in regard to the current function and approach of car layout to operate within.*

## Boundary conditions

Safety:

- The decision to go for a scenario where the operating domain of the vehicle consist of only fully autonomous vehicles (single mode), indicates that the number of accidents could be decimated. Consequently, passive safety systems such as crumble zones and impact resistance can be reduced.
- Because the vehicle is operated solely by the ADSs, there is no human driver and no driving controls (such as a steering wheel, pedals and anything else related to the driving task).
- Any other outside function related to the driving tasks (a relatively flat windscreen that can be dried by the windscreen wipers for good visibility, a windshield and side windows that account for the required vision angles, and low and high beam headlights lights) are therefore rendered obsolete as well.
- For the perceived safety, acceptance and satisfaction it is important that the feeling that the car should evoke is trust, especially now the behaviour of the vehicle is not within the control of the user.

Traffic flow:

- To benefit the most of autonomous technology, beside V2V communication it is preferred to have a system in place of V2I communication, which is only viable to implement with a higher user intensity, advocating for ares where a lot of AVs are driving.
- With the situation that the car can be hailed at any given moment , trips without any occupants in the car are going to occur. Therefore the communication with pedestrians and other road users with non-motorized vehicles should be clear. This is also the case when the car is occupied, because the passenger is not in charge of the behavior.

Convenience:

- The vehicle is used for the daily commute and additionally for trips within the city, like shopping or going to appointments. Some of the desired functions relevant for this short distance travel are watching in the driving direction, using the smartphone, working, relaxing (listening to music, eating/drinking and doing nothing).

Comfort:

- In the car interior comfort is an important attribute and can be addressed by visual appearance of materials (e.g. touch and feel, shape, color). The physical comfort of seats (contact area, material softness and body sensitivity) and preferred seating angles can be implemented as well and the seating position affects the size and proportions of the car. But most (physical) discomfort appears after 45 minutes, which is longer than the envisioned 30 minutes trip length.
- Seat adjustability is needed for cars with driving positions and potentially desirable for passenger seats to decrease physical discomfort. But with the short trip length, and the scenario with intense (shared) use, reducing moving parts (which are more prone to breaking down) is preferred.

Health:

- Due to the fact that people who used to be drivers become passengers in the AV and lose control and associated motion anticipation capability, more people might become susceptible to motion sickness. A forward facing seating layout reduces the chance and severity.
- Additionally, looking at the horizon in the direction that the car is bringing you is also preferred in this respect.

Ownership:

- The shared car system is different than private onership. People are less carefull and therefore parts are damaged more easily. The car is also used more intensively, as it can be hailed by anyone at any given time during the day. Beside bringing you to your destinations, the car itsels is also driving some distances without passenger.
- Because it is shared, people are will be more inclined to get a smaller car that fits their needs for that time. When buying a car you want it to fit every need you think you will encounter, and therefore a twoseater is often not sufficient for other purposes than the ones it is used by only yourself. The smaller footprint -physically and ecological- could result in more space in the city and less emissions and depletion of resources.

Material:

- The material choice (focus on plastics) allows for weight reduction and more economical vehicles.
- The sensors are to be integrated in some of the plastic exterior parts, which is not possible with metal (and difficult with glass).
- The shared mobility type and fleet ownership allows for a focus on a system where parts are replaced and recycle

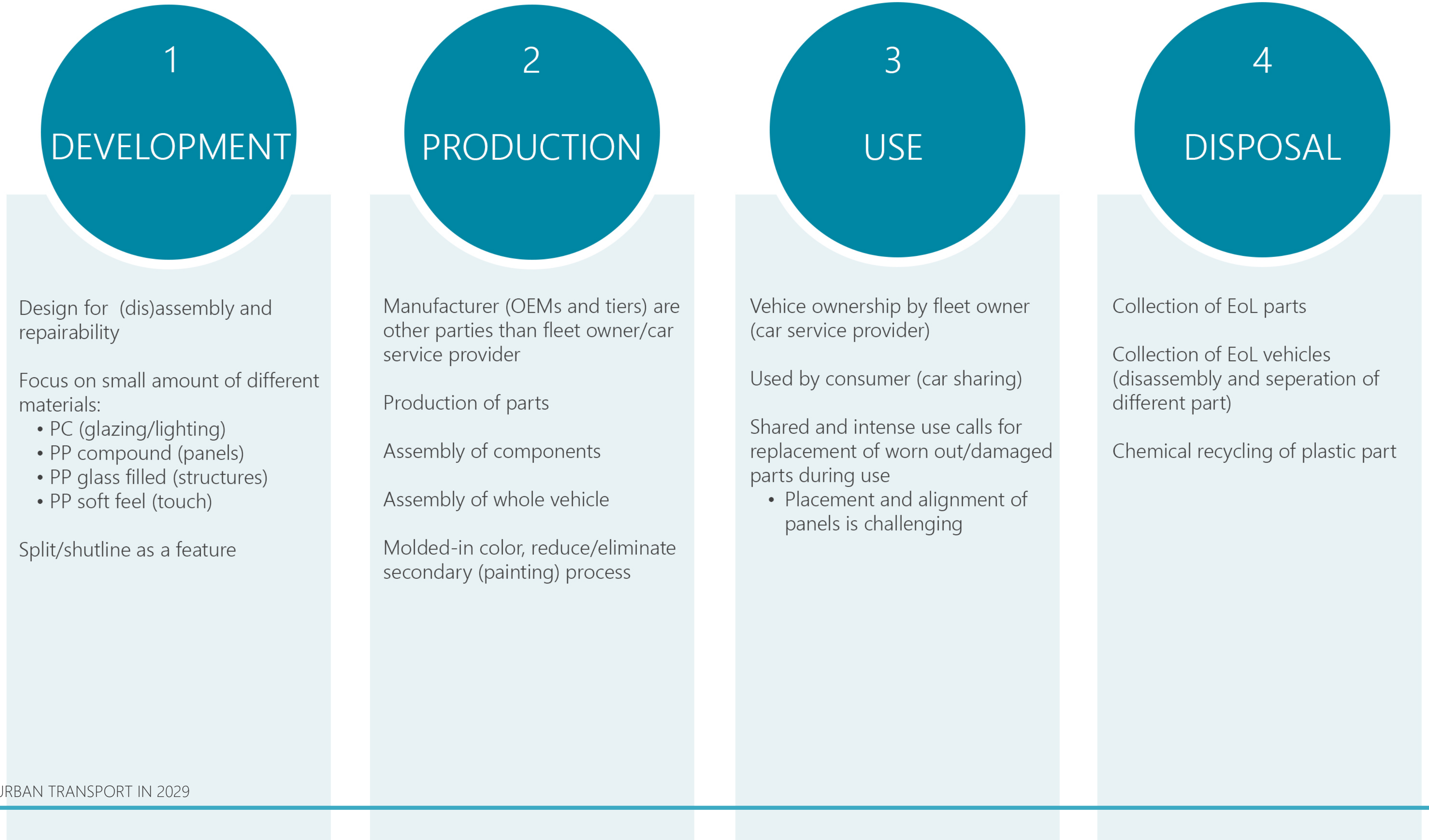
# Life cycle

The chosen scenario of the shared purpose-built twoseater vehicle for the commute and citytrip allows for a different approach of vehicle development and life cycle of the car itself and components. Especially for a raw material supplier as SABIC it is interesting to see what can happen with parts and materials during the vehicle use.
The shared aspect -and accompanied fleet ownership- allows for a more clear system to see what happens with parts. Fleet owners check and service their cars frequently and if parts are damaged, broken or worn out, they can replace them. Due to the fact that the re are only several vehicle owners for a lot of cars, collection of replaced parts and do something with it is more convenient.

I see an opportunity here for a system where replaced parts and the whole vehicle at the end of life (EoL) can be collected and send to recycling. Some aspects that can be considered and are affecting eachother are depicted in figure 17.

Reducing the amount of different material makes seperation and determination of the grades more easy. Keeping the design for repairability in mind and replacement of parts, makes that extra attention can be paid to easy acces to parts that are prone to wear (especially now the cars are shared and more intensively used, indicating that people might be less carefull an might even vandalize parts).
Additionally, panel alignment issues that might appear with part replacement, can be accounted for in the design of the exterior. SABIC can add value in the process by collecting replaced parts reprocessing them. This can be by the process of mechanical recycling or chemical recycling (see Appendix F for an overview of the recycling system).
Chemical recycling is especially promising, as the process bring the parts back to the chemical building blocks and therefore the quality of the newly compounded polymers is the same as virgin (from fossil feedstock).

*Figure 17: considerations and notes at the four parts of the life cycle of the vehicle*



# Package dimensions

*In order to substantiate the choice for the main outer dimensions of the vehicle I took a look at two aspects: the height needed when looking at human anthropometrics and benchmarking of different city cars, which might be comparable in size. Additionally, improving the seating layout is bound to affect comfort and increase csutomer loyalty.*

## Anthropometry

Currently car seat can be categorized as follows: the driver seat, front passenger seat (which is often similar to the driver's seat) and the rear passenger seats (which can be either shaped as a bench or seperate seats). Driver seats should be shaped an adjustable in such a way that it allows the driver to perform his driver's task properly. With the single-mode autonomous vehicle in my scenario, every seat is a pasenger's seat, as there is no human driver. Additionally, with only two seats in the car and changing safety precautions (no need for seat belts, just as in other form of public transportation) the main seat angles and layout can change.
In this respect, Kilinçsoy (2018) performed a research on the preferred rear seat postures for passengers, which data is also valid for any seat in autonomous cars. As showed in figure 18 the measured joint angles for a standard seating position are about 100° for knee angle and 105° for the trunk-tigh angle. Combined with a 14,5° angle of the seat bottom in respect to the horizontal (Z) plane and looking at the anthropometric data (5th, 50th and 95th percentile, figure 18) of Dutch people (from whom all the relevant data is available on DINED as opposed to other nationalities), this is my reference point for the vehicle development.

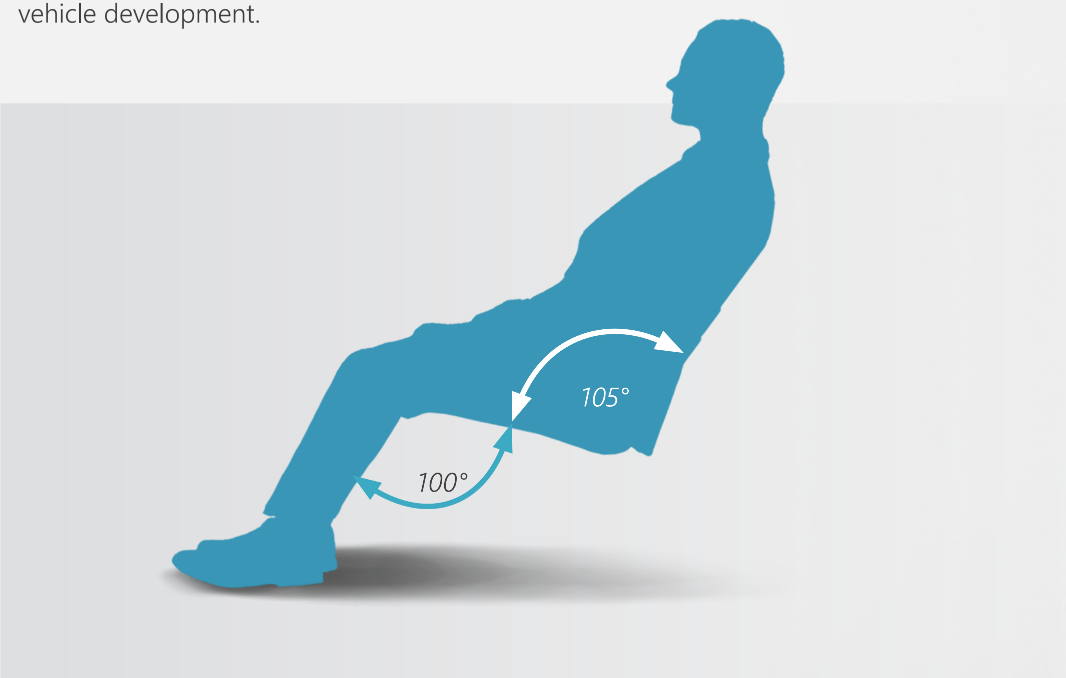



*Figure 18: preferred joint angles for a standard passenger seating position*

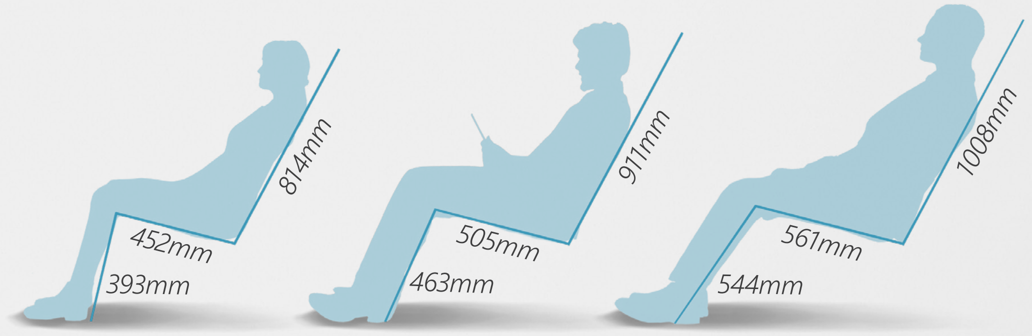



*Figure 19: P5 female (NL, 20-60) P50 mixed (NL, 20-60) P95 male (NL, 20-60)*

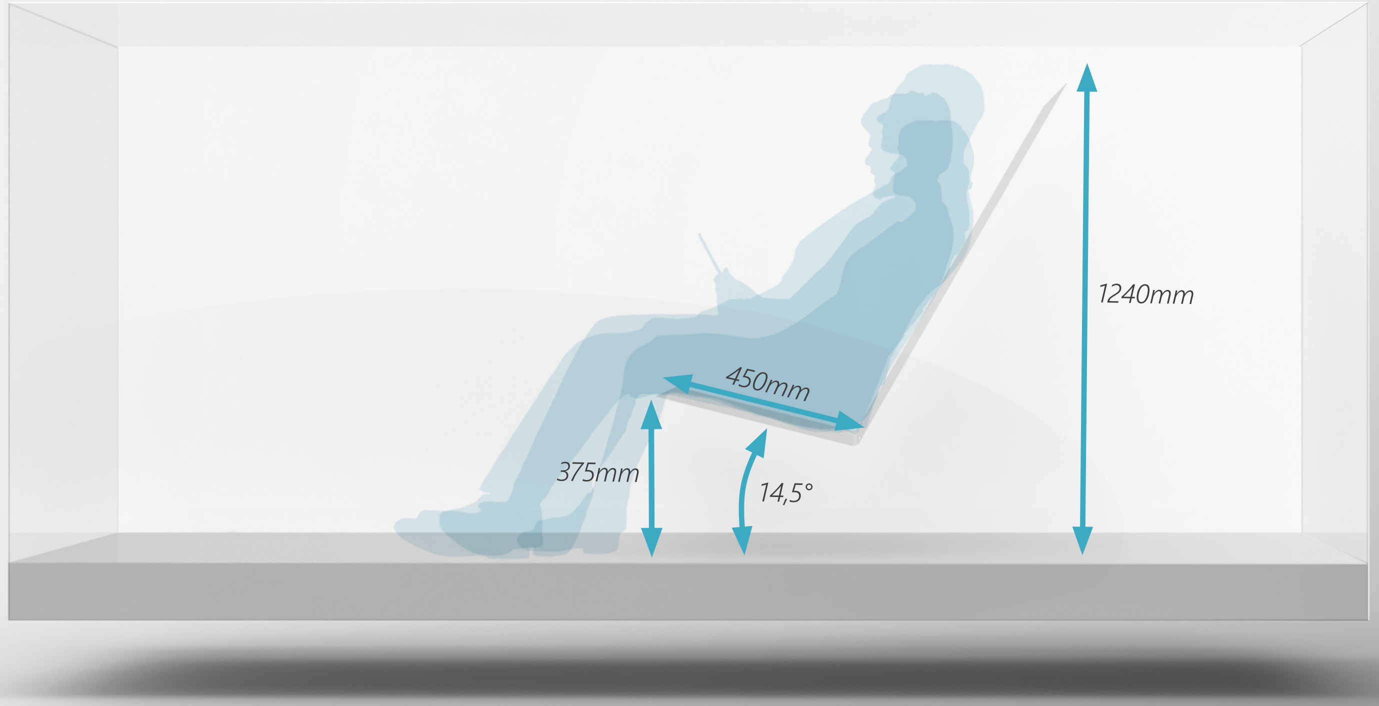



*Figure 20: chosen seat dimensions in package*

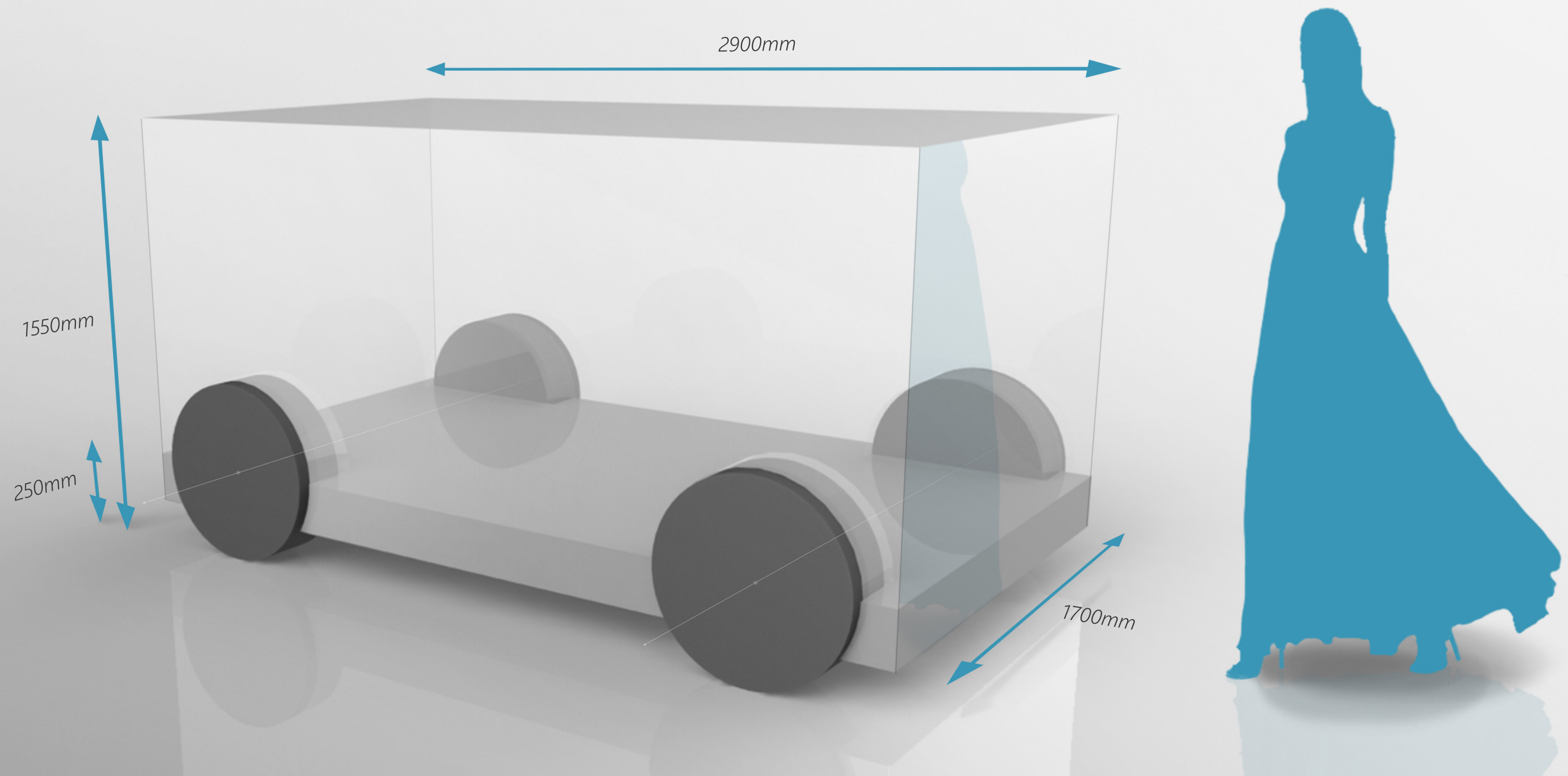



*Figure 21:: starting point for the packaging dimensions*

## Box size

Before starting the process of further developing a design for the chosen direction, the package outlines are decided. With the redundancy of passive safety features such as crumbles zones and pedestrian safety measures, the layout can be slightly different than usual: in order to maximize interior space, the wheels can be placed towards the corners of the vehicle. Besides, this enhances maneuverability and stability -with most of the vehicles mass within the car's axles- which is beneficial for the handling of any vehicle and especially for small city cars.
To get a feel for the dimensions of city cars, I compared some of them as bencmark:

| *Car* | *Lenght* | *Width* | *Height* | *Wheelbase/ avg. overhang* |
|---|---|---|---|---|
| • VW up! | 3540 | 1641 | 1489 | 2420 / 560 |
| • Smart fortwo | 2695 | 1663 | 1555 | 1873 / 411 |
| • Renault Twingo | 3590 | 1640 | 1550 | 2490 / 550 |
| • Fiat 500 | 3546 | 1627 | 1488 | 2300 / 623 |
| • Suzuki Swift | 3840 | 1735 | 1495 | 2450 / 695 |
| • Toyota IQ | 2985 | 1680 | 1500 | 2000 / 493 |
| • Opel Adam | 3698 | 1720 | 1484 | 2311 / 687 |

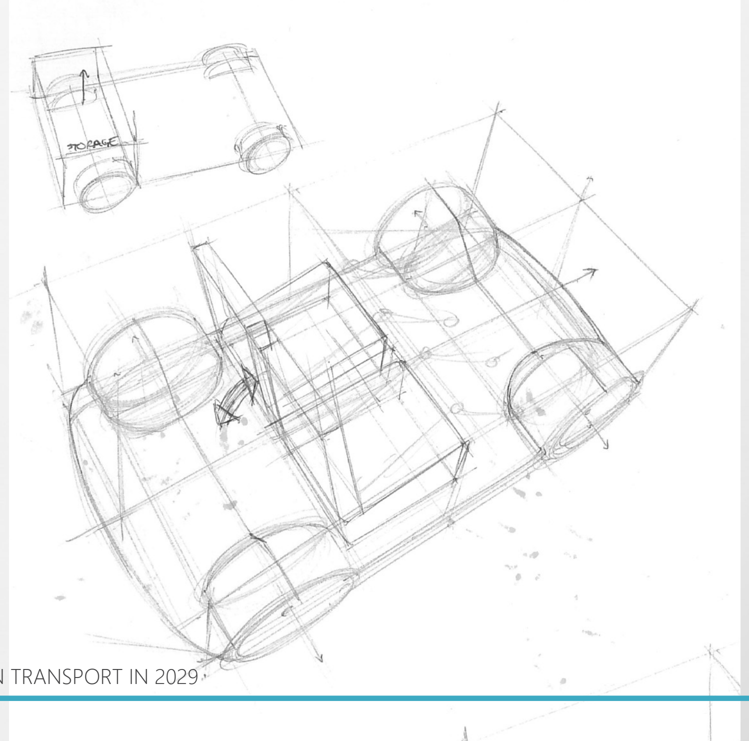
I positioned my package dimensions next to the Toyota IQ, which is either a very small fourseater or a twoseater with sufficient luggage space.

Based on these choices for the required dimensions I drafted a rough platform that I used as a template for the further vehicle design. Detailed imformation about the powertrain layout is out of the scope of this visionary autonomous vehicle. But an educated guess is made based on the rough packaging requirements of the electric vehicle drive train:

- For the suspension system, steering equipment and shock absorbers some space is reserved around the wheels' axles
- At the same location, I accounted for the electric motors and
- The position of the battery pack is dependend on the interior package layout

Based on this powetrain layout and chassis, I started thinking about the interior layout of the vehicle (see Appendix G). The seats need to be forward facing and due to the small footprint of the vehicle the options were limited. To limit the height of the vehicle and bearing in mind the seat angles as determined before, combined with easily accessible storage space, I decided that the somewhat more conventional seat and storage layout works is the best option.

The position and the way that the doors open is related to the layout decision. They can be located in the front, rear and sides of the car.  Choosing the aformentioned interior layout, side door are most sensible, as it allows the users to step in the car directly from the streetside, whereas front or back doors result in the passengers walking a short distance in the car before sitting down. Additionally, the heigth of the car interior should allow for person to stand up, which would result in either a very high car, or a immense door that opens with the roof as well (see Appendix H).



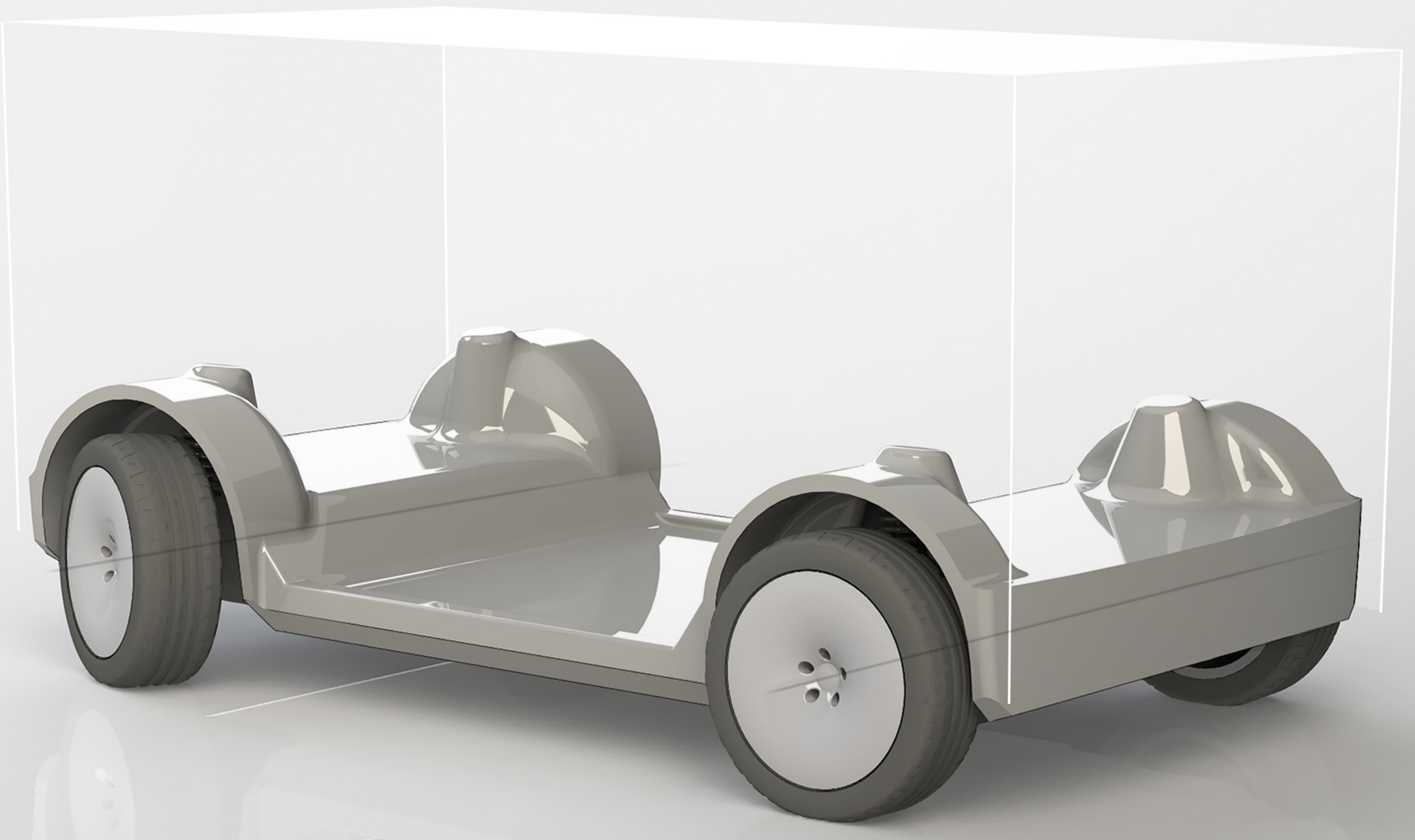
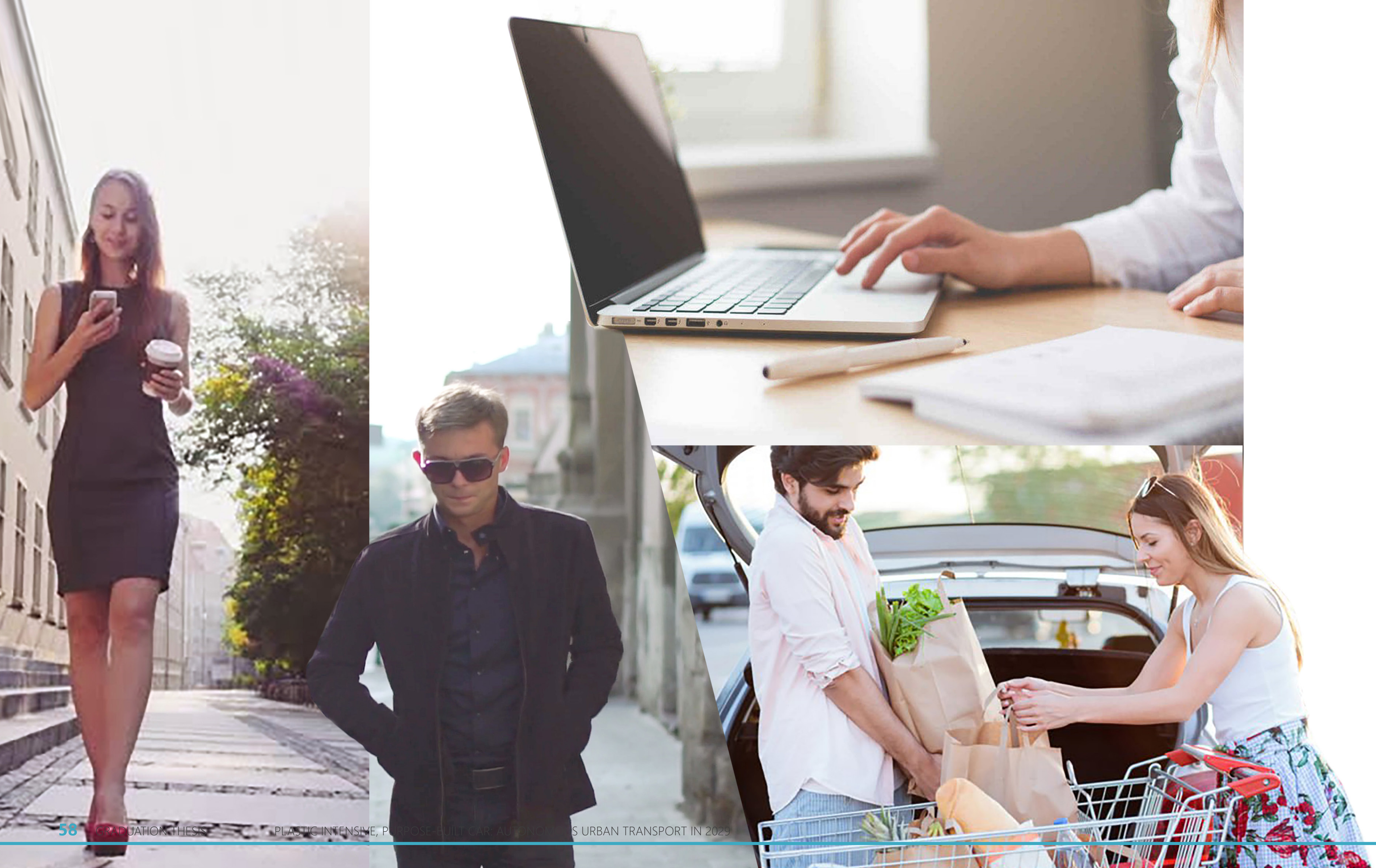


*Figure 22: rough platform layout as underlay for sketches and design with realistic dimensions*





# Inspiration

## User and functions

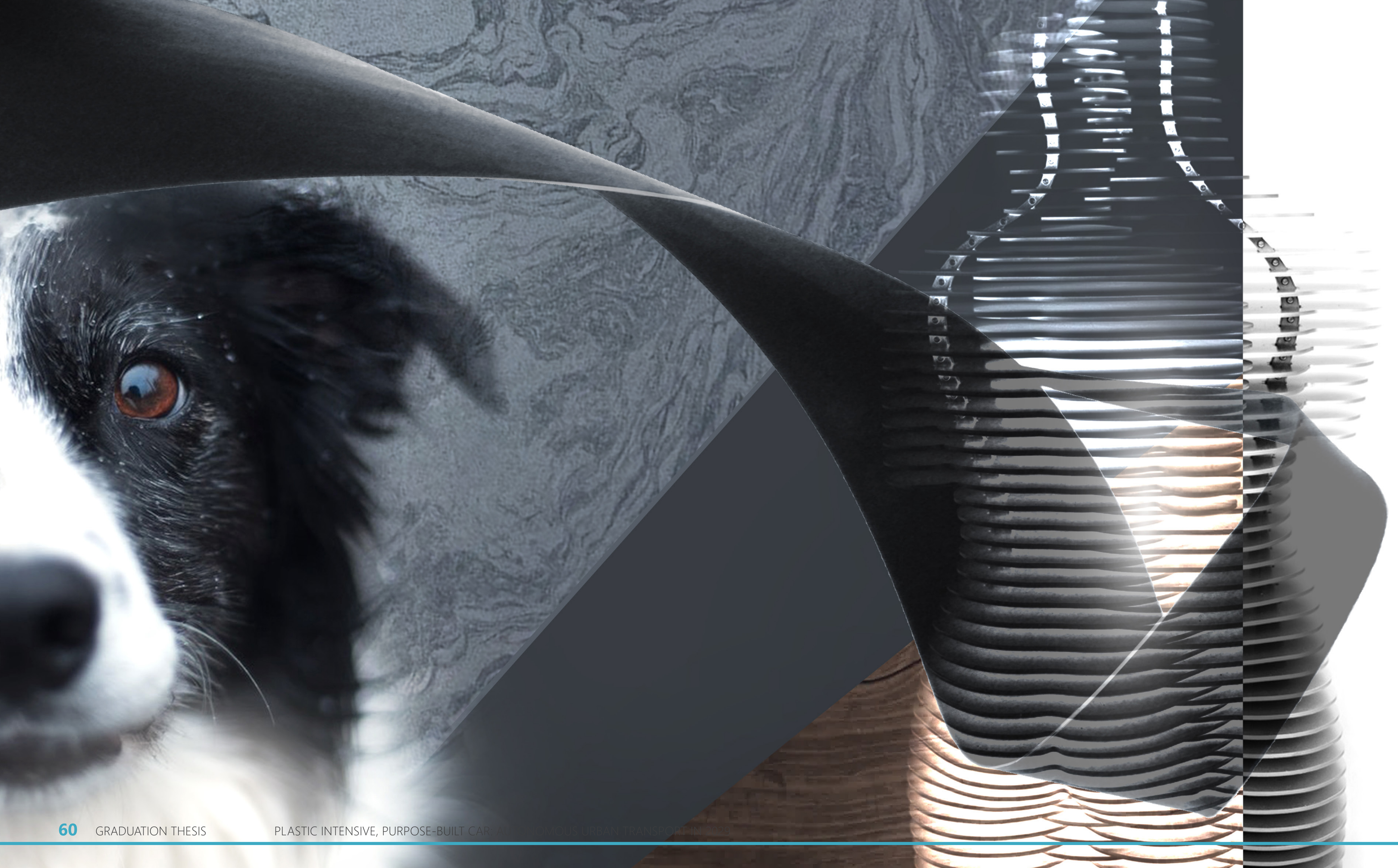
After the scenario choice decision, I can further define the actual envisioned user and the functions of the vehicle.

As the vehicle is intended to be used within the periphery of urban areas, the user is a city dweller. The main function of the vehicle is the commute and therefore a significant part of the time the car is used by someone witin the age range of the working population, but mainly by users from 20-40 years old.

Functions relevant for the short city trip are working (on the laptop, tablet or phone)

Outside work, people do other things where they prefer to use a car, for example going shopping or going to an appointment.

*Figure 23: users and functions collage*



## Character

As mentioned before, it is important for acceptance and satisfaction that the feeling that the car should evoke is trust. Looking into all the different definitions (create confidence and matching expectations with reality and take away risk and uncertainty) and familiarizeing myself with the proposed human-robot trust scale as proposed by Schaefer (2013), I selected some traits that can be addressed by the styling and integration of functions of the car:

- Communication between the vehicle and its users (warning for potential risks and predictability of the vehicle's behavior, in order to foster reliability), creating a sense of protection (feeling of safety, embracement by the vehicle, reliability and security), and evoke a feeling of pleasantness (enjoyment, approachable and dependable).
- Clear communication (showing where to go, warning for potential risks)
- Protection (safety, reliable, secure, embraced, defend, loyal)
- Friendly and pleasant (happy satisfaction, enjoyment, likeable, approachable)

As an emotive reference the collage shown at the left is used. A dog is rather often charaterized as being loyal to the persons taking care of him and shows happiness when interacting with them. This represents the protectiveness and pleasentness of the car. strong divisions and color contrast shows the potential of duality

*Figure 24: emotive reference collage (Moubax, 2019; Köhler, 2016; Kvesitadze, 2017)*

for emphasizing on aspect or another. Everything needs to come together, just as in the artwork shown at the far right, where two humans seems to merge. The ribbon wraps around the features and keeps everything together, providing a protective feeling.

To create a sense of dependabilty I visualized a steady, stable and strong (geometric) collage. The building shows a geometry a bit similar to a mountain: as it reaches the top the volume becomes more narrow and towards the bottom there is more visual weight.
The same goes for the bench at the left: and the outwards stance looks stable.
The sharp transitions, lines and chamfers displays a strong and confident look, but it is good for a design to look balanced and therefor I decided to combine the sharpness with subtle curves and lines with little curvature, as depicted in the pentagonal volume at the right and the ribbon connecting to it.
This ribbon also visualizes the trait of protection, by embracing the the passenger.

*Figure 25: design and form collage (SpaceShapersArchitects, 2019; Domo nova, 2017; Peugeot, 2014; Köhler, 2016))*

## Surfacing

Without a line-up of cars and the absence of a car design heritage, designing a distinct vehicle that sets apart from other cars is challenging. But the changing function, layout and requirements of the autonomous car, allows for different proportions and surface divisions.
On the other hand I decided to look into trends of vehicle surfacing to understand what car companies are doing in this respect, which will be taken as a reference for the exterior design, bearing in mind the fact the the panels will be made from injection molded plastic panels (polypropylene) and polycarbonate for the greenhouse. The collage  in figure 26 shows the surfacing of cars of Infiniti, Mazda, Peugeot, Audi, BMW and Genesis.

*Figure 26: surfacing collage (*Audi, 2019; BMW, 2018; Genesis USA, 2018; Infiniti, 2018a/b; Mazda, 2018; Peugeot, 2016*)*

# Panel gaps

For exterior panels alignment of adjecent panels in general is very important. Often car exteriors are designed with a monolithic approach, where the overall surfacing are developed to fit the envisioned character. But to make it manufacturable the surfaces are split up into different panel, such as doors. lids, quarter panels and bumpers. As the shape is continuing from one panel to another, misalignment of panels respectively to eachother create uneven panel gaps, but more importantly lines and reflections will not continue in the as the designer intented (simplified depicted in figure 27).

When desinging large parts in plastics in general, but also bearing in mind the intensive use of my envisioned scenario of autonomous shared vehicles, there are some aspects to consider that will affect the design:

- The part size and/or the distance from the injection point to the farthest point of the part is among ohter things dependend on the flowability of the used material and the maximum possible pressure for injection.
- Sink marks that occur where there are differences in material thickness (such as places with ribs and injection points) are considered surface flaws and should be avoided or masked.
- The thermal expansion and moister absorption of plastics is higher than metals, which means that the dimensional stability is less. With changes in temperature and humidity, panels can expand and contract, resulting in varying panel gaps.
- With the replacement of panels during the life cycle and the thermal expansion of the parts in mind, permanent fixtures are not desirable. Allowing for some movement makes that panels can misalign over time

This indicates that there are some limitations that should be accounted for and simply converting any desing into viable products, without considering the material properties -being e.g. metal, plastics or glass- is short-sighted.

You could wonder if these criteria are relevant within the shared vehicle system; you also might not care about this in other public means of transport. But this being a shared car and not a shared ride, I assume that it feels to be closer to a private vehicle in the sense that it is used on a regular basis by just one person (or two), and therefore a certain representativeness and neatness is desired.

*Key notes:*

- *Masking injection points*
- *Account for thermal expansion*
- *Masking misalignment*

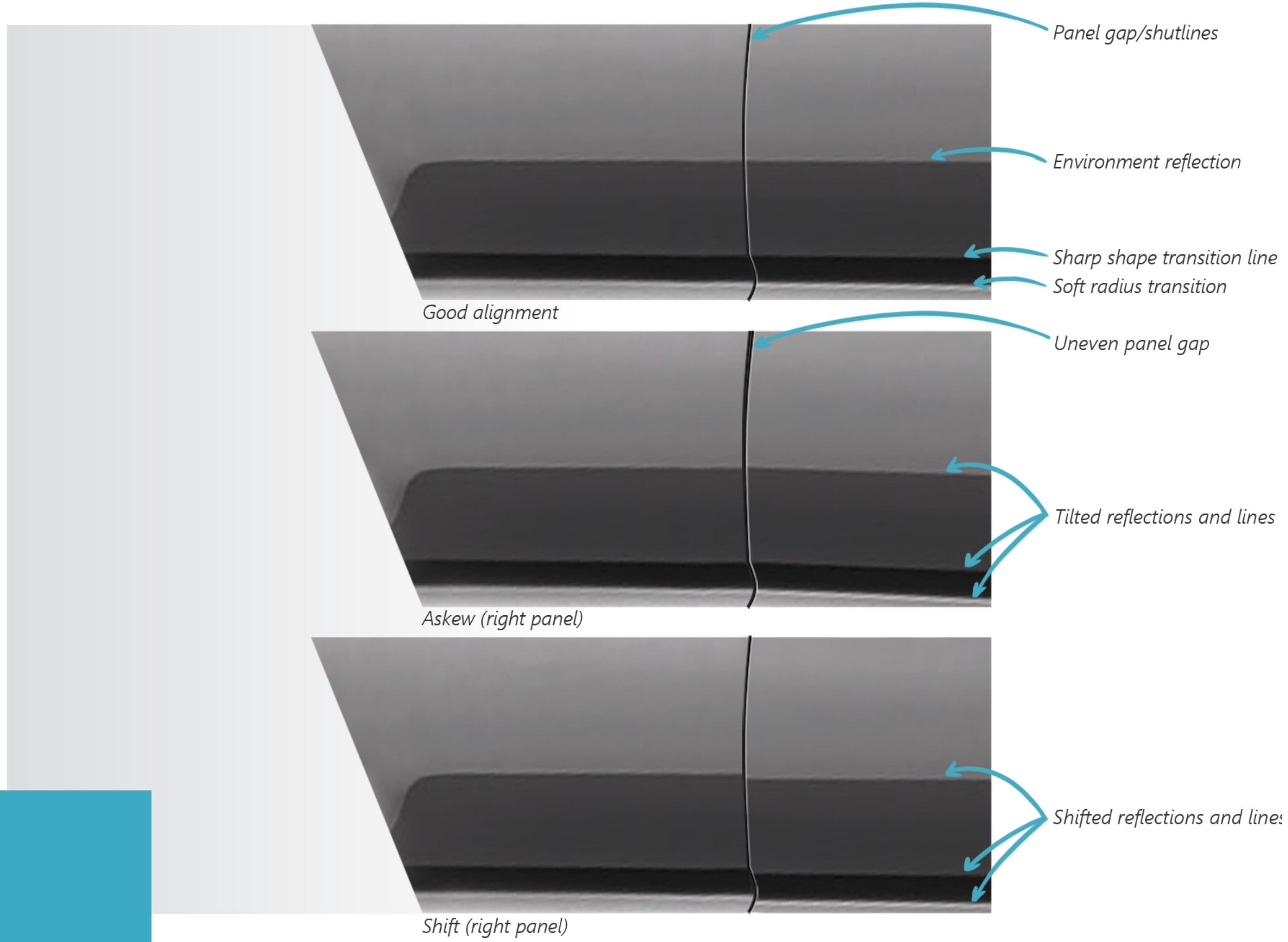



*Figure 27: traditional panel alignment and possible problems*

## With continuity

The high gloss painted finish that you see on most cars nowadays is something that shows very crisp reflections in the surface, rather than casting shadows. When the surface has a more satin or even matte finish, as showed in figure 28, than reflection are more blurred and shadows become more apparent. A poorly aligned panel is now only visible in the gap differences and the non-continuity of sharp shape transition lines, as seen in the bottom image.
The step in reflection on the other hand is virtually becoming invisible.

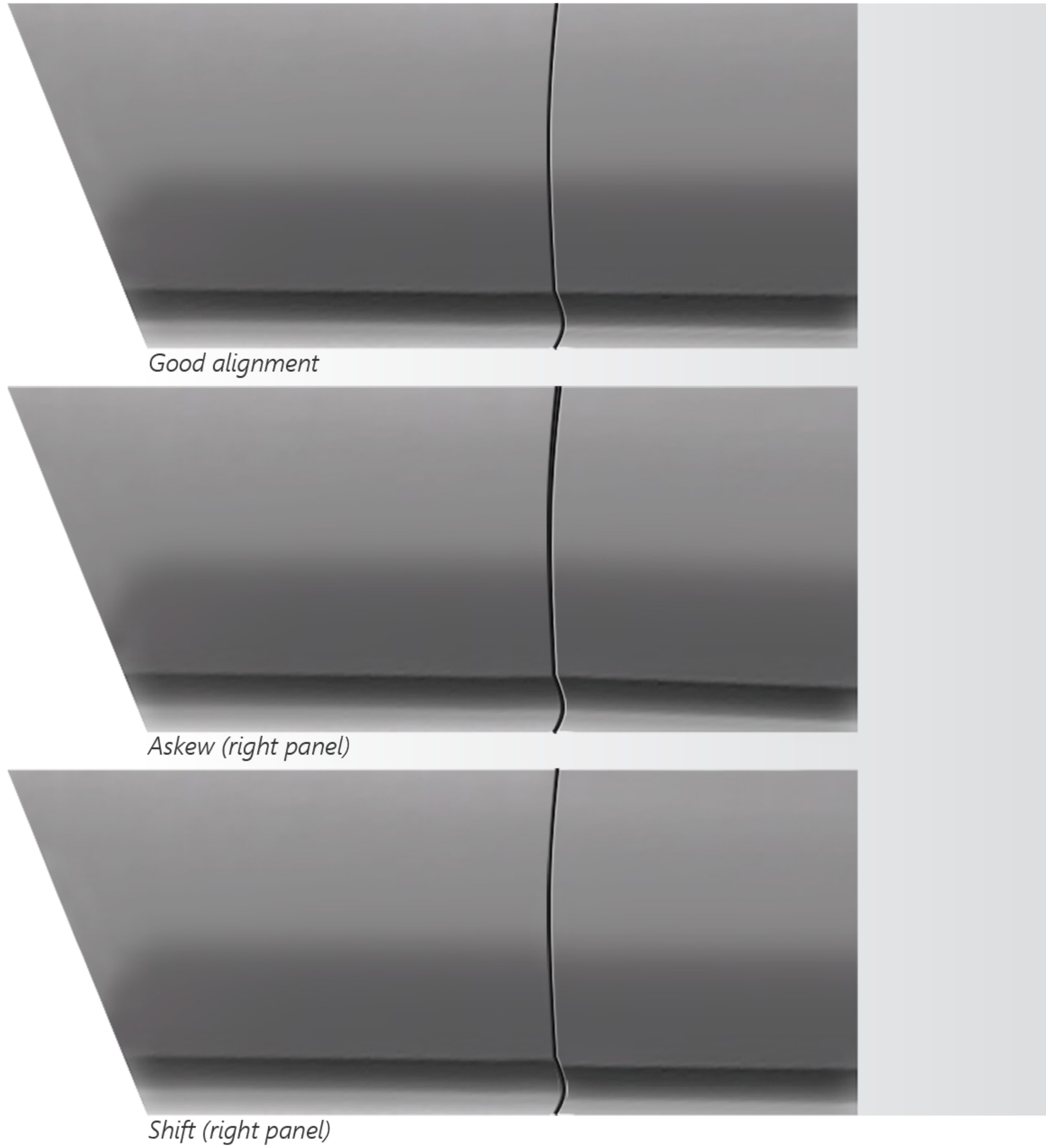



*Figure 28: panel alignment with matte finish*

Another option for panel alignment where the interpanel appearance is continuous, is using the shutline gap as a feature. Illustrated in figure 29, this is simply demonstrated by increasing the shutline gap significantly. By doing so the uneven panel gap in the middle picture practically disappeared to the eye and the tilt in lines and reflections are also less visible as it is missing the reference of a direct adjecent panel.
At the bottom image the step down is still visible, albeit it less eyecathing due to this large distance between them. In a design this type of gap can be used to create depth to the exterior, an accent color can be added to the part that is now black (shadow) or indirect lighting features can be implemented. Additionally the shape itself can also contribute to the overall body design and communicates a certain fairness by not hiding away imperfections, but using it in its advantage.

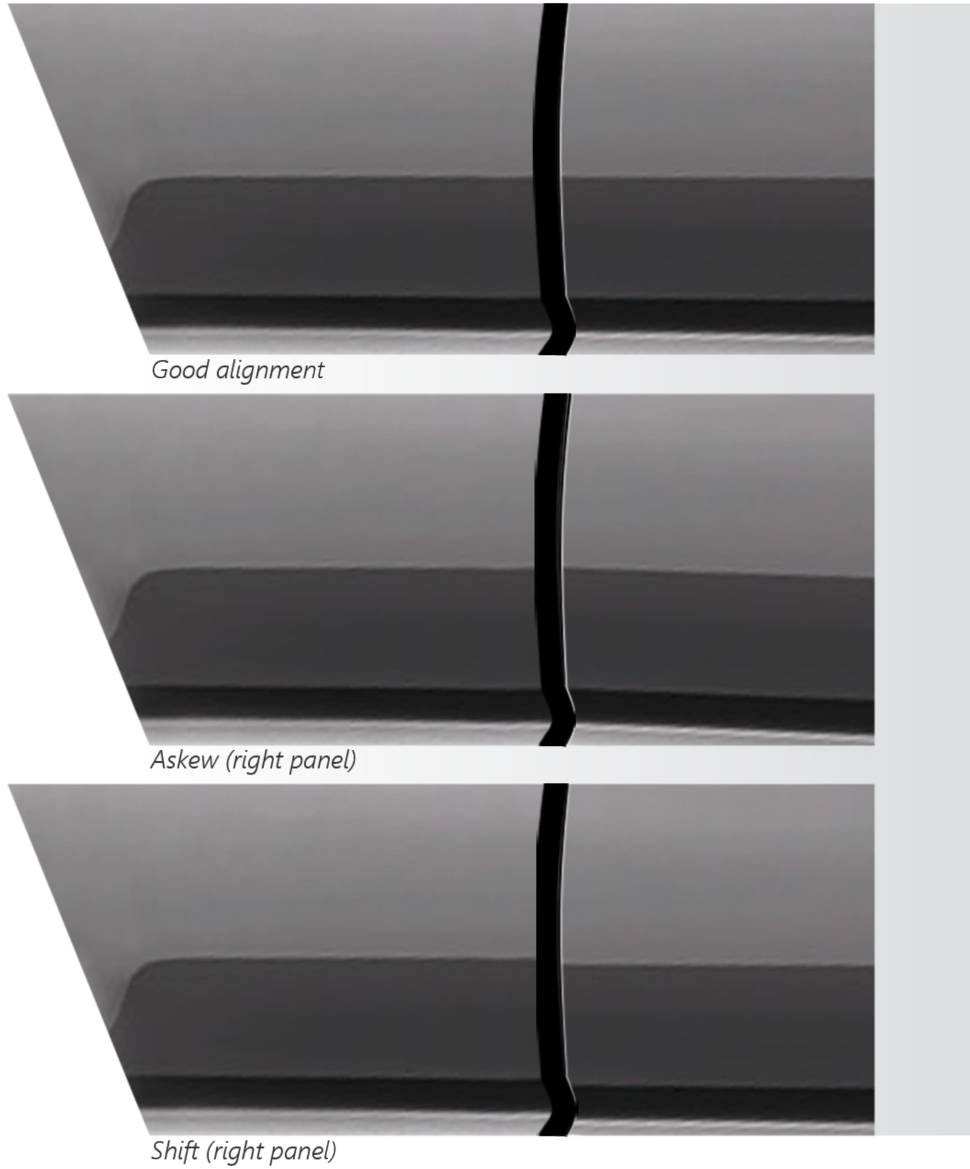



*Figure 29: panel alignment with deliberate gap feature*

## WITH INTERRUPTION

Beside the aforementioned two options with interpanel shape continuity, another option can be to use panel gaps as an introduction to something else. For example an abrupt shape transition as depicted in figure 30. As there is no continuity in shape (maybe only the edges of the parts that are adjecent to eachother) flaws in panel placement can only be recognized by the differences in the width of the panel gaps (as seen in the middle picture, askew).

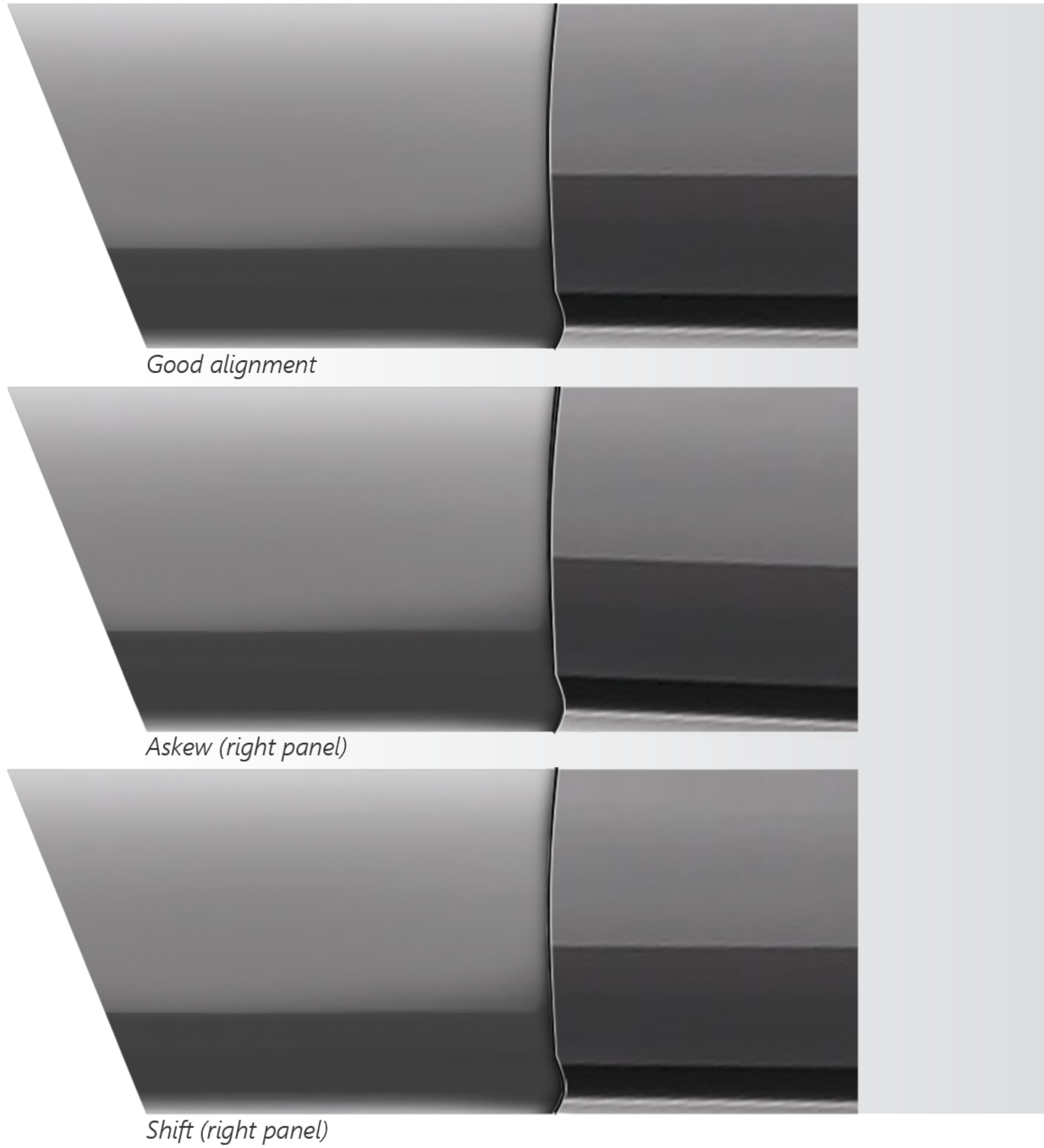



*Figure 30: panel alignment with deliberate shape transition*

A potential solution that is a little bit of both -surface continuity and interruption- is the one showed in figure 31. By changing color or finish between panels, a discontinuity is suggested, but the shape is still continuing. This interruption works quite well as the eye is drawn to the contrast between the two panels and shifts the focus from possible imperfections in alignment.

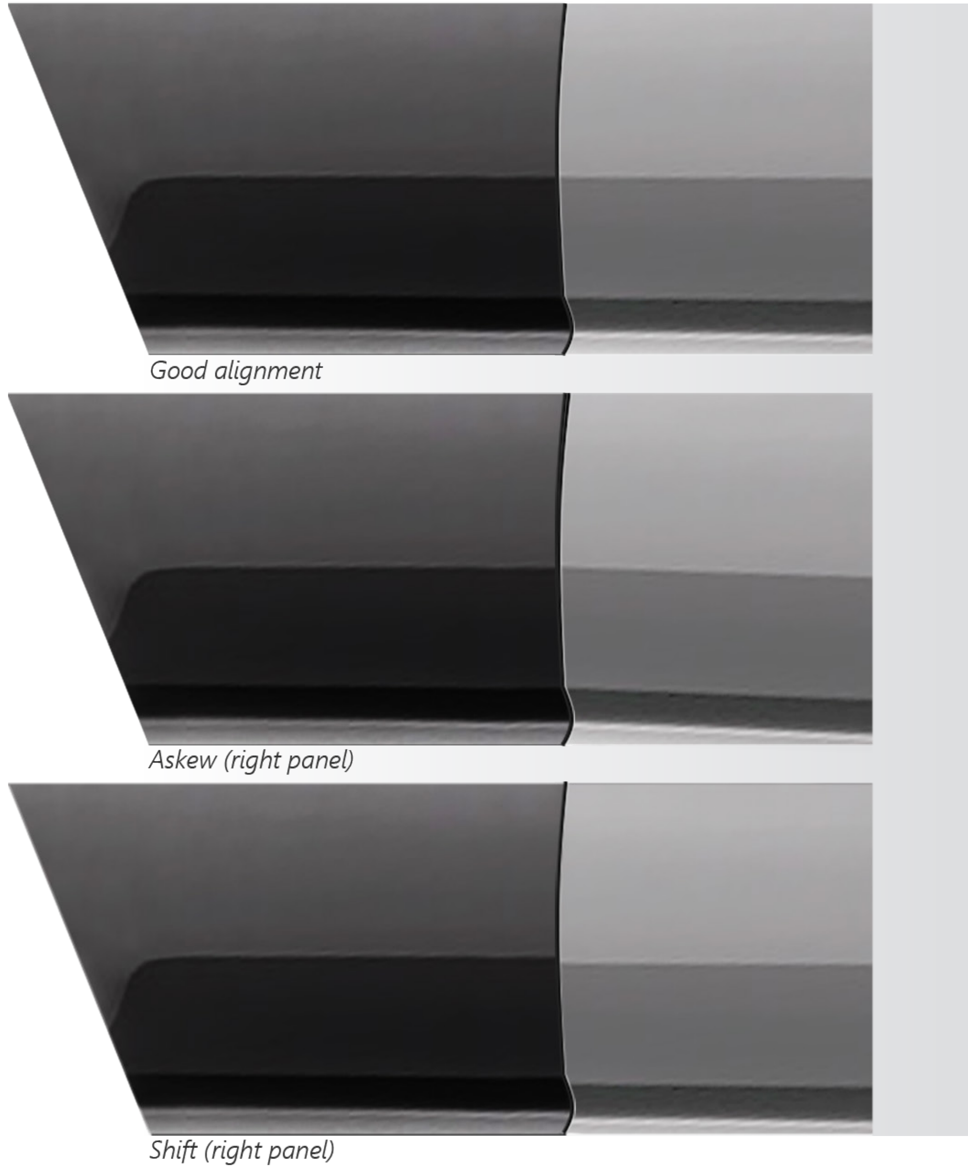



*Figure 31: panel alignment with color/finish differences*

# Design implementation

## Exterior

After a lot of sketching (of which a small selection can be found in Appendix J) and looking for interesting lines using the underlayer with the dimensions I mentioned before, I ended up with these three ideas. The middle design (figure 33) shows some more subtle curves, whereas the left and right (figure 32 and 34) are more angular and sharp. They all share the strong diagonal lines that I was after, but I implemented it in different ways.

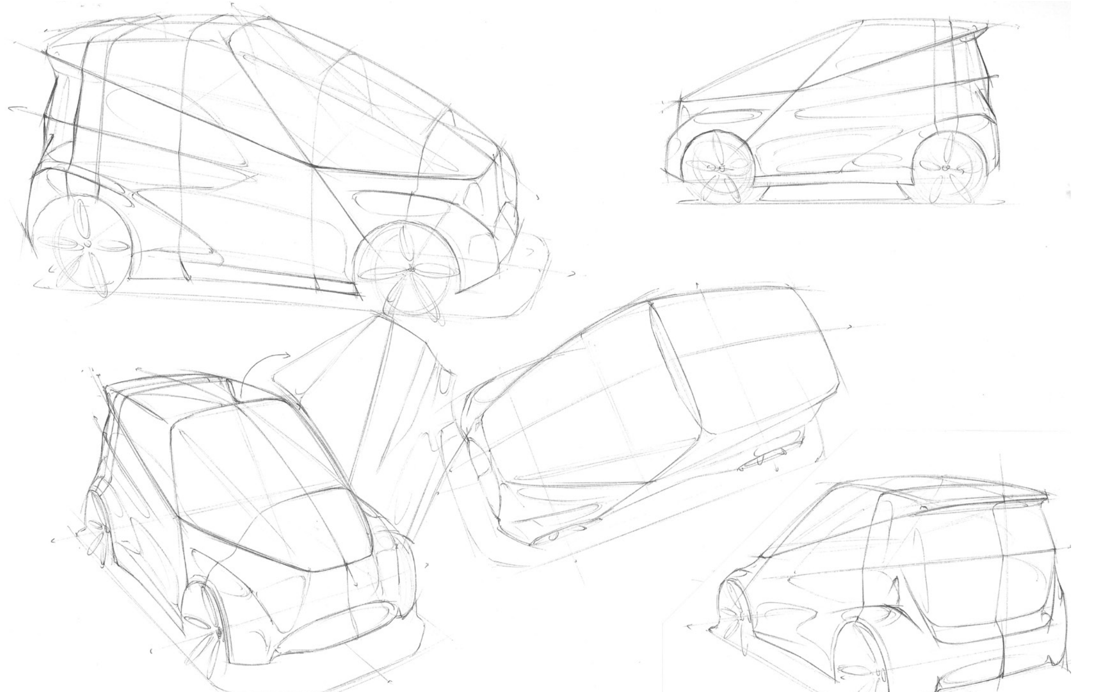


*Figure 32: design idea 1, strong triangle theme*

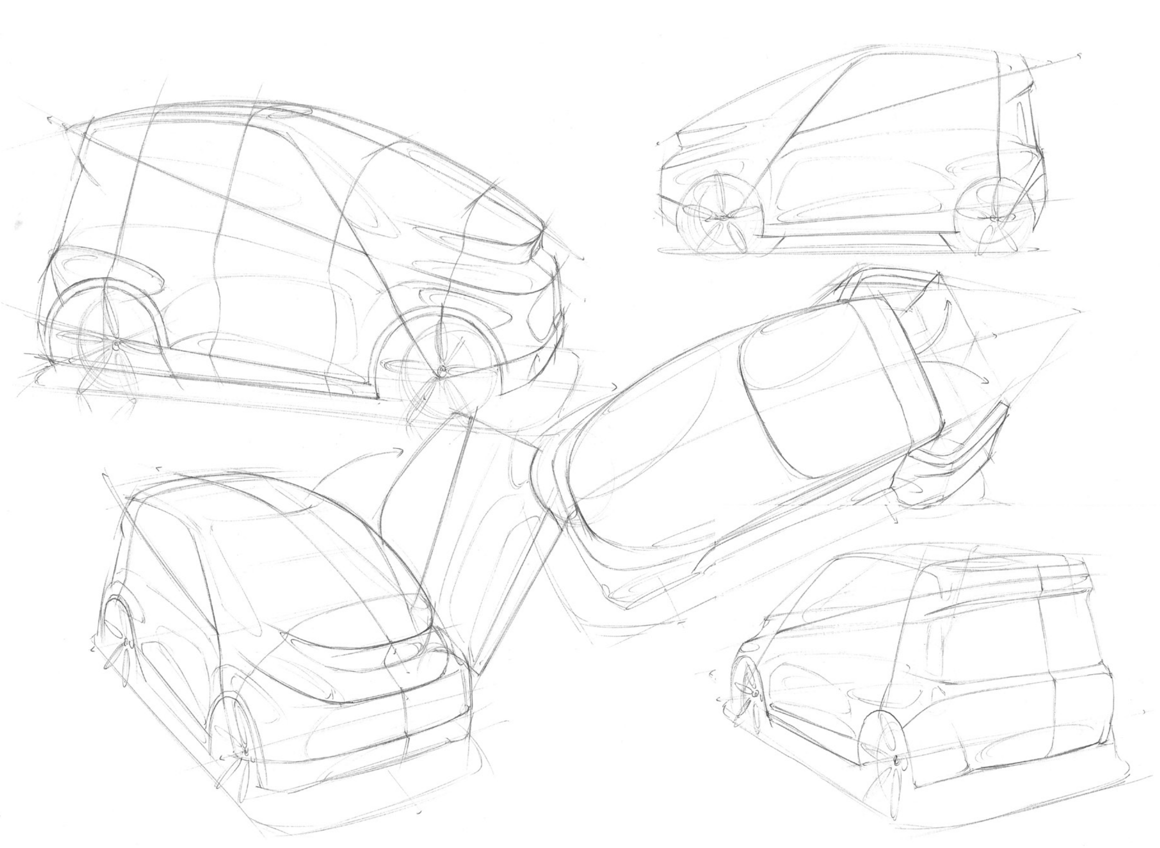


*Figure 33 design idea 2, softer surfaces*

I found designing a car that look nice and has pleasing volumes on such a small platform to be rather challenging, especially considering I had to work without a brand identity or design heritage.

On the other hand there are more possibilities to step away from conventional two or three box layouts and create something unique keeping the autonomous character of the car in mind.

I decided to continue developing the left exterior design idea, as I really found this to combine strong graphic lines, with some subtle curvatures. To some degree, design features of the other ideas were also added to the final design, such as the shape transition in the bottom front glazing of the second design and the more rounded front fender of the third design.

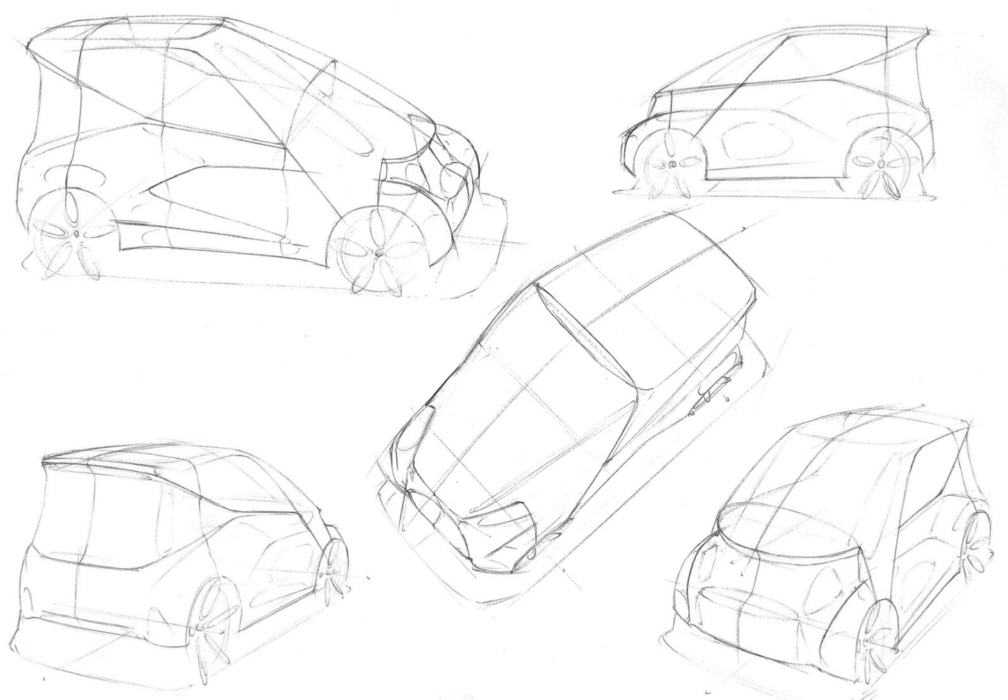


*Figure 34: design idea 3, strong lozenge with softer front*

This is the exterior design that is used for starting the desing in SolidWorks. When putting real dimensions to it, some features, shape transitions and volumes changes, but the overall feeling should remain.

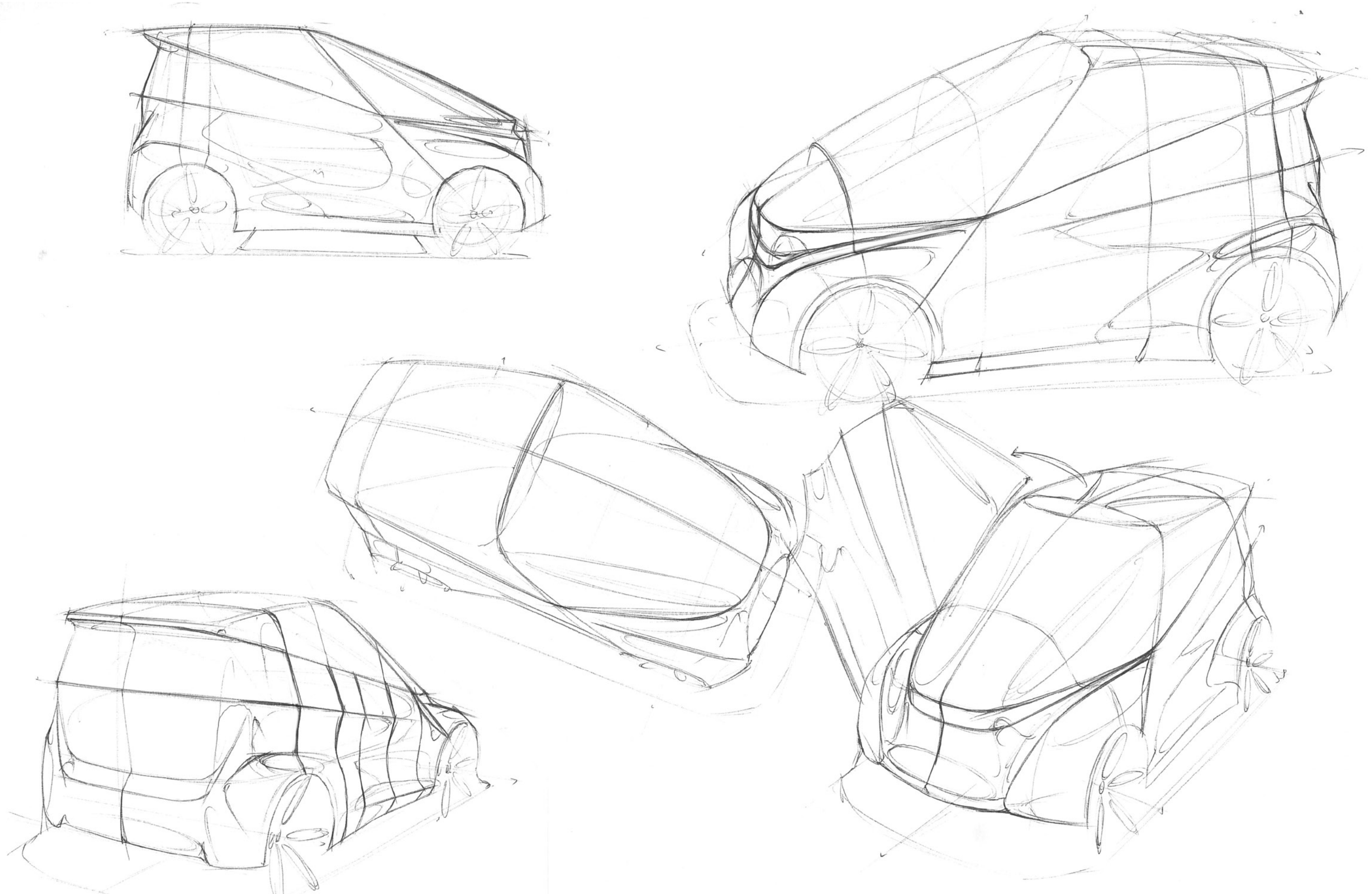


*Figure 35: final exterior design idea to further develop in CAD*

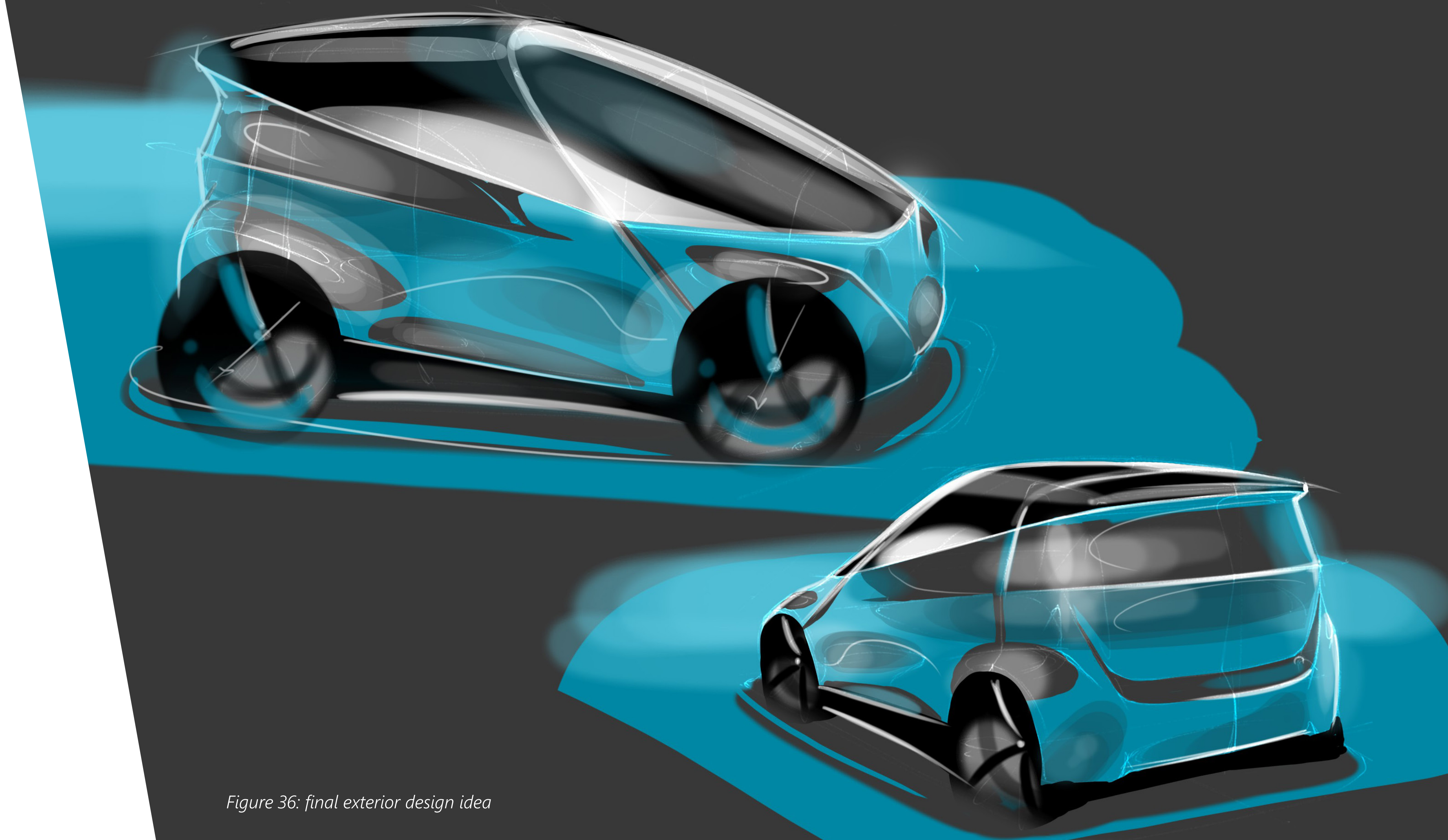


*Figure 36: final exterior design idea*

# Interior

The design of both the interior and exterior happened simultaneously and are both affected by eachother, in terms of styling as well as in function. There are so much decision to be made, for example whether to go for a seperate seat lay-out or one bench, what details and functions to consider and what to assume (it is not possible to develop every detail). A selection of sketches for the interior can be found in Appendix K.

The main idea for the structural part of the vehicle is shown in figure 37. The seat bottom area sits on top of the platform and the side sills cover up structural longitudinal beams. The a-pillar goes from one side to another and carries the greenhouse. The division of functions is emphasized by the different seats and doo panel insert at the left and right, as shown in figure 38. In stead of adjusting the seats to their needs, the users chooses the seat that fits their requirements at that time best.

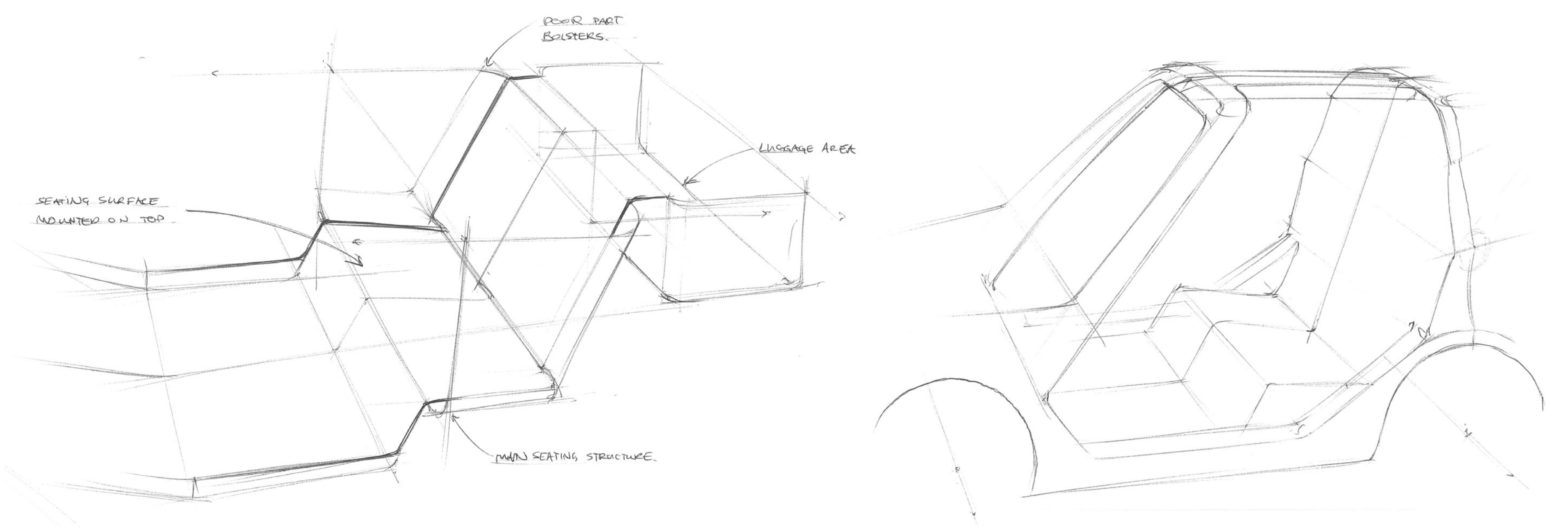



*Figure 37: main interior construction*

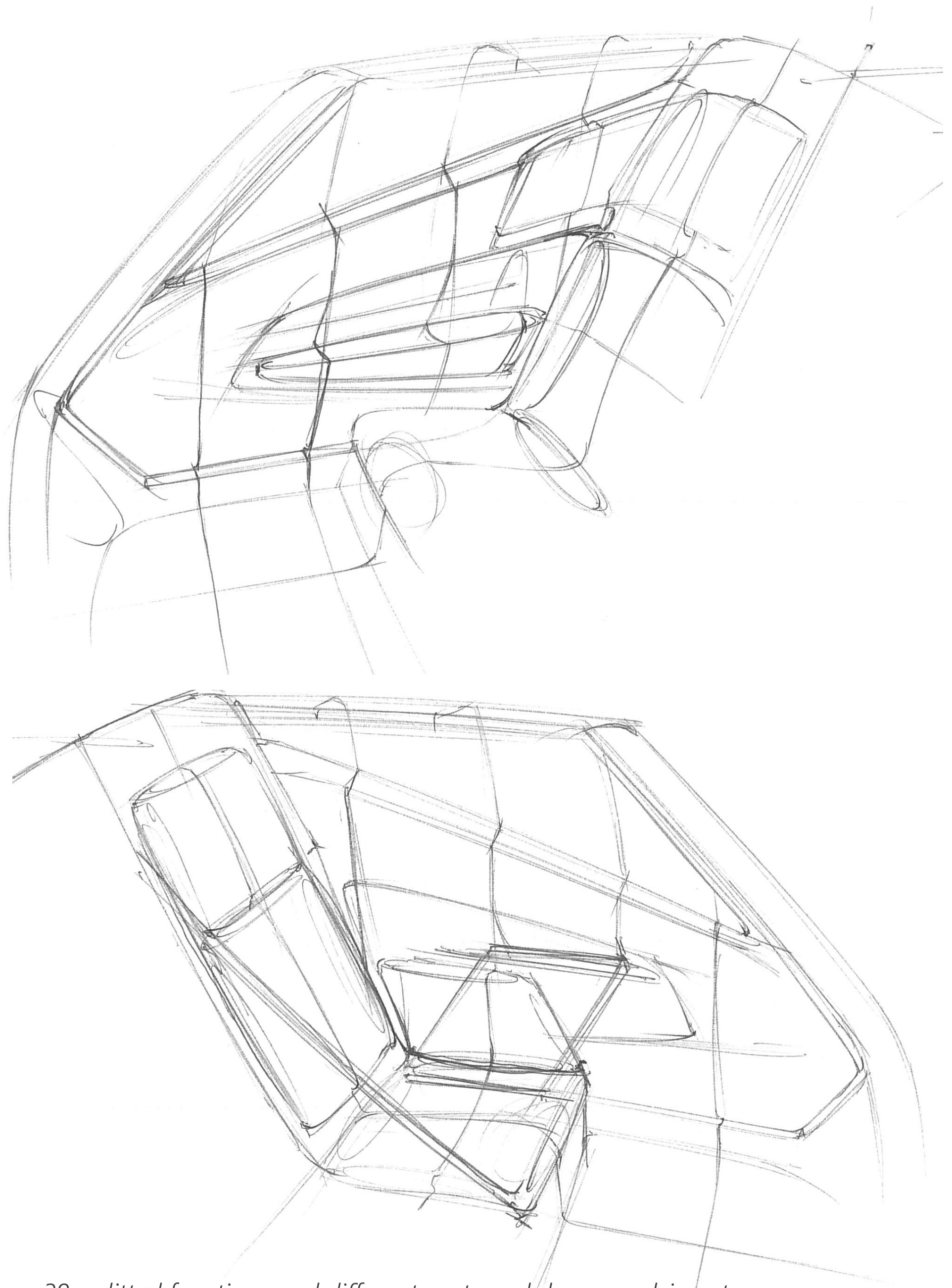


*Figure 38: splitted functions and different seats and door panel-inserts*

The different possible uses in the interior are highlighted by a clear division in the interior as mentioned before. Passengers can sit back and relax, user their phones, connect with the car's entertainment system, have something to eat or drink or do some work.
The a-pillar that continues from one side to the other is accentuated and is an important graphic in the inteiro. It also depicts the embracing nature that I am after in the desing, to create trust and dependability.

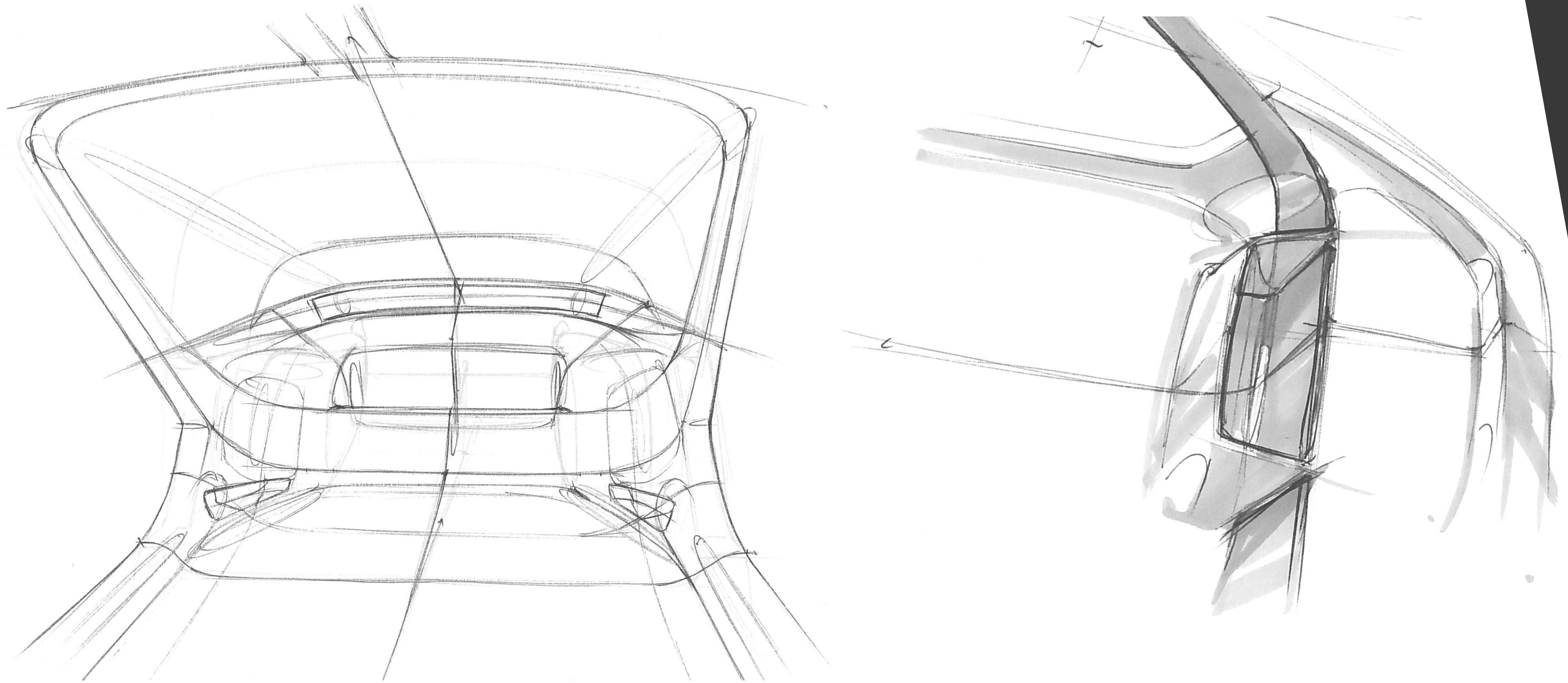
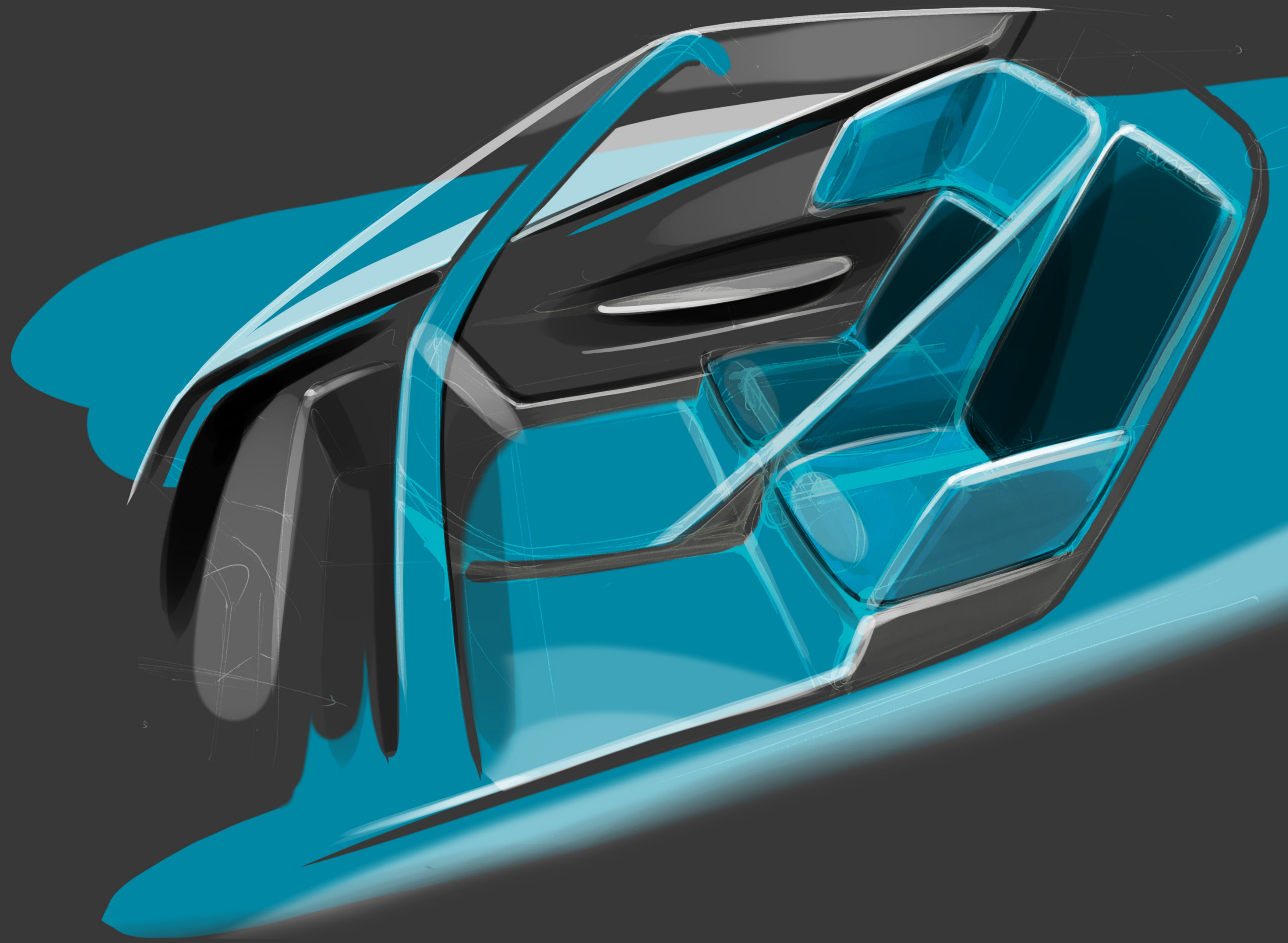


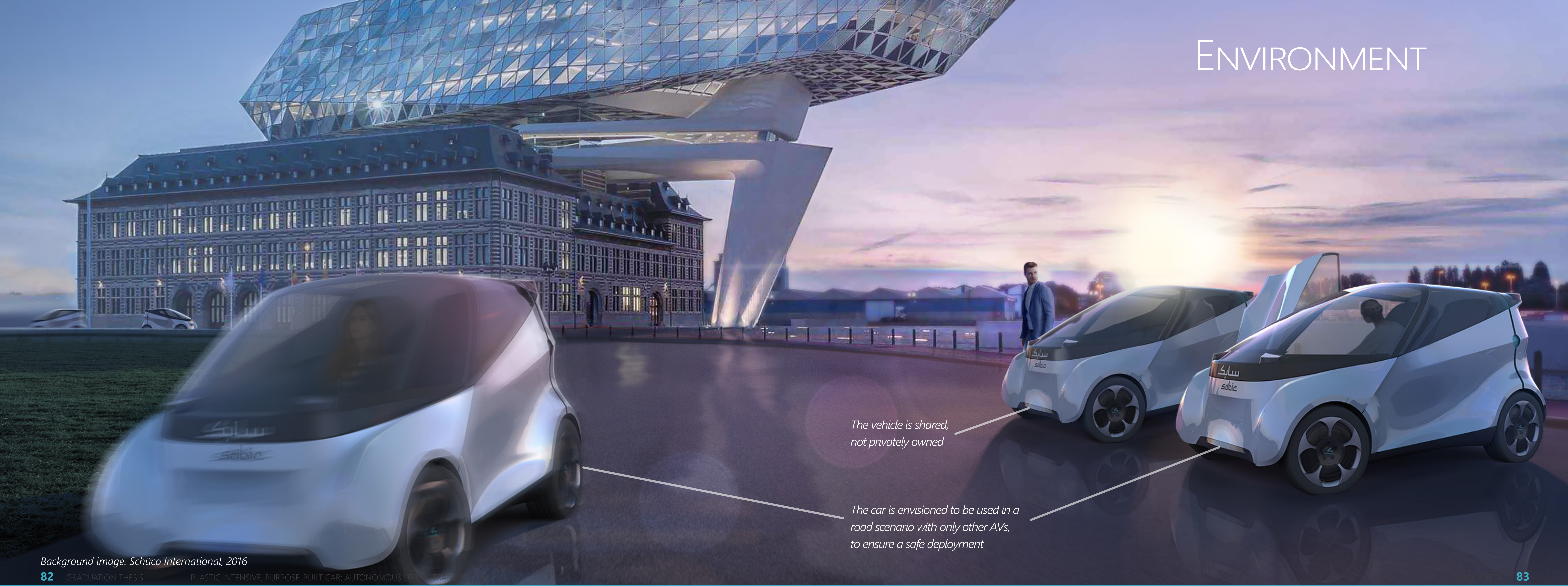
*Figure 39: final interior design idea to further develop in CAD*



# 5

# Final concept proposal

*In this chapter you wil find the final design proposal. The use, special features and how all the research comes together in this design is highlighted in high quality CAD renderings. The images are accompanied with only the necessary text to indicate what you are looking at.*




# Environment

*The vehicle is shared, not privately owned*

*The car is envisioned to be used in a road scenario with only other AVs, to ensure a safe deployment*

*Background image: Schüco International, 2016*

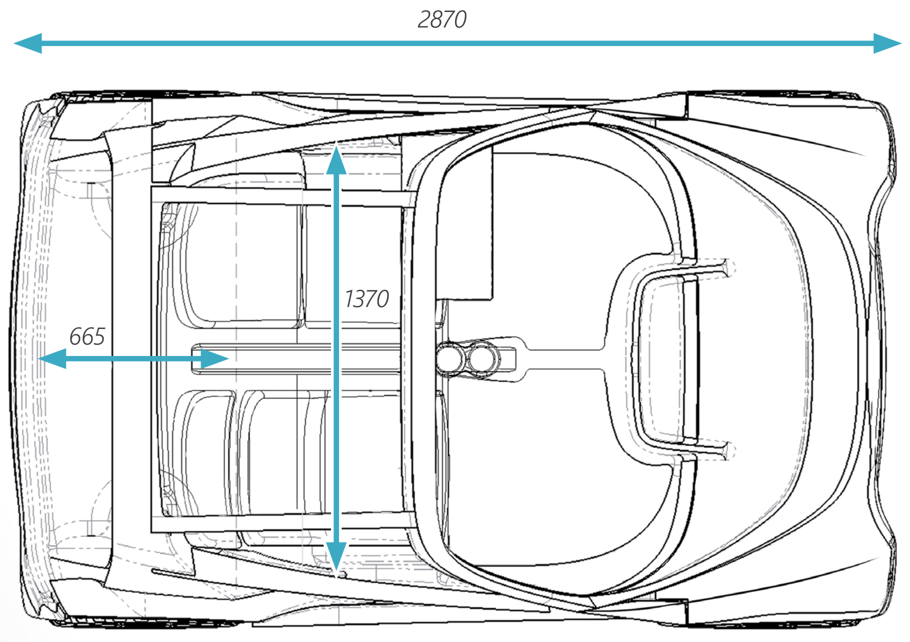

*Background image: Artgallery online, 2019*

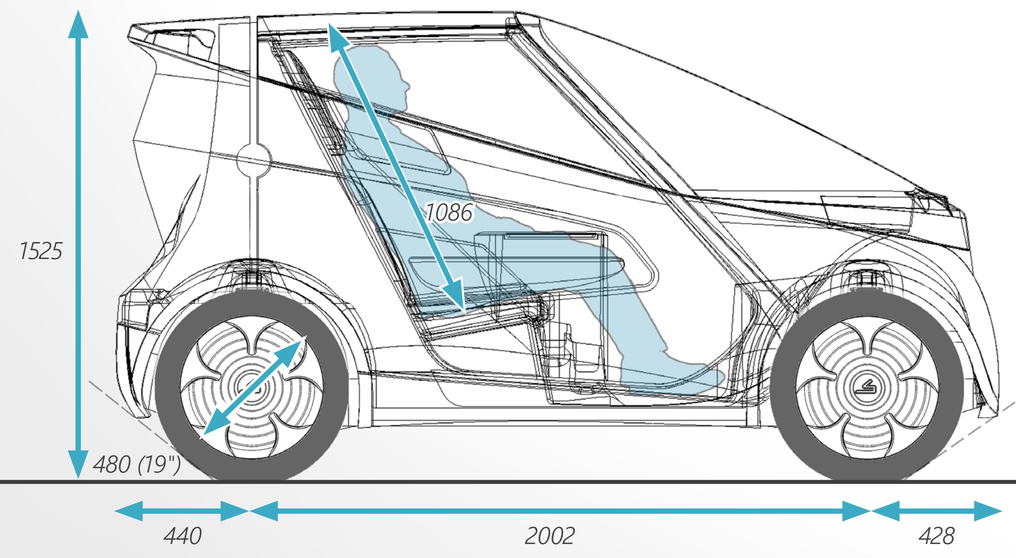
# LIFE CYCLE

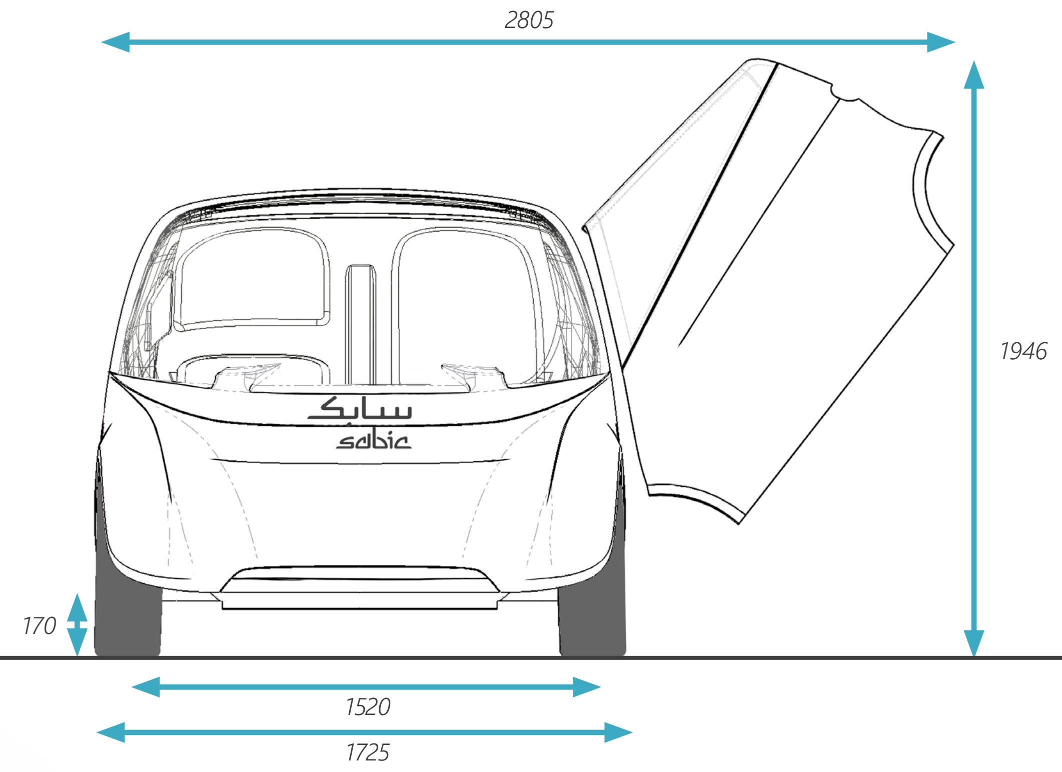
The expected intensive use of a shared vehicle as this one, is posing some challenges especially when looking at damaging of parts, but also wear and tear: the fact that it is used more frequent than privately owned cars makes it more prone to damaging, and the shared nature of the car makes that users tend to be less careful when using it.

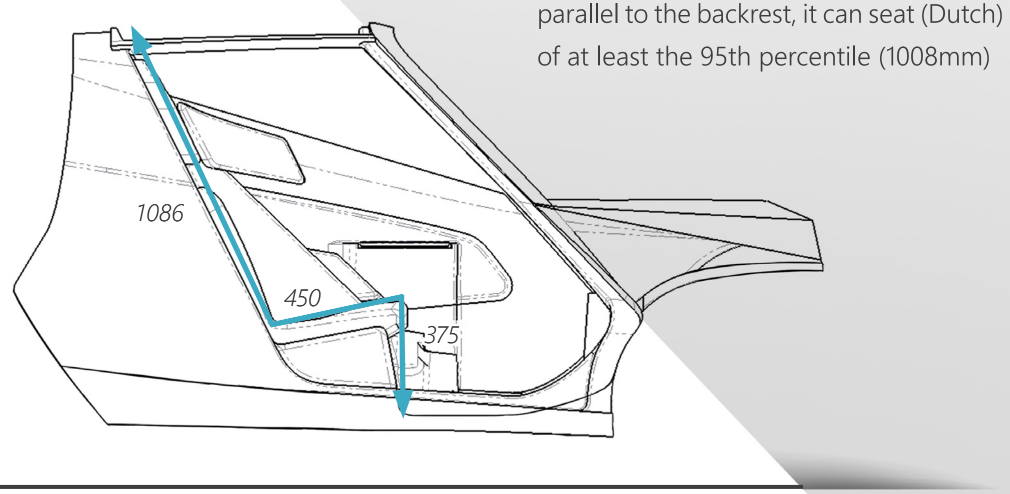
Therefore I decided to develop an idea for a system in which the car is being serviced frequently in order to keep it clean and representable for the users. Parts that are damaged or worn down can be replaced and the damaged parts are collected by the car service provider (fleetowner). Once in a while, the collected damaged parts are handed over to a recycling plant. The selective use of only two material families (PC and PP) in this concept benefits the collection and seperation before recyling.

One of the considerations of designing in plastics, is to account for thermal expansion. These changes are mainly visible at the panel gaps and surface continuity, especially in the exterior. With replacements of parts, panels need to be aligned properly. Misalignments would also be visible at the panel gaps. So by deliberately using features to hide imperfections due to issues with alignment and thermal expansion, these two aspects are resolved.



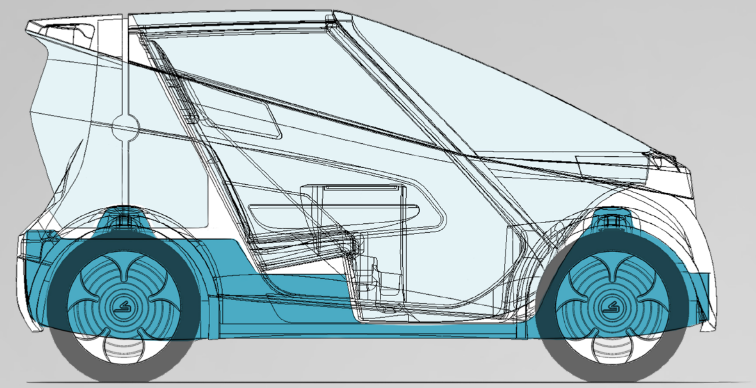



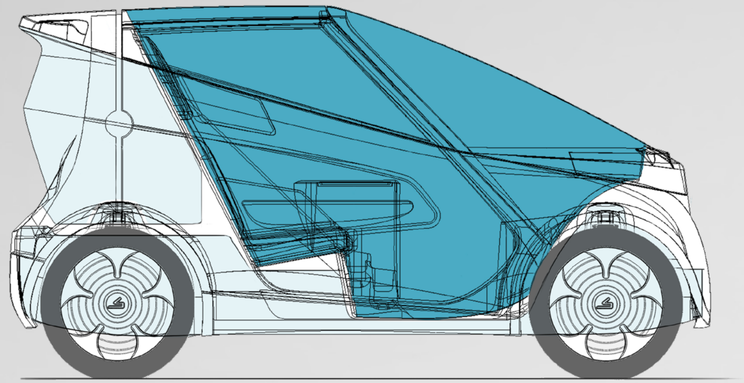

# BLUEPRPINT

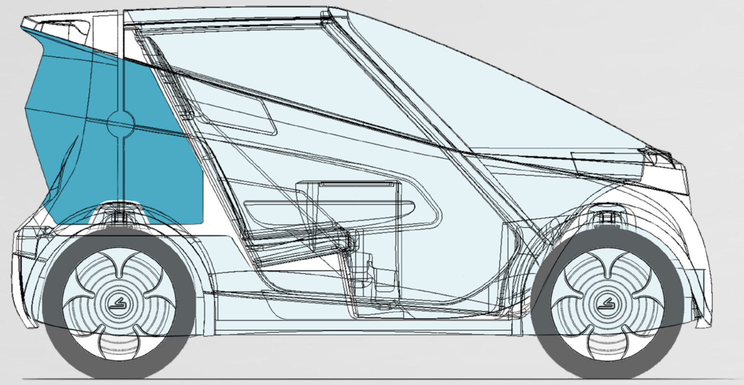
With the aformentioned box dimensions -driven by the high interior seating position and package layout- wich I used as a reference for the design, the final dimensions are showed here. With CAD modelling the design, and taking a closer look at the true volumes, lines and curves, the dimensions changed a little bit, but not more than +-2 per cent.

The heigh of the door when opened, is with 1946mm still lower than the minimum required 2100mm floor height of public garages. So if needed, it can be parked there as well.

With the height from the seat bottom to the roof being 1086 mm, parallel to the backrest, it can seat (Dutch) people with seating height of at least the 95th percentile (1008mm)







*Platform*

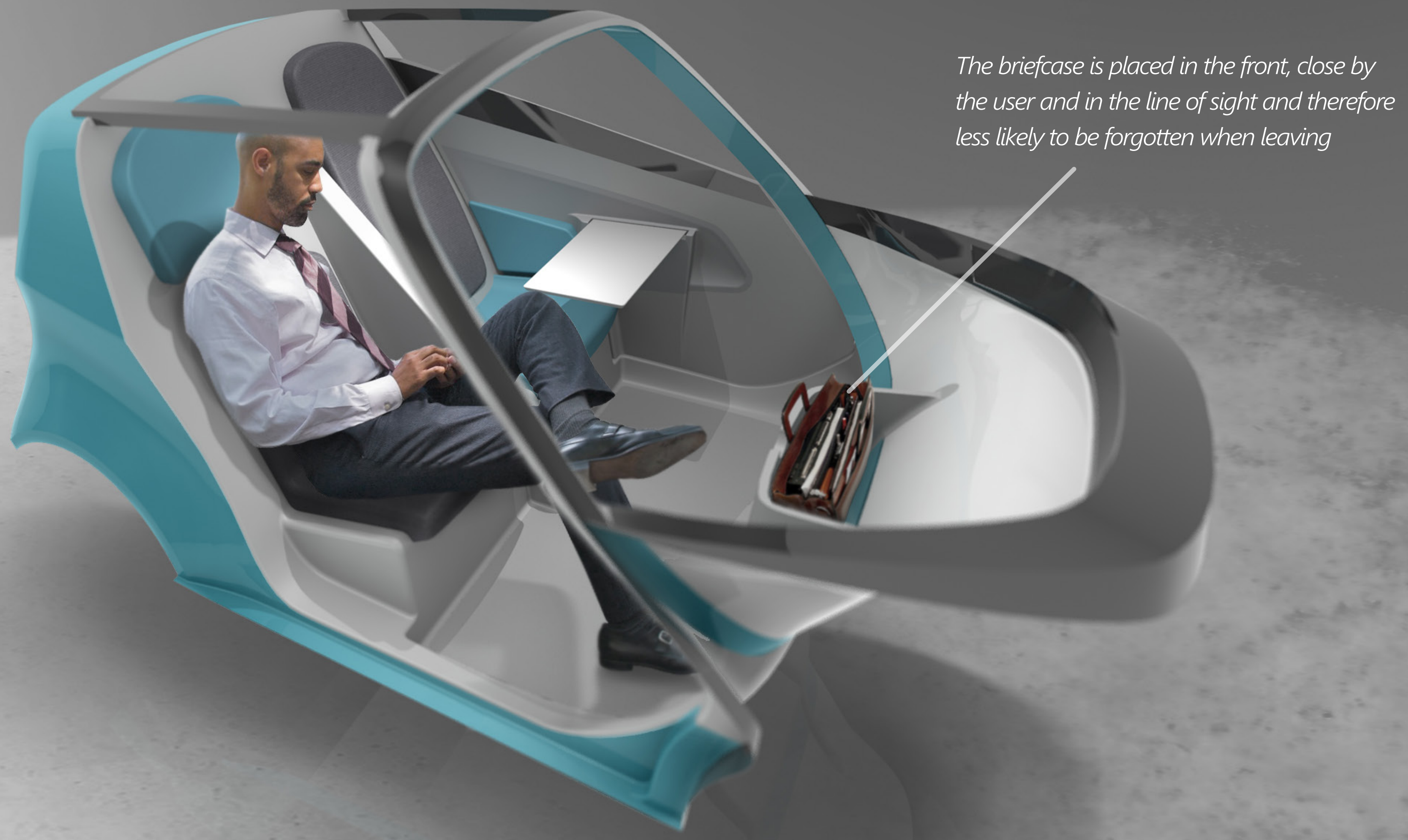
This conceptual vehicle is not intended to be produced and therefore the exact specifications of the drivetrain are irrelevant. However, the general dimensions and layout has partially driven the interior configuration. With space between and in front of the rear wheels, this is an ideal location for components such as the electric motor, battery and control unit. between the front wheels I accounted for steering. Of course there is a need for som structureal reinforcement in the floor, hence the thickness of the bottom and longitudinal beams in the sills.

*Cabin*

The main interior part is the cabin in which the passengers are seated. The shape is outlined by the steep front DLO part. The passengers are seated towards the back of the cabin and in the front there is both legroom and some storage space. The shape is simplefied in the sense that a strong division is made between the cabin and the storage area in the back; the wall follows the shape of the seats' backrests and seat bottom.

*Storage*

When the passenger need to bring something to work, other than the usual bag, or if the car is used for another purpose outside the peak hours of commute traffic, there is a storage area in the back of approximately 380 liters. This is convenient for the trip to the shopping mall or supermarket as well.



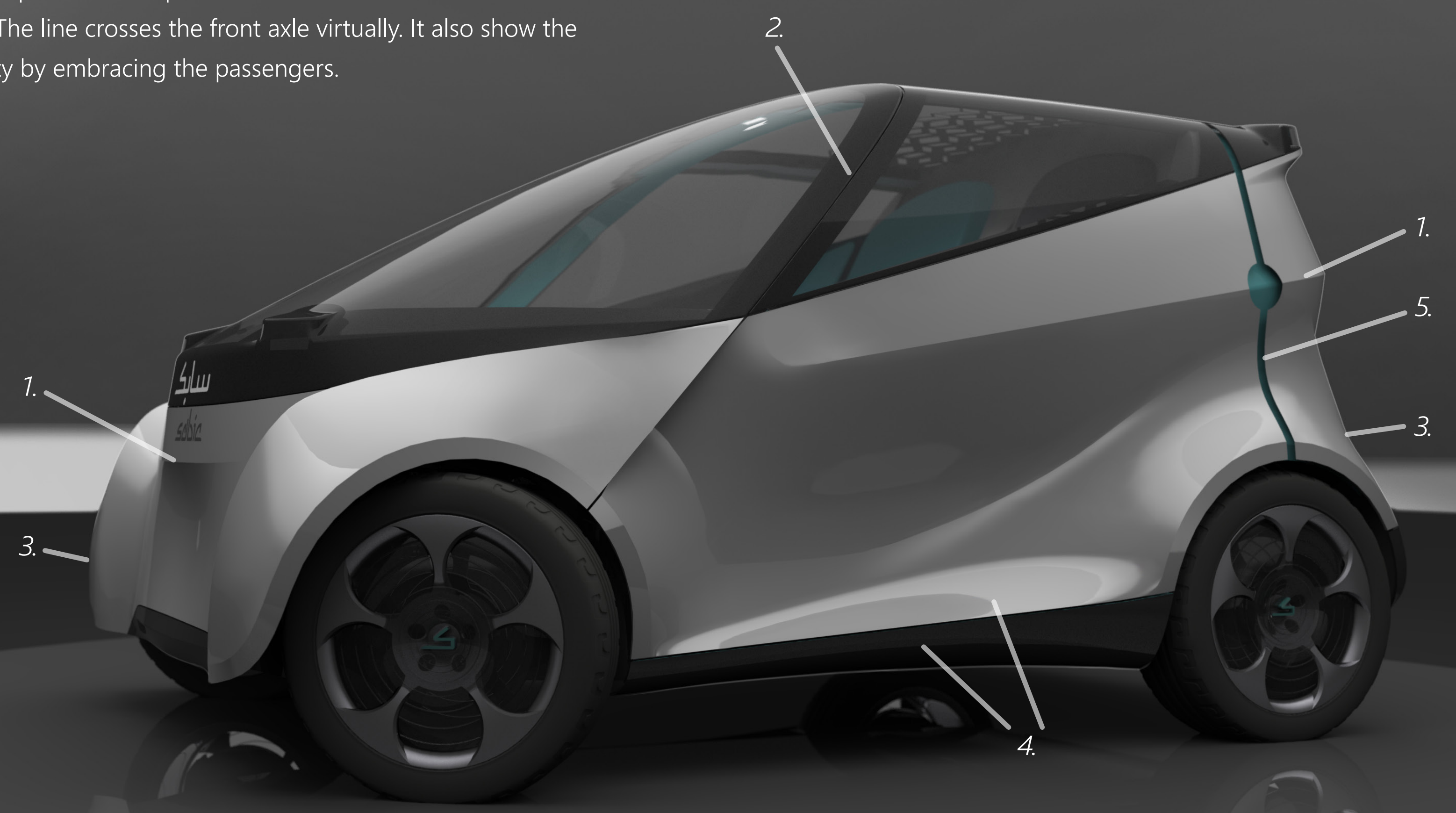
# Design overview

1. The main shoulder line is sharp/straight/diagonal, continues around the back, dissolves at the front fender, but continues in the front. Embodies the envisioned safe embraced feeling and brakes up the height of the main surface between bottom and DLO.

2. The A-pillar line, wraps around the car and continues in the front fender. The line crosses the front axle virtually. It also show the sense of safety by embracing the passengers.

3. The wheels are placed on edges and the body gets wider towars the bottom edges. This creates a strong and stable stance.

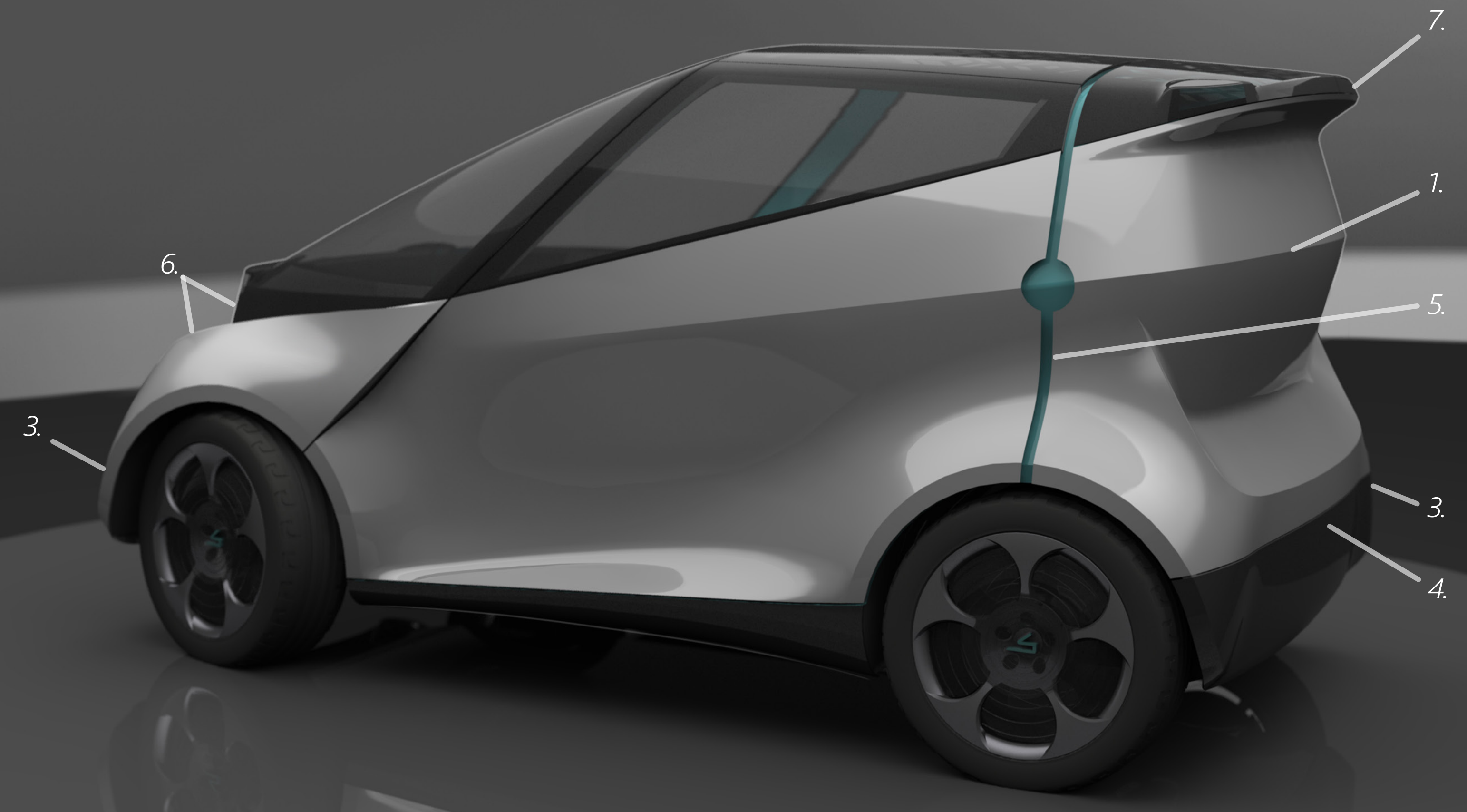
4. The black sill and rear bumper breaks the visual height of the main surface, just as the light catching indent just above.




5. The rear door division is a straight vertical cut-out, exactly above the rear wheel center when looking from the side, making it a straightforward and honest devision. But the surface shape gives the splitline a more distinct silhoutte when looked upon from an angle.

6. The front window stretches all the way to the frontmost part, but from the a-pillar on, it gets narrower, which makes that from the rear angle the fender seems to stick out further., creating the impression of a protruding nose.

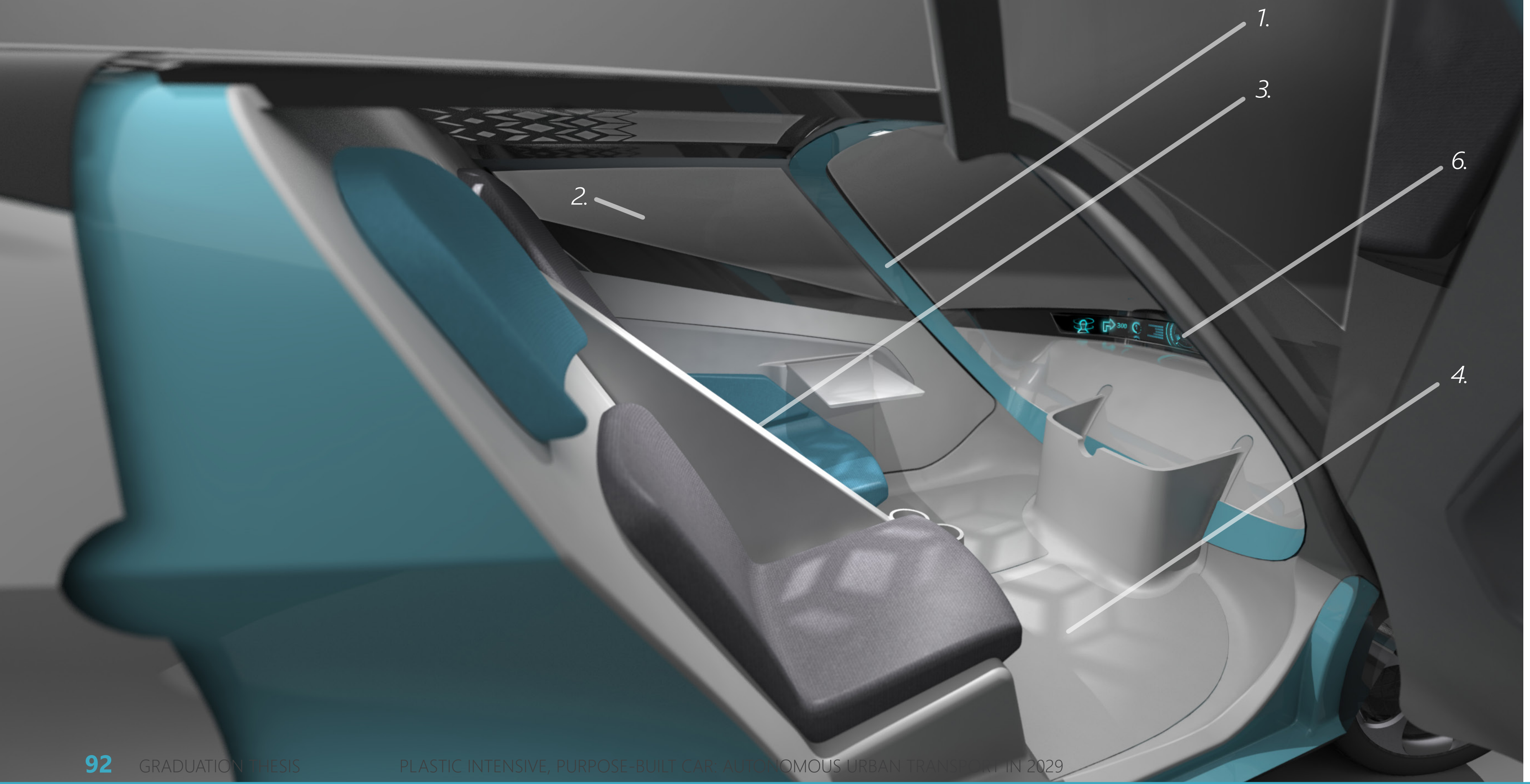
7. The spoiler increases lenght, without adding too much visual weight to the rear. It aslo adds to a dynamic posture



1. The a-pillar with a accent color revolves all the way around the DLO and on the floor, creating the sense of a ribbon wrapping around the car, protecting the user.

2. The front window is there for people who like watching the road ahead and to help prevent motion sickness. There is no need for rear and side windos. Yet I decided to make small windows on the side, letting in some light and the posibility to look outside a bit, but retaining some privacy which attributes to the perceived safety.

3. The division wall between the left and right seat emphasize the asymmetry and different functions of both sides. The passenger can choose the preferred mode (work or non-work) by choosing at what side to sit: The left side can be used for work with for example a laptop on the retractable table. This is accentuated by emphasizing the seat bottom. The right side is more focussed on relaxation by emphasizing the headrest. So with a fixed configuration, it is still possible to choose your preferred mode.



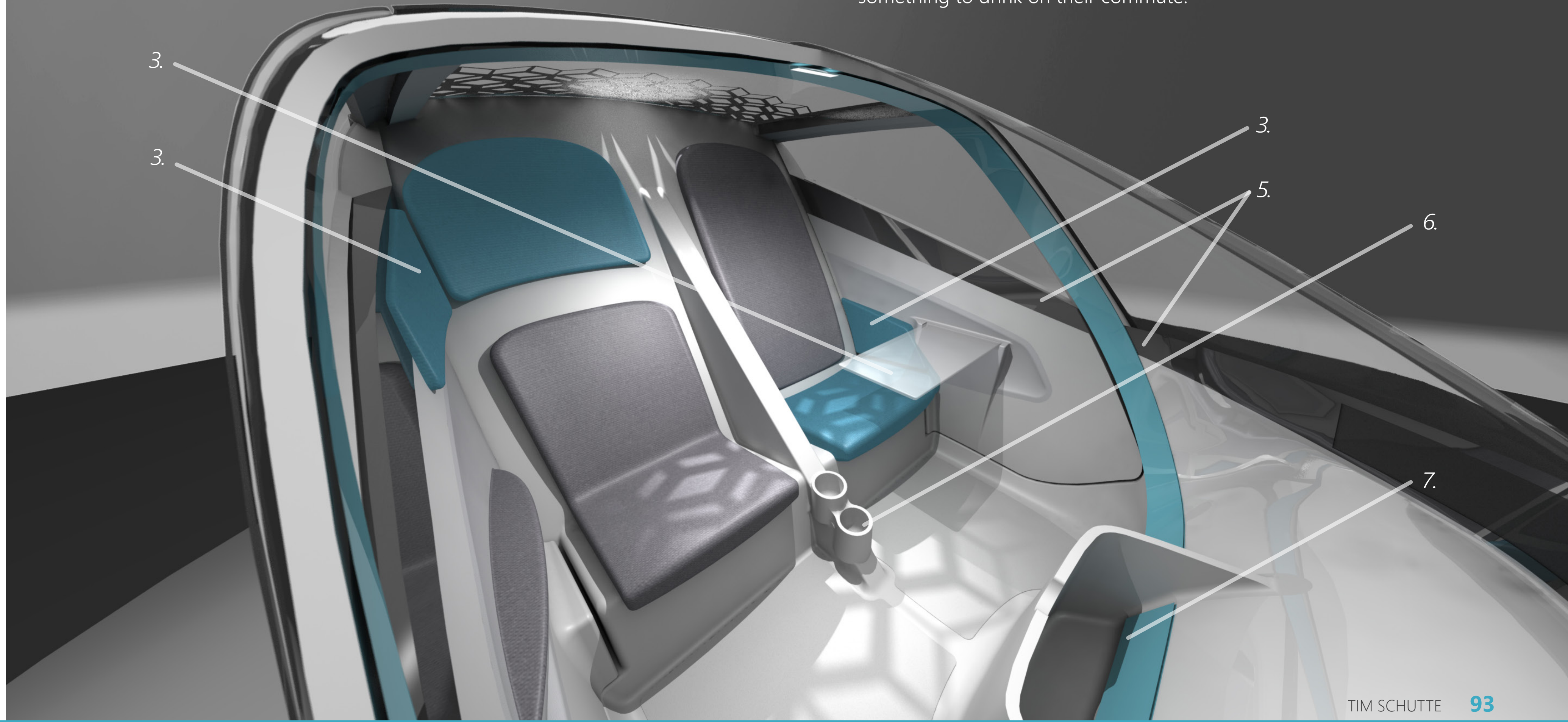

4. The roof pattern casts an interesting shadow on the car's interior. but can be eliminated by turning on the interior lights.

5. The bottom DLO edge of the exterior is repeated in the interior, creating a black accent strip on the door panels and continuing after the green a-pillar, describing the front outline of the interior.

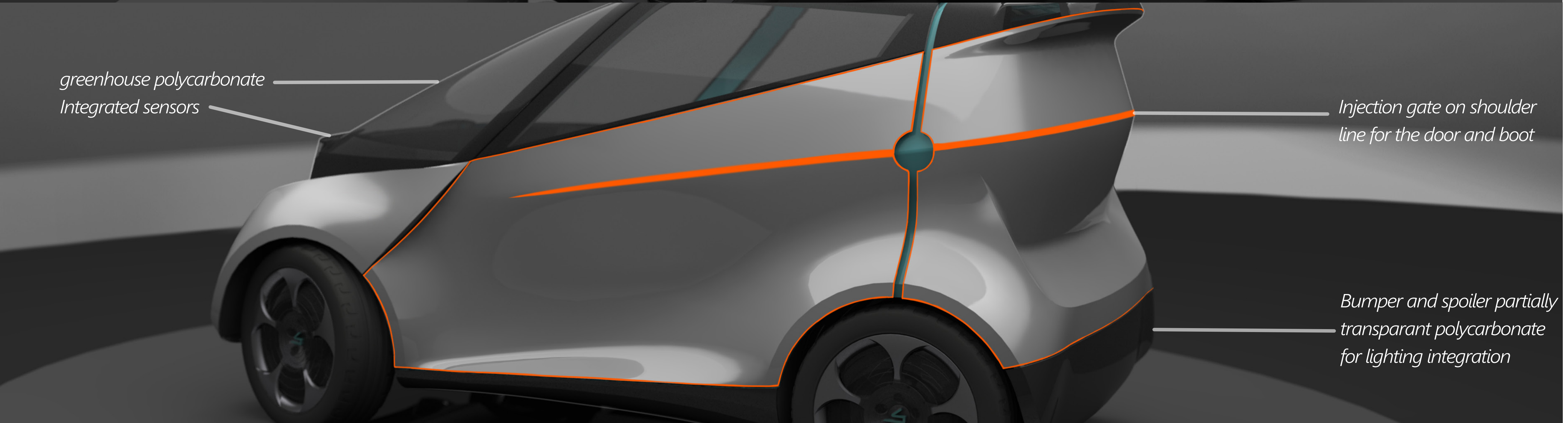
6. In the black front trim underneath the window is a screen placed, which can provide the user with information about e.g. the direction that the car is driving, creating trust by predictability.

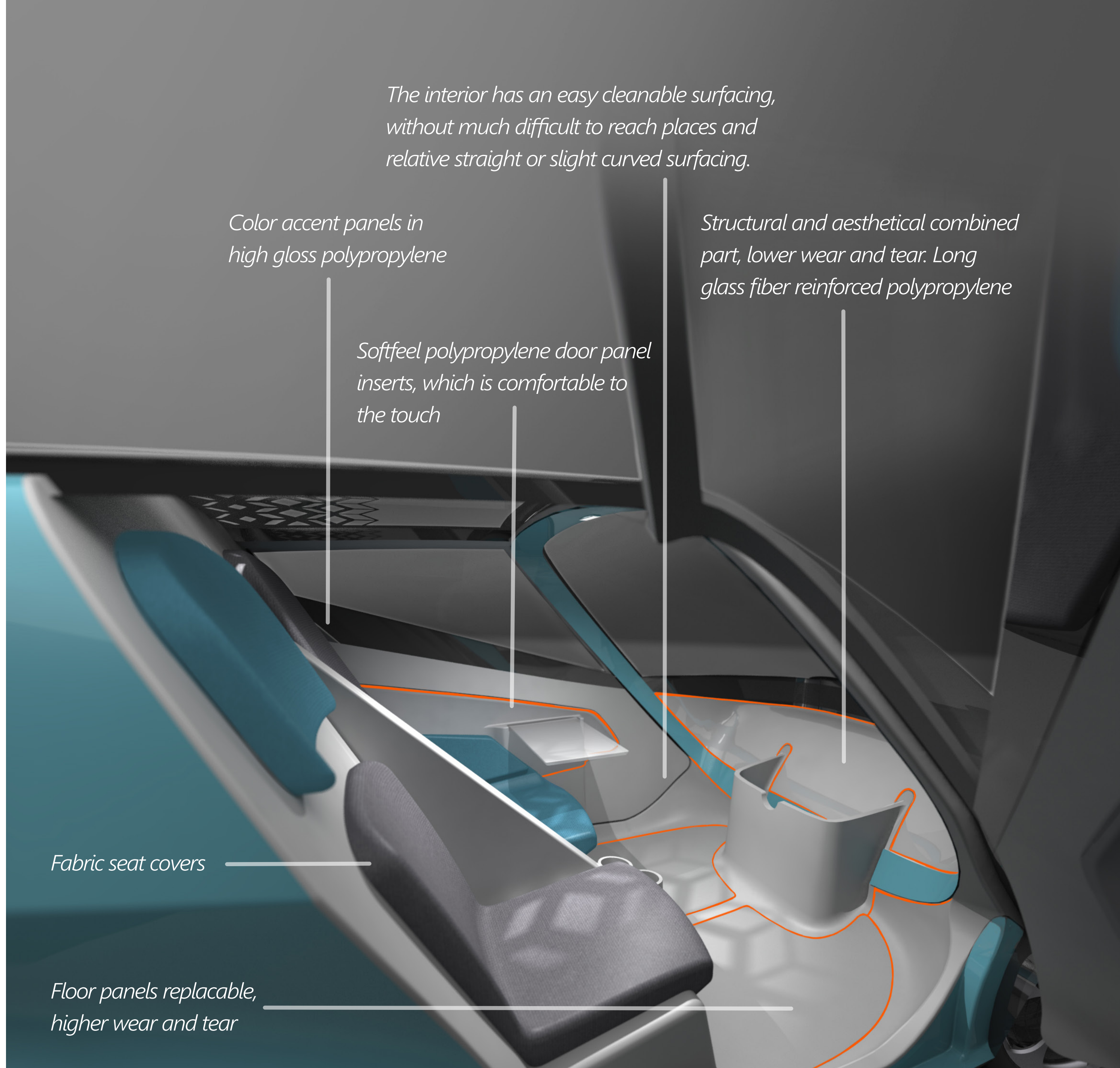
7. In the front is a dedicated area to put a handbag, briefcase, backpack or other product the passenger wants to keep close.

8. Cupholders are available for people that like to bring something to drink on their commute.

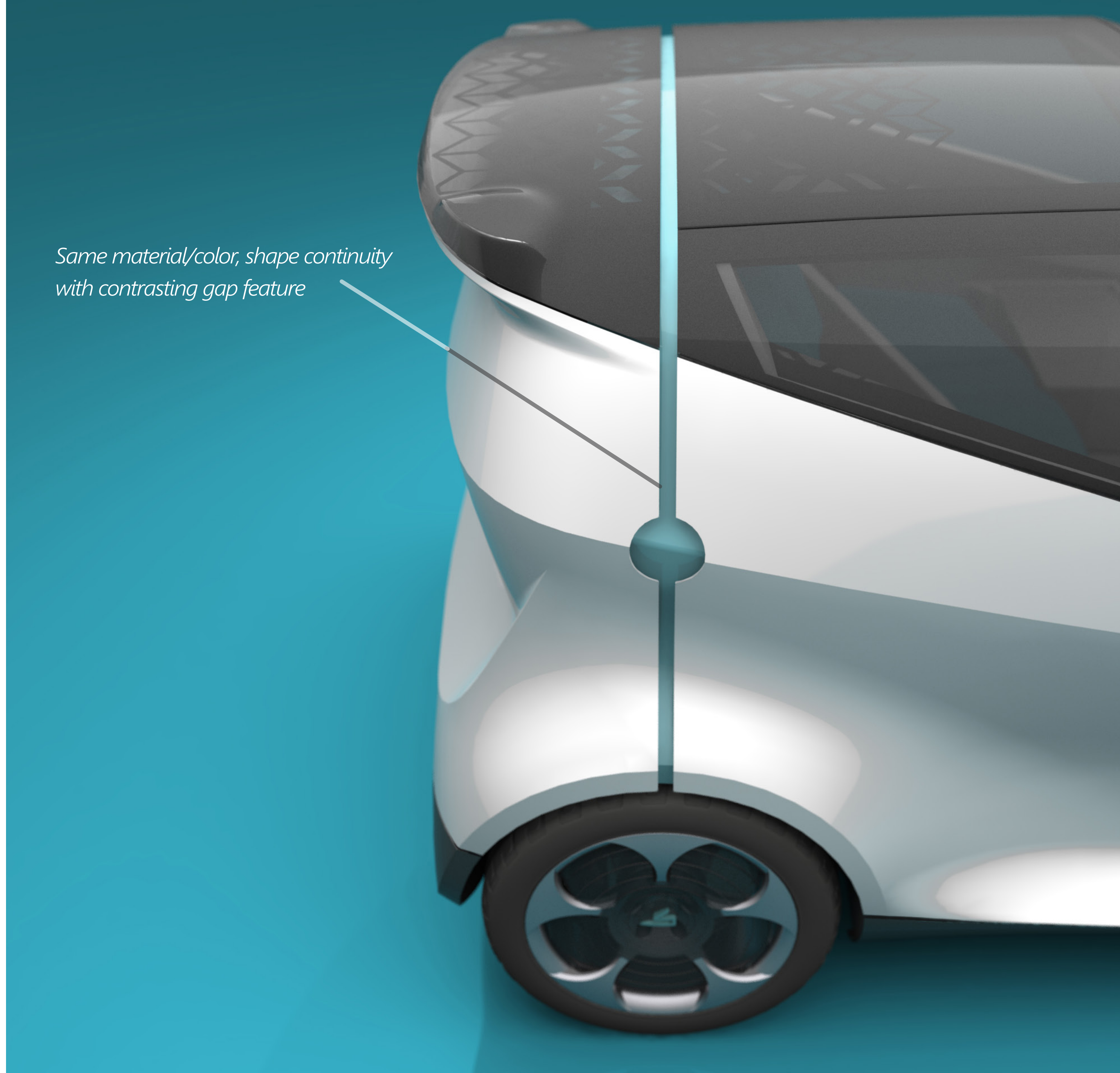


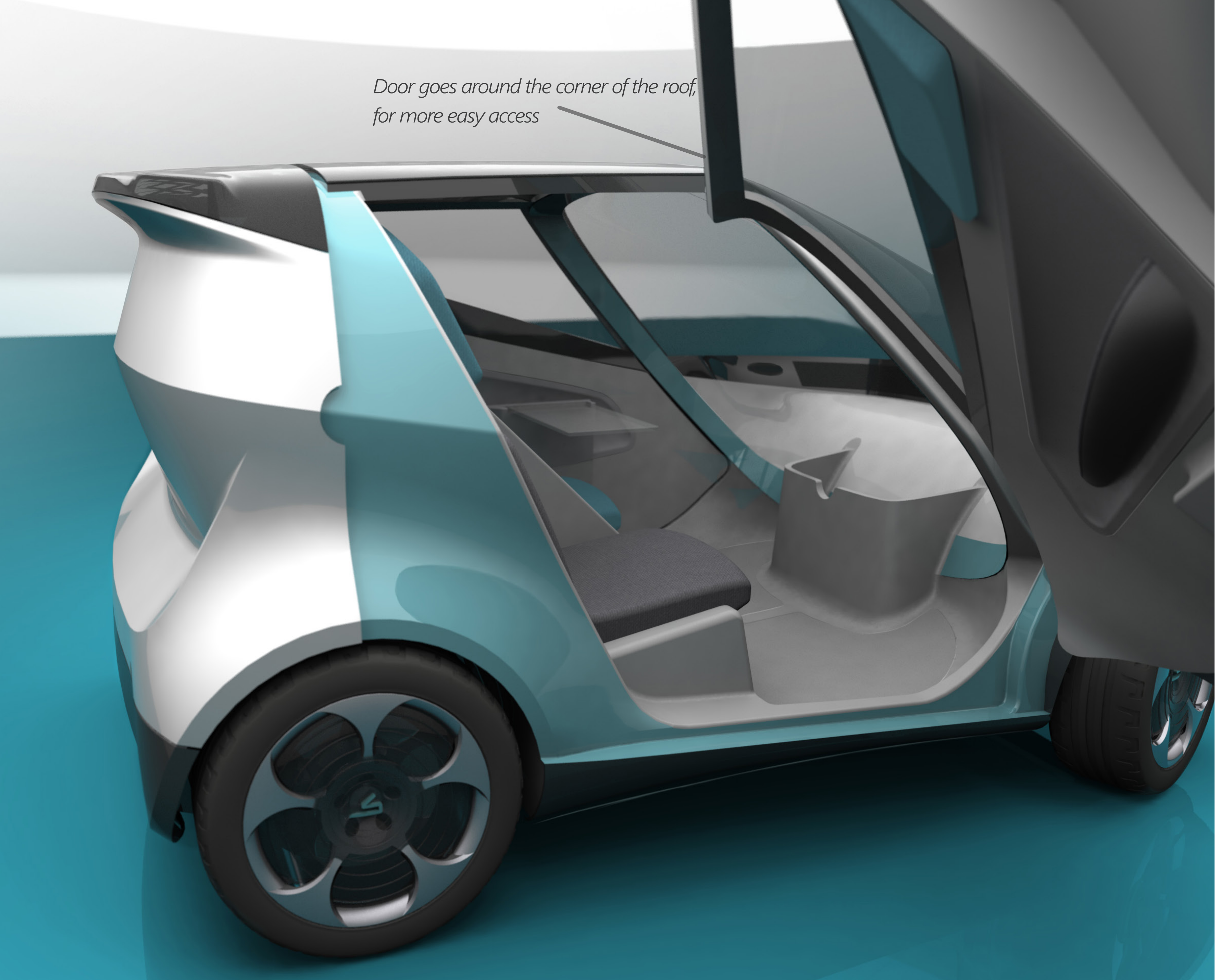
# Material overview

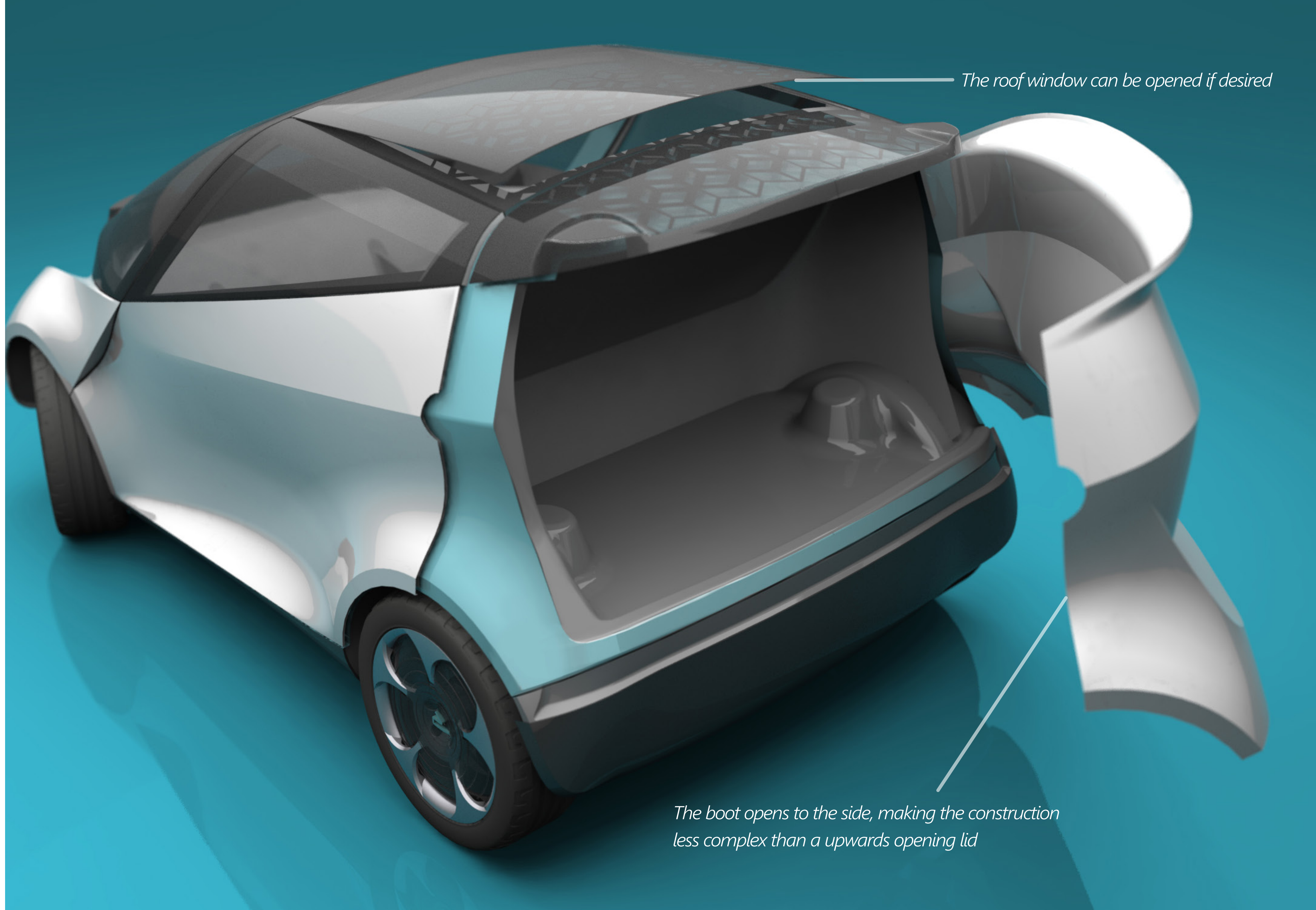



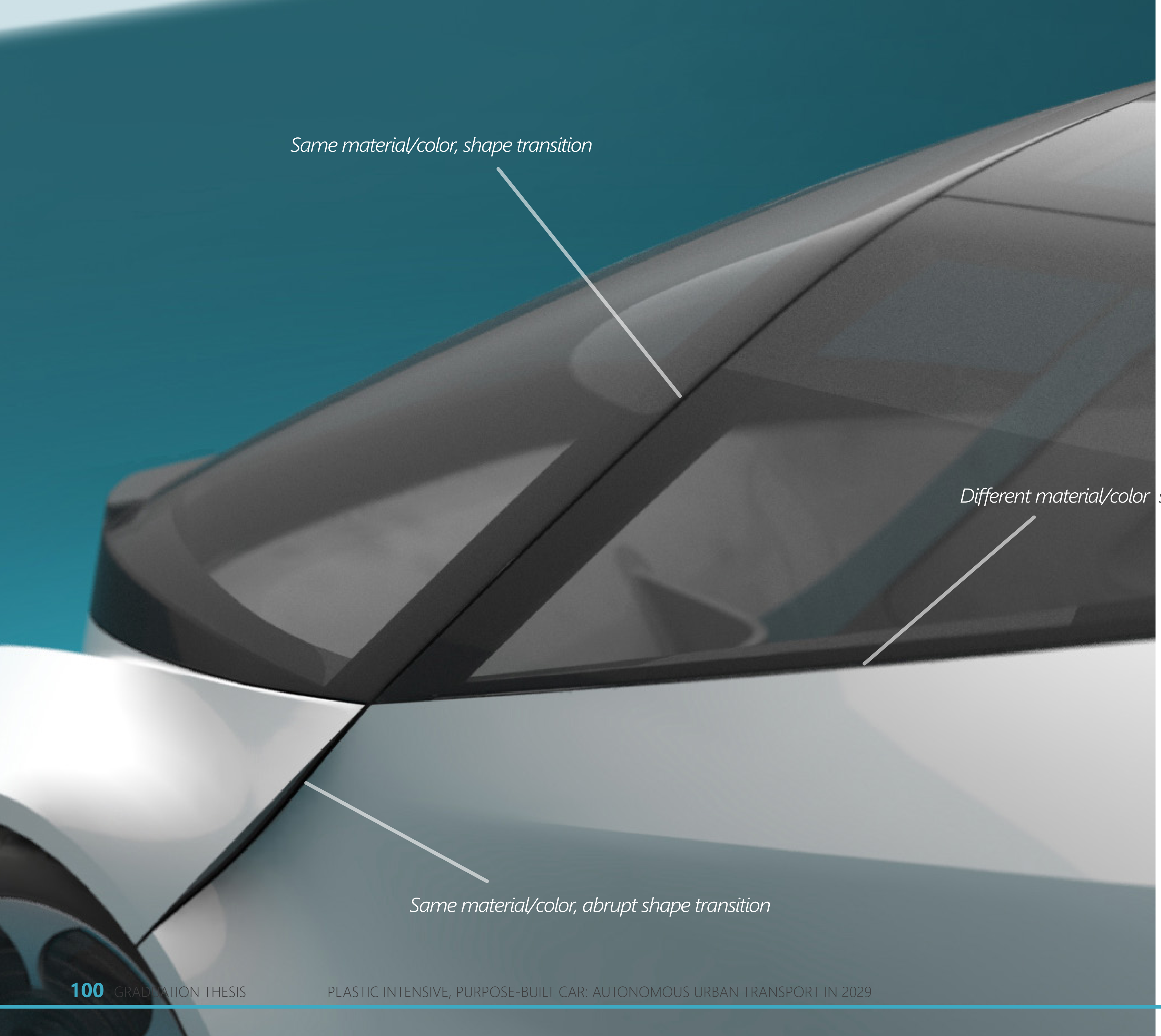



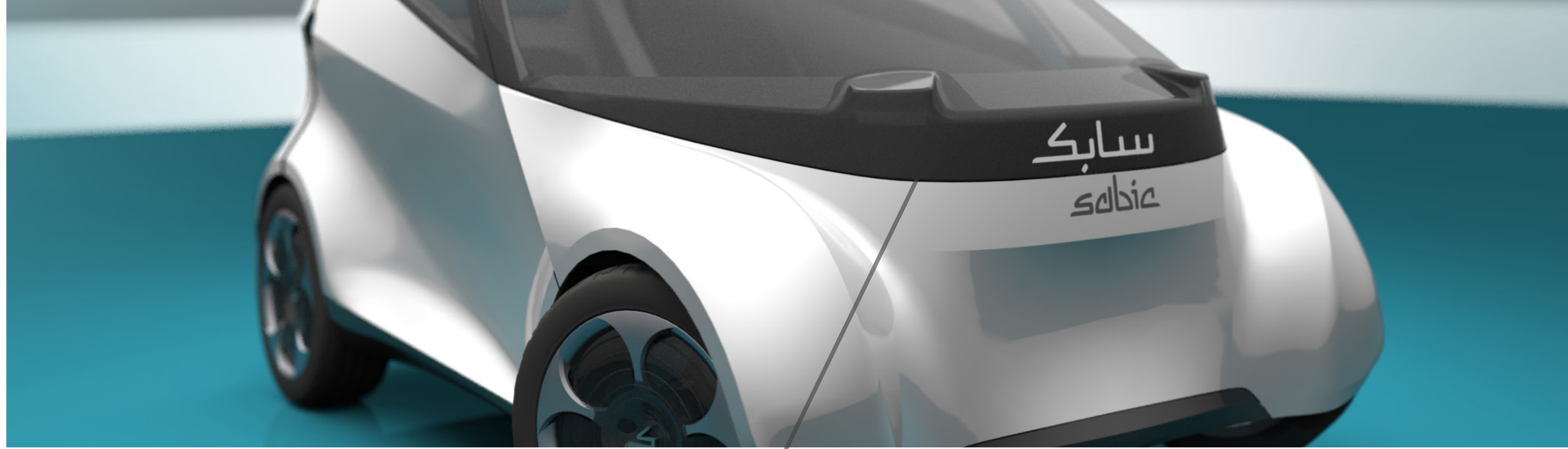
# DESIGN DETAILS


Door goes around the corner of the roof, for more easy access

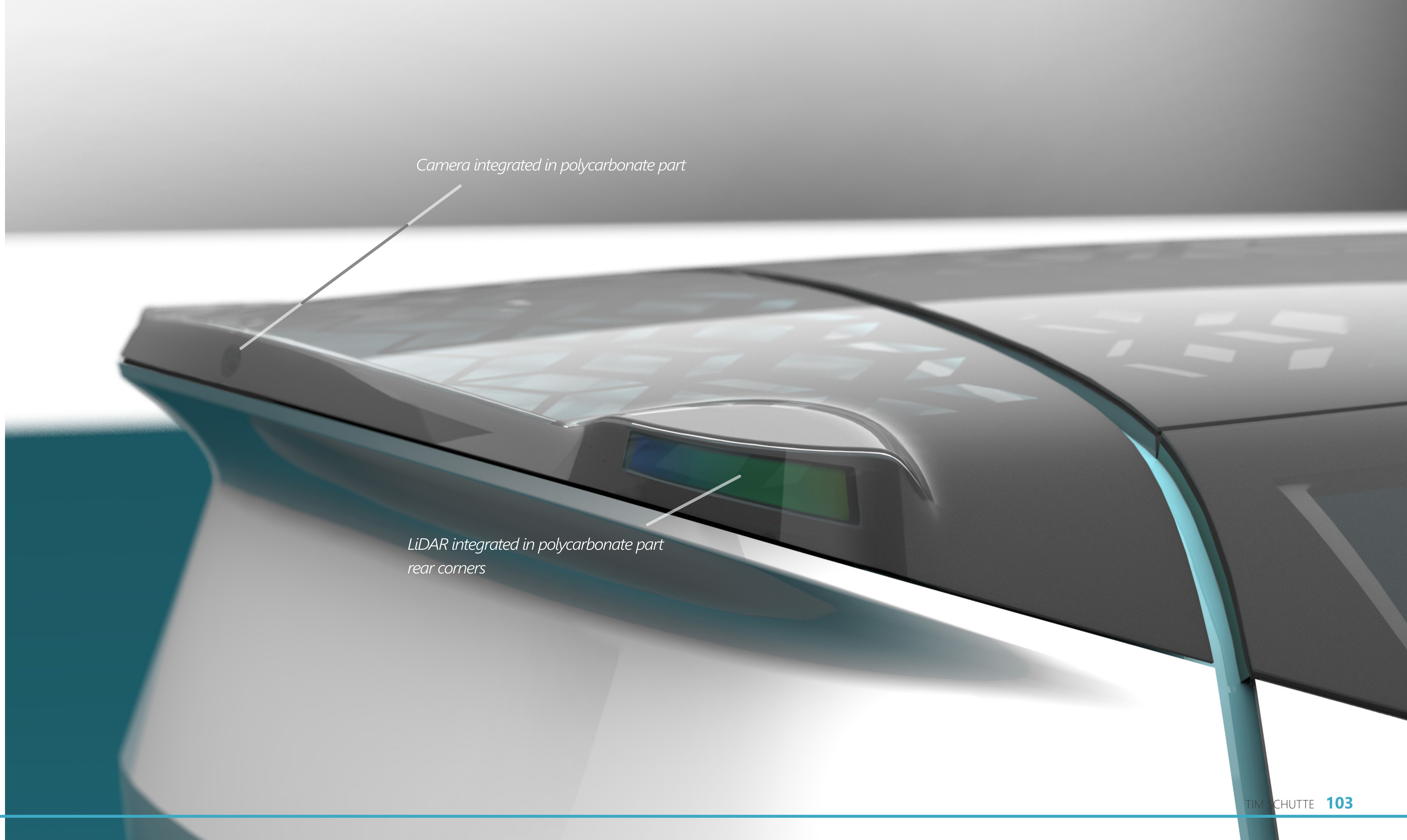

The roof window can be opened if desired
The boot opens to the side, making the construction less complex than a upwards opening lid


Same material/color, shape transition
Different material/color, shape continuity
Same material/color, abrupt shape transition


سابك
sabic
Different material/color, shape continuity


Different material/color, shape continuity
Different material/color, shape transition


Camera integrated in polycarbonate part
LiDAR integrated in polycarbonate part
front corners
سابك
sabic


Camera integrated in polycarbonate part
LiDAR integrated in polycarbonate part
rear corners

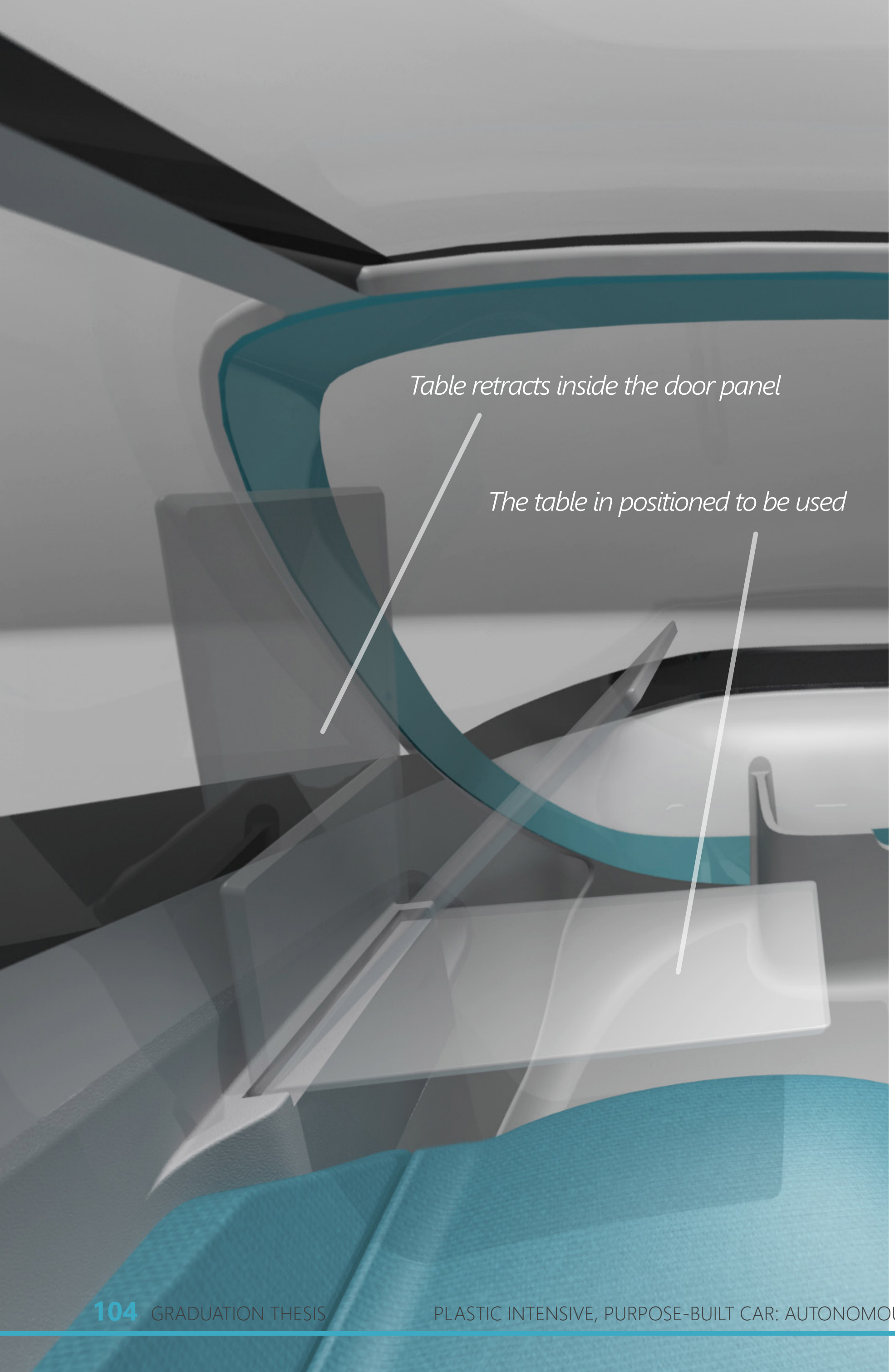
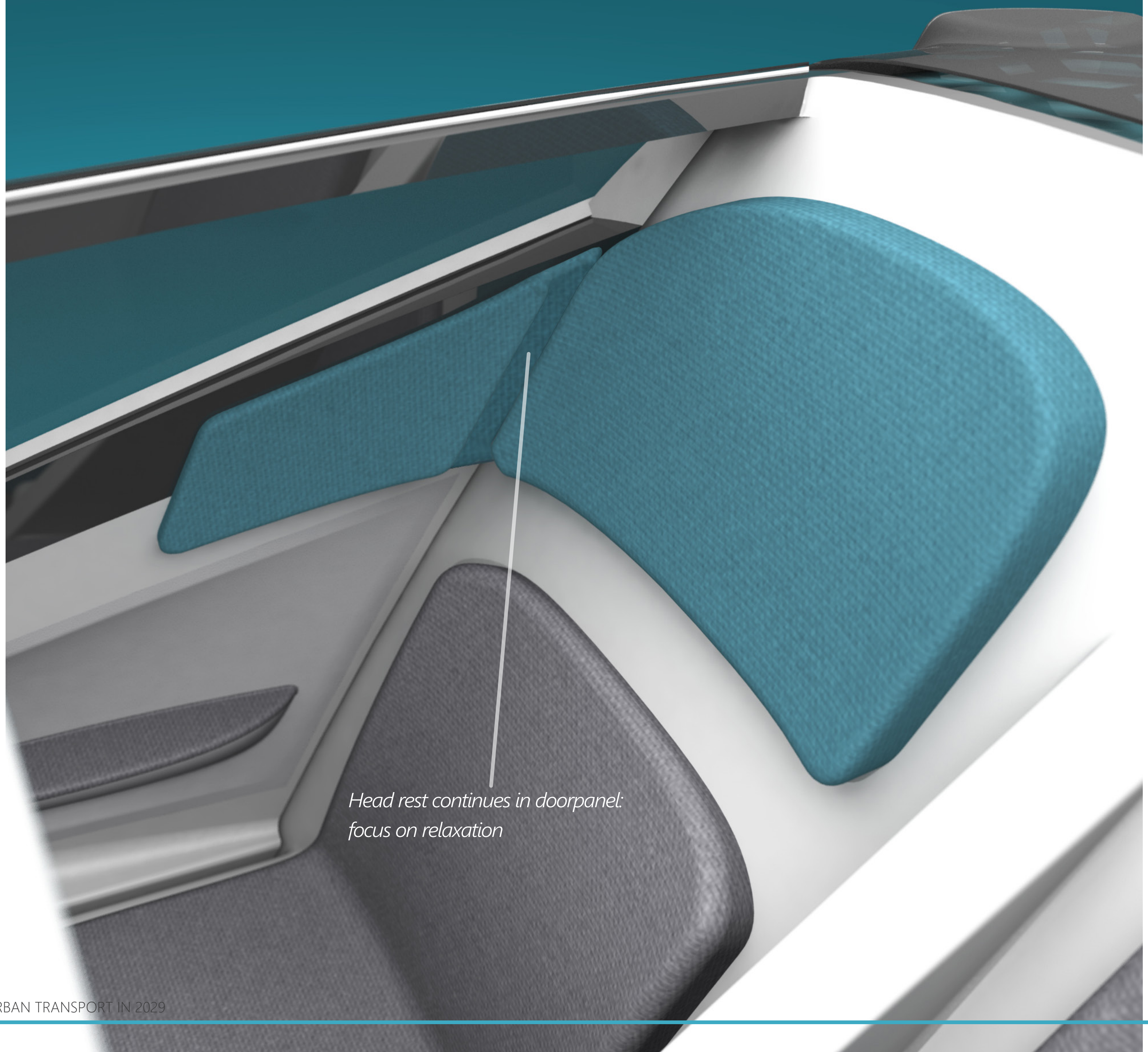
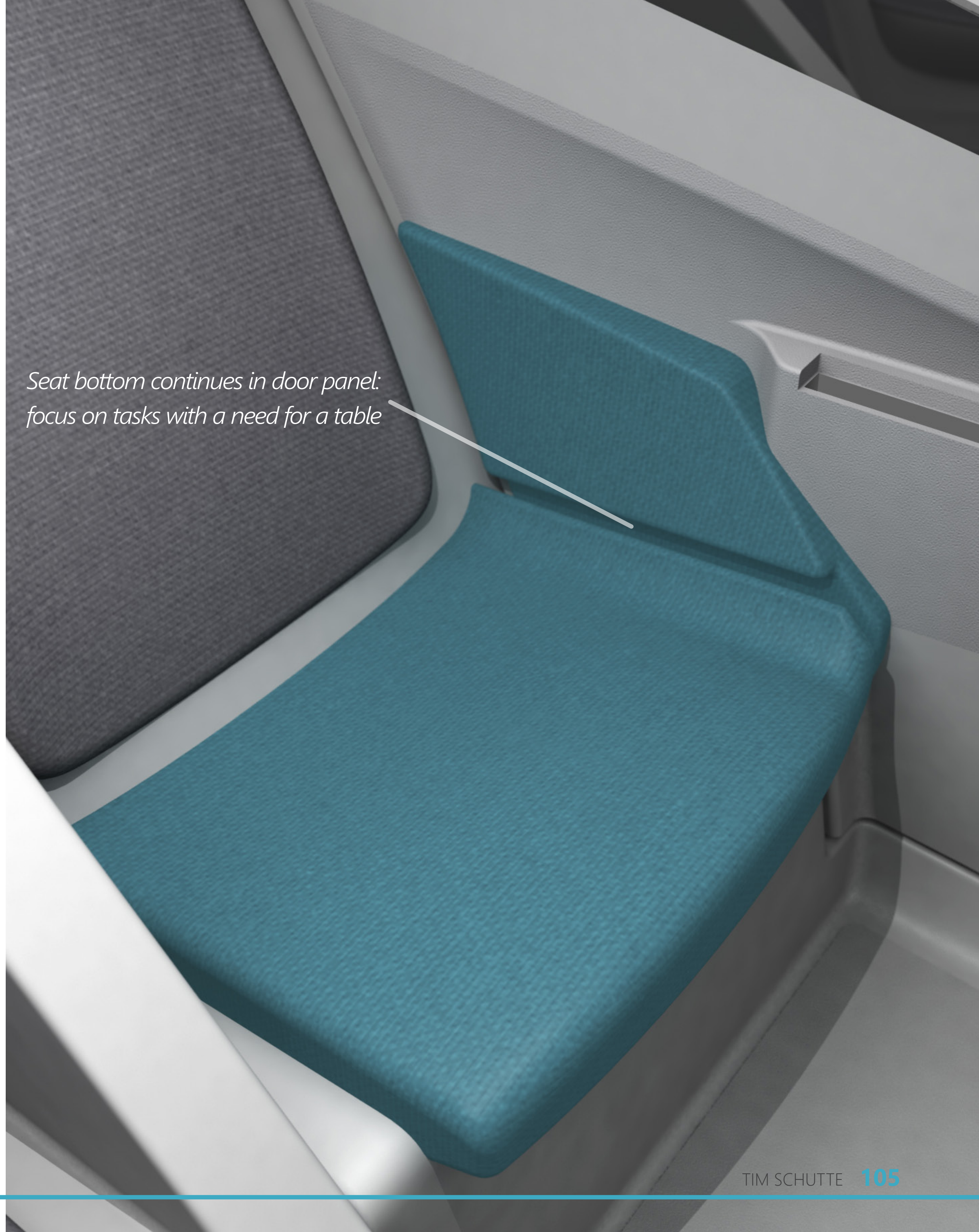


Table retracts inside the door panel
The table in positioned to be used


Head rest continues in doorpanel:
focus on relaxation


Seat bottom continues in door panel:
focus on tasks with a need for a table

# 6

# Discussion

*At the end of this graduation project, it is good to look back and reflect on decisions that were made. A expert review is conducted in order to hear feedback on the project, which serves as an addition to the recommendations for topics that can be looked into in the future.*

# Evaluation

*In order to validate my conceptual vision for an autonomous purpose-built vehicle for urban transportation in 2029, I tried to ask different experts in the automotive field to take a look at the proposal and give general feedback on what they find to be positive and negative about it. However, it turned out to be more difficult than expected, both due the fact that I can not discuss the project with anyone outside the company and project team and the difficulty of finding people that have a profound knowledge of most of the relevant aspects of this project and are available for commenting. That is why I decided to conduct one in-depth interview with one specific colleague instead of multiple others. My interviewee has an exceptional breadth of experience in the company, ranging from leading the automotive application testing center to being the global expert in body panels and closures as well as the current regional marketing representative for structures.*

## Expert review

*Geert-Jan Doggen*

With his background in the company as a Sr. business development manager for the automotive department of SABIC Innovative Plastics and prior experience in other projects, related to among other things innovation, body panels and glazing, Geert-Jan is well aware of a lot of different automotive projects running in the company, as well of developments of the automotive industry in general. This makes his feedback on my project very valuable and relevant.
In the interview, he indicated that the features driven by the research, such as the interior functions and the car sharing, purpose-built solution space, was well thought through. He also recognized that I looked into the ergonomics and appreciated how the dimensions of the seats, the functions of the car and the well-being of the users are considered.
One of his first remarks considering the focus on the commuter trip was why there is seating for two in stead of one, but the explanation of the secondary function of the car beside the peak hours of the commute justified the choice for him. The same goes for the additional storage space in the back of the car.

Being well aware of the developments of autonomous transportation, he finds it to be very interesting, but also hard to imagine how AVs will actually impact transportation. But my proposal adds another interesting scenario to the already introduced visions of other companies.

Additionally, there were also several comments and points of attention, some of which I already realised before and put in the recommendations. For example, He noticed that the car did not have any lighting features. They are expected to still be needed in the future -at least the main features, such as front and rear lights and indicators-, but this is an aspect on detail level that I did not cover at this project.
I implemented somewhat large parts on the design, assuming that with future developments this can be realised more easily. With the current technology and material composition, Geert-Jan indicated that producing parts in these sizes is rather challenging. Additionally, changing a smaller part which is damaged is preferred over replacing a large part with only little damage compared to its size. Therefore he thinks that splitting up some parts into multiple parts can benefit this idea of part replacement. If such a system is implemented, time will tell if parts are actually going to be replaced or not (this choice might be driven by the costs of repair or complexity of assembly).

He also wondered if the choice for leaving out the seatbelts is realistic. With todays approach of active and passive safety systems it might be difficult to imagine a future where this is not needed anymore. However, in most other forms of public transport there are also no seatbelts anyway.
The possibility of a interchangable platform was recognized when I showed the images of the blueprint and the package. This is something that is implemented sometimes in other concept cars as well and is indeed a interesting idea to look into in the future.

# Conclusion

*SABIC was interested in seeing how the expected transition to autonomous transportation can change the way that cars take shape and how their thermoplastic materials can play a role. I developed a concept that combines knowledge of the autonomous developments and the use of plastics into an inegrated design that addressed lots of different related aspects.*

The aim of this project was to come up with an integrated conceptual design of an autonomous vehicle that answers to particular needs of the passengers and explore possible new areas of interest for SABIC. The research that shaped my knowledge of the developments of autonomous cars, combined with the already launched concepts and visions by OEMs, lead the direction for the scenario choice.
The fact that the car is shared, which means in this case that it is used by different people at different times, allows for a purpose-built car. People that own a car themselves often make a decision on what car to get on apsects like size, price or costs. However, often the car might be overqualified for some of the trips (for example the decision to get a car with 4 seats, which is needed for some of the trips, but most of the times they are alone in the car). With this concepts I showed that within a shared car system, there is a opportunity for more purpose-built vehicles.

The urbantrip scenario that was chosen to develop further is a convincing purpose-built car, with a small footprint, both physical and ecological. It shows an interesting potential in terms of material use and integration of different parts and functions. But moreover, it shows the potential of a system of manufacturing, deploying and using, replacing, and recycling of (parts of) the car. The expected increased influence of shared car service providers can be traced back to this: these fleetowners see the need for purpose-built cars and require cars that are well maintainable and kept in good shape during its life cycle, forcing car manufacturers to look into possibilities to cater for these needs.

In general, it can be assumed that the interior of autonomous vehicles opens up new posibilities, especially for single mode AVs where there is no need for any instrument related to the driving tasks. With my proposal an open, spacious cabin is created and the users can choose what seat to take, as they are both different. in-cabin storage space is also brought back to a minimum, as the short distance urban travel doesn't need a lot of spots to put your belongings.

Particulary at the exterior, but also in the interior, the styling was used as a means to communicate a certain feeling toward the users. For the acceptance of concept of the self-driving car, trust is an important trait that was translated into a strong, stable looking desing with angular features, combined with smoother surfaces and curves to make the passenger feel at ease.

# Recommendations

*With this proposal I tried to implement a lot of available knowledge on several relevant aspects and bring them all together in an integrated conceptual design. Providing an alternative vision on how the trend of autonomous transportation can change the automotive industry in general and for SABIC as raw material supplier in specific, I thought of a lot of different aspects. The flipside of this is that still some attention could be paid to the details of for example manufacturing, technology implementation, and interior function design.*

- The way that lighting features could be implemented can be looked into in the future. With a single mode AV in a AV-exclusive scenario, some lighting functions become obsolete but other optical systems take their place (sensors).

- I showed some of the potential of the increased use of plastic parts in the future with autonomous transportation, such as the implementation of sensor devices into PC glazing parts, the possibility for sharp shape transitions and a system of easy repair, replacement and recycling of parts that are prone to wear. But on detail level there is more possible, such as the possibility of strategic placement of aerodynamic features, air conductors and repeating aesthetical patterns and textures on panels.

- I also accounted for some guidelines for the use of thermoplastic parts, such as the general draft direction of parts, injection molding film gate position of some parts (and masking the sink marks) and the thermal expansion under temperature differences, inducing deviations in panel gaps and alignment. Maybe there are currently still some limatations in part sizes or flow length. However, in the future, these limitations might dissolve, due to new techniques. It is good to further consider how injection molded part sizes could increase, especially for exterior use, without having undesirable sinkmarks.

- The exterior dimensions and volumes are driven by the functions, needs and lay-out of the interior. Therefore I started out with determining this, before looking at the exterior. But because a decision for a part of the exterior is influenced by the interior and vice versa, I also looked at the design of the interior after determining parts of the exterior and the main interior functions. However, because of these iterations and the interplay, even more thorough ideation could be put into more detailed interior functions, designs and material implementation.

- The more intensive use of shared vehicle like this was a reason for me to look into a system of damage part replacement, but other possible solutions, such as scratch-resistance materials or healing materials could be further researched.

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