FEASIBILITY STUDY ON A RADICALLY NEW L6E VEHICLE CONCEPT

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1 EXECUTIVE SUMMARY

Within this deliverable, the development of the virtual L6e vehicle is described in detail and the question is answered, if it is possible to integrate the modular EU-LIVE powertrain into a radically new vehicle. It describes the results of two tasks, the design contest (T4.1.0) and the overall L6e vehicle design (T4.1.5) [1].

Based on the results of an international open innovation design contest, carried out in the first phase of the development, a new and unconventional exterior design for the third EU-LIVE vehicle has been selected. It has been used as a basis for the following development steps, from which a virtual prototype resulted. Besides the exterior shape, a package plan and a simplified CAD model have been created, integrating the EU-LIVE powertrain and carry-over components provided by the project partners. Multi-body and aerodynamics simulations have complemented the developed prototype. A feasibility study has further been conducted on the prototype design, which examines the vehicle's market and technical potential for a further development.

With the creation of the virtual L6e vehicle and the successful integration of the battery electric powertrain components, one of the key research questions has been answered. It confirms that it is possible to integrate the EU-LIVE powertrain into a radically different vehicle, compared to the scooter-like two- and three-wheeler concepts of the L3e and L5e category. The EU-LIVE powertrain provides a modular system that can be integrated into a variety of L category vehicle concepts and provides effective cost reduction by increasing production volumes.

Keywords: L6e vehicle, virtual prototype, open innovation design contest, multi-body simulation, aerodynamics simulation

2 OBJECTIVES

In this deliverable, the development process of the virtual L6e vehicle prototype, developed within tasks 4.1.0 “design contest” and 4.1.5 “overall L6e vehicle design” is described. Besides the L3e scooter and the L5e three-wheeler, it is the third vehicle developed within this project. One of the key research elements of the EU-LIVE project is the development of a modular powertrain architecture for L category vehicles as an element of a common-part strategy to increase development and cost efficiency. Whereas the L3e and L5e vehicles have a similar suspension layout at the driven axle, an adaptation of the commonly used powertrain components is possible. As general proof of concept, the battery electric components of the EU-LIVE powertrain are adapted to a new L6e vehicle, which is radically different to the other two vehicles. By this, the conceptual idea of a modular powertrain for all L category vehicles is proven.

To find a third vehicle concept, an open design contest has been launched, addressing design students and young professionals. In this non-restricted competition, which has been advertised to European design schools but also on design platforms, people from all over the world have participated. Based on the winning design, the new vehicle concept has been developed.

With the support of the project partners, a package plan and a CAD model of the L6e vehicle have been designed. It combines an interior layout, a basic body structure and redesigned exterior with the modular EU-LIVE powertrain and a carry-over suspension system. While the difference between the radically new L6e and the other two scooter-like vehicles is relatively high, the integration of passenger car components has been realized as another approach for cost reduction. The virtual vehicle is furthermore the basis for multi-body and aerodynamics simulations, verifying the chosen vehicle design.

Based on the final design, a feasibility study has been carried out, analysing the market and technical potential of the new vehicle. In addition, an analysis of potential needs for changes to homologation requirements and regulations has been conducted.

With the development of the L6e vehicle, the following objective and ambitions named in the Grant Agreement of the EU-LIVE project have been addressed.

Objective n°3.c: Virtual demonstration of a radically new ultra-light four-wheeler as a BEV concept, developed in an open innovation contest and making use of the modular EU-LIVE powertrain system.

Ambitions:

- 1.4.1 Transfer of know-how from automotive high-volume to L-category industry
- 1.4.8 Innovative vehicle architecture
- 1.4.14 Comfort / Usability

3 DESCRIPTION OF WORK

This deliverable describes the development process of the radically new, virtual L6e vehicle prototype. It combines the results of the design contest of task 4.1.0 and the development of the virtual prototype of task 4.1.5. The results of the design contest are hereby the direct input for the virtual prototype as its design determines the direction of development. Part of task 4.1.5 is also the simulation based analysis of the L6e vehicle. Its simulation itself is carried out in work package 3, but the results are also part of this document.

Deliverable 4.3 is structured in the following way: In chapter 3.1, the L6e vehicle will be categorised within the EU-LIVE project and its development process will be described. Chapter 3.2 contains the results of the open design contest of task 4.1.0. The following two chapters 3.3 and 3.4 describe the results of the vehicle development and the simulation based analysis of the vehicle. The final sub-chapter 3.5 contains a feasibility study of the new vehicle, considering the market and the technical feasibility and an analysis of potential needs of changes to homologation requirements.

3.1 Development of an L6e vehicle

In this chapter, the L6e vehicle within the EU-LIVE project is described. First, an overview on L category vehicles is presented and general requirements for vehicles of these classes are summarised. Then, the motivation for designing a third vehicle as an additional virtual prototype is presented. Finally, the overall development approach for the vehicle is presented, which also describes the framework for this deliverable.

3.1.1 Overview on L category vehicles

Individual transport with motorised vehicles within the European Union is broadly divided into travel by scooters and motorbikes or by car. Directive 2007/46/EC establishes the framework for the approval of motor vehicles [2]. This includes passenger cars of the M1 category, small city cars to vans and Sport Utility Vehicles, but also buses (M2 - M3 category), trucks (N category) and trailers (O category). All passenger and commercial vehicles below the M1 category that require a vehicle registration are approved on the basis of Regulation (EU) No 168/2013, abbreviated ECE R 168 [3]. It comprises powered two-, three- and four-wheeled vehicles such as powered cycles, mopeds, motorcycles, quads and quadricycles, establishing seven categories from L1e to L7e vehicles. Each vehicle category is further divided into sub-sections.

Within the EU-LIVE project, three vehicles are developed: an electrically powered two-wheeler L3e motorcycle, a hybrid tricycle for the L5e category, and an electrically powered light quadricycle L6e vehicle [1] which is the focus of this deliverable. In Table 1, an overview on all seven main vehicle categories with their main characteristic requirements is presented. In addition, the data of the first generation Smart car as one of the smallest mass-production M1 cars is presented in comparison. The three categories for which an EU-LIVE vehicle is developed are marked in blue.

Between the two- and three-wheeled mopeds and motorcycles of the L1e to L5e categories, which are often non-weather protected, and passenger cars of the M1 class exists a gap, filled by lighter four-wheeled vehicles of the L6e and L7e categories. As shown in Table 1, the permissible dimensions and the masses of the L6e and L7e vehicles are similar. The main differences between the light (L6e) and heavy quadricycles are the maximum continuous power output, the vehicles' maximum designed top speed and the maximum number of passenger seats. Although the L6e category is more restricted than the L7e category, its value rests in the option to drive a L6e vehicle at the age of 16 and with lower driver's licence categories [4]. This is possible due to the reduced power output and the lower top speed. With partially favourable acquisition and operating costs, it offers cost-effective individual transport. Because of the two categories' similar dimensions and masses, it is possible to design a light electric vehicle that, with only small changes, can be homologated for both vehicle categories.

Category	L1e	L2e	L3e	L4e	L5e	L6e	L7e	M1 (Smart)
Category name	Light two-wheel powered vehicle	Three-wheel moped	Two-wheel motorcycle	L3e + side-car	Powered tricycle	Light quadricycle	Heavy quadricycle	Motor vehicles
Length			Depending on sub-category up to 4000 mm					2500 mm
Width			Depending on sub-category up to 2000 mm					1510 mm
Height			Depending on sub-category up to 2500 mm					1520 mm
Number of wheels	2	3	2	2 + side car	3	4	4	4
Maximum design vehicle speed	L1e-A ≤ 25 kph others ≤ 45 kph	≤ 45 kph	No speed limit	No speed limit	No speed limit	≤ 45 kph	L7e-B1&L7e-C ≤ 90 kph	135 kph
Maximum continuous power	L1e-A ≤ 1 kW others ≤ 4 kW	≤ 4 kW	No power limit	No power limit	No power limit	L6e-A ≤ 4 kW, L6e-B ≤ 6 kW	L7e-A, L7e-B2, L7e-C ≤ 15 kW	30 kW - 55 kW
Mass in running order	Tech.permis. mass decl. by manufacturer	≤ 270 kg	Technically permissible mass declared by the manufacturer		≤ 1000 kg	≤ 425 kg	≤ 450 / 600 kg dep. on category	720 kg - 805 kg
Seats		≤ 2		≤ 4 motorcycle + side car & ≤ 2 in side car	≤ 5	≤ 2	≤ 4	2
	 [5]	 [6]	 [7]	 [8]	 [9]	 [10]	 [11]	 [12]

Table 1: Overview of the L-categories of regulation No 168/2013 and for comparison a Smart Mk I (M1-category)

The L6e-category sets the framework for light quadricycles. It is, as all categories of ECE R 168 further divided into sub categories. This includes light quads (L6e-A) and light quadricycles (L6e-B) for passenger transport (L6e-BP) and for utility purposes (L6e-BU). The main requirements for L6e vehicles are listed in Table 2. The category selected for the EU-LIVE project is once more marked in blue.

	Category	Sub-categories			
	L6e	**L6e-A**	**L6e-B**	**L6e-BP**	**L6e-BU**
Category name	Light quadricycle	Light on-road quad	Lights quadri-mobile	L6e-B for passenger transport	L6e-B for utility pur-poses only
Length	≤ 4000 mm	≤ 4000 mm	≤ 3000 mm	≤ 3000 mm	≤ 3000 mm
Width	≤ 2000 mm	≤ 2000 mm	≤ 1500 mm	≤ 1500 mm	≤ 1500 mm
Height	≤ 2500 mm	=	=	=	=
Number of wheels	4	=	=	=	=
Maximum cont. rated power	-	≤ 4000 W	≤ 6000 W	≤ 6000 W	≤ 6000 W
Maximum design vehicle speed	≤ 45 kph	=	=	=	=
Mass in running order	≤ 425 kg (excl. battery)	=	=	=	=
Seating	≤ 2	=	=	=	=

Table 2: Technical requirements for L6e vehicles

The focus for the development of the virtual prototype is set on a vehicle of the L6e-BP category, which is optionally capable to be used as a utility vehicle, when equipped with a loading bed. The technical data shown above are the basis of for the virtual prototype.

3.1.2 The L6e vehicle within the EU-LIVE development approach

One key research aspect of the EU-LIVE project is the development of a modular architecture for L category vehicles that enables building a wide range of different vehicles more cost-efficiently through reduced development cost and common-part strategy. A key aspect of this architecture is a range of electric and plug-in hybrid powertrain components, which are suitable for different vehicles and can be combined to form different vehicle configurations.

To show the flexibility of the concept, two real-life prototypes are developed. One of these is a plug-in hybrid electric vehicle (PHEV) for the L5e vehicle category, the other a battery electric vehicle (BEV) for the L3e category. Both vehicles share the basic electrical powertrain components, including the same battery technology as well as the same in-wheel motors (IWM). As far as the development of the two real-life demonstrators is concerned, the use of the IWM with a rear swing arm for both prototypes is relatively easy, as both have motorcycle-styled suspensions.

To show the benefit of the modular approach, powertrain components are also transferred to a radically new L6e category vehicle to be created as a virtual prototype. Its exterior design is selected first as the result of an open innovation design contest. It establishes the direction of development for the whole vehicle.

3.1.3 Development approach for the EU-LIVE L6e vehicle

Within this sub-chapter, the development approach for the L6e vehicle is described. Although the development of the virtual prototype is only part of task 4.1.5, the results of the open innovation design contest influence the direction of development directly as they define the exterior shape of the future vehicle. The exterior design sets the boundary conditions for the package model, the interior layout and the chassis. Therefore, the described approach includes the design contest as one key element. The single steps in the development process are described in the next paragraphs but also pictured in Figure 1.

The decision that the L6e vehicle category will be the basis for the development of the third EU-LIVE vehicle has already been defined in the description of work. Therefore, the requirements of EU Regulation 168 (Table 1 and Table 2) set the framework for the further development. The first step in the development of the L6e vehicle is the conduct of the open innovation design contest. As the design contest's objective is to find unconventional designs from outside of the consortium, the requirements for the designers are as general as possible. They are defined by ECE R 168, results of a user needs study conducted in a previous task and by consortium partners' input. In the second phase of the two-phase design contest, each designer is presented with a very simplified, customized package model to ensure the convergence of design and technology in an early stage of the development. The winning concept, which is selected by a jury, not by the developers of the virtual concept, then forms the basis for all the future development steps.

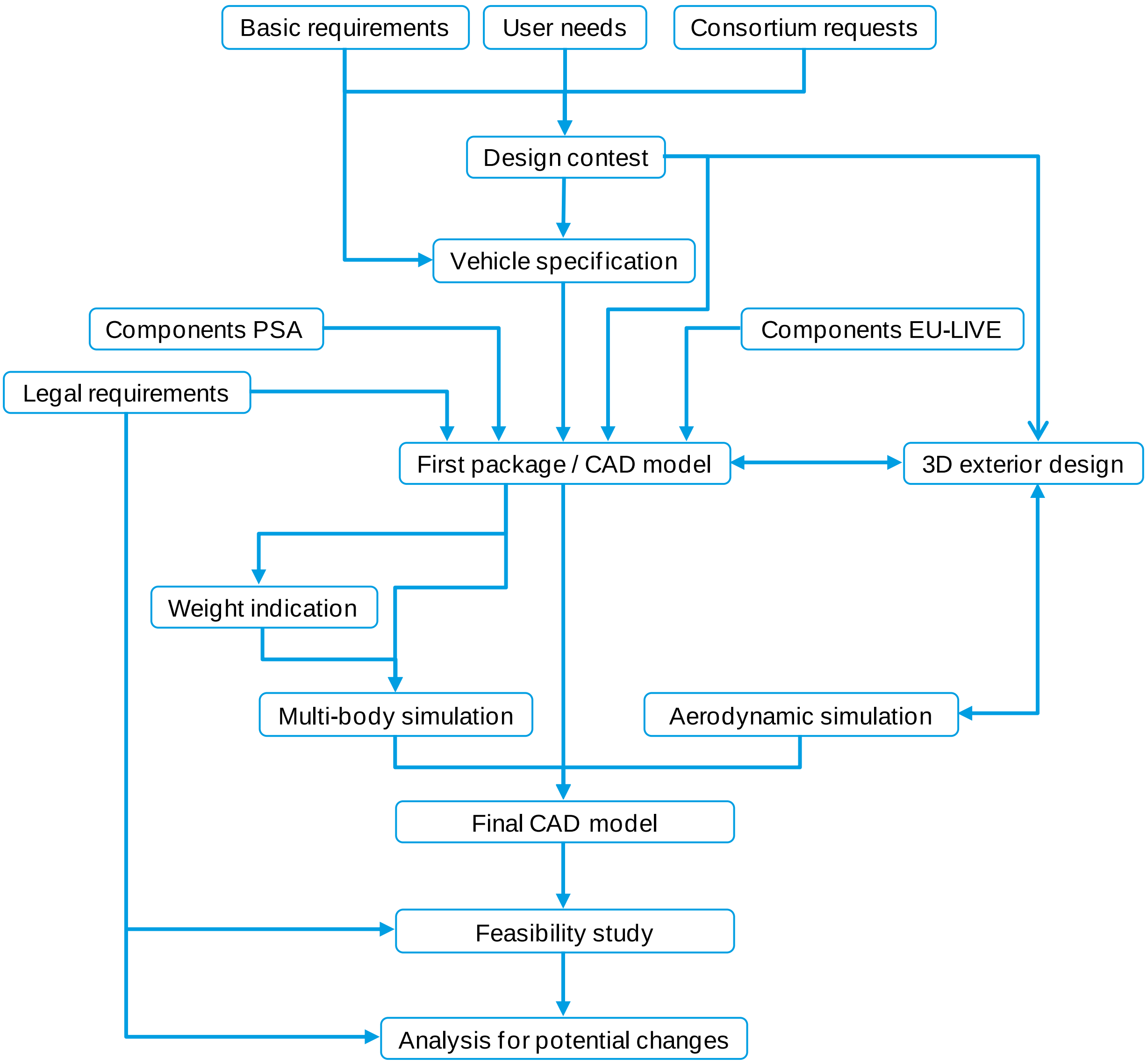

Figure 1: Flow chart of the development approach

Based on the results of the design contest and the requirements of EU Regulation 168/2013, the first vehicle specifications are defined and a first CAD package model created. Besides the exterior design, it includes the EU-LIVE powertrain components as well as interior and chassis component dummies provided by PSA. The simplified CAD model is then complemented with a simplified body structure. As the vehicle specifications are defined, further regulation requirements such as fields of vision are taken into account.

The package CAD model is the basis for the redesign of the winning exterior model. It is also used to derive the position of components and component assemblies for a weight indication as well as the mounting points of the chassis. Both results combined are the input parameters for the multi-body-simulation. The CAD package model with included manikins is further used to build the 3D exterior model out of the winning design concept. Both the CAD and the 3D exterior models are then optimized together in an iterative process. Both simulations and the iterative optimization result in the final CAD and package model.

This final vehicle model is the basis for the feasibility study, analysing the vehicle's market and technical potential. Together with the legal requirements, previously used as input for the first package model, potential needs for changes to homologation requirements are analysed, as well.

In the following chapters, the results of this development process are described. As there have been several iterations during the process, only the final results are presented.

3.2 Open innovation design contest

The design contest was planned as the first development step of the L5e and L6e vehicles, starting already in December 2015. It was supposed to end at the end of March 2016, two months before the overall vehicle design for both vehicles was scheduled to start. Using the concept of the modular powertrain platform as a basis, the design contest was initiated to receive fresh and unconventional ideas from outside the project consortium. Target groups for the contest were students and young professionals in industrial design and engineering as well as in other relevant fields. It was however decided that PSA would create the exterior design of the L5e vehicle in-house. Therefore, the design contest focused only on the L6e vehicle. The advantage of this decision was that the participants focused their work on only one concept, resulting in a larger number of designs to select the winner.

Within this chapter, the structure and schedule of the design contest with the requirements, the jury and design schools, the design phases of the contest and, at the end of this chapter, the final results are presented.

3.2.1 Schedule

As the processing time of the design contest task has only been scheduled for four months, it has been decided to start the preparations of the design contest early, to give the participants as much processing time as possible. A first structure for the design contest has been proposed during the EU-LIVE kick-off meeting in June 2015, splitting the processing time for the participants in two parts. First, an application phase, lasting two and a half months, starting at the end of November and a redesign phase, lasting one month, starting at the end of February. Between the two phases, a two-week period has been scheduled to evaluate the submitted designs, select a number of participants for the redesign phase and to prepare the juries feedback for them. The announcement of the final winners has been scheduled on April 18th.

To start the application phase at the end of November, the internal preparations started in July. In this internal process, the requirements for the L6e vehicle have been defined, a jury selected, the judging process created, as well as content for a teaser and the website written. In addition, all project partners have been asked to propose possible jurors and design schools that should be contacted. To create a high awareness of the upcoming design contest, leading design schools around Europe have been contacted in September and provided with a leaflet. At the same time, the design contest has been first featured on the EU-LIVE website. Two weeks before the application phase started, a reminder had been sent to the design schools and the final design contest website had been activated. Furthermore, internet design platforms have been contacted and the EU-LIVE design contest featured. The main milestones of the design contest are displayed in Table 3.

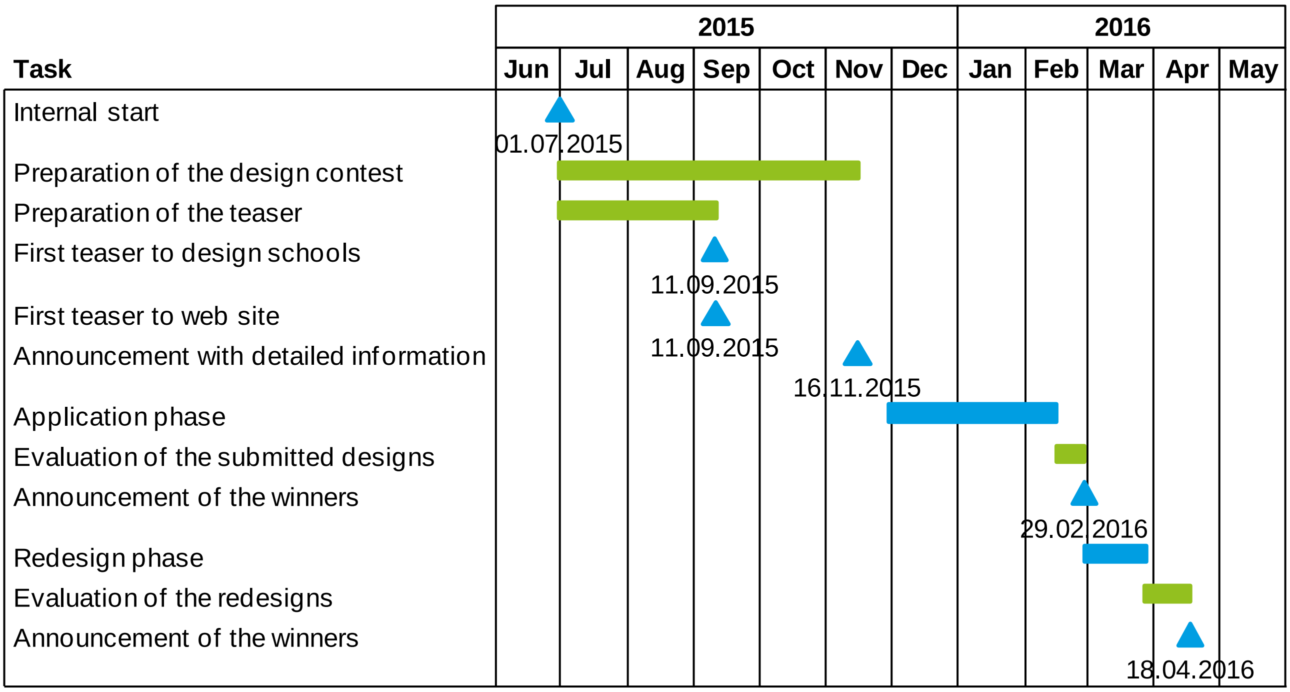

Table 3: EU-LIVE design contest schedule

In the following chapters, the previously mentioned milestones and content of the design contest are described and the results of both design phases are presented.

3.2.2 Structure

In this chapter, the content created during the internal preparation phase of the design contest is described. It includes information of the contest, requirements, the jury and the judging process as well as the leaflet and fact sheet. Some content has been directly included on the EU-LIVE website, some has been used internally, for example during the evaluation.

General information and the award

On the EU-LIVE website, an additional page for the design contest has been created. It features all necessary information about the design contest, including a short motivational text, called the brief:

> "The Brief"
>
> Future urban mobility calls for more space for people and less space for cars as well as for environmentally compatible vehicle concepts, saving resources and minimizing local noise and air pollutant emissions. Motor vehicles in the Light (L-) category already offer an interesting complementary solution to public transport, walking and cycling. Yet, at present, L-category vehicles are still not sufficiently attractive to end users. EU-LIVE will provide a comprehensive solution, which covers a range of three different L-category vehicles (L3e, L5e and L6e). The design contest is the foundation for the L6e-category. Your concept will serve as the sound basis for the virtual prototype. Send us your sketches of a fresh and unconventional car and submit your concept until February 14, 2016"

In addition to the brief, a number of frequently asked questions (FAQ) have been compiled with further information, such as who can submit designs, what has to be submitted, if teams are allowed or what an L6e vehicle in general is and who stands behind EU-LIVE. The complete list of FAQs is included in appendix A.1.

To offer an incentive to the winning participant, the further use of the winning design for the virtual prototype development has been highlighted. In addition, a price of €6000 has been awarded to the first three winners, split into €3000, €2000 and €1000.

Requirements

The requirements given to the participants have been as little as possible, to provide as much design freedom as possible. The requirements have been divided into hard and soft facts. Hard facts are based on EU ECE R 168/2013, already described in Table 1 and Table 2, but adjusted to the needs of the EU-LIVE project. As the winning concept is selected as the basis for the future vehicle, the hard facts have been chosen in respect to a small city car. It is designed for being manoeuvrable, with the legally admissible maximum length reduced from 3 m to 2.5 m to allow for transversal parking along roads. Furthermore, the legally admissible maximum height has been reduced from 2.5 m to 1.9 m, which is the minimum height of multi-storey car parks. The maximum width of the car, the number of wheels and passenger seats have been set as described in the EU regulation.

The soft facts have been presented in a continuous text, to give the participants a feeling for the vehicle and the environment, it is designed for. Some facts are part of ECE R 168/2013, such as the top speed of 45 kph, or the EU-LIVE description of work (DOW), with the use of IWM. In addition, user needs for small electric vehicles in everyday situations had been identified within work package 1 “user needs” [13]. Some of them have been included in the soft facts as well, to create a vehicle more suitable for city use. Identified and included user needs are for example: easy to park, safety, safe transport of everyday goods and all weather usability. The soft facts read in detail:

> “Soft facts”
>
> Make up your mind and design a fresh and unconventional ultra-light vehicle concept for two passengers. The small but modular electric vehicle for future mega-cities shall use in-wheel motors and be designed for a top speed of 45 kilometres per hour. Your concept covers the needs of individual transportation on the first hand, but also could meet the requirements for business solutions. Keep in mind that car sharing gets more important and could be a future use case.
>
> Our findings show that users have a strong need for safe, usable L-category vehicles which are easy to park and allow a convenient transport of the typical everyday goods. Regardless of the vehicle’s top speed, safety always takes a high priority and the protection of the passengers should not be neglected. Your body design offers all weather usability and an optional alternative door or entrance concept allows accessibility from at least one and a maximum of three sides. Providing comfortable mobility, easy parking and storage space will also serve the customers’ needs.”

To create a quick and clear overview of all requirements, an additional diagram has been designed, displayed in Figure 2.

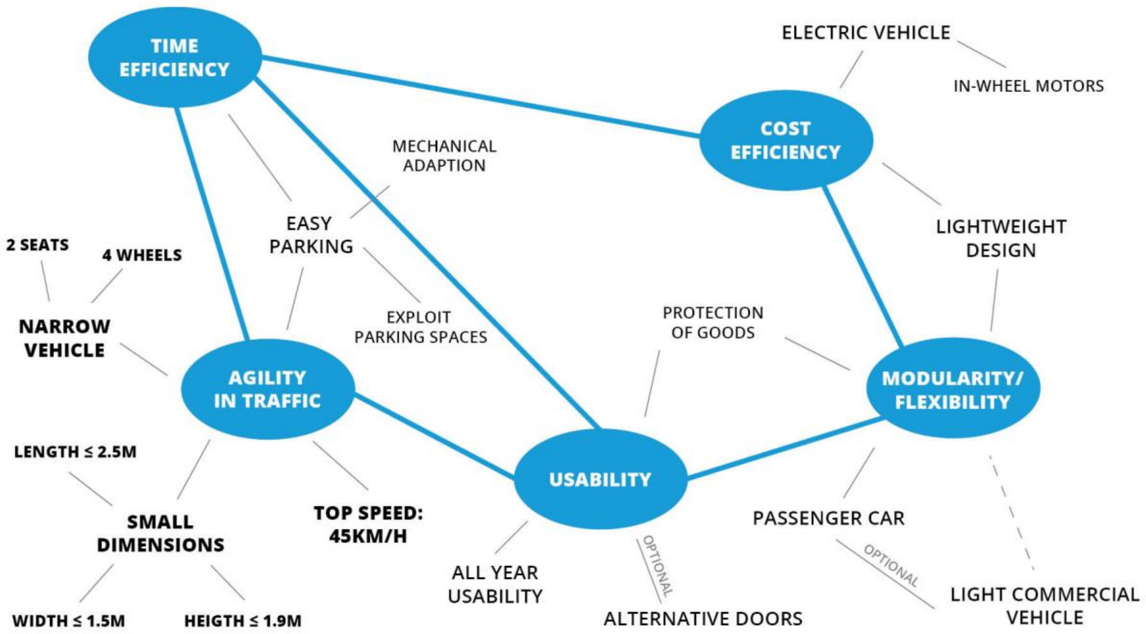

Figure 2: Requirements for the EU-LIVE design contest

The diagram has been added to the requirements section of the website along the hard and soft facts.

Jury

As stated before, all project partners have been asked to name jurors to participate in the evaluation process of the submitted designs. As the jurors have not necessarily been part of the project consortium, a non-disclosure agreement has been formulated for external participants. As the winning design is subsequently used for the development of the virtual prototype, a basic level of manufacturability had to be fulfilled. Therefore, not only design expertise has been required for the jury, but also a technical perspective desired. The jury comprised of four designers, three from the EU-LIVE consortium and one external expert, and three engineers, all part of the consortium. The jury members were:

> Damien Basset, Peugeot Scooters – Head of Advanced Design and Brand Identity

> Lutz Eckstein, Institute for Automotive Engineering (ika) RWTH Aachen University – Director

> Thomas Fournier, Group PSA – Car Designer

> Lutz Fügener, Pforzheim University – Professor for Transportation Design

> Rüdiger Heim, Fraunhofer-Institute for Structural Durability and System Reliability – Vice Director

> Daniel Huber, Spirit Design – Managing Partner, Strategic Design

> Werner Rom, VIRTUAL VEHICLE Research Center – Head of the Area "Cross Domain"

Judging process

To allow for an easy and consistent evaluation of the submitted designs, a standardized questionnaire has been created. The participants have been informed in advance, that their designs would be rated against the following criteria with a fixed weighting:

> Fulfilment of the requirements	> 35 %
> Originality of the design	> 35 %
> Quality of the design	> 15 %
> Opportunity for series production readiness	> 15 %

To avoid individual interpretation of the four criteria by the jurors and to create a more detailed evaluation, the criteria have been divided into sub-criteria where possible, each with a number of evaluation items. Each item had to be rated from 1 (sufficient) to 5 (excellent). According to the weighting, a total score for each vehicle has been calculated. The complete evaluation sheet is shown in appendix A.2.

Design schools, leaflet and fact sheet

In order to make sure that the EU-LIVE design contest would create high awareness within the design community, it has been decided to promote it by sending out leaflets to design schools and design platforms. The project partners have proposed a total of 45 design and art schools as well as technical universities. The complete list of schools is attached in appendix A.3. The schools have been contacted three times. First at the end of September 2015 by e-mail, sending out the leaflet. Then they have been called, to make sure the e-mail has been received. Finally, shortly before the official start of the contest, a mail reminder has been sent out with an attached fact sheet.

The leaflet is a short one pager with the call to design future urban mobility. An introducing text, teasing the L6e vehicle and a time table has been added. It does not include any information about requirements for two reasons. First, the research on the user needs had not been finalised when the leaflet has been sent out and second, it has only been sent to the 45 design schools, while it had to be avoided to give a selected number of students an unfair advantage. The leaflet is shown in Figure 3.

Figure 3: Leaflet for the design contest

The fact sheet has been created as a handout for the participants. Its two-page design includes the main information also listed on the website. The first page includes “the brief”, information about the award, the time table and lists the jury members. The second page includes all requirements and the information on the judging process. As all contents have been described on the previous pages, the fact sheet is included in appendix A.4. The fact sheet has been available on the design contest website, has been sent to the design schools attached to the reminder mail and has also been sent to various design websites. The mail to the design platforms has resulted in listings on numerous websites focusing directly on design contests, such as Contest Watchers [14] or Car Body Design [15].

3.2.3 Design phases

For the application phase, the participants have been asked to send sketches or renderings of their designs with a minimum of two and a maximum of five pictures. They had to present at least two different perspectives with at least one mandatory three-quarter front view. In addition, a short description of the submitted concept has been requested. It gave the participants the chance to describe the motivation behind their concept and their understanding of the defined challenge. The designs, the description and an optional picture of the participant/ team had to be uploaded via an input form, which also queried contact information and requested a confirmation

of the conditions of participation. The conditions of participation are listed in appendix A.5. As stated in there, the intellectual property of the submitted designs remains with the contenders. However, EU-LIVE and its partners are allowed to use, publish and develop the designs without further notification.

During the application phase, the consortium received a total of 92 submitted designs, 14 during the penultimate day and 56 during the last day. Out of all submitted designs, two had to be rejected due to missing information. Due to high qualitative differences of the submitted designs, one juror with a design background preselected out of the remaining 90 designs 28 possible contenders. The remaining designs, together with the design descriptions, have then been sent to the jury. In Figure 4 six designs are exemplarily illustrated. The designers are named in [16].

Figure 4: Six submitted designs 4X-E, Aquair, Easy, koku, vis-a-vis 2.0, ze micro car [16]

Winners of the application phase

Based on the judges' evaluation, the six best-placed concepts of the application phase have been selected for the redesign phase. In Figure 5, these six designs are illustrated and presented in alphabetical order.

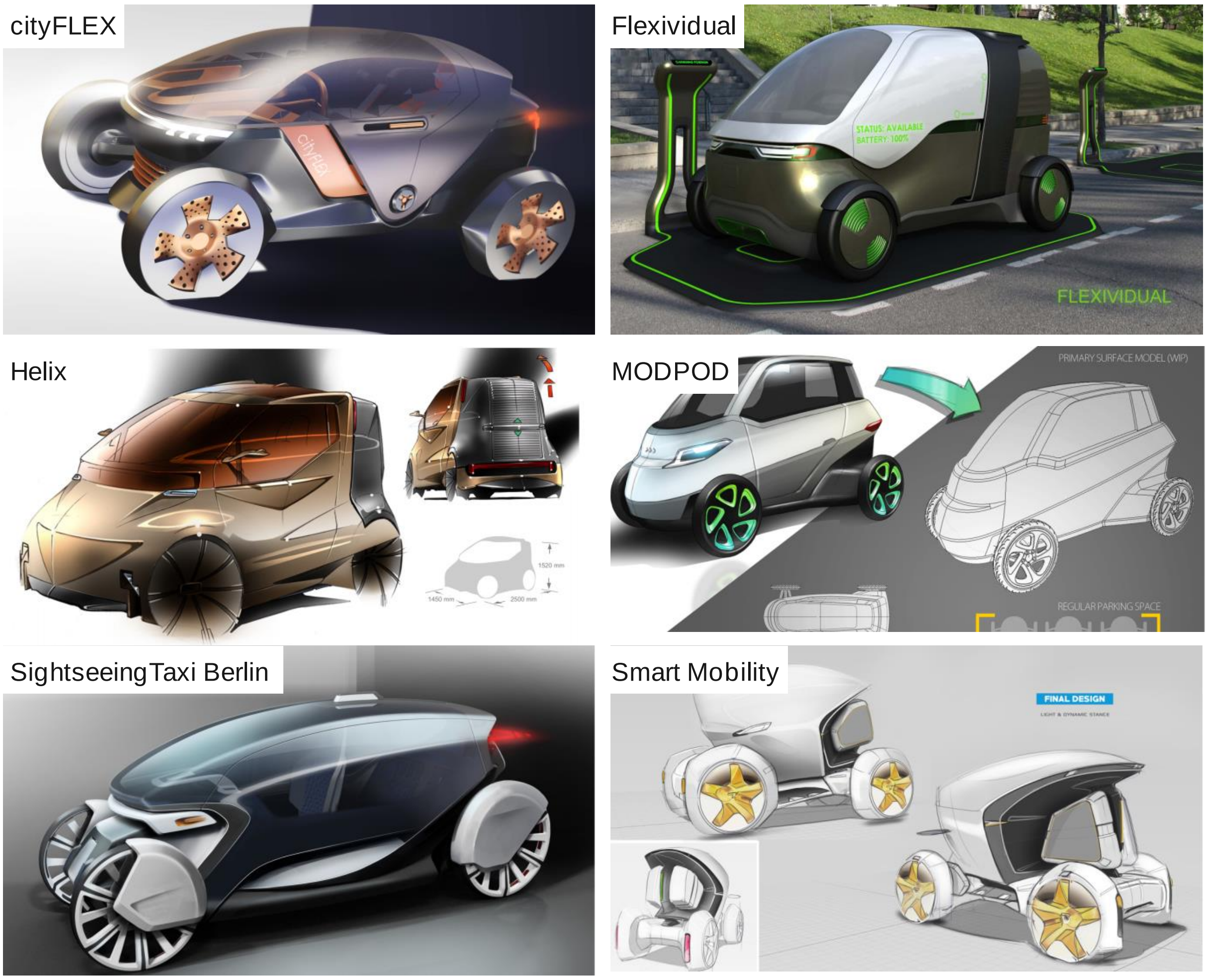

Figure 5: The six winning designs of the application phase (in alphabetical order) [17]

Requirements for the redesign phase

As partly apparent from the pictures shown above, the vehicles do not necessarily fully match the requirements put for the application phase. Especially the exterior dimensions do not seem to fit. For example, Sightseeing-Taxi Berlin seems to be too long to match the 2.5 m specification to seat two passengers behind each other in comfort.

To secure the fulfilment of the requirements by each design and to secure the possibility of a further development of each design during task 4.1.5, an individual package has been created for each car. It contains basic components, consisting of a battery pack, IWM and wheels as well as exterior dimensions and two manikins, arranged as the designers have arranged them. To create the package, first, sketches in side, front and top view have been scaled to match the exterior dimensions given by the designers. Second, tires, IWM and two 95 percentile male manikins have been added. The manikins have been placed to match basic comfort angles, described in literature such as “H-Point” [18], but also to leave enough room for crash deformation zones for front and side impact. The minimum deformation zone dimensions have been derived from expert knowledge, based on experience gained during other projects. This also means, placing the driver thus far backwards that his feet are behind the front wheels’ centre axis to prevent the squeezing of the feet in case of a front impact. Finally, a battery pack has been added, where space was left. A package plan for the SightseeingTaxi Berlin in side and top view is illustrated in Figure 6. The battery and the IWM are displayed as the yellow circle and rectangle, the crash deformation zones are displayed via the red rectangles. The front tires are displayed for both straight line driving and cornering and show the required space outside the body.

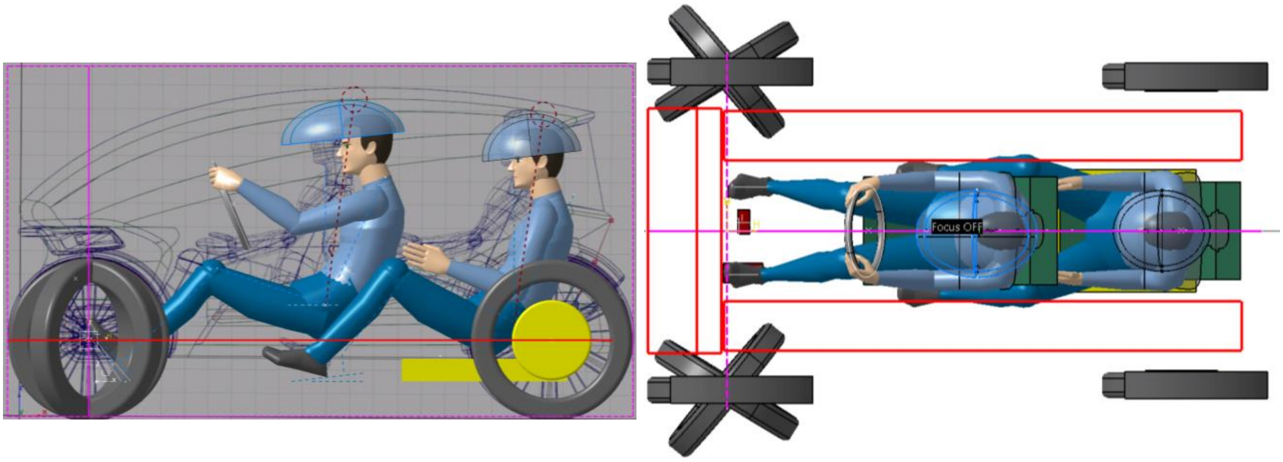

Figure 6: Package plan for SightseeingTaxi Berlin in side and top view

Based on the package plan and comments from the jurors, an individual feedback has been written for each contender of the redesign phase. For SightseeingTaxi Berlin for example, the vehicle floor had to be lowered, to provide enough space for the passengers' feet and the battery. The same has been stated about the headroom of the two passengers. In addition, the bodywork had to offer enough space around the front axle to turn the wheels. The feedback, together with pictures of the package in front, side and top view, scaled to 1:25 and designed to be painted over, have been provided to each designer.

Redesign phase

For the redesign phase, all designers have been asked to rework their concepts to match the provided packages and to consider the comments from the jury. This time, they have been asked to include two-dimensional front, side and top views as well as two three-quarter views of front and back. A maximum of eight pages with descriptions, blueprints and designs has been allowed and afterwards provided to the jury one more time.

3.2.4 Results

For the second review session, the jury has been provided with a slightly shortened questionnaire. The questions regarding the dimensions have been deleted, as the package models have ensured that all vehicles match the dimensional requirements. Out of the six final designs, the jury has selected a top three.

The top three designs are the following:

> 1st: cityFLEX by Robert Hahn
> 2nd: SightseeingTaxi Berlin by Jörn Lutter
> 3rd: Smart Mobility by Hugo Bricout

The second placed SightseeingTaxi Berlin combines the flexibility of a bike rickshaw with the comfort of a conventional taxi. The vehicle operates as a common offer to move between destinations in the urban space with the advantage of getting interesting information about the places passing by.

The third placed Smart Mobility is a concept for short trips through the city. It has a scalable platform, which expands when travelling with a passenger. In addition, it carries a couple of top cases, located outside the passenger compartment, which can be adapted for professional needs. The second and third placed vehicles are illustrated in Figure 7.

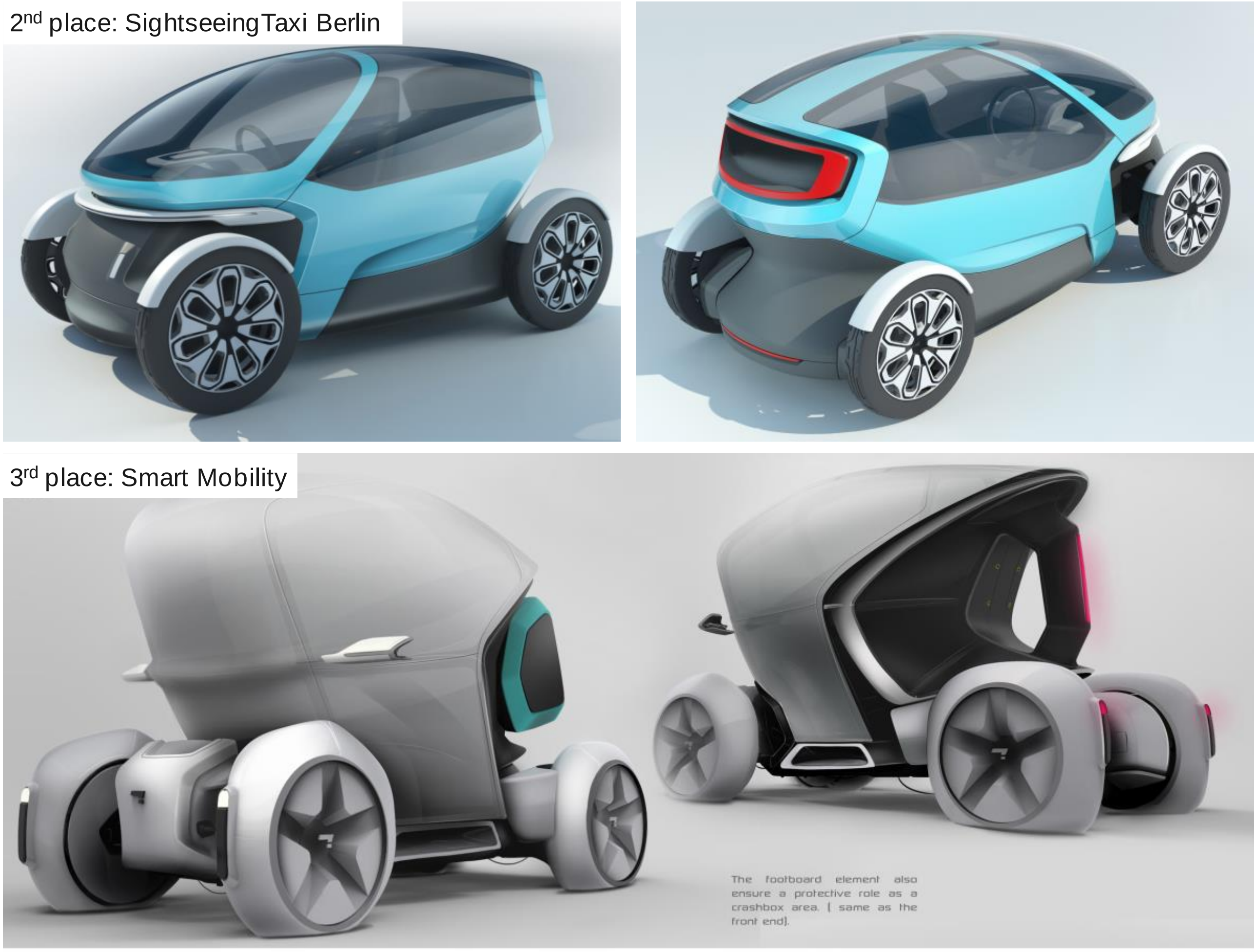

Figure 7: 2nd and 3rd placed vehicles of the design contest

The overall winning design is the cityFLEX concept, which originally has been designed as a one+one-seater, featuring two driving modes. One was a closed cabin mode for one passenger and the other one as an open cabin vehicle for two passengers or for transporting additional luggage behind the seat. Due to the requirements of an all year usability combined with the two-seater layout, Mr. Hahn has redesigned the cabin dimensions, included a fully functional seat and increased the crash deformation zones. The results of the redesign are illustrated in Figure 8 and Figure 9.

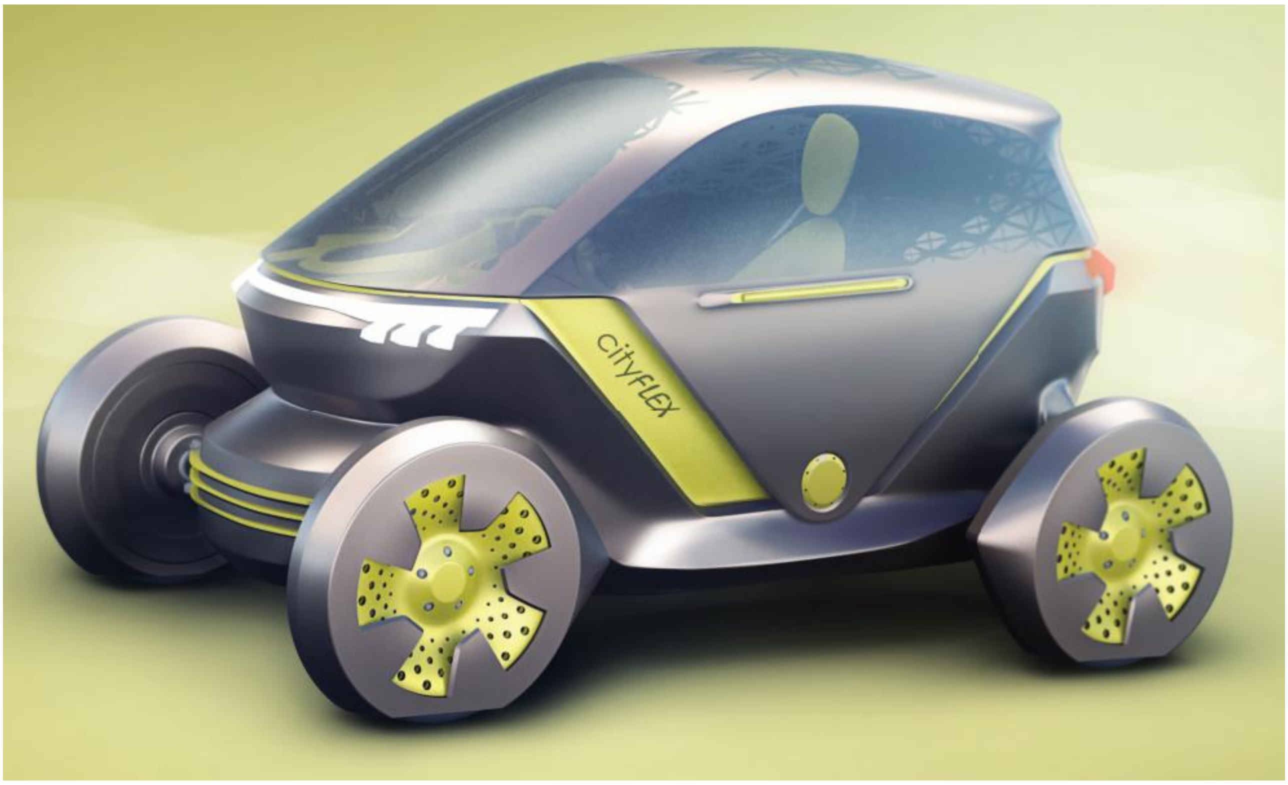

Figure 8: Winning cityFLEX concept

Figure 9: Detailed views of cityFLEX concept

The cityFLEX concept forms an interesting basis for the subsequent development of the L6e vehicle, which is described in the following chapters.

3.3 L6e vehicle design

In this chapter, the development of the virtual L6e vehicle concept is presented. This includes the vehicle requirements and basic layout decisions, a description of included components and the presentation of the package plan and the simplified CAD model. The CAD model is the basis for corresponding multi-body and aerodynamics simulations, which are part the next chapter 3.4.

The vehicle design is influenced by four elements: the exterior design, legal requirements, EU-LIVE powertrain components and vehicle components provided by PSA to be used as carry-over parts. In a first step, a basic interior layout is selected, based on vehicle requirements and the exterior design. In further steps, this layout is further detailed with the additional components, creating an overall package. In parallel to the development of the package plan, the exterior design is adapted to the package, forming the overall CAD model. In chapter 3.3.1, the basic layout decisions are explained and requirements presented. In chapter 3.3.2 the carry-over components are described, which are used to define the package and exterior design in detail. The final layout is described in the last sub-chapter 3.3.3.

3.3.1 Basic interior layout and vehicle requirements

The winning concept of the design contest defined the direction of development for the new L6e vehicle and the overall layout of the car with an open wheel concept. This exterior shape has to be matched by an interior and package concept. Therefore, the interior layout has been decided initially and legal requirements have been gathered, which could influence the further development. The EU-LIVE consortium has supported the initial development.

Basic interior layout

The initial layout created for the cityFLEX concept features a one+one-seat arrangement, allowing for a small vehicle footprint, despite using an open-wheel concept. A blueprint for the concept is shown in Figure 10.

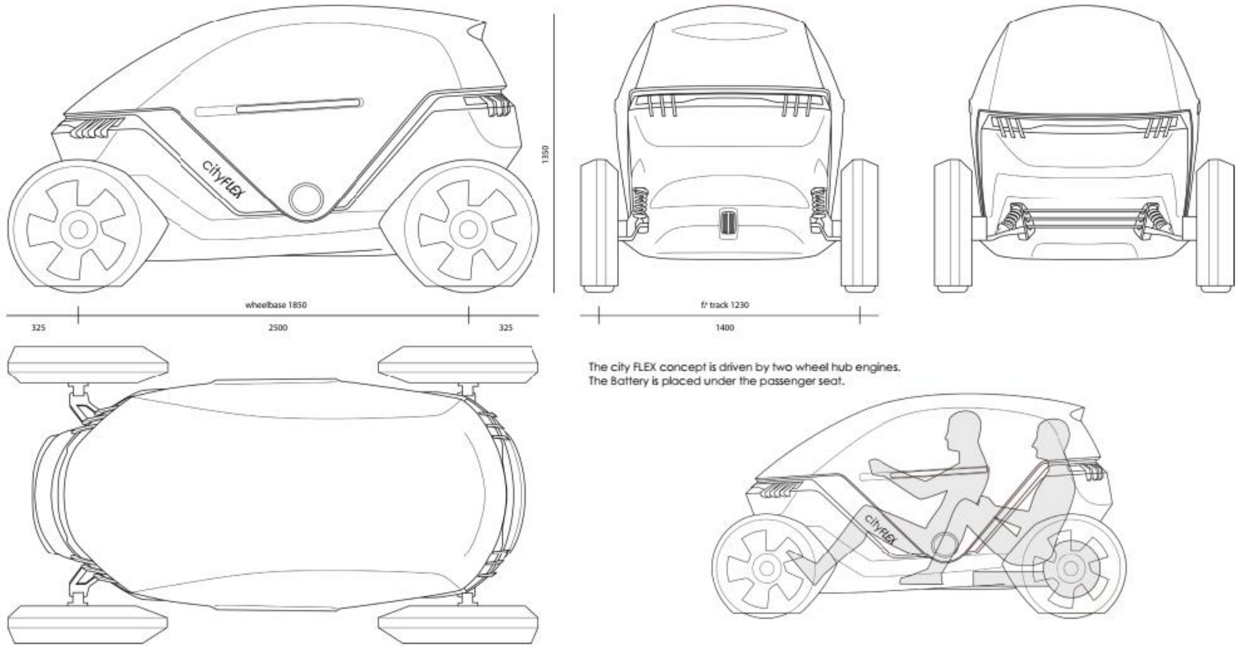

Figure 10: Blueprint of the cityFLEX concept

With a concept width of 1400 mm, cityFLEX is not narrow enough to meander through traffic as a scooter does. Therefore, is has to offer a seating comfort that is comparable to small passenger cars. The cabin however has a width of 1110 mm, whereas a 95 percentile male has a shoulder width of only 525 mm [19]. With a typical

shoulder room of roughly 37 mm to the interior trim on either side in a micro car [18] and with neglecting the width of the interior trim itself, cityFLEX has an unused interior room of roughly 511 mm in width for a one+one layout. It is therefore either possible to increase the efficiency of the vehicle with a narrower design or to increase the comfort of the passenger in the second row with a different seating layout. As the EU-LIVE L5e vehicle already features a narrow design and the different vehicle concept of the L6e vehicle shall show the modularity of the powertrain, different interior concepts are compared.

As the cabin width does not allow for a side-by-side arrangement – two 95 percentile males sitting shoulder to shoulder already require at least 1050 mm cabin space – the two possible seating options are the current one+one layout or a diagonal offset concept. Both concepts are opposed in Figure 11, overlaying the top view of the vehicle with a basic layout configuration.

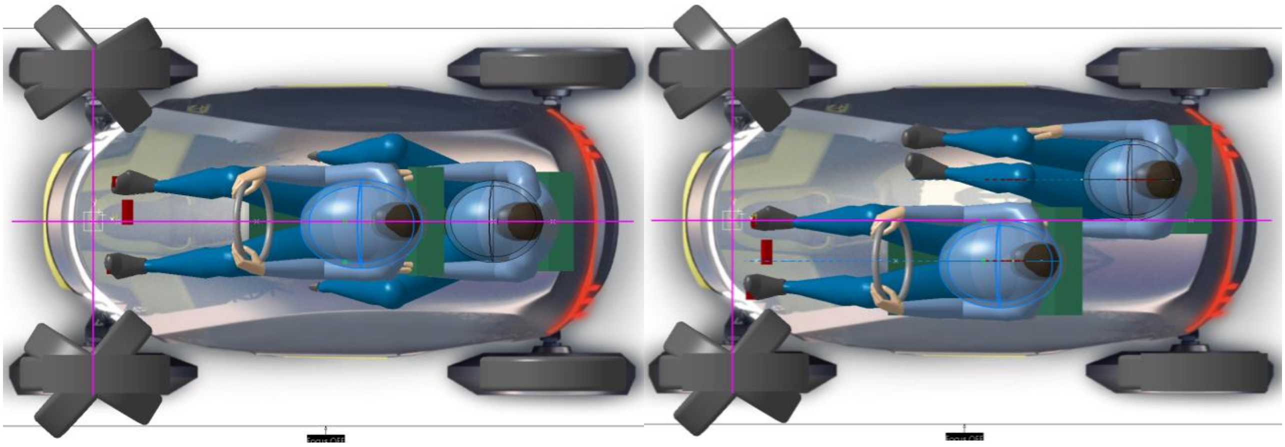

Figure 11: One+one and diagonal offset seating layouts

As it becomes apparent, the rear passenger in the one+one layout has to sit in an uncomfortable position. Furthermore, he is not able to enter and leave the vehicle when the driver is sitting in his seat. With the diagonal offset layout, entering and sitting more comfortably is both possible for the rear passenger. With a longitudinal offset of 530 mm and a lateral offset of 330 mm in the current setup, it also leaves enough shoulder and hip room to the outer contour, to seat both passengers in greater comfort. Based on the investigated boundary conditions, it has been decided to further investigate the diagonal offset layout.

The all-electric L6e vehicle uses the EU-LIVE powertrain, with two IWM and the battery pack of the L3e scooter. With the IWM mounted outside the cabin, the battery pack is the largest powertrain component to be mounted inside the vehicle. It is placed underneath or near to the passengers, within an area with minimum deformation in case of an accident. The IWM is placed on the rear axle, allowing for a short and easy cable routing to the battery and the power electronics. Additional powertrain components that need to be included are described in chapter 3.3.2.1.

In addition to the interior layout and the basic powertrain configuration, PSA as one of the Original Equipment Manufacturers (OEM) in the consortium, has provided further components that help to create a more detailed CAD model. They are described in chapter 3.3.2. Based on the additional components, the package model can be designed in more detail. Then again, this requires an adaptation of the exterior model, to match the concept.

Requirements

During the early stage of the design phase, essential parameters of the future vehicle are defined. In case of the L6e vehicle, they are influenced by the exterior design, the parameters provided for the design contest and regulation requirements as well as the EU-LIVE powertrain and components of the shelf. Basis for the development of all L category vehicles is ECE Regulation 168, which has already been mentioned before with basic parameters documented in Table 1 and Table 2. It is supplemented by Regulation No 3/2014 [20]. General requirements demanded in ECE R 168/2013 are defined in detail in R 3/2014 for each vehicle category. Where information beyond this is required, it refers to additional ECE regulations.

Within D2.1, ECE R 168/2013 already has been analysed broadly for requirements that need to be fulfilled by the three vehicles [21]. As in Annex II of the original document, the requirements have been listed in the three groups: Part A, environmental and propulsion performance requirements, Part B, vehicle functional safety

requirements and Part C, vehicle construction and general type-approval requirements. Although the L6e concept is only developed as a virtual concept, it is designed to meet the regulation requirements where possible. As D2.1 only lists the regulations themselves but has not defined specific requirements out of these, ECE R 168/2013 and R 3/2014 have been analysed once more specifically for the L6e vehicle. In Table 4 the results on how to fulfil the requirements, when to fulfil them and on what consequences they have for the vehicle are listed. The letter-number combinations in the left column refer directly to the original requirements listed in Annex II of the regulation. The missing items in the listing have already been stricken of in D2.1.

With only a simplified design, many requirements cannot be verified in detail. As the L6e vehicle will additionally explore a new concept, potential needs for changes to homologation requirements and regulations have to be analysed later on. Therefore, some requirements may not necessarily have to be fulfilled.

No	Subject	Regulation	How to be fulfilled?	When?	Consequence?
B2	Braking, including anti-lock and combined brake system	ECE R 78	L6e vehicle has to meet the same requirements as L2e vehicles, including a service brake, parking brake and ABS	Design and development phase	Add basic brake components already part of assemblies, provide space for additional components for further development phase
B3	Electrical safety	ECE R 100	To be complied with in detailed development phase	Development phase, not part of the project	No further action
B5	Front and rear protective structures	ECE R 26	Fulfilled if No C7 is ok	-	-
B6	Seats, their anchorages and any head restraints	ECE R 17	Integration of seats as PSA carry-over part, shall fulfil ECE R 17	Design and development phase	No further action
	Safety glazing materials and their installation	ECE R 43	Detailed selection of glazing materials and their related requirements depending on final production design	Development phase, not part of the project	No further action
	Heating system	ECE R 122	Integration of a heater system as a PSA carry-over system	Detailed analysis of defrosting on physical prototype not part of the analysis	Integration of heater system
	Forward field of vision	ECE R 125	CAD analysis	Design phase	Analysis of forward field vision
	General safety of motor vehicles	UE R 672/2010	Not applicable for vehicle with less than 15 kW power output	No further action	
	General safety of motor vehicles	UE R 1008/2010	Detailed integration of windscreen wipers and washer fluid	Mainly development phase, not part of the project	Provide space for additional components for further development phase

No	Subject	Regulation	How?	When?	Consequence?
B7	Speedometer	ECE R 39	L6e vehicle has to meet requirements for L2e	Development phase, not part of the project	Interior design and integration of onboard electronics not part of the project
	Driver operated controls	ECE R 60	Applicable for L3e vehicles	No further action	
	Hand controls, tell-tales and indicators	ECE R 121	Meet requirements of Regulation No 3/2014, annex VIII, 2 – 2.2.1.6 or ECE R 121; detailed description of tell-tale design	Development phase, not part of the project	Interior design and integration of onboard electronics not part of the project
B8	Installation of lighting and light-signalling devices	ECE R 3/2014, Annex IX	L6e/L7e: meet requirements of 1.10 – 2.5 of annex IX	Design and development phase	Design phase: provide spaces for required lighting devices (annex IX, 2.2) Development phase: design lighting in detail
	Reversing and manoeuvring lamps	ECE R 23	Has to be fulfilled	Design and development phase	Provide space for reverse light
	Installation of lighting and light-signalling	ECE R 3/2014, Annex IX	Colour definitions and type-approved lighting of ECE R 48 may be taken as an alternative	No further action	
	Installation of lighting and light-signalling	ECE R 53	Applicable for L3e vehicles	No further action	
	Side marker lamps	ECE R 91	Has to be fulfilled	Design and development phase	Analysis of installation space
B9	Rear-view mirrors	ECE R 46	Has to be fulfilled	Design and development phase	Analysis of installation space
	Rear-view mirrors	ECE R 81	Only applies to motorcycles	No further action	

No	Subject	Regulation	How?	When?	Consequence?
B11	Safety belt anchorages and safety belts	ECE R 3/2014, Annex XII	L6e vehicle with a mass in running order > 270 kg shall be fitted with safety belt anchorages and safety belts on seats	Development phase, not part of the project	Seat belts shall be anchored to the lower vehicle body, anchorages integrated during detailed design of vehicle body
B12	Safety-belts, restraint systems	ECE R 16	L6e has to fulfil requirements of N1 vehicle	Detailed specification of seat belts is part of the development phase (not part of the project)	None during design phase
	Seat strength	ECE R 17	Integration of seats as PSA carry-over parts, shall fulfil ECE R 17	Design and development phase	None during design phase
	Child restraint systems	ECE R 44	If child restraint is equipped, it shall meet requirements of ECE R 44	Development phase, not part of the project	No further action
B13	Steer ability, cornering, properties and turn ability	ECE R 3/2014, Annex XIV	Description of driving tests	Physical prototype test, multi-body-simulation secures safe cornering	Multi-body-simulation will be performed on virtual prototype
B16	Vehicle occupant protection	ECE R 3/2014, Annex XVII	Requirements regarding the interior fittings	Development phase	Interior design not part of the project
B18	Vehicle structure integrity	ECE R 3/2014, Annex XIX	Vehicles shall be designed and constructed as to be sufficiently robust to withstand their intended use over their normal lifetime	Design and development phase	Design phase: create a sufficient basic structure; validation part of development phase
C7	External projection	ECE R 26	Has to be fulfilled	Design and development phase	Analysis of exterior design

Table 4: Legislative requirements for the L6e vehicle

In D2.1, additional design requirements have been defined. They are mainly stated as “to be defined” (TBD). This is because the document has been written in parallel to the design contest when the winning concept still had to be selected.

With a seating layout selected and the legal requirements in mind, preliminary vehicle parameters are defined. As they are adapted during the further development process, the final parameters are presented in chapter 3.3.3.

3.3.2 Vehicle architecture

One of the main reasons to create the virtual L6e vehicle is to verify the EU-LIVE modular powertrain architecture concept by integrating it in an additional vehicle, which does not have the characteristics of the L3e or L5e vehicle with a single rear wheel or narrow rear track and a rear swing arm chassis. Therefore, all required powertrain components for the electric vehicle are added to the package design. The configuration is described in chapter 3.3.2.1.

To create a more detailed package design and to create a basis for the simulation, PSA provided additional chassis and interior components. As they are not specifically designed for small L6e vehicles, they are used for geometrical analysis and as reference components, which may be replaced during an additional development phase, which however is not a part of this task and the DOW. Nevertheless, the provided components do further proof the feasibility of the EU-LIVE concept. The provided chassis and interior components are described in the chapters 3.3.2.2 and 3.3.2.3.

3.3.2.1 Powertrain

The EU-LIVE powertrain features both combustion and electrical engine components that can be combined in different ways to create petrol, hybrid or purely electric vehicles. For the L6e vehicle, the powertrain is a combination of both the L3e and L5e vehicle layouts. The basic architecture is comparable to the L3e scooter, as both use all-electrical systems. The L6e features the same high capacity battery system but combines it with two IWMs and two inverters, one for each motor. This inverter IWM layout can be found on the L5e vehicle. The combustion powertrain section of the L5e vehicle is not integrated in the L6e vehicle. The system is operated through several components that form the control unit. It is also intended to use an onboard charging system, as direct competitors like the Renault Twizy also do. Additionally, a 12 V onboard power system is integrated to run low voltage components. A detailed description of the EU-LIVE powertrains with all technical data is given in the deliverables of work package 5 [22]. In Figure 12, the basic layout of the L6e vehicle’s powertrain and the integrated components is shown.

The EU-LIVE powertrain architecture is designed as a 48 V system, with all components, the battery, the inverters and the IWMs, featuring an air cooled design. A heavy liquid cooling system is therefore not required. This is especially helpful, as the L6e category has a legal weight limitation of 425 kg excluding the battery, which does not exist for the L3e category and is extended to 1000 kg for the L5e category (compare Table 1). The battery has a modular design, allowing to create systems with different capacities. For the EU-LIVE L6e vehicle, the battery has a capacity of 5.3 kWh and a mass for two modules of 27 kg, which is added to the 425 kg vehicle mass limit. If a higher capacity is required, additional battery modules can be added.

ECE R 168 limits the maximum continuous rated power of L6e vehicles to 6 kW. Each of the IWMs, designed to power the L5e vehicle to higher speeds than 45 kph, have to be limited to 3 kW by the control unit. The motor itself with its mechanical design is integrated without changes. It features an integrated disc brake system, facilitating the integration of the system. As the open-wheel design of the L6e vehicle is significantly different from the other two vehicles, the swinging arm is not part of the powertrain layout. Instead, the motors are linked to a double wishbone rear axle, provided by PSA. The inverter assembly is the same as it is in the L5e vehicle.

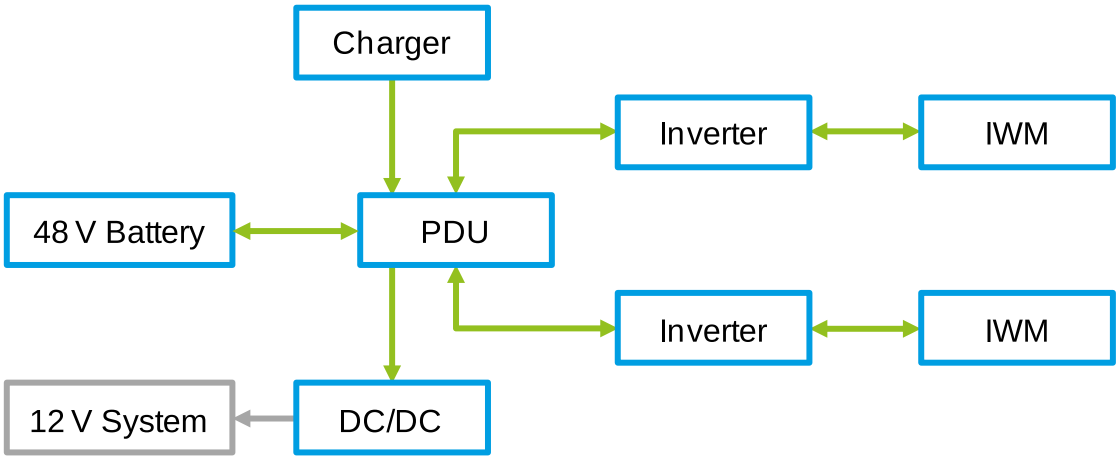

Figure 12: Basic powertrain layout of the L6e vehicle

For the package design of the L6e vehicle, all powertrain components are integrated in the vehicle. Where possible, the original CAD design of the components is used. Others are replaced by dummy components with the same dimensions and masses as the original components intended. This is due to an early integration of components that are still in development.

3.3.2.2 Chassis components

In addition to the EU-LIVE powertrain components, it seems useful to integrate additional chassis and interior components from the other two vehicles, to fully exploit the common-part strategy. The wide disparities between the scooter-like L3e and L5e concepts and the passenger car-like L6e vehicle make this step however difficult. The integration of the rear swing arm of the scooters is not feasible due to the open wheel concept of the winning exterior design model. The distance between the tyre contact patch and the body is too wide to integrate a body sided attachment point inside the cabin. With a different exterior design without open wheels, the swing arm could have been integrated, as well. The front suspension of the L5e vehicle uses a three-wheeler suspension, which is not adaptable to a conventional suspension. Therefore, PSA has provided a front and rear suspension system as well as a steering gear with steering column. As the components have been designed for various exhibition vehicles and regular passenger cars, but not specified for a light L6e vehicle concept, they are used as placeholders to create a more realistic CAD model.

The front and rear suspension has originally been designed for a small concept car. It is a double wishbone suspension on both axles. As the original suspension has a wider track than the new L6e vehicle, it has been adapted to 1345 mm front and rear. The front axle's mechanical design with its kinematics, wishbones, wheel carriers, anti-roll bar and disk brakes system is taken over without changes.

The integration of the IWM on the rear axle requires the design of new wheel carriers, which do not need to include wheel bearings and a wheel hub but only connect the mounting points of the two wishbones and the tie rod with the mounting points of the IWM and function as a sub frame. As the IWM already features a disc brake assembly, the one originally integrated to the rear axle has also been removed.

The provided steering gear and column has also been designed for a PSA concept vehicle and has been adapted to the track width and the mounting points of the front axle. It is used to validate the installation space within the concept and to prevent installation space conflicts with other components that are installed in the wider front end and foot area. In Figure 13, the chassis components integrated in the L6e vehicle are displayed. Additional information on the suspension is provided in chapter 3.4.1, where the simulation model is described.

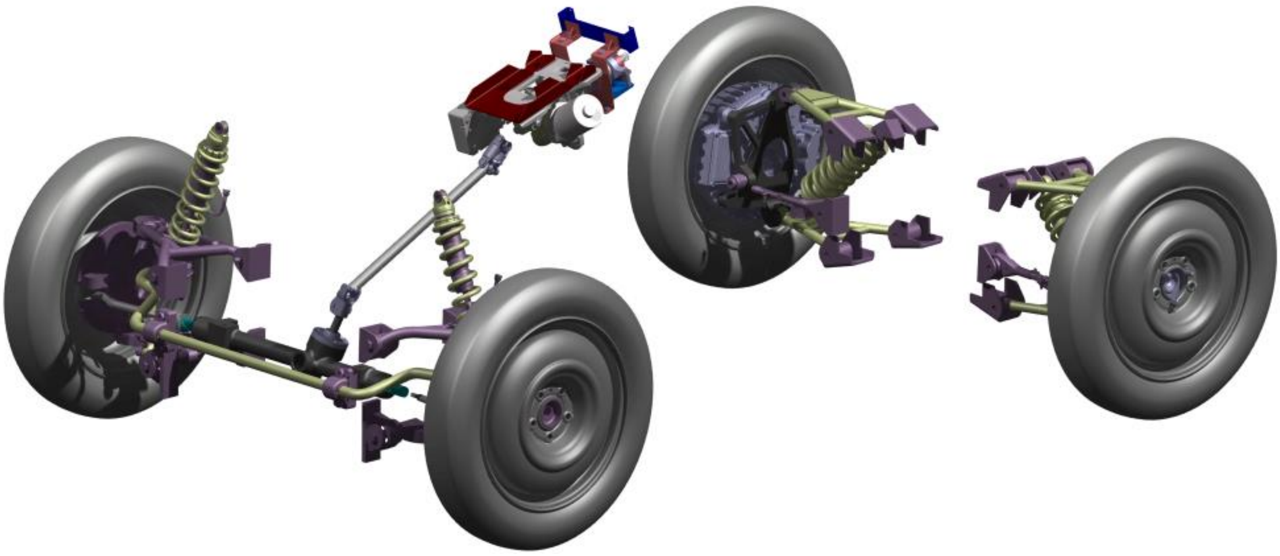

Figure 13: Front and rear suspension and steering system of the L6e vehicle

For a further development of the vehicle, which is not part of task 4.1.5, the integrated components would need to be dimensioned to the specific load cases of the vehicle.

3.3.2.3 Interior components

The seats for the L6e concept vehicle are taken from a three-seater layout concept, comparable to the McLaren F1 [23]. Out of this concept, only the driver and one passenger seat are integrated and positioned to the designed interior concept. The passenger seat has a fixed design, whereas the driver seat is adjustable.

Besides the seats, PSA provided a pedal box. While the accelerator pedal assembly is complete, the brake pedal needs to be complemented by a master brake cylinder and a compensation tank. As an ABS system will be mandatory in the future, a control block is included as well. To increase comfort, a heater and ventilation system with a PTC system is included in the vehicle as well. As most of the components are mounted in front of the firewall, the frontend space is used sensibly. The seats and the heater and ventilation system are displayed in Figure 14.

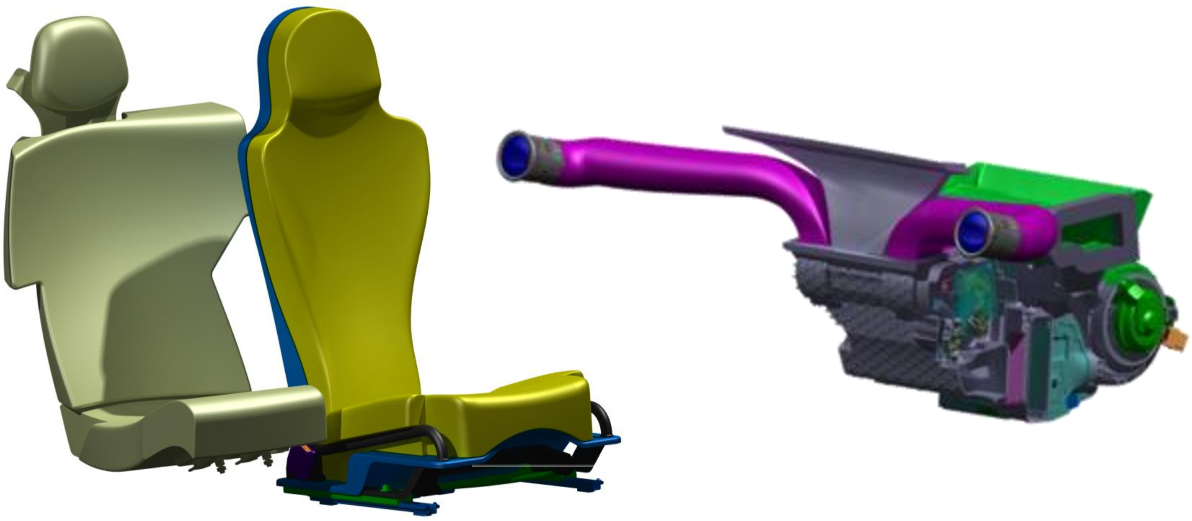

Figure 14: Seats and heater/ventilation system

Together with the steering column, which is part of the steering gear assembly, the main interior components that are needed to design a package model are available.

3.3.3 Vehicle concept

Within this chapter, the results of the developed vehicle concept are presented. It includes the overall package layout with geometrical dimensions and the arrangement of powertrain components (chapter 3.3.3.1), the interior concept with the seating layout (chapter 3.3.3.2) as well as the lower body structure (chapter 3.3.3.3) and the exterior redesign (chapter 3.3.3.4). Based on the package, a weight estimation is done as input for the multi-body simulation (chapter 3.3.3.5). The simulation itself is part of chapter 3.4. As the different assemblies influence each other, only the final layout is presented.

3.3.3.1 Overall package layout

Overall dimensions

The overall vehicle dimensions are defined by the exterior design, the provided chassis components as well as by the legal requirements. To stay as close to the cityFLEX design as possible, the provided components are arranged to meet the exterior design surfaces as close as possible.

The overall length of cityFLEX concept is already within the EU-LIVE target range of 2.5 m, exploiting the limit to the maximum. This still allows for transversal parking within the road space but provides maximum freedom for the further elaboration. The wheelbase of the original concept is 1.85 m, which is also taken over for the package model. After a slight adjustment to the original design, the front overhang is 0.33 m.

The width of the vehicle is influenced by the exterior design and limited by ECE R 168 to 1.5 m. With an original design width of already 1.4 m, the cityFLEX concept does not allow to drive between lanes. As the design concept only indicated a suspension system, the track width is increased to 1345 mm at the front and rear axle. Despite that, the characteristics of the vehicle remain unchanged. With an overall width of 1.5 m and a normal traffic lane width of over 3 m, it is for instance still possible to overtake cyclists without cutting into their safety zone. Additionally, two transversally parked L6e vehicles use less space than one mid-size economy car, but still provide enough room to enter and leave the vehicle. In Figure 15, the parking space exploitation of a VW Golf V and the L6e vehicle is displayed. By parking closer together or using gaps between already parked cars, the parking space exploitation can be even better.

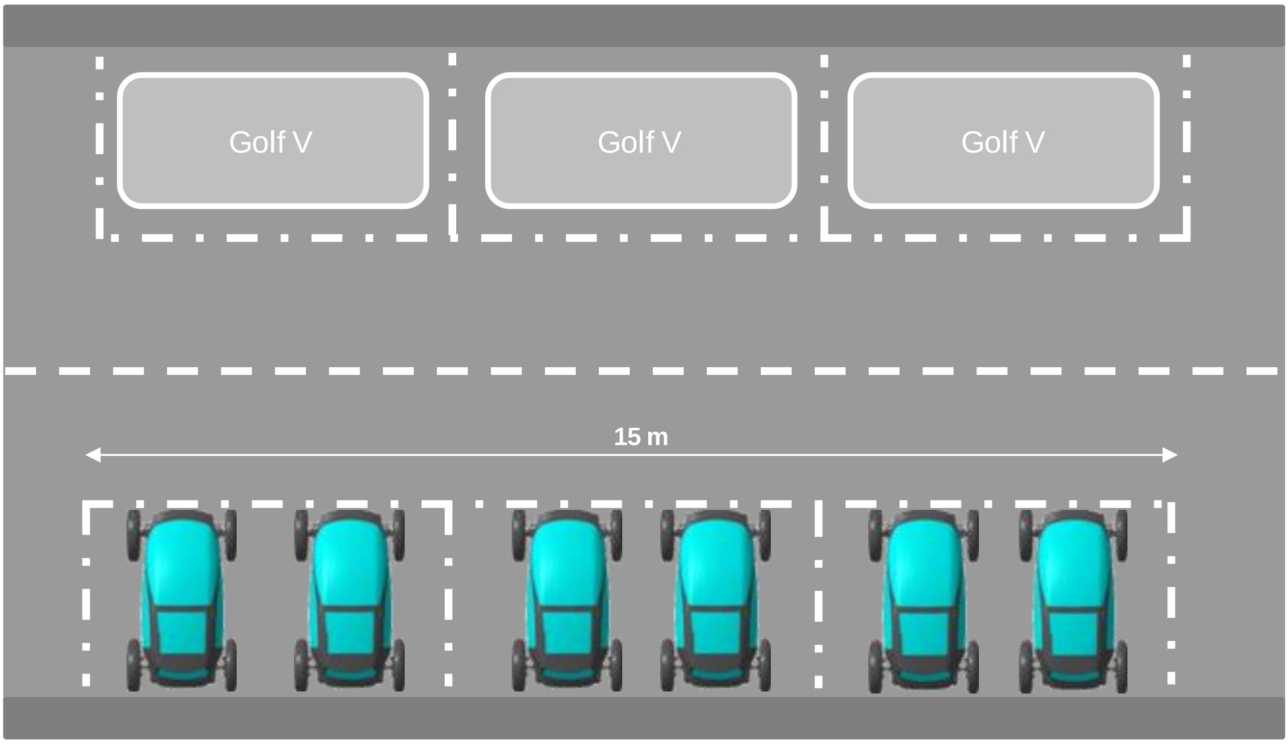

Figure 15: Transversal parking

With 1.35 m, the cityFLEX's height is considerably below the given limit of 1.9 m. The proportions of the vehicle and the required headroom of the two passengers significantly influence the actual height of the concept. With

the increased track, the roofline is elevated to 1.43 m without influencing the overall design. With these dimensions, the L6e concept still fulfils the user needs of a narrow and agile vehicle that is easy to park and makes full use of parking spaces. With the closed cabin design, the vehicle also has all-year usability.

Powertrain and heater layout

The largest powertrain component, the two-module battery system, is integrated underneath the passenger seat. As the battery is an air-cooled component, the cooling plate can be integrated in the vehicle’s floor. The centred position, within the deformation free zone of the vehicle, also allows for a low centre of gravity. Behind the battery and between the rear tires and the two IWMs the two inverters are located. The close location of the components allows for a short wiring and reduces the additional masses. In front of the battery, the battery charger and several low voltage components are located. With this vehicle concept, it is possible to mount the complete powertrain to the vehicle floor providing more flexibility for interior layout.

Within the interior, the heater, besides the seats, is the largest component to be installed. In contrast to most heater systems, which are located within the passenger compartment, the blower housing and PTC heater of this unit are mounted in front of the firewall, requiring room almost only for the air outlets inside the passenger compartment. As the space in the front end of the L6e vehicle is not required by any other component, it is used reasonably.

The complete chassis and powertrain layout is displayed in Figure 16 within the vehicle exterior shape. The two battery modules are arranged parallel to each other (purple). In front of them, there are the low voltage components, represented by a box, which includes a DC-DC converter, charger and control electronics.

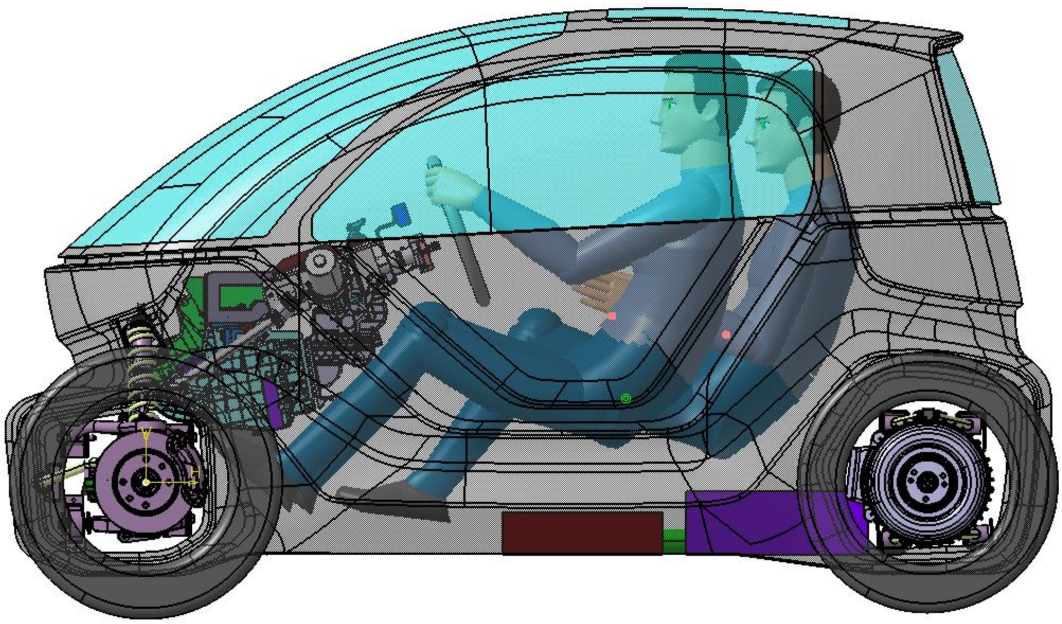

Figure 16: Overall package layout

3.3.3.2 Interior layout

During the first step of the L6e development, the general seating concept has already been defined, selecting a modified side-by-side design with a rearward moved passenger. Based on this layout, the definition of the seating concept with its seating angles is created, based on experience values for small and micro cars and adapted for the L6e vehicle. To allow for comparability, the nomenclature of common vehicle parameters is internationally standardized [24]. In the following, the parameter defined for each dimension is given in brackets. To provide a good, passenger car-like comfort even for such a relatively light vehicle, the interior dimensions are close to automotive standards. Reference dimensions of other cars are described in literature [18], [25].

Height and posture

Based on the exterior design, specifying ground clearance and roofline, the dimensions of the battery and the required construction height of the seats, the H point, the centre of the pelvis, for both seats is specified. The

vertical position of the H point is a compromise between enough headroom and a comfortable, higher seating position, providing maximum space within the cabin and an easy accessibility.

The H point height (H5) is 508 mm above ground, with a chair height, the vertical distance between the H point and the accelerator heel point (H30), of 290 mm. This leaves the reference of heel to ground to 218 mm. Taking micro cars and small electric cars into account, H5 and H30 are within normal parameter ranges for vehicles of this size. The heel for the passenger (H98-2) is 190 mm above ground with a chair height of 300 mm.

The driver’s back angle (A40-1) is set to 22°, with a reference for passenger cars between 20° and 25°. As the passenger is located further back, but has to use the same door opening, which is limited by the B-pillar, its back angle is slightly more vertical in comparison to passenger cars. He has a back angle of 24°. By this, he does not have to straighten himself up that much, when leaving the vehicle. The effective headroom (H61-1 and H61-2) is set to 1000 mm for the driver and 980 mm for the passenger. It is measured as the intersection between the roof line and the a line through the H point angled 8° backward from the vertical.

Lateral and longitudinal location

Even with a redesigned overall outer cabin width of 1121 mm, it is not possible to place two 95-percentile male passengers side-by-side. With the selected interior concept, the driver’s and passenger’s lateral location (W20) are each 180 mm off the longitudinal vehicle symmetry plane. The provided rear seat offers a slightly rotated seating position the vertical axis, which is carried over for this concept. For the L6e concept, it is set to 4°. With the longitudinal offset of 294 mm between driver and passenger, there is enough room for a second row passenger.

As the vehicle concept does not feature an interior design yet, the shoulder and hip room cannot be determined exactly. With a door panel width of approximately 65 mm for a comparable reference vehicle, the shoulder and hip room can be estimated for the L6e concept. It adds up to 52.5 mm on each side, if you subtract W20, half the width of a 95-percentile male (262.5 mm) and the assumed panel width from half of the cabin width. This number is close to the average of micro cars (~ 38 mm) and small electric cars (~ 50mm) but may change if an actual interior is created.

The estimated hip room (W5) is calculated with a hip width of 420 mm for a 95-percentile male [19]. The cabin width of the L6e vehicle is 964 mm at its narrowest position, measured in a zone 75 mm above and 25 mm below the H point. It is at a design indentation; the regular width in this area is 1032 mm. These two parameters leave a room of 92 mm or 126 mm between the cabin and hip. For comparable passenger cars, the hip width is between ~ 65 mm for micro cars and ~ 102 mm for small electric cars. Depending on the interior design and taking the 65 mm inner panel design as a reference, this leaves approximately 61 mm hip room if the inner panel is narrower along the design indentation. For the rear passenger, the values are comparable.

The longitudinal distance between H and heel point for the driver (L53) is 800 mm. For micro cars, this value varies between 700 mm and 850 mm. For the passenger, this distance is set to 700 mm with the difference to the driver that there is additional room in front of the passenger, due to the rearwards placed seat.

Front visibility

The driver’s field of vision for automotive vehicles is regulated within UN ECE Regulation No. 125 [26]. The mandatory opening angles for the front visibility wherein the windscreen has to be transparent are 5° below the horizontal axis and 7° above the horizontal axis, running through a 95 % eye ellipsis. For the L6e vehicle, the lower opening angle is 13° below the horizontal axis. Depending on the final upper cowl, the upper opening angle is at least 26°. The vehicle also fulfils the additional criteria, the angle of obstruction by the A-pillars and the non-existence of other obstructions within the driver’s 180° forward direct field of vision.

In Figure 17, the interior dimensions of the vehicle are displayed.

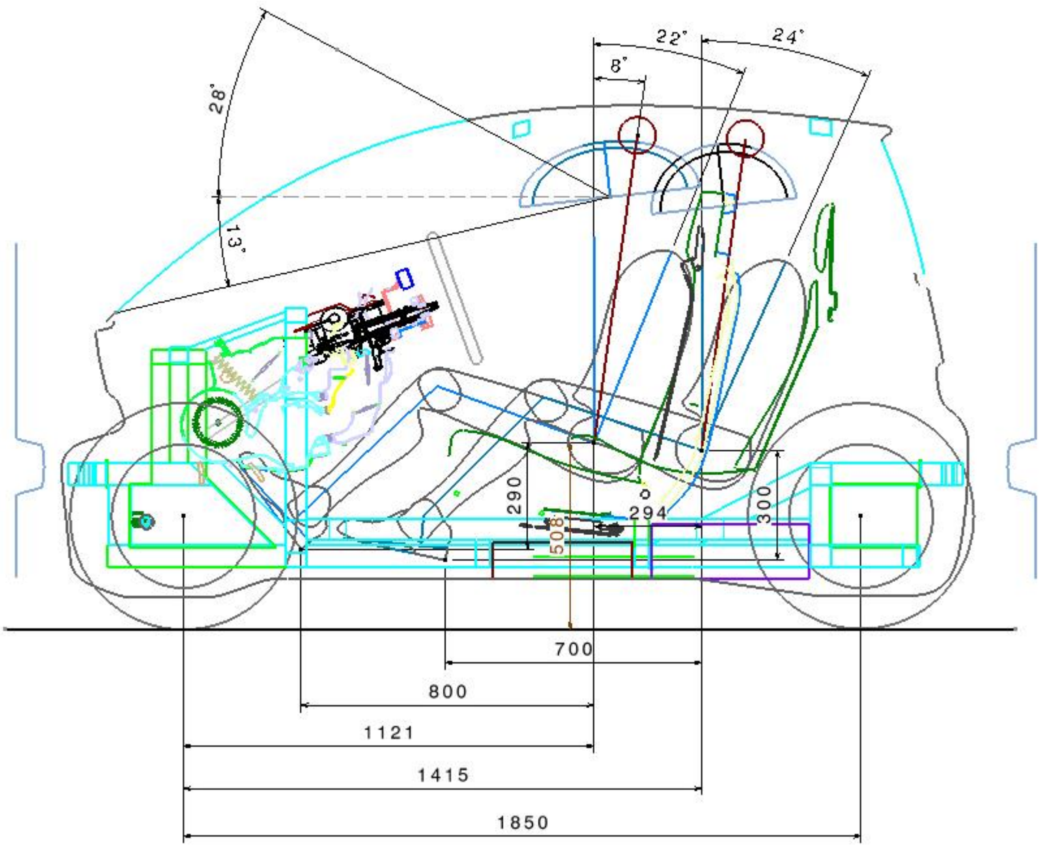

Figure 17: Interior dimensions of the vehicle

Due to the tapering shape of the exterior behind the B-pillar, the boot is not as spacious as in passenger cars. Nevertheless, it offers enough space to transport a box of water. If the passenger seat includes a sliding mechanism, the transport volume will increase significantly.

3.3.3.3 Body structure

The expected production volume and the sales price of the L6e vehicle are low, which limits the economically possible body structure concept. A unibody design, as in most passenger cars, is besides other reasons not feasible due to high tooling costs. A monocoque design has high production costs as well. This leaves space frame designs with tubes or extruded sections as cost efficient body structures that can be complemented with a number of purpose designed elements. As the exterior panels, which are not self-supporting body parts, cover the body structure, the vehicle has a multi-material-body design. This construction method is common practice for L category vehicles, realised in Aixam vehicles, the Tazzari Zero or for the Twizy [27], [28], [29].

For the concept phase of the L6e vehicle, a simplified body structure is designed, which represents the main load paths within the vehicle. The structure is created from extrusion profiles with 40 mm by 60 mm cross-section. It serves for the installation space and sight obscuration analysis. As the first design features only type of one cross-section, some members are over dimensioned and can be adapted based on structural analysis, which is however not part of the project. In Figure 18 the basic body structure of the vehicle is displayed. Profiles are coloured in cyan, sheet metal elements are coloured in green. The design features continuous longitudinal beams in the floor structure. Longitudinal beams in the front and rear on barrier height level complement them. In Figure 19, the main load paths along the longitudinal beams are marked in orange. The track width of 1345 mm at front and rear provides an increased design space between the longitudinal beams, which may be used to integrate additional energy absorber elements.

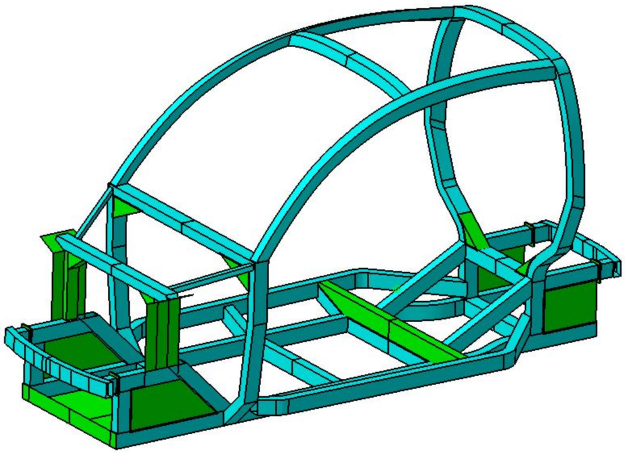

Figure 18: Basic body structure of the L6e vehicle

Between the A and B pillar, the longitudinal beams are supplemented by profiles along the side sills. Together with transversal beams that connect the side sills and the longitudinal beams as well as the A pillars/roof lining, a passenger compartment is formed. Within the transversal and longitudinal main beams, a deformation stiff area is created, in which the 48 V battery and the low voltage components are located (see Figure 19 purple (battery) and red (low voltage)). In combination with the continuous beams, the torsion and bending stiffness is improved by the integration of closed, ring-shaped structures in the vehicle's longitudinal and transversal direction. The A-pillar and B-pillar structures form a torsion stiffening transversal rings (yellow circles in Figure 19). They are connected by the roof linings, which, together with the main beams, form approximated longitudinal rings (red lines in Figure 19).

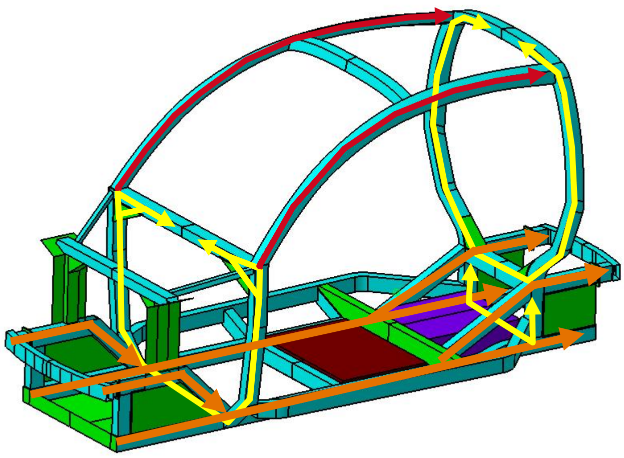

Figure 19: Ring-shaped structure and integrated electronics

Together with the powertrain and chassis components and the interior package design, a simplified CAD model is created. As the body structure, especially the A- and B-pillars as well as the roof linings, and the exterior shape influence each other, they have been adapted in numerous design iterations. Figure 20 shows the complete CAD model of the L6e vehicle including the exterior design. In appendix A.5, the concept specifications are given.

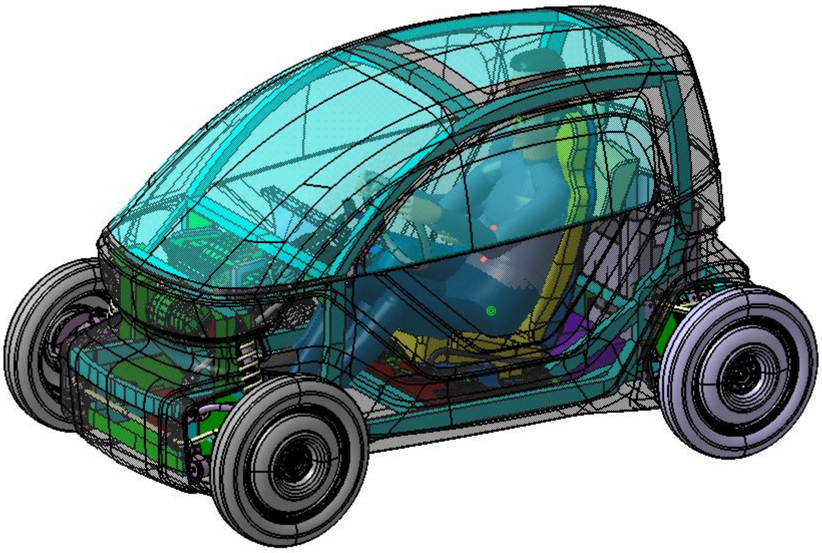

Figure 20: CAD design of L6e vehicle

3.3.3.4 Exterior design

The EU-LIVE exterior design of the L6e vehicle is based on the winning cityFLEX concept, created by Robert Hahn. As the interior, compared to the original seating layout, has been changed and the suspension has been detailed, the exterior design has been reworked and adapted to the new boundary conditions.

In a first step, the existing cityFLEX model has been used as an input to design the package plan with the powertrain and chassis components. It then has been completed by the body structure. Based on the boundary conditions of the package model, for example the head, shoulder and hip room or crash deformation zones, the exterior has been refined in several iterative steps. Taking into account with legal requirements regarding lighting, see ECE R 48 [31], the final design has been created as a surface model. It still reflects the original idea of the concept, but interprets it with additional elements of suspension and powertrain.

In Figure 21 and Figure 22, the exterior design of the L6e vehicle concept is shown. With the fresh and unconventional design, it offers a four-wheeled supplement to the other two vehicles. Over a possible subsequent development, elements such as the wheel covers have to be adapted.

Figure 21: Three-quarter side view

Figure 22: Three-quarter front view

3.3.3.5 Weight Indication

For the L6e vehicle, a weight estimation has been performed. It serves as input for the multi-body simulation and provides an estimated centre of gravity.

Based on benchmark data, numerous electric vehicles have been analyzed concerning their weight distribution of the main assembly groups of body, chassis, drive train, electrics and electronics as well as the interior. Electric vehicles on the market today show an approximately linear relation between the vehicle's volume and its masses. In Figure 23, the vehicles' masses including their batteries are plotted over the vehicles' box volumes for numerous current BEV. For the two open wheel concepts, the Renault Twizy and the EU-LIVE L6e vehicle, the approximated volume without the open wheels has been used for the calculation, as the volume between the wheel houses is not used for any vehicle components.

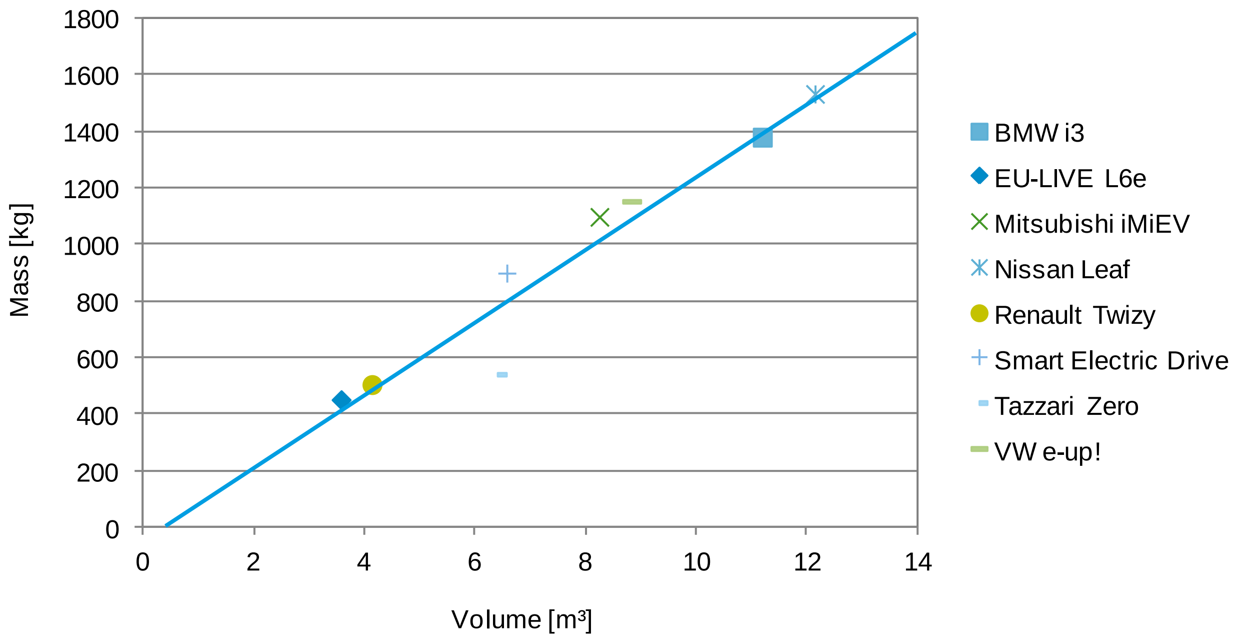

Figure 23: Weight to volume ratio of various electric vehicles

As the proportional distribution of the assembly masses of the analysed vehicles is comparable, the weight distribution for the L6e vehicle is calculated based on the detailed benchmark data of one vehicle and scaled down to an overall vehicle mass of 425 kg, excluding the battery. For the powertrain and some other components, the exact masses are already known and have been included to the calculations. In Figure 24, the target weight distribution for the L6e vehicle is shown.

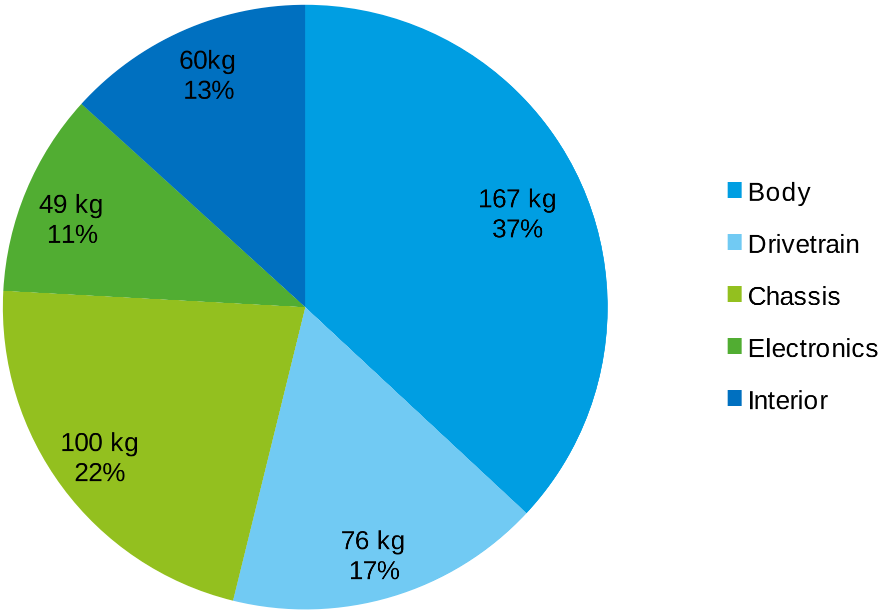

Figure 24: Weight distribution for the vehicle assembly categories

With the information regarding the vehicle's masses, the multi-body chassis simulation is performed. The weight estimation is however obtained for the L6e maximum legal mass in running order of 425 kg without batteries.

3.4 L6e vehicle simulations

Within this chapter, the results of the multi-body and aerodynamics simulations are described. Both simulations have been performed with higher speeds than the permissible 45 kph an L6e vehicle is allowed to reach. This has been done to secure the possibility to register the vehicle additionally within the L7e category.

3.4.1 Multi-body simulation

To analyse the driving dynamics of the L6e vehicle and to verify the suspension setup, a multi-body simulation model has been set up using the MBS software MSC ADAMS/Car. ADAMS/Car models are parametric and use a modular structure mirroring the subassemblies of physical vehicles. In the subchapters 3.4.1.1 to 3.4.1.3, the simulation model as well as the simulation itself are described and a conclusion is given.

3.4.1.1 Simulation model

The model used for this analysis consists of the sub-models described in the following sections. A list of model parameters is given in Table 5. To perform virtual driving tests, the ADAMS/Car environment includes a driver model providing steering, throttle, brake, gear and clutch demands to the vehicle model. The outputs of the driver model can individually be configured for open or closed loop control. Figure 25 shows the simulation model of the vehicle.

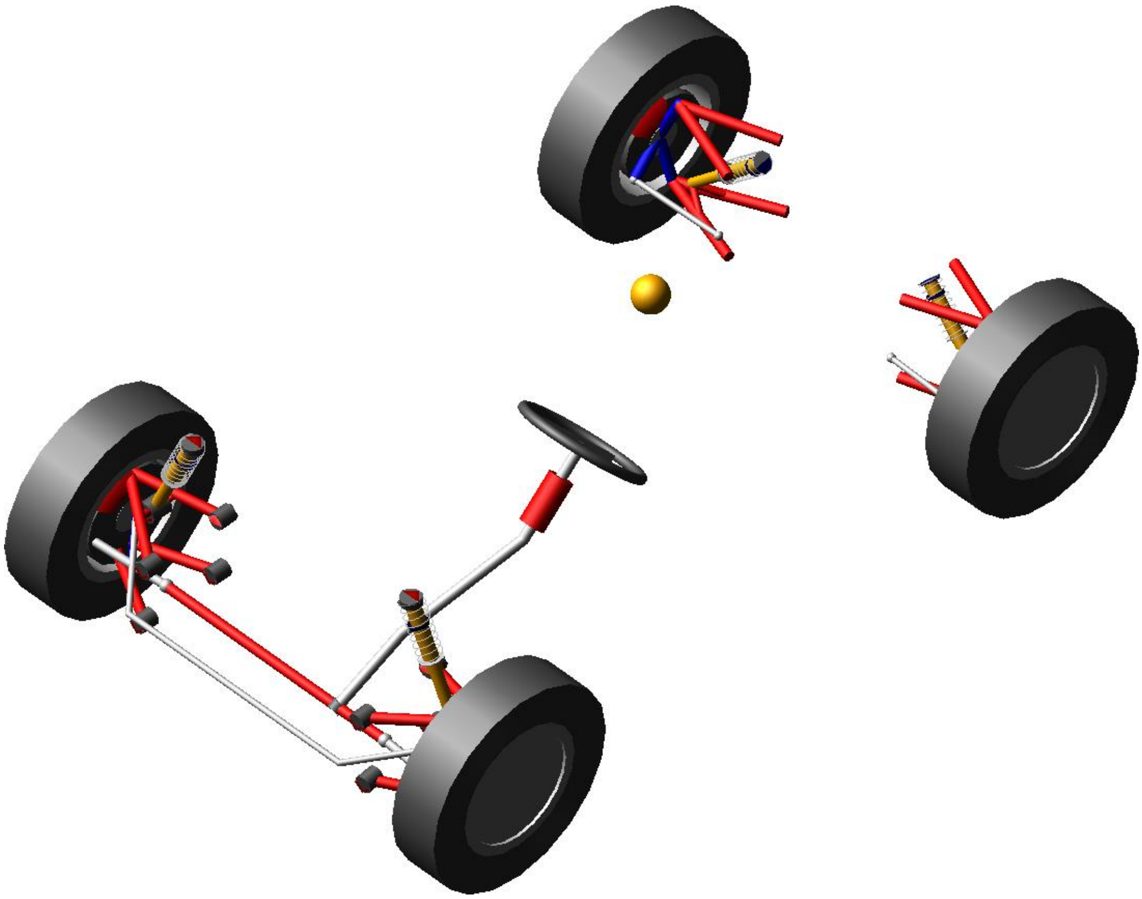

Figure 25: L6e MBS simulation model

No	Parameter	Input value
1	Total Mass	454.9 kg
2	Unsprung mass front	37.6 kg
3	Unsprung mass rear	53 kg
4	Payload	180 kg
5	Wheelbase	1.85 m
6	Track width	1.345 m
7	Distance CoG to front axle	1.036 m
8	Distance Payload to front axle	1.401 m
9	Front eigenfrequency unladen	1.36 Hz
10	Rear eigenfrequency unladen	1.65 Hz
11	Front eigenfrequency laden	1.21 Hz
12	Rear eigenfrequency laden	1.27 Hz

Table 5: Simulation model details

Body

For the purpose of this analysis, the vehicle body has been modelled as a single rigid body. Stiffness properties of the real structure are neglected within the scope of this analysis.

Front suspension

The front suspension is a double wishbone suspension, where the wheel carrier is guided by an upper and a lower a-arm and the tie-rod. Vertical springing is provided through coil springs over tubular shock absorbers. To provide additional roll stiffness, a stabilizer is acting on the wheel carriers. Modelled components are thus the wheel hubs, wheel carriers, lower a-arms, upper a-arms, tie-rods, lower dampers, upper dampers, left and right half of the stabilizer bar, and the stabilizer linkages. All connections between the parts are modelled as kinematic joints. The springs and dampers are depicted through characteristic curves as shown in Figure 27 and Figure 28. The stiffness of the stabilizer bar is modelled through a rotational spring. The front suspension model is shown in Figure 26.

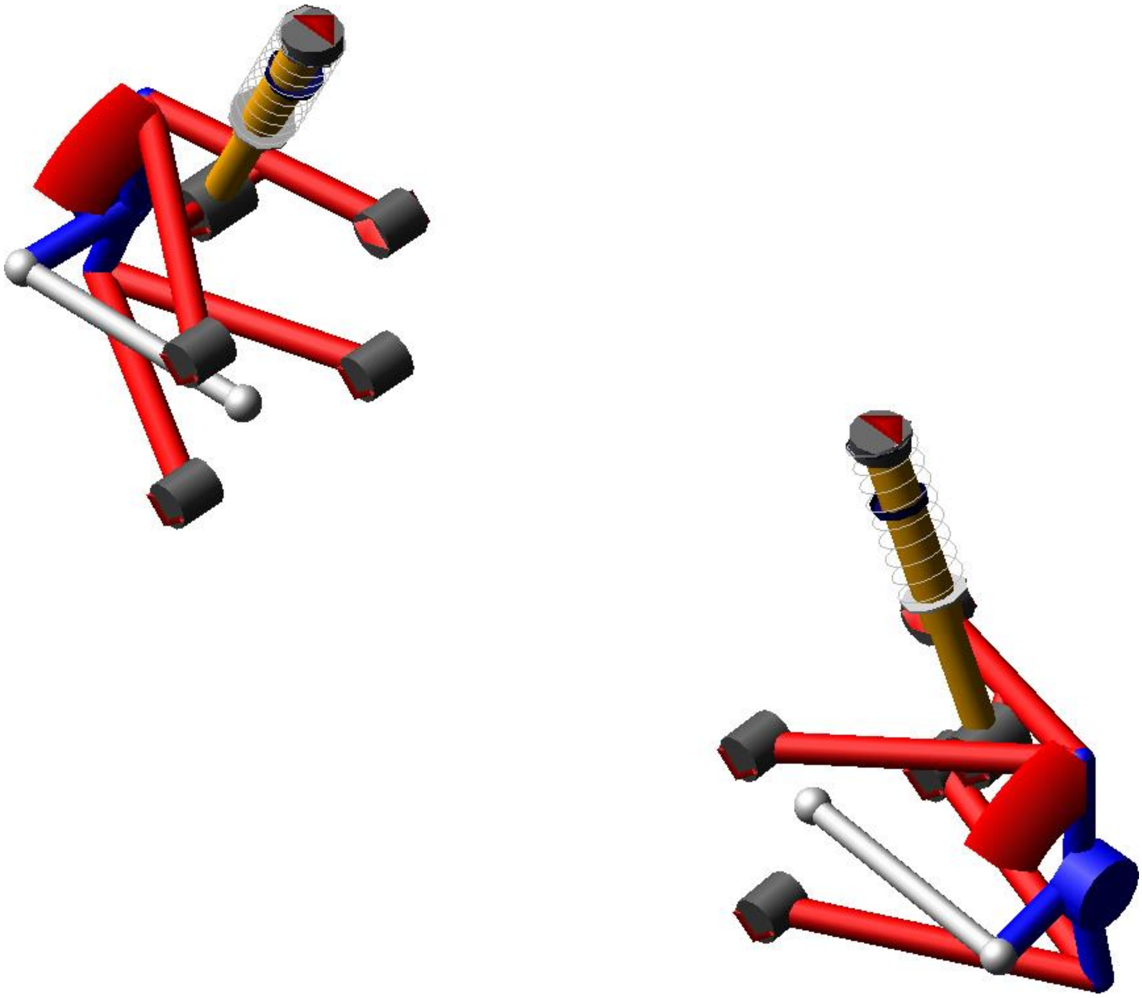

Figure 26: MBS model of the front suspension

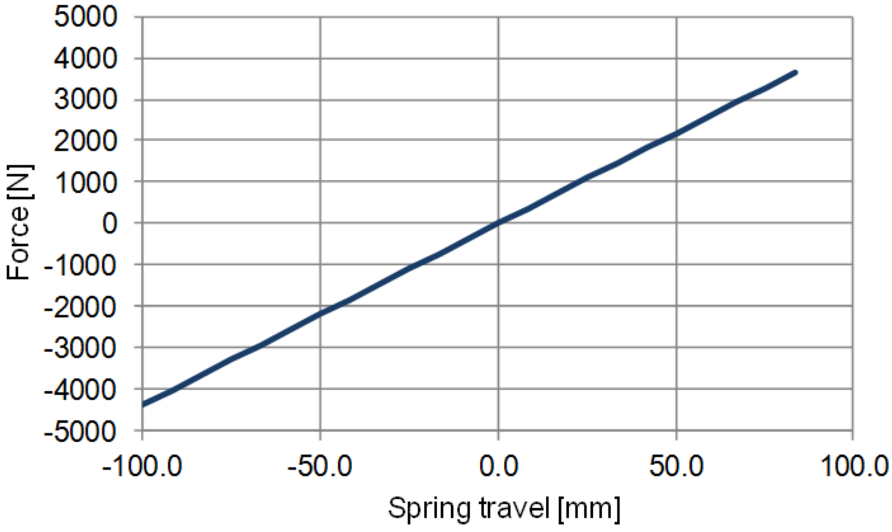

Figure 27: Characteristic curve of the front springs

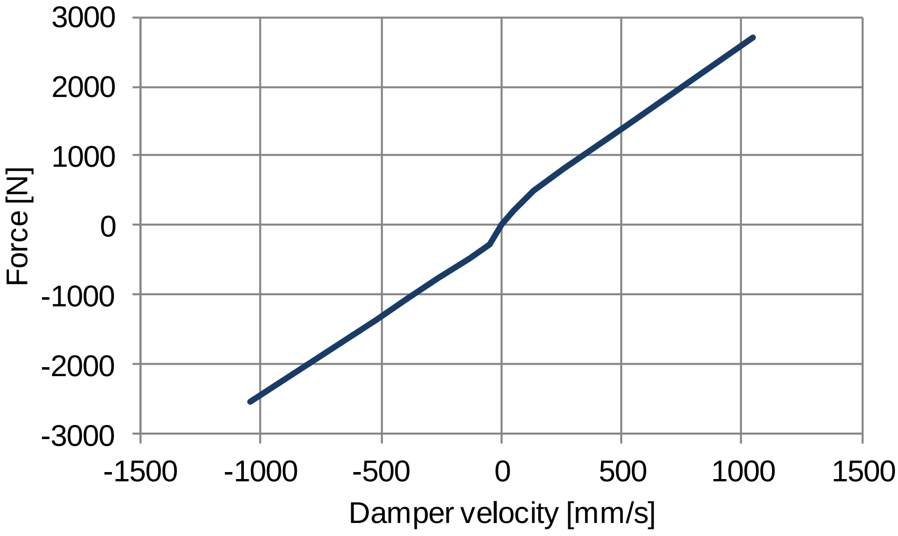

Figure 28: Characteristic curve of the front dampers

Rear suspension

The rear suspension, like the front suspension, is realized as a double wishbone suspension using the same structure of components described above, however without a stabilizer. The model is shown in Figure 29. The characteristic curves of springs and dampers are shown in Figure 30 and Figure 31.

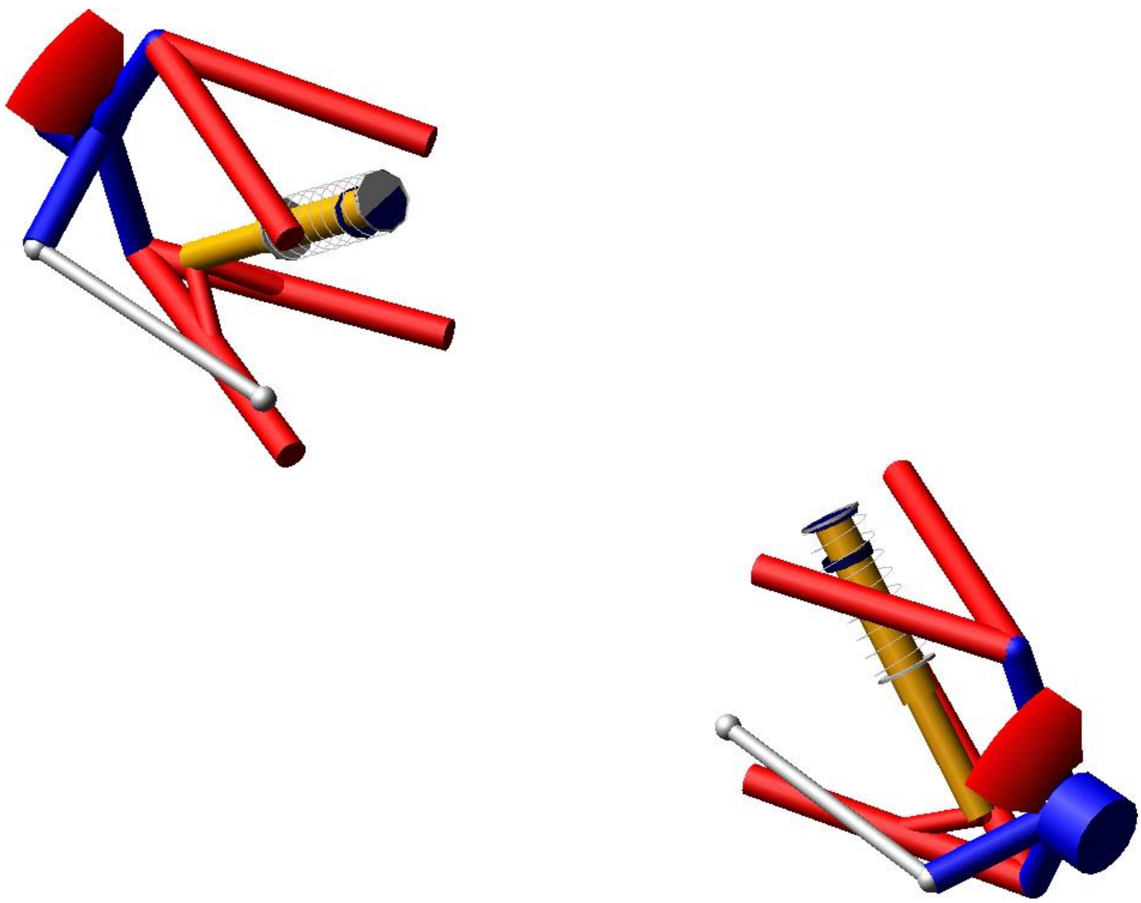

Figure 29: MBS model of the rear suspension

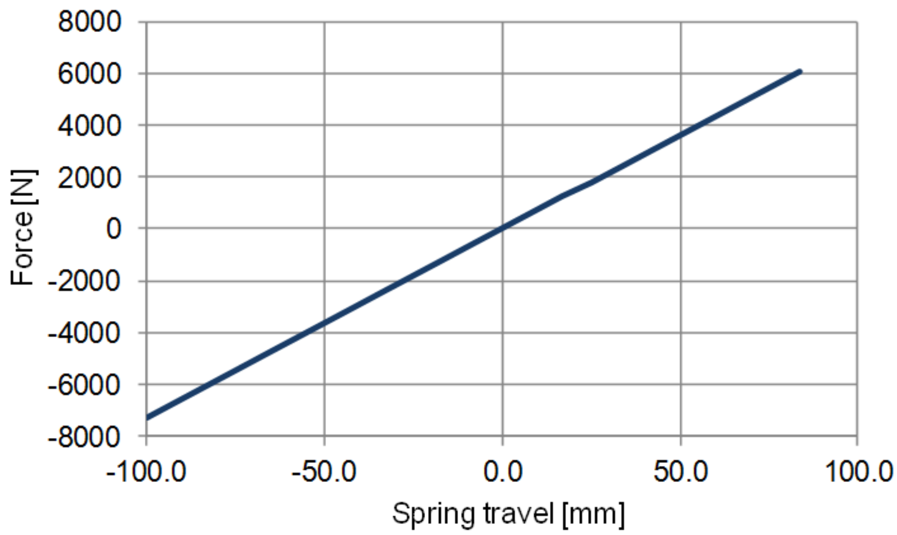

Figure 30: Characteristic curve of the rear spring

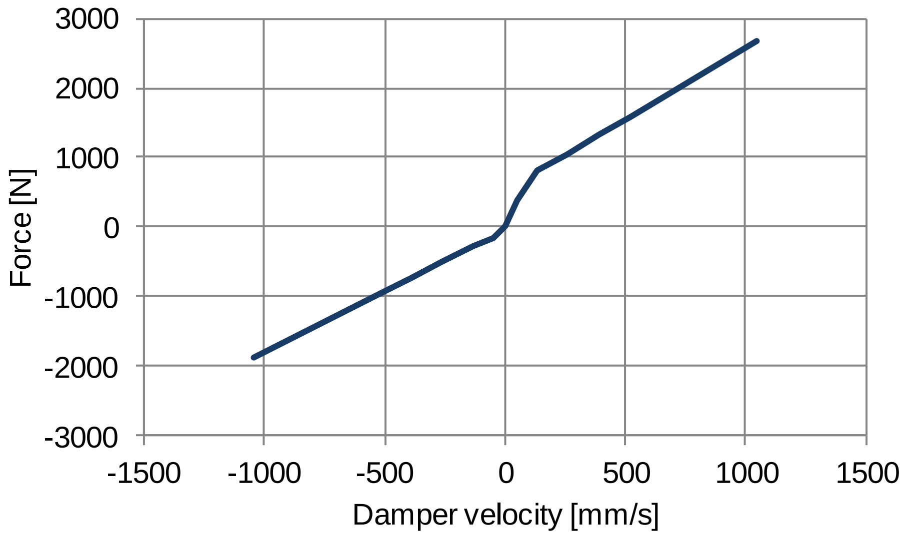

Figure 31: Characteristic curve of the rear dampers

Steering system

The steering system is a rack and pinion steering consisting of the rack housing, the steering rack, the lower and upper part of the steering column and the steering wheel. All parts are assumed rigid for this analysis and all connections are modelled as kinematic joints. The steering system provides the driver model with an input for the steering angle.

Powertrain

The powertrain subsystem consists of two point torque actuators, one for each rear wheel, acting between the wheel hubs and wheel carriers. The subsystem receives the throttle input from the driver model. The throttle value is then used to compute the magnitude of the torques through a generic characteristic map and the rotational velocities of the driven wheels. As longitudinal dynamics are no focus of this analysis, a more detailed modelling or parameterization of the powertrain is not carried out.

Wheels

Front and rear wheel submodels each consist of two rigid bodies, depicting the masses and inertias of the rim and tire assemblies. Tire forces are computed through “Magic Formula” tire models using a generic parameterization. In Figure 32 the side force vs. slip angle characteristics at different wheel loads as evaluated on a virtual tire test rig are shown. Figure 33 shows the results for the aligning torque for the same simulations.

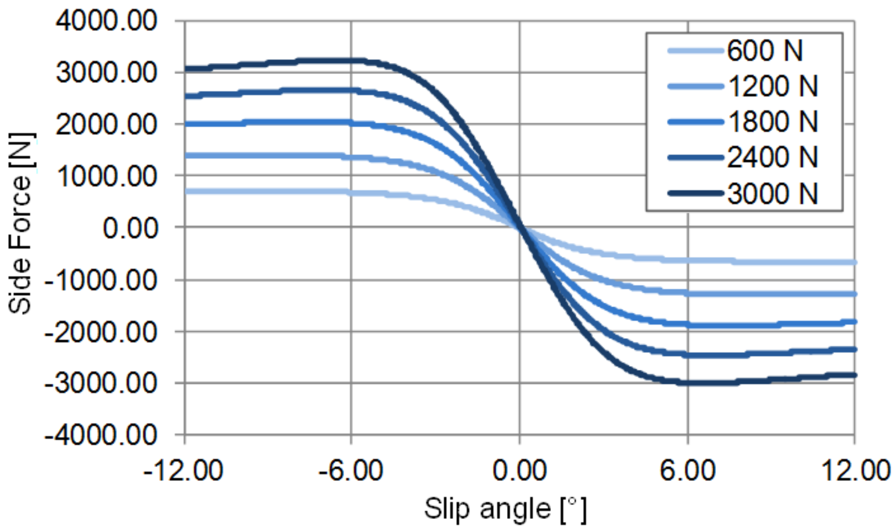

Figure 32: Side force characteristics of tire model

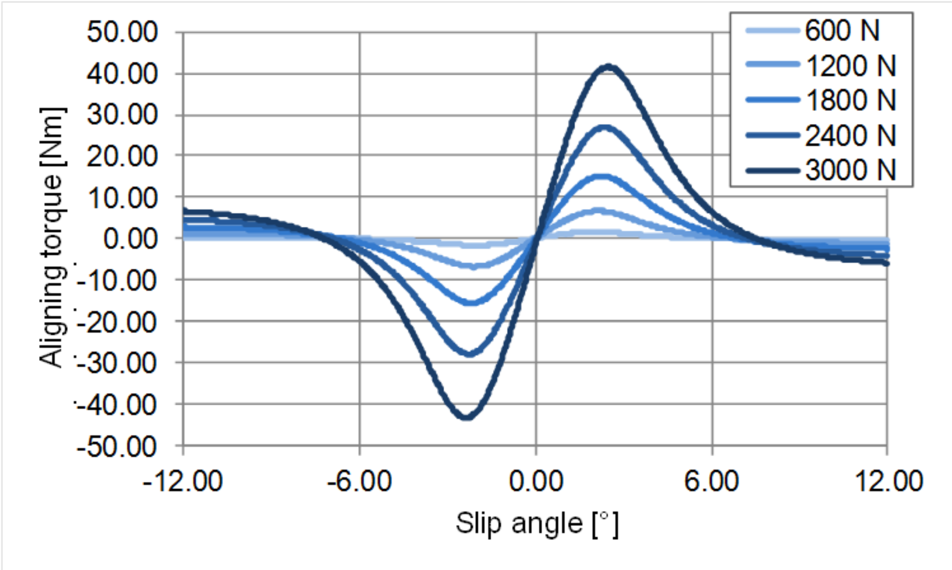

Figure 33: Aligning torque characteristics of tire model

3.4.1.2 Driving manoeuvres

A series of driving manoeuvres has been performed to analyze and verify the driving dynamics of the L6e vehicle. While L6e regulations limit the vehicle's top speed to 45 kph, manoeuvres were also performed at higher velocities to evaluate the potential to upgrade the vehicle into the L7e category for example.

Constant radius cornering

The constant radius cornering manoeuvre is intended to analyse the steady state behaviour of the vehicle during cornering. To this end, the vehicle is driven at increasing longitudinal speeds on a constant radius. The final speed is that at which the vehicle is no longer able to drive on the chosen radius. To simulate the manoeuvre, both longitudinal and lateral control is performed by the ADAMS/Car driver model. Speed is increased gradually to achieve quasi steady state conditions at all times as well as to minimize any influence of the quality of the driver model on the test results. Starting speed for the simulations within this task is set to 9.9 m/s, corresponding to a lateral acceleration of 0.1 g. The speed is increased linearly, with a longitudinal acceleration chosen to achieve a mean rate of change of lateral acceleration of 0.1 g/s. Figure 34 shows the resulting speed profile for this manoeuvre. The simulated velocity exceeds the maximum speed of the L6e vehicle, but was chosen to demonstrate vehicle behaviour under standard conditions for this test. The vehicle is simulated in fully laden configuration.

Figure 35 shows the radius of the path of the vehicle's centre of gravity. The maximum acceptable deviation of the actual path from the desired path is 0.5 m. This is achieved up to a lateral acceleration of 0.89 g, which corresponds to a vehicle speed of 29.6 m/s.

Figure 36 shows the steering wheel angle needed to maintain the desired path. Starting from an angle of 21.3 deg, it shows a strictly increasing characteristic, reaching a final value of 67.3 deg at maximum lateral acceleration. The self-steering gradient at 0.4 g is 10.4 deg/g. Figure 37 show the corresponding sideslip angle, which again shows a strictly increasing behaviour, reaching 2.9 deg at maximum lateral acceleration and a gradient of 2.8 deg/g at 0.4 g. All in all, the self steering properties of the vehicle show a pronounced understeering behaviour under steady state conditions.

Figure 38 shows the vehicle's roll behaviour under lateral acceleration. The roll angle at maximum lateral acceleration is 4.5 deg. The slope at 0.4 g is 4.8 deg/g, demonstrating sufficient roll stiffness of the vehicle's suspension.

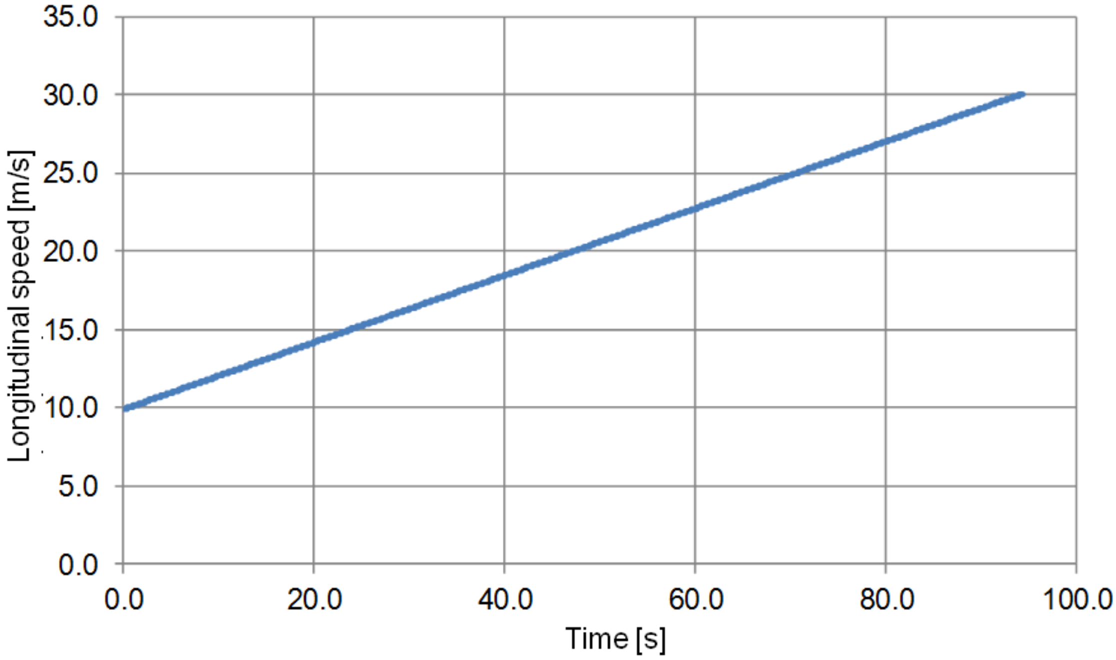

Figure 34: Vehicle speed during constant radius cornering

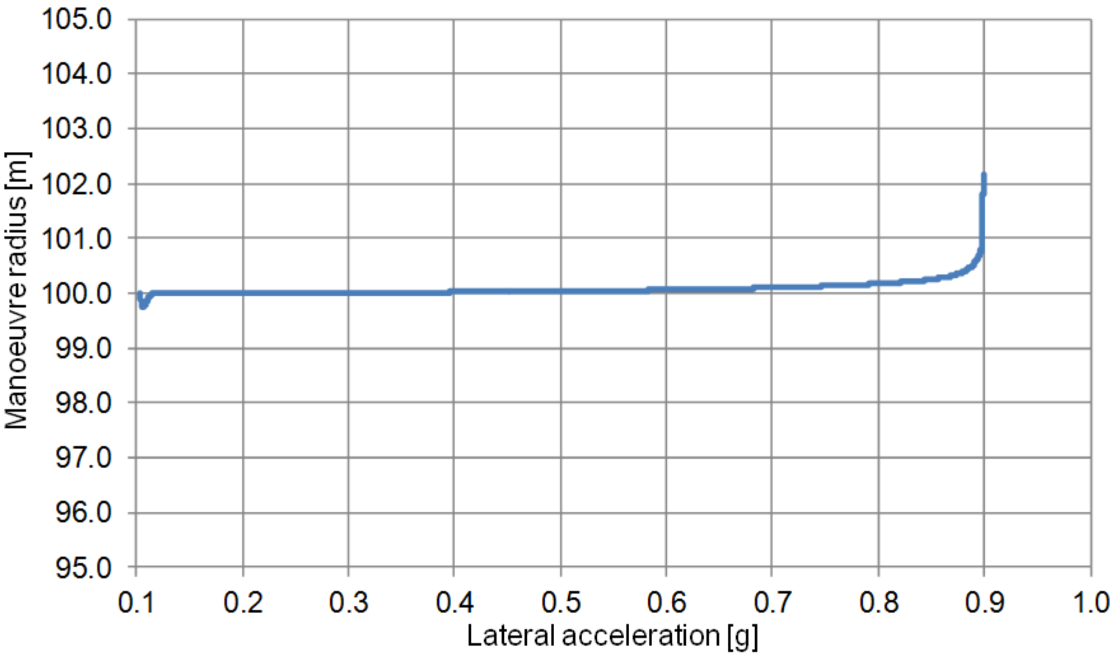

Figure 35: Manoeuvre radius vs. lateral acceleration

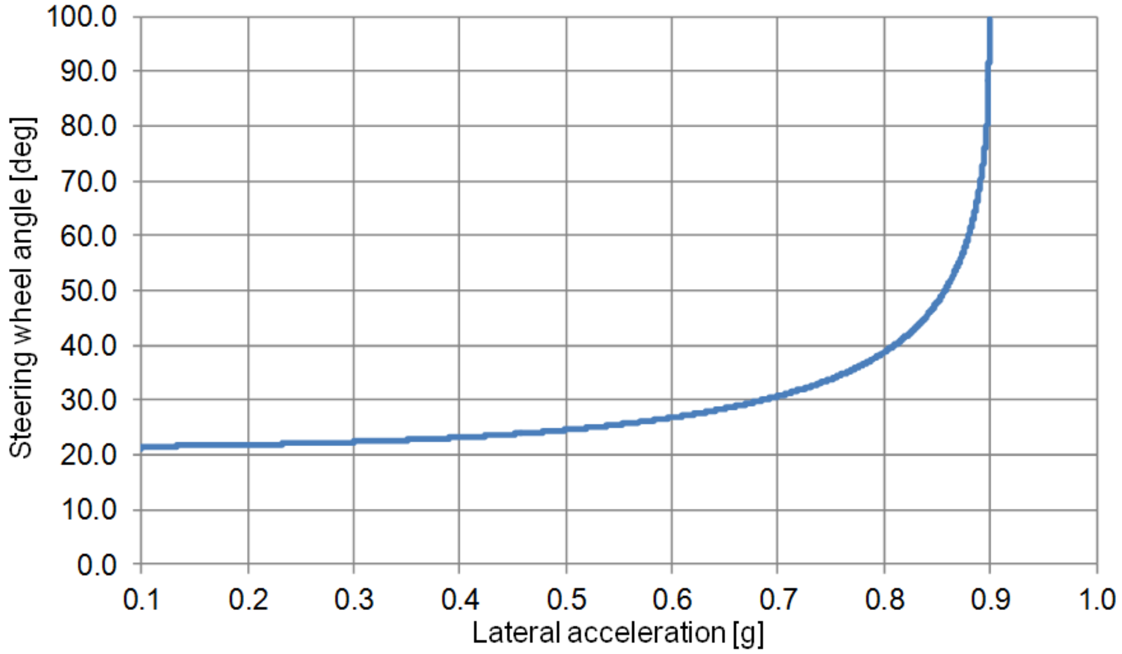

Figure 36: Steering wheel angle vs. lateral acceleration

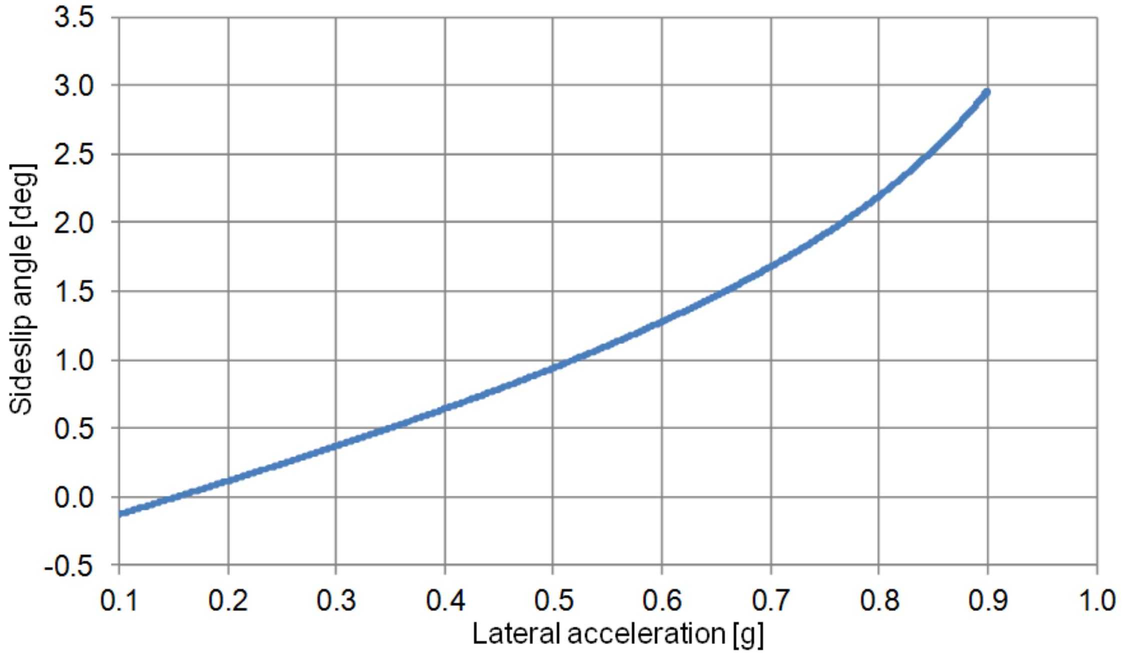

Figure 37: Sideslip angle vs. lateral acceleration

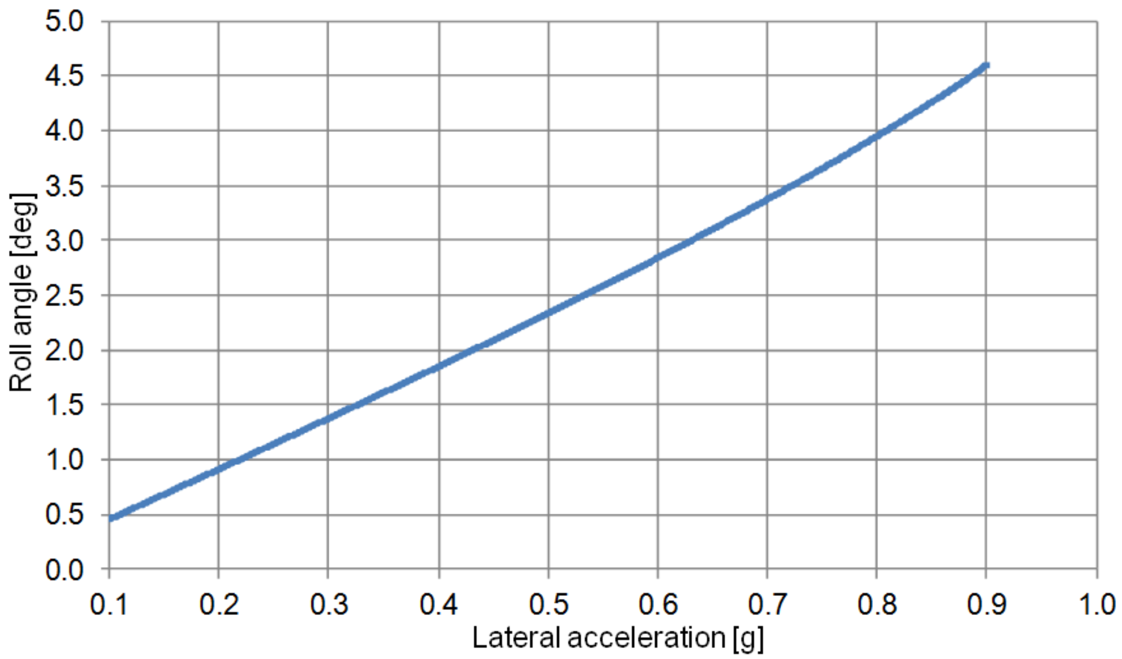

Figure 38: Roll angle vs. lateral acceleration

Step steer

The step steer manoeuvre is intended to analyse the transient behaviour of the vehicle during the transition from straight line driving to steady state cornering. To this end, starting from the vehicle being driven at constant longitudinal speed in a straight line, the steering wheel angle is rapidly increased to a value chosen to achieve a certain lateral acceleration after the vehicle has settled to a steady state cornering condition. To simulate the manoeuvre, longitudinal control is performed by the ADAMS/Car driver model to maintain a constant vehicle speed, while the steering angle follows a predefined step function. Starting speed for the simulations within this task is set to 12.5 m/s. The chosen steady state lateral acceleration is 0.6 g. The steering angle is raised from 0 deg to its final value within 0.31 s, corresponding to a steering wheel angular velocity of 300 deg/s. The vehicle is simulated in fully laden configuration.

To achieve a steady state lateral acceleration of 0.6 g at 12.5 m/s longitudinal velocity, a necessary steering wheel angle of 92.5 deg is determined in a pre-test. The resulting time history of the steering wheel input is shown in Figure 39. The steering wheel angle begins to increase at t = 0 s and reaches 50% of its final value at t0 = 0.15 s. This point in time is used as reference for the analysis.

Figure 40 shows the vehicle's lateral acceleration response to the steering input. It reaches 90 % of its final value after 0.18 s (response time) and a peak value of 0.65 g, corresponding to an overshoot value of 8.3 % after 0.32 s (peak response time). After the initial overshoot, the lateral acceleration settles quickly to its steady state value, showing a well damped behaviour.

Figure 41 shows the time history of the yaw rate. Response time is 0.19 s, peak response time is 0.22 s and the overshoot value is 2.6%. As with the lateral acceleration, the yaw rate shows a well damped behaviour.

Figure 42 shows the time response of the roll angle during the manoeuvre. Response time is 0.24 s, peak response time is 0.41 s and the maximum angle is 3 deg, corresponding to an overshoot value of 8 %. This shows a good control of the body roll movement.

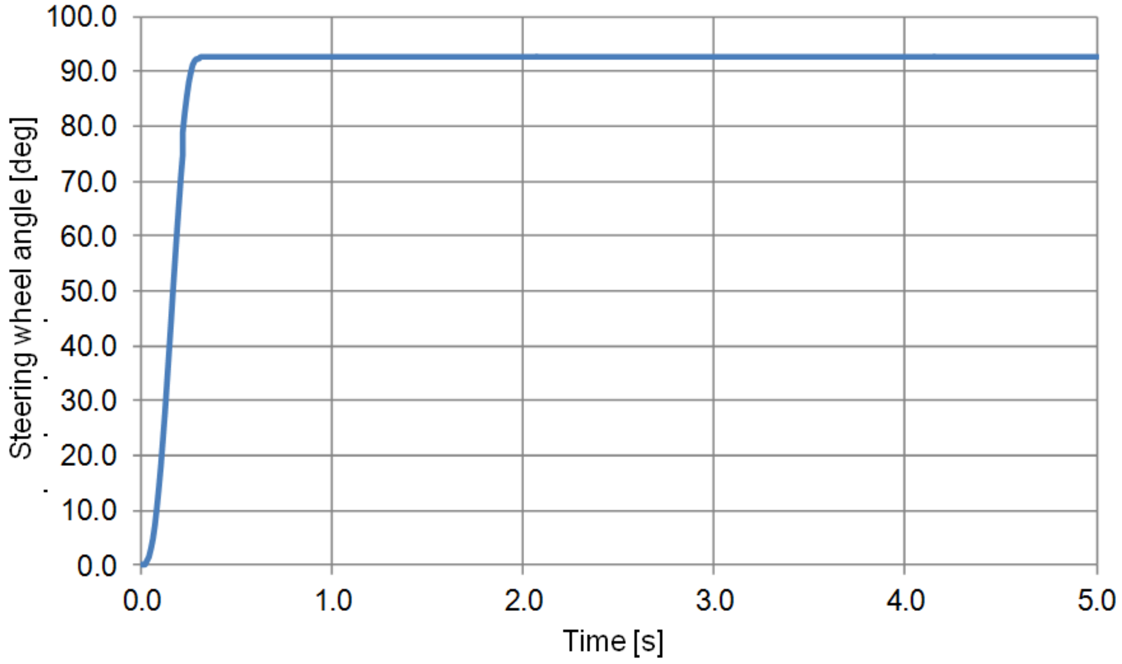

Figure 39: Steering wheel angle during step steer manoeuvre

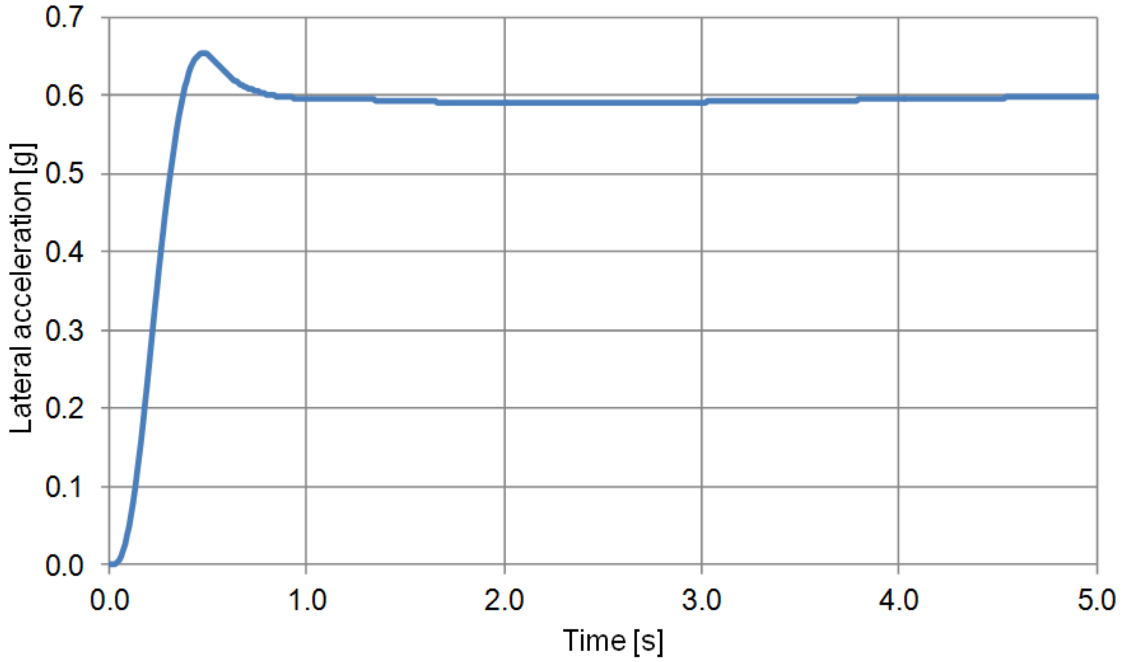

Figure 40: Lateral acceleration during step steer manoeuvre

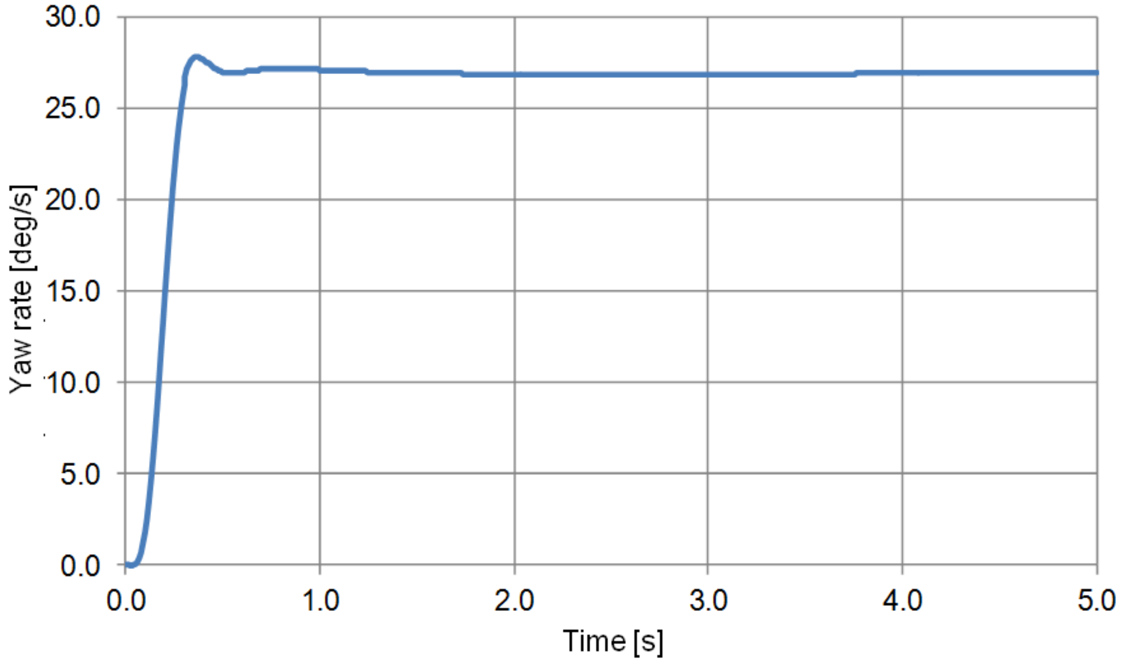

Figure 41: Yaw rate during step steer manoeuvre

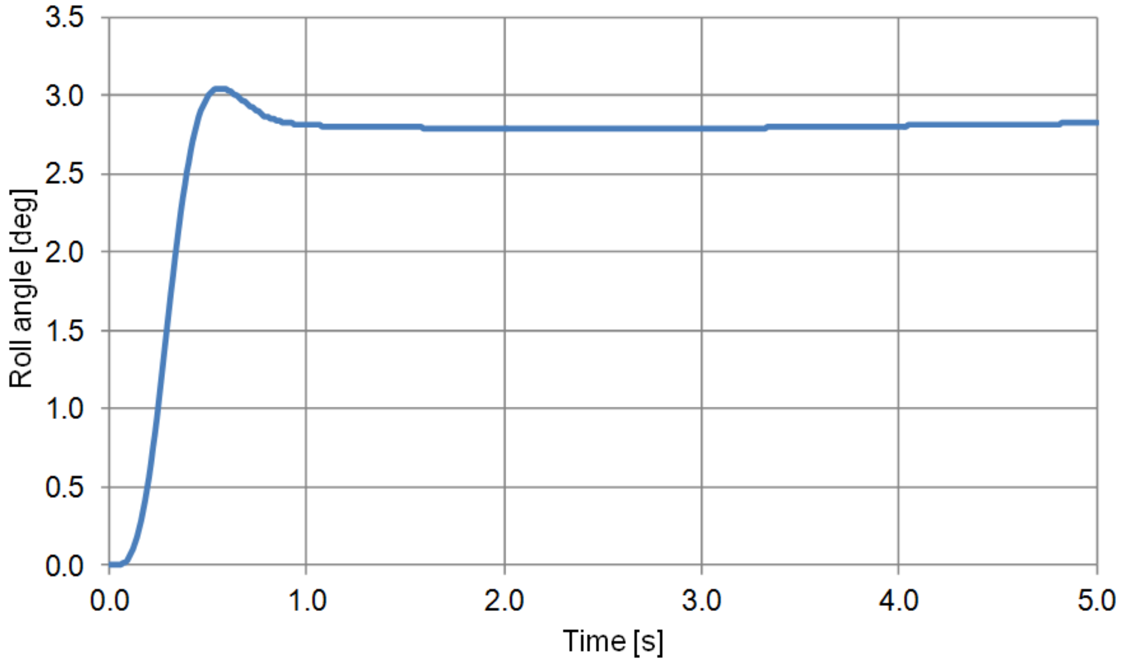

Figure 42: Roll angle during step steer manoeuvre

Swept sine steer

The swept sine steer manoeuvre is designed to evaluate the response of the vehicle to steering inputs in the frequency domain. The driver model is set to keep the vehicle at a constant longitudinal velocity of 45 kph and 80 kph, respectively, while a sinusoidal input with varying frequency is applied to the steering wheel. The frequency is increased from 0.1 Hz to 4 Hz, the amplitude corresponds to a steady state lateral acceleration of 0.4 g at the given manoeuvre velocity. These amplitudes were determined in a pre-test and set to 54.4 deg for

45 kph and 15.7 deg for 80 kph. Figure 43 shows the steering input, Figure 44 and Figure 45 show the resulting yaw rate and lateral acceleration responses for the manoeuvre simulated at 45 kph. These time histories are then used to estimate the transfer functions from steering wheel angle to yaw rate and lateral acceleration. The frequency responses (magnitude response and phase response) of these transfer functions are shown in Figure 46 to Figure 49 for a longitudinal velocity of 45 kph and in Figure 50 to Figure 53 for a longitudinal velocity of 80 kph. In both cases, a drop in lateral acceleration response does occur only at higher steering frequencies, with a peak of 1.2 Hz for 45 kph and 0.5 Hz at 80 kph, while the eigenfrequency of the yaw velocity magnitude is very well damped for both manoeuvre velocities. As expected, amplification factors and phase shifts are larger at the higher driving speed, but overall lag remains small, reaching 60 deg at 1 Hz for the acceleration response at 80 kph, indicating a good controllability of the car.

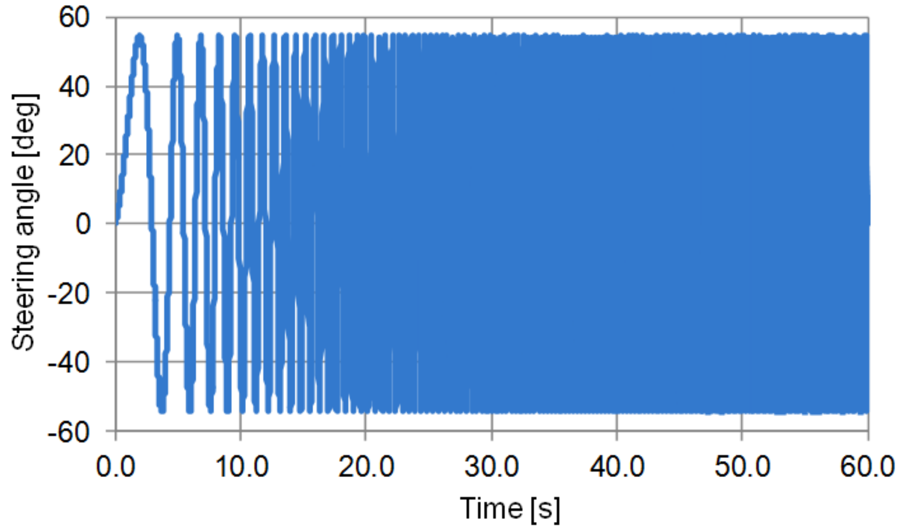

Figure 43: Steering wheel angle vs. time for swept sine steer manoeuvre, 45 kph

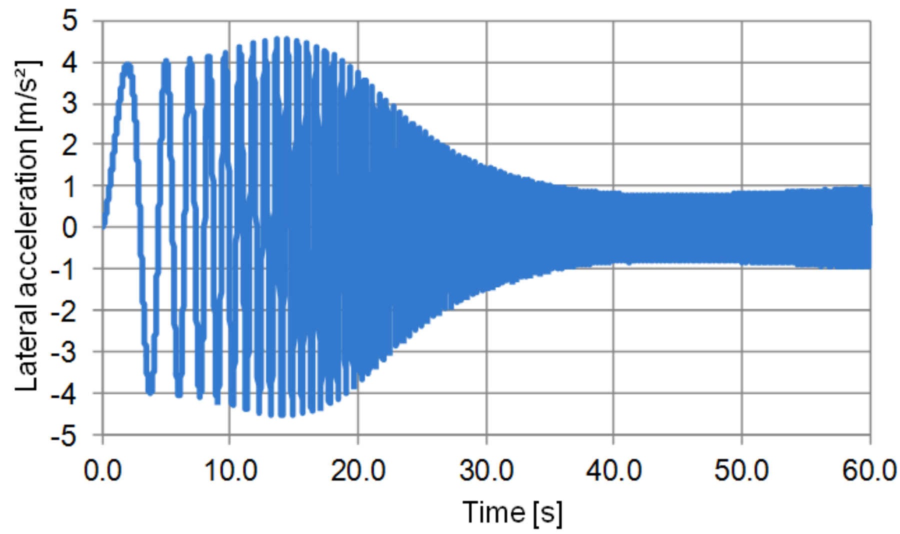

Figure 44: Lateral acceleration vs. time for swept sine steer manoeuvre, 45 kph

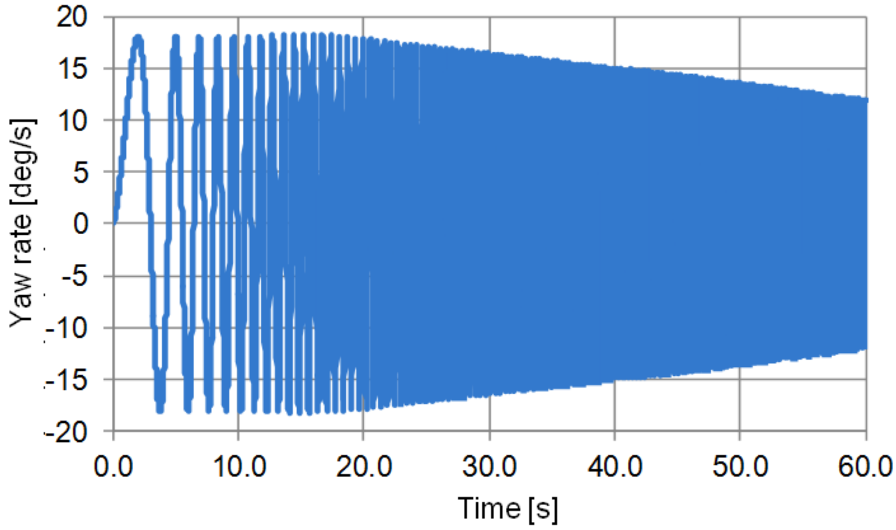

Figure 45: Yaw rate vs. time for swept sine steer manoeuvre, 45 kph

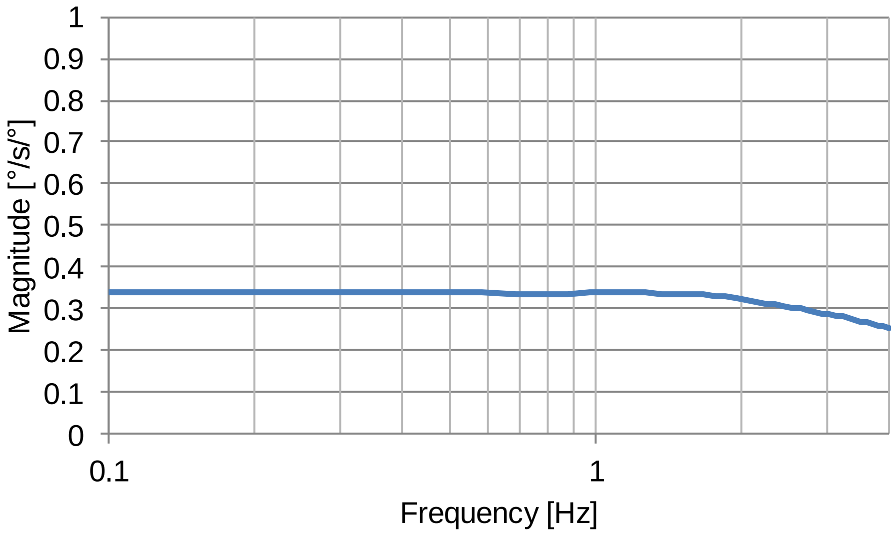

Figure 46: Steering wheel angle to yaw rate, amplitude response at 45 kph

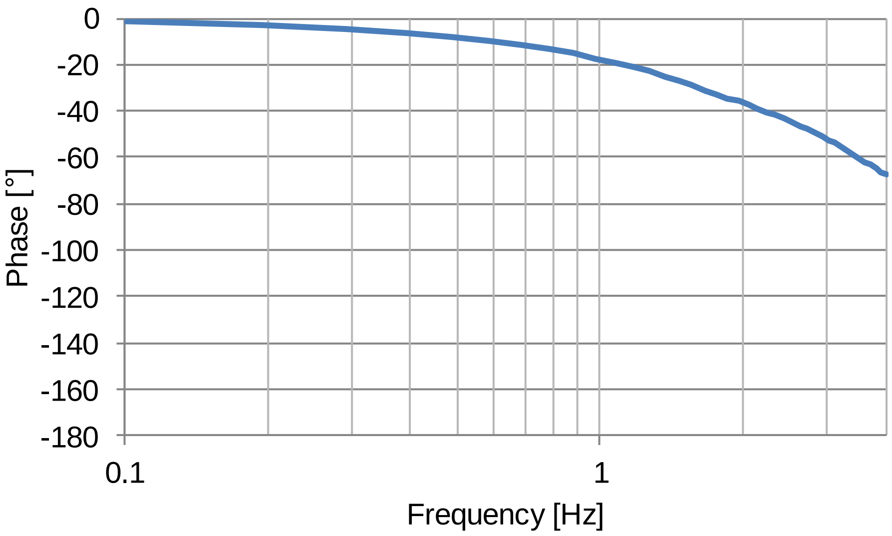

Figure 47: Steering wheel angle to yaw rate, phase response at 45 kph

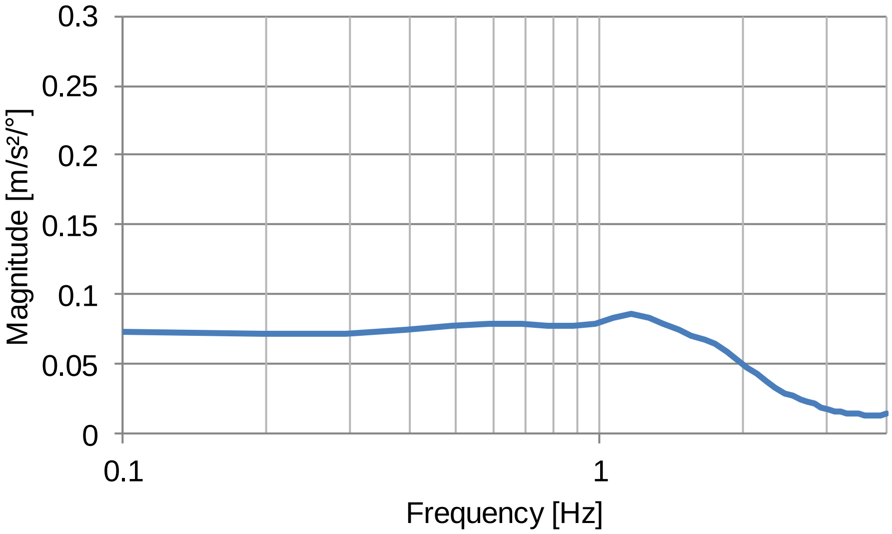

Figure 48: Steering wheel angle to lateral acceleration, amplitude response at 45 kph

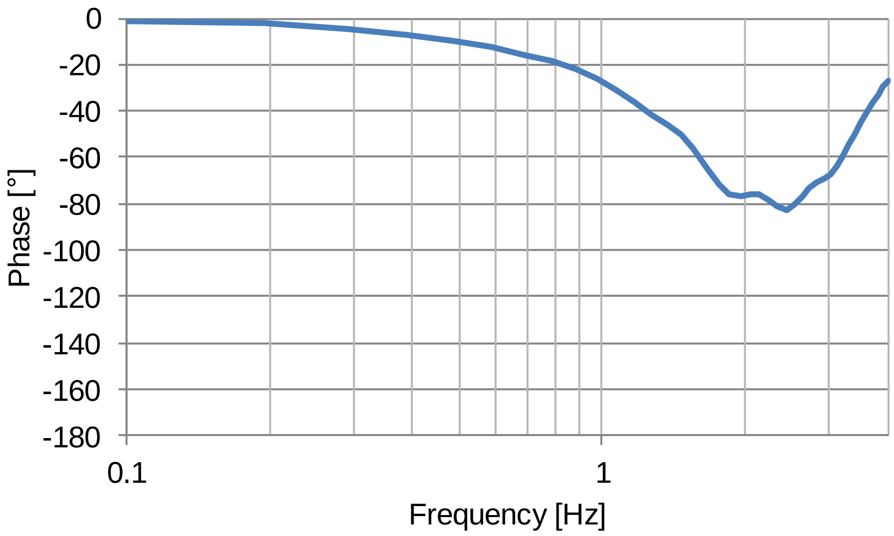

Figure 49: Steering wheel angle to lateral acceleration, phase response at 45 kph

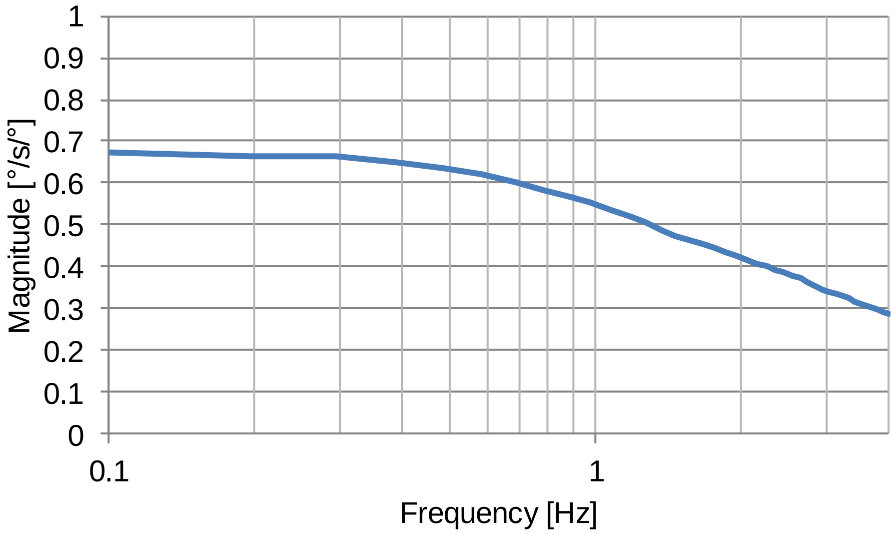

Figure 50: Steering wheel angle to yaw rate, amplitude response at 80 kph

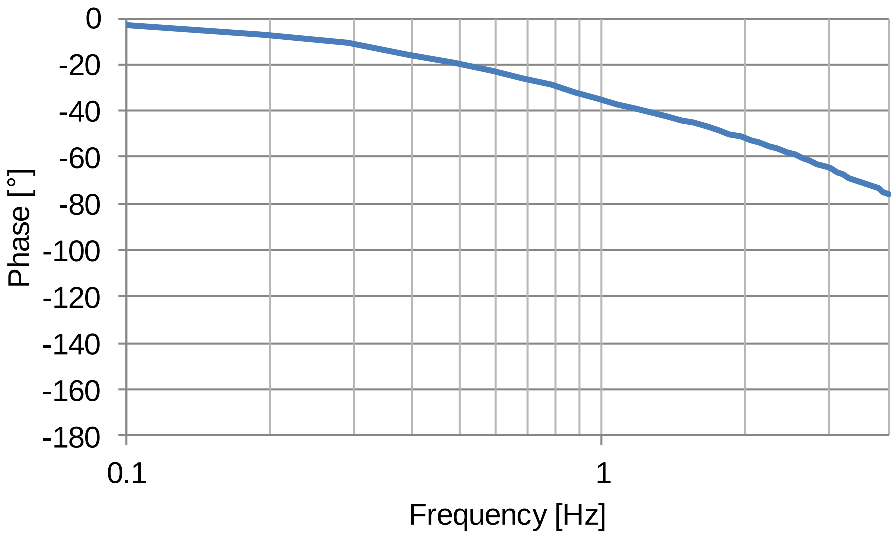

Figure 51: Steering wheel angle to yaw rate, phase response at 80 kph

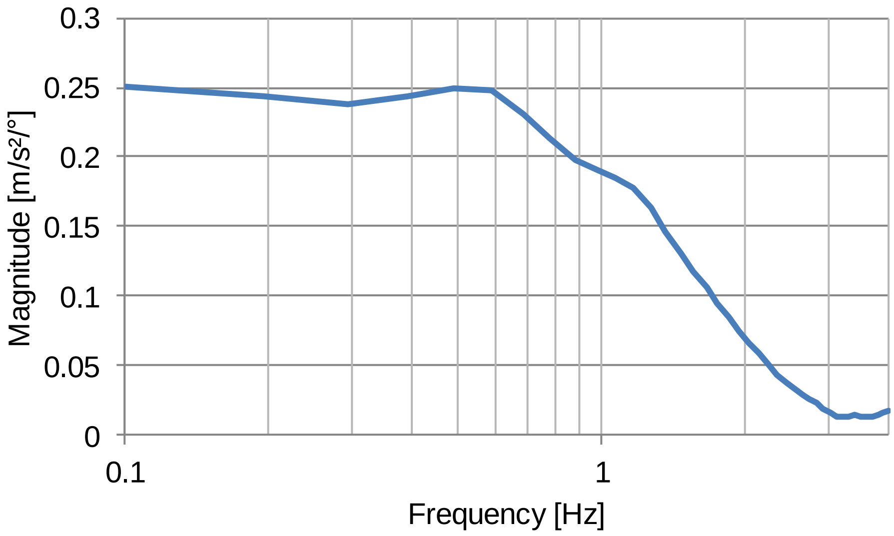

Figure 52: Steering wheel angle to lateral acceleration, amplitude response at 80 kph

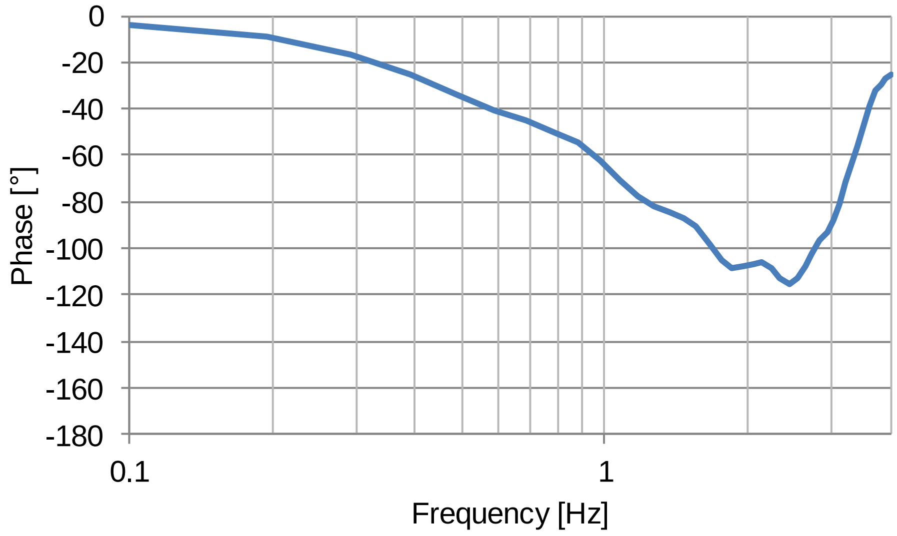

Figure 53: Steering wheel angle to lateral acceleration, phase response at 80 kph

Fishhook

The fishhook manoeuvre is a highly dynamic manoeuvre designed to test the rollover stability of a vehicle. In a pre-test, first a ramp steer manoeuvre at constant longitudinal velocity is performed to determine the steering angle necessary for 0.3 g of lateral acceleration. The standard velocity used for this test is 50 miles per hour. For the purpose of this analysis, evaluation speeds of 45 kph (maximum L6e speed) and 80 kph are chosen. In the fishhook manoeuvre itself, starting from a straight-line driving situation, the steering wheel angle is rapidly increased at a rate of 720 deg/s to 6.5 or 5.5 times the steering wheel angle determined in the pre-test. This angle is held until the roll velocity decreases to zero, i.e. the roll angle has reached its maximum. At this point, the steering wheel is turned at 720 deg/s to the opposite steering angle at the same magnitude. Figure 54 and Figure 55 show the time histories of the steering wheel angle for both speeds and both steering wheel angle factors. Evaluation criterion for the manoeuvre is the avoidance of a two-wheel lift-off, i.e. the wheel load must never become zero for both wheels on the same side of the vehicle. Figure 56 and Figure 57 show the wheel loads for the four performed manoeuvre configurations. It can be seen that, while there is a severe drop of wheel load especially at the front axle, at no point there is a complete loss of ground contact for both wheels of one vehicle side. It can therefore be concluded that the vehicle shows a good resistance against dynamic roll-over when driving on a flat surface without further external influences. While not the primary scope of this manoeuvre, the yaw rate responses as shown in Figure 58 and Figure 59 also show a good yaw stability.

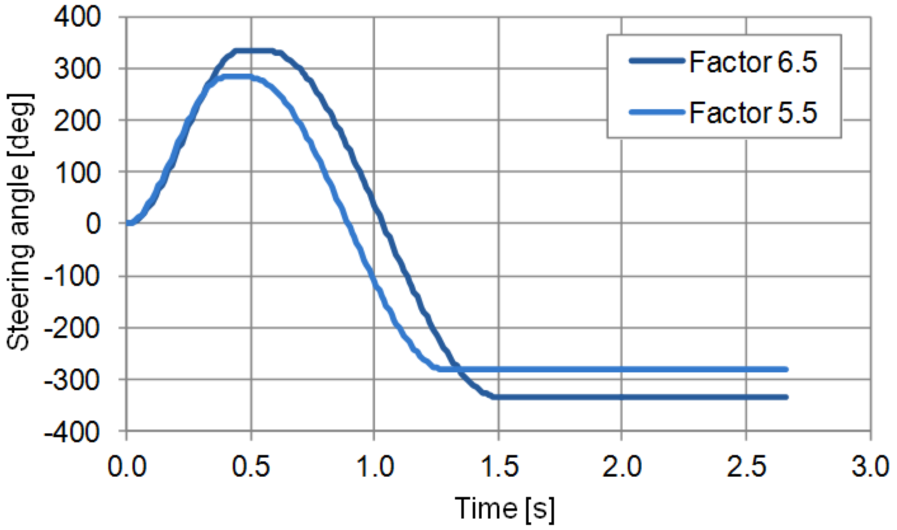

Figure 54: Steering angle vs. time for fishhook manoeuvres, 45 kph

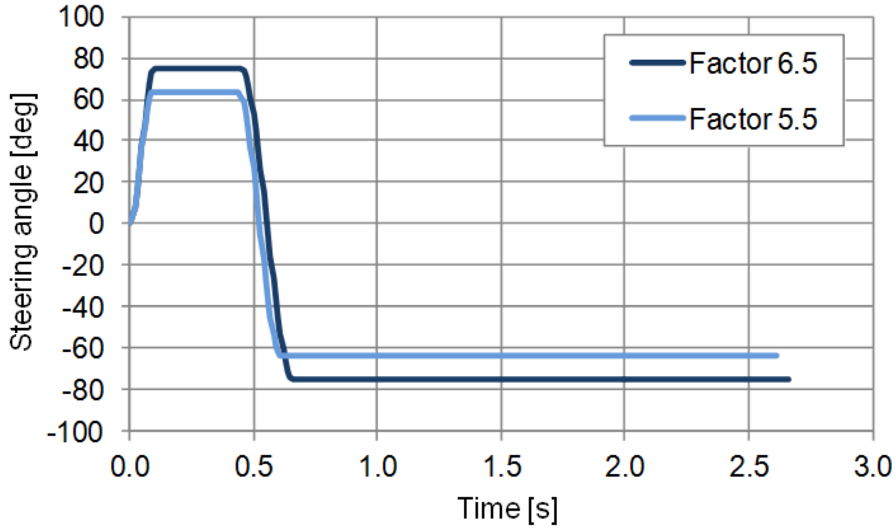

Figure 55: Steering angle vs. time for fishhook manoeuvres, 80 kph

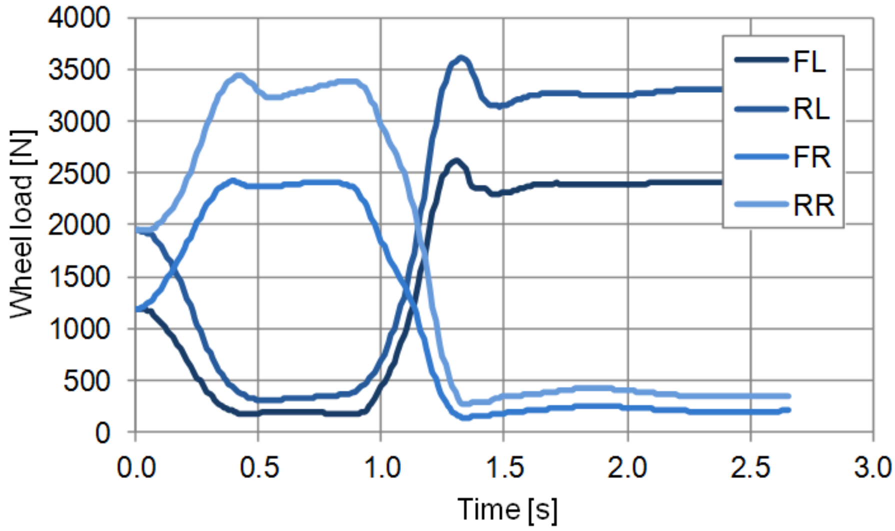

Figure 56: Wheel loads vs. time for fishhook manoeuvres, 45 kph

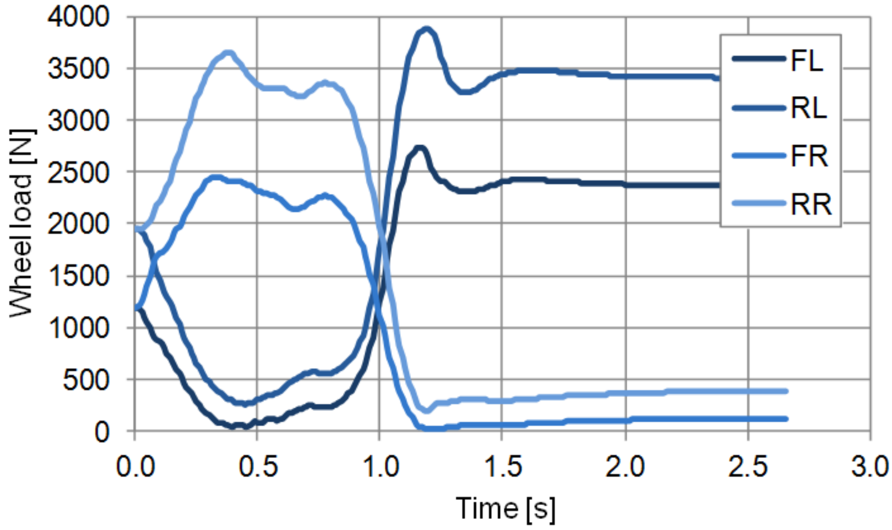

Figure 57: Wheel loads vs. time for fishhook manoeuvres, 80 kph

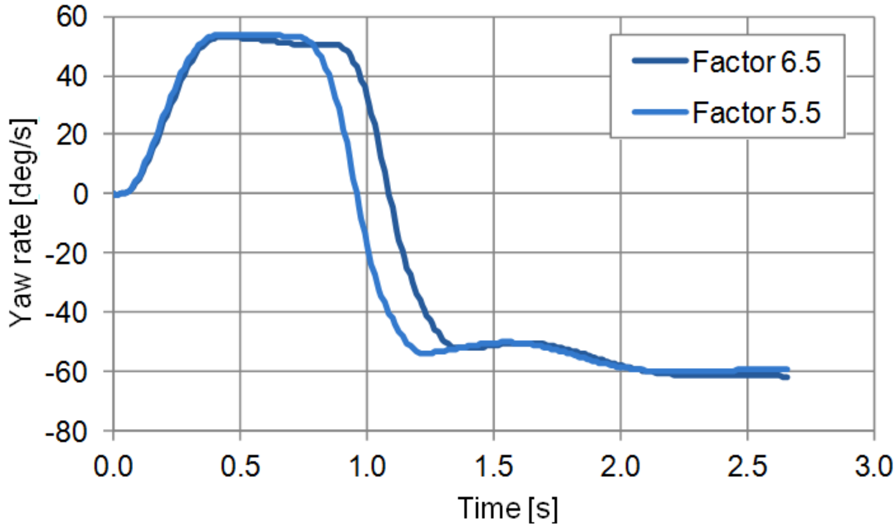

Figure 58: Yaw rate vs. time for fishhook manoeuvres, 45 kph

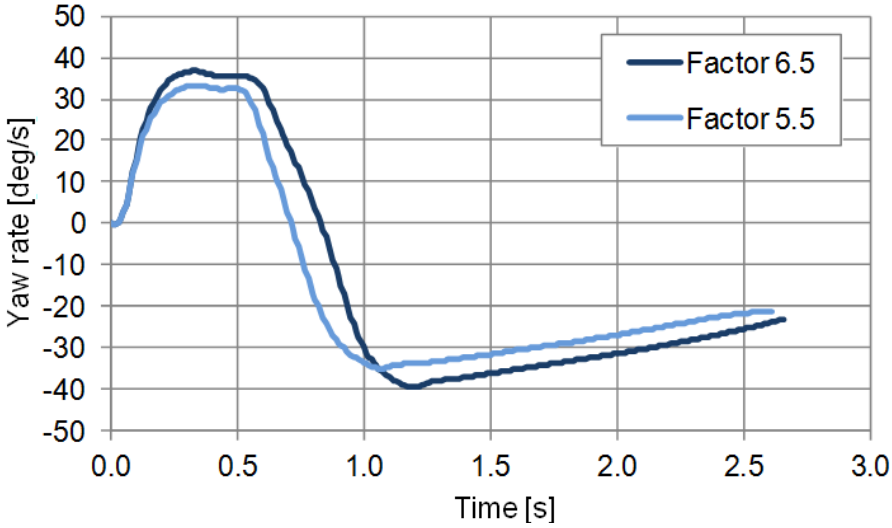

Figure 59: Yaw rate vs. time for fishhook manoeuvres, 80 kph

3.4.1.3 Conclusion

A MBS model of the L6e vehicle has been built up to analyse its driving behaviour. The modular and parametric structure of the model would allow for an easy modification of the model to assess the effect of design changes to the vehicle or to adapt or expand the model to be used for different types of analysis, such as generating design loads for the body structure or suspension components. The vehicle model has been subjected to a range of different virtual driving tests at its design speed of 45 kph as well as at higher velocities as they would be necessary for an expansion of the design into e.g. the L7e category. All performed manoeuvres showed a satisfactory and safe driving behaviour.

3.4.2 Aerodynamics simulation

In the following section, the aerodynamic evaluation process of the L6e vehicle is discussed, which is carried out in a virtual environment by performing numerical simulations using the computational fluid dynamics (CFD) solver STAR-CCM+10.06.010. The purpose of this preliminary investigation is to study the external flow field characteristics around the vehicle and to get an initial estimation of the aerodynamic drag coefficient value. Overall, the numerical evaluation process is broadly split into three sub tasks – pre-processing, solving and post-processing.

In the pre-processing phase, the simulation model is prepared for the CFD solver, which includes domain discretization, providing physical properties and solver conditions as input parameters. For the current evaluation, only vehicle exterior components are considered. CAD data of vehicle exterior and other sub-assemblies is first converted to watertight single surfaces before importing them into the CFD tool. The vehicle surfaces are then surface meshed and placed in a (virtual wind-tunnel) fluid domain. Figure 60 shows the vehicle body and the chassis sub-assembly prepared for discretization.

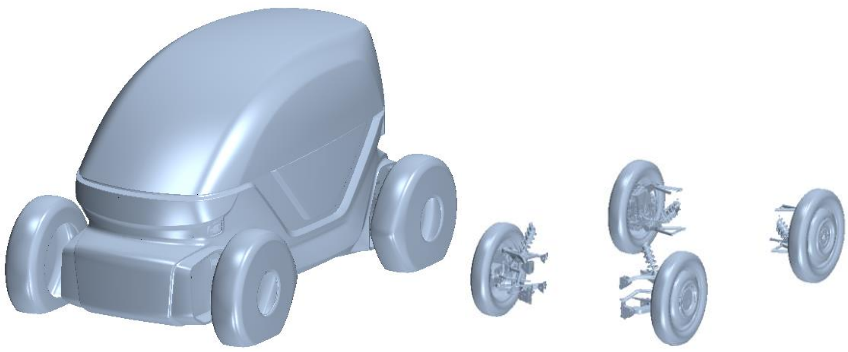

Figure 60: Vehicle sub-assemblies and Y+ distribution

The complete fluid domain is discretized by means of different types of meshing operations. Boundary layer regions in near wall areas are discretized by means of prism layer mesher. Various mesh refinements are specified in areas where good resolution is required. Figure 61 shows the discretized vehicle model in fluid domain and prism layer mesh, which will resolve the turbulence boundary layer.

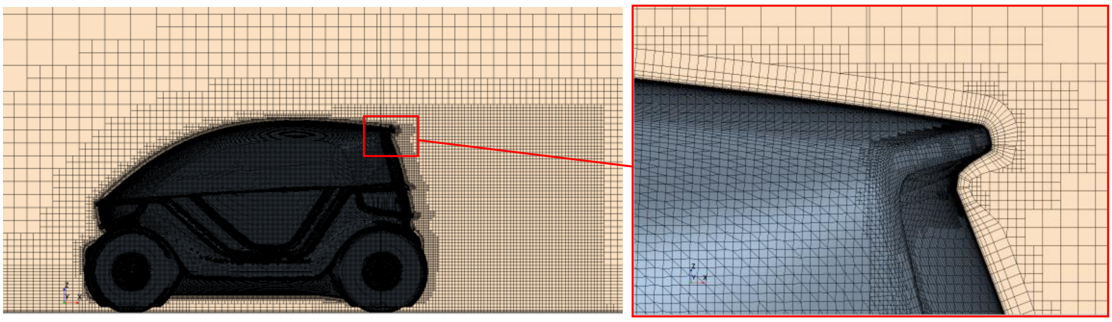

Figure 61: Domain discretization and prism layer mesh

In Table 6, the parameters used for the simulation are listed. In order to emulate the wind tunnel environment, the vehicle is fixed (with wall boundary conditions) and boundary motion inputs are given to the ground (with wall boundary translational velocity) and wheels (with wall boundary rotational velocity).

In the second phase, the actual solution process is performed by the solver in a parallel run on the cluster. Simulations are carried out for 5000 iterations. Multiple simulation runs have been conducted to improve the mesh resolution and achieve stable simulation runs. During these runs, the solution process has been monitored by tracking solver residuals, maximum velocity, inlet pressure and other such criteria. For the vehicle, evaluations have been performed for three different vehicle wind relative yaw angles with the mesh model being the same for all three but only changed inlet and outlet boundary conditions.

No	Boundary motion	Input value
1	Projected area in x-direction	1.64 m²
2	Single airstream domain	42,017,765 cells
3	Wind velocity	90.0 kph
4	Wind yaw angles	0°, 5°and 10°
5	Ground motion considered	90.0 kph
6	Wheel rotation considered	45 radian/s
7	Physics (Turbulence models)	Realizable k-Epsilon Two layer (Two layer all y+ wall treatment)

Table 6: Simulation model details

In the third phase, the files obtained after the simulation runs are post-processed to quantify the results in terms of aerodynamic evaluation parameters. Table 7 shows a summary of the drag coefficient values obtained for different relative wind yaw angles after taking the average for the last 500 of the total 5000 simulation iterations.

The drag coefficient values have been calculated with the reference wind velocity of 90 kph and a projected vehicle area of 1.64 m² in vehicle's longitudinal direction. A usual observation is that the drag coefficient value increases with an increase in wind yaw angle from 0° to 10°. However, in this model there is no significant increase in this value. A single value of the vehicle drag coefficient can be given with the help of the weighted drag coefficient value for three yaw angles, which is calculated to 0.457. Figure 62 shows the accumulated drag values along the vehicle's longitudinal direction. These curves help highlighting the contribution to C_x values by reference to a vehicle feature. For example, at 10° yaw angle, a major contribution to the drag is due to flow

separation behind the vehicle (in wake). In the current model, the wheels are completely detached from the body and are covered with wheel covers. The first noticeable peak in the C_x values can be seen at the end of the front wheel housing.

	Average C_{x0} (Last 500 steps)	Average C_{x5} (Last 500 steps)	Average C_{x10} (Last 500 steps)
Yaw	0	5	10
Drag value	0.456	0.457	0.465
Weighted Drag Value ($0{,}23 \cdot C_{x0}+0{,}62 \cdot C_{x5}+0{,}15 \cdot C_{x10}$)		**0.457**	

Table 7: Weighted drag coefficient values Cx

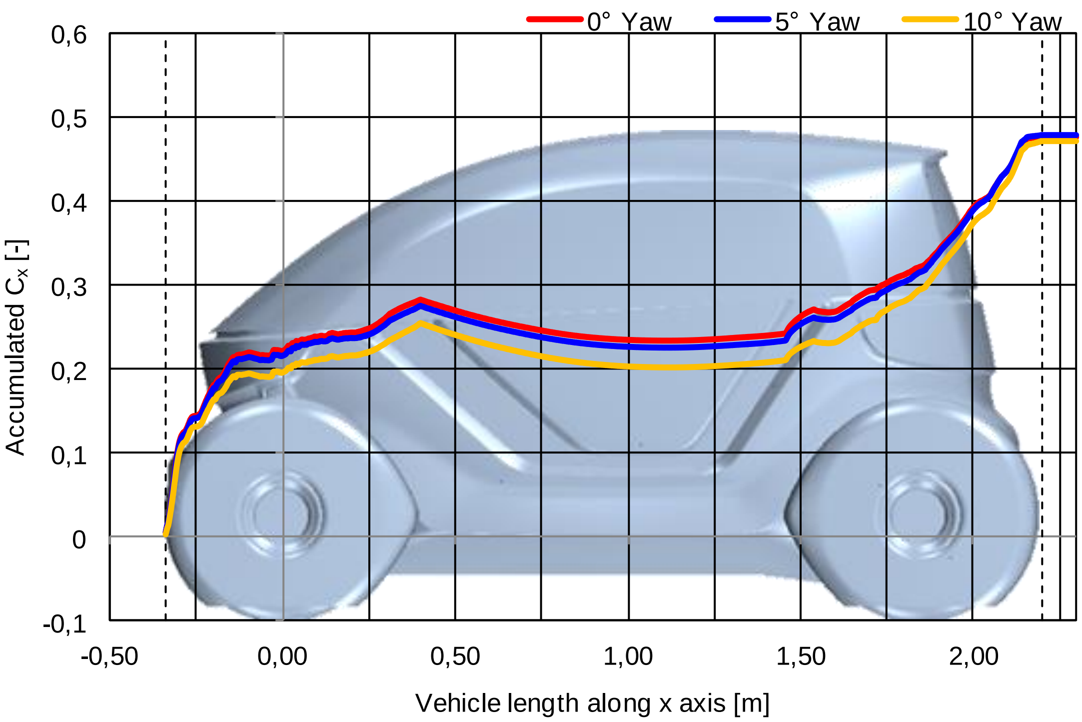

Figure 62: Accumulated drag coefficient along the vehicle x direction [C_x]

As the powertrain components are air cooled, a flow through the front grill has not to be considered. In Figure 63, the pressure coefficient and wall shear stress distribution across the vehicle body at 0° wind yaw angle are displayed. A stagnation point in the front lower region is spread across the front up to the wheelhouses. A negative pressure coefficient on the wheel housings shows the gains in terms of reducing the drag forces in the longitudinal vehicle direction. Major wall shear stress can be seen at the small curvature radii features and on the chassis components. Details such as door gap and channels are not included in the geometry, which will further add to these high shear stress regions.

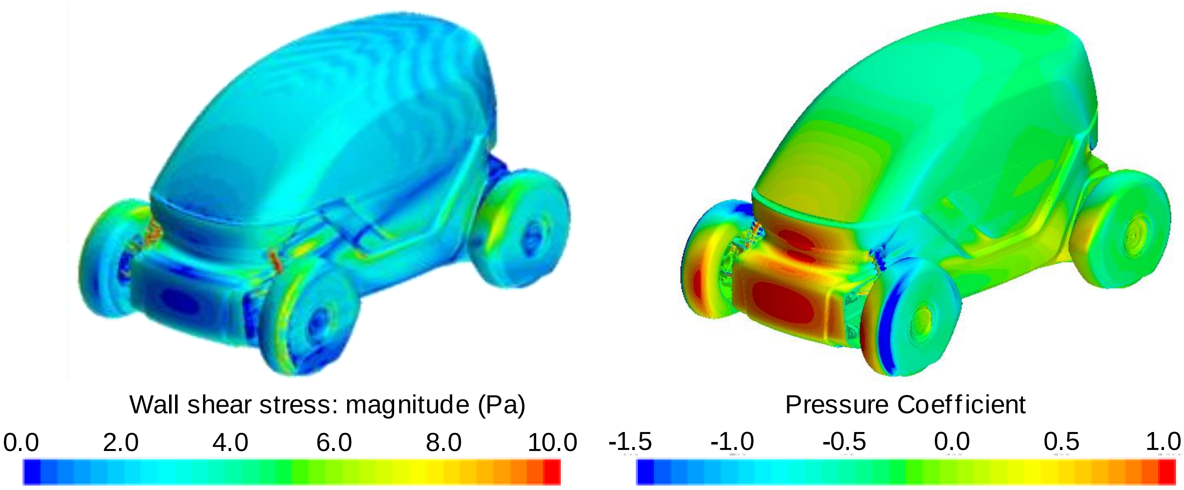

Figure 63: Wall shear stress and pressure coefficient distribution

In order to evaluate the region of the flow separation, iso-surface contour plots for a total pressure coefficient of zero are created as shown in Figure 64 for 0°, 5° and 10° wind yaw angles respectively. It can be seen that there is no considerable flow separation in the A-pillar region (conventional separation prone region) as the radius of curvature is considerably large and uniformly changing in vehicle x direction. Major flow separation is in the lower vehicle region. Main contributors for those are the un-sprung vehicle components. Against the expectation, 10° yaw angle does not show much difference in the flow separation characteristics as compared to the 5° yaw angle. This could also be one of the reasons for the small difference in the numerically evaluated values of the drag coefficients.

Figure 64: Iso-surface contour in fluid domain with total pressure coefficient = 0

Thus that, evaluation of the L6e vehicle shows a weighted drag coefficient value of 0.457 and the simulated C_x value shows low sensitivity to different wind yaw angles. Compared to passenger cars, the drag coefficient value is relatively high, which is due to the open wheel design and the flat front surface. It is however within the reach of other small vehicle with same characteristics, such as the EU-LIVE L5e vehicle.

3.5 Feasibility study on the radically new vehicle

The feasibility study for the radically new L6e vehicle analyses the vehicle's potential for realization from two perspectives. One is a market-based analysis, the other a technical analysis of the vehicle's concept. The basis for the market study is the vehicle concept and data of other L and M1 vehicles as well as the user needs study, described in deliverable 1.2. Furthermore, the previously cited UN ECE Regulation 168/2013 and the related regulations are used as a framework for the technical analysis of the study.

3.5.1 Market feasibility study

The feasibility of the EU-LIVE L6e vehicle in respect to the market can be evaluated on its market potential and its fulfilment of the user needs.

Market potential

Vehicles of the L6e and L7e category are designed as a cost-effective alternative for small M1 passenger cars with favourable acquisition and little running costs. Furthermore, vehicles of the L6e category can be driven with a simplified driver's licence, which is legal at the age of 16.

Nevertheless, the market for BEV L6e and L7e vehicles is relatively small, which is presumably partial due to a low diversity of manufacturers and vehicles. The European Alternative Fuels Observatory lists only nine different manufacturers that have sold more than ten L6e or L7e BEVs per year in Europe, including Norway and Switzerland, whereby two of the nine manufacturers sell golf carts and off-road quads, which are part of these vehicle registration classes as well [31]. In Table 8, the sales numbers are listed. The manufacturers of golf carts, Garia, and off-road quads, Polaris, are marked in italics.

Manufacturer	2016	2015	2014	2013	2012	2011	2010	2009	2008
Aixam	33	35	85	71				1	1
Club Car	5	2	1						
Comarth	155	205	47	1					
Estrima	6	33			1				
Garia	182	30	6						
Ligier		6							
Mega	10	3	3						
Melex	30	9			1				
Polaris	42	9	2						
Renault	2281	2065	2303	3049	2830				
Tazzari			7	2	12	42	10		
Xindayang		5							
Others	14	13	1						1
Total	2758	2415	2455	3123	2844	42	10	1	2

Table 8: Sales numbers of L6e and L7e BEVs in Europe [31]

Between 2008 and 2016, 13,650 L6e and L7e BEVs have been sold in Europe in total. The Renault Twizy leads the sales numbers of light four-wheelers. Since its introduction in 2012, it has been sold 12,528 times for L6e and L7e vehicles combined. Aixam in comparison, a French manufacturer of several BEV L6e vehicles, has sold 224 vehicles between 2013 and 2016, but only 68 within the last two years [31]. The smaller manufacturers reach sales numbers lower than five percent.

In a study regarding the first users of electric vehicles in Germany, published by the German Aerospace Center (DLR) and conducted between December 2013 and February 2014, the Twizy is the most possessed BEV of private owners with approximately 40 % market share for L6e, L7e and M1 vehicles combined [32]. In 2013, it has been sold 834 times in Germany, but with no information on shares for commercial or private use [31].

The study states that 84 % of private households with a BEV own a second non-electric car. It also states, that the BEV is often bought out of interest in the technology or for environmental reasons. It can be presumed that the sales price is a purchase factor, but not the decisive one, as combustion engine vehicles, which offer more comfort than for example a Twizy, are available at lower prices. The BEV is used for an average of 43 km per day, but with less travelled mileage per year, compared to a non-BEV. The high percentage of Twizys used by

private owners can be explained by three factors. First, the number of available M1 BEVs has been small until 2013, with only a handful of different vehicles freely available on the market. Second, the sales prices of battery-electric M1 cars were two to three-times the Twizy's price and third, the electric range of M1 BEVs was often comparable to the Twizy. A higher sales price has therefore been a purchasing argument for the Twizy. The results of the study suggest that the BEV in the business to consumer market (B2C) in Germany is used as a short distance commuter vehicle, but not as a replacement for the normal car.

Since 2014, the sales figures of the Renault Twizy have been relatively steady with an average of 2216 units sold in Europe and 607 sold in Germany. The M1 BEV market in Germany however has been increasing constantly. In Figure 65, the sales figures for the Twizy and for all BEV M1 vehicles are displayed. It has to be said however, that the graphs display sales numbers for business-to-business (B2B) and B2C combined with no information on the distribution between the two segments. The DLR study however indicated, that the Twizy is mostly used in the B2C market, whereas BEV M1 vehicles are spread to both market segments. Nevertheless, the sales figures of M1 vehicles suggest that sales numbers have been increasing in both markets.

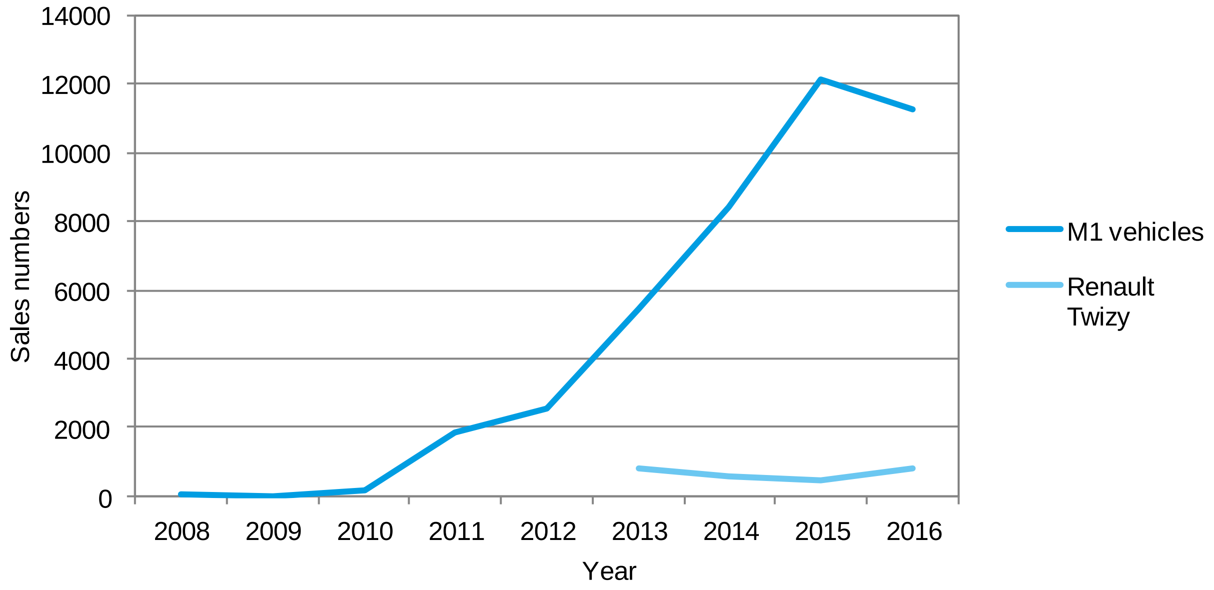

Figure 65: Sales figures of M1 cars and the Renault Twizy [31]

As sales prices for M1 electric vehicles drop slowly but continuously, with the announcement of small, lower priced electric vehicles and base prices fewer than € 16,000 [32], M1 vehicle prices get closer to the Twizy and other L category vehicles. With a buyer's premium of € 4,000 for battery electric M1 vehicles, granted by the German government, the price difference between a Twizy (L6e: starting at € 6,950; L7e: € 7,650 [34]), is less than € 4,350 as the buyer's premium is not applicable to L category vehicles [35]. The previously mentioned Aixam L6e BEV, which offers a closed cabin, doors, a heater unit and passenger car-like seats, costs € 14,390 as a base model [27]. Almost the same sales price as a small M1 BEV without buyer's premium, but with the limitation in top speed.

With the small price differences, a possible disadvantage in range and less flexibility and comfort, compared to a small M1 BEV, the future EU-LIVE L6e vehicle has to offer a low sales price, comparable to the Twizy, but with a unique selling proposition (USP) over it, to be able to compete on the market.

With the required integration of two EU-LIVE IWM, the continuous power output is high enough to design the L6e four-wheeler as a L7e vehicle, which is electronically limited to 6 kW and 45 kph. This provides the advantage to use it as a car-sharing vehicle, which adapts its power output to the driver's license. This may however require a special registration permit and lead to a potential change in homologation requirements. A similar idea seems possible for families, where 16-year-old children can use the same vehicle as their parents. A system with a public-private shared vehicle also seems possible more easily, as young people could rent such a car. Furthermore, the offset side-by-side seating layout offers easier access and more comfort compared to the Twizy, when travelling with a passenger. The wider cabin additionally results in an increased interior and therefore more luggage space, which provides the possibility of easier transporting small goods. With the closed cabin and a heater unit, it also offers all year usability.

Nevertheless, the expected sales numbers for the future L6e/L7e vehicle seem low. A common-part strategy, not only for the powertrain, but also for interior components could provide a USP over other direct competitors. Compared to the Twizy, a closed cabin is provided and compared to other L6e/L7e vehicles, the sales price would be significantly lower.

User needs fulfilment

Besides the market potential, the user needs identified in deliverable 1.2 are used to analyse the L6e vehicle concept regarding its fulfilment of the user's desires [13]. Within the deliverable, the desires have been clustered into six overall needs. Their fulfilment cannot be evaluated in detail with the current design status, but a general trend can be provided.

- >The customers' need for information about the vehicle and the surrounding traffic situation is fulfilled by the infotainment system. This could be supported by integration of modern smartphone connectivity. Detailed information for example on the current vehicle status, presumably in a special app, would fulfil the need for car-to-owner communication.
- >With the possibility to adapt the vehicle's power output and with the option to boost the 6 kW for a short period, a sensible driving experience/pleasure is possible. The torque output of the electric motors will provide an advantage over small combustion engine L6e vehicles that cannot adapt to the driver and his driver's licence.
- >Customers desire themselves and their vehicle to be safe, not only when driving but also when picking up a car sharing vehicle or leaving the vehicle parked. The integration of a basic load path concept to the simplified design and the available space within the exterior concept leave room to integrate crash deformation elements in a following detailed design phase. The closed cabin, in comparison to the Twizy, fulfils the need to leave the vehicle safe when parked.
- >The integration of the EU-LIVE modular powertrain, which is featured in additional L category vehicles, should lower the overall costs and provide a good cost-efficiency. The integration of additional off the shelf components should increase the potential for fulfilling the customer's need.
- >The time-efficiency of the vehicle is partially fulfilled by the vehicle's size, which allows it to exploit parking spaces very well. A simplified payment system as well as the reservation of available parking spaces could later be part of a new car sharing system, which for example accounts the costs via the phone bill or together with a public transport system. The efficient use of parking spaces could be rewarded by cities.
- >The wish for eco-friendliness and the need for the use of alternative fuels are fulfilled by the integration of an all-electric powertrain. It could be further improved by the integration of interior and exterior components that are easy to recycle, as the body panels are currently planned as non-structural parts.

As far as it is possible to answer the user needs in this early stage of the development, they are fulfilled by the L6e concept. Nevertheless, they must be kept in mind for a following, detailed development process.

3.5.2 Technical feasibility study

The technical feasibility of the L6e vehicle can be analysed based on the ECE Regulation 168/2013, deliverable 2.1 and the detailed information in Table 4. As the concept only exists in an early development stage with no detailed design, the fulfilment of regulation requirements cannot be analysed in detail. A general answer is nevertheless possible.

Based on the design contest requirements, the exterior already met basic parameters of ECE R 168. During the following design phase of Task 4.1.5, the parameters of the L6e vehicle have been chosen to stay within the ECE regulations. By integrating existing chassis, powertrain and interior components, the vehicle complies with additional regulations that are fulfilled by the components themselves.

With the integration of the suspension assembly at the front axle and the IWM with integrated brake discs at the rear axle, a basic brake system is available. The development phase would require the detailed technical design of the system itself. An installation space for the brake system has however been secured. The same applies to the integration of the powertrain, which is also based on carry-over components. The integration of the 48 V battery and the low voltage components in the underfloor of the vehicle allows for greater interior space and places the system within the non-deformation zone of the passenger compartment.

Due to the little number of safety requirements for L category vehicles, the interior components only have to comply with requirements for seats and seat belts. The seats as PSA carry-over parts already fulfil the regulations. A secure mounting of the safety belt anchorage to the lower body structure can be secured during the

development phase. A detailed analysis of the integrated heater unit should also be part of a later development phase. The integration of the system itself secures the fulfilment of the B6 requirements.

The field of vision has been analysed based on the package design, the frame and the exterior shape. In this early design phase, the vehicle fulfils the requirements regarding sight obstruction. The integration of an interior design might restrict the field of vision further, but with adaptations to the preliminary exterior and frame design, a compliance with the regulations should be possible. The multi-body simulation has generally proved the steerability and driving stability (B13). By simulating all driving manoeuvres with 80 kph, the stability for an L7e vehicle has been proven, as well.

To create a cost-effective L6e/L7e vehicle that can challenge the Renault Twizy, as many OTS components as possible should be integrated in the new concept. As the L6e design is closer to a M1 passenger car than to the L5e vehicle, the integration of passenger car OTS seems more feasible. Nevertheless, as the overall vehicle mass is a critical factor of L6e/L7e vehicles, light components are required. A common-part strategy between the EU-LIVE vehicles should be followed as far as possible during a development phase of the L6e vehicle, especially concerning interior components and infotainment.

3.5.3 Conclusion

The technical feasibility of the L6e vehicle is given for this level of detail. With that, it has been proven that the integration of the EU-LIVE modular powertrain to a vehicle radically different from the other two EU-LIVE concepts, is possible. Even with the conceptual disadvantage of the open wheel concept, which wastes installation space between the front and rear tires, the integration of the battery pack and other powertrain components is possible. With a different exterior shape, for example the Flexividual or Helix concept (see Figure 5), the integration of the L3e/L5e rear arm seems possible as well.

The relatively small market for L6e and L7e vehicles however requires a good market and sales strategy even if the powertrain costs are lower, due to expected high sales number of the L3e and L5e vehicles. One option to increase market share for the L6e vehicle could be a city car-sharing system where the vehicle’s electronics derestrict the motors to a combined 15 kW power output if the driver is allowed to operate an L7e vehicle. In combination with the other two EU-LIVE models and presumably M1 cars, the car-sharing user would have the option to choose the right vehicle for each purpose.

An additional option to increase the sales potential could be the use of the underbody, chassis and powertrain for different vehicles of the L6e/L7e segment, such as small lorries and delivery vans. The scalable battery system could be used to offer different ranges without great adaptations.

3.5.4 Needs for changes to homologation requirements and regulations

As the EU-LIVE L6e vehicle and direct competitors like the Twizy or the Aixam eCity fulfil the regulations, it is possible to design a light car for this category. Therefore, there is no direct need for changes to homologation requirements. The small sales numbers indicate however that the L6e vehicle class may not perfectly be designed regarding the markets’ needs.

During the design process of the L6e vehicle and the market research, it appeared however that the small differences in the overall vehicle mass between the L6e and L7e category could be levelled by increasing the 425 kg limit of the L6e category to the 450 kg of the L7e category. It would allow the development of an L6e vehicle, which is also legal in the L7e category, without losing the 25 kg weight difference.

One of the main differences of the two largest quadricycle categories over the M1 class is the absence of passive safety requirements apart from the seat and seatbelt regulations. If a real market for light vehicle arises, it seems indispensable to define basic standards in respect to passive safety. With the low top speed, its purpose as a small city car and the low vehicle mass, it should not need to fulfil M1 criteria but rather offer an appropriate degree of passive safety.

A main disadvantage of L6e vehicles however is their permissible maximum speed of 45 kph, just below the common city speed limit of 50 kph. Even if these speeds are not permanently, but peak driven in normal traffic situations, a vehicle with an overall width of 1.5 m constitutes an obstacle on single lane streets that cannot be easily overtaken when travelling at its speed limit. This situation may not only be difficult for the faster vehicle but also inconvenient and uncomfortable for the L6e driver. A low attractiveness of a vehicle with a maximum speed of 45 kph can be presumed, as well, especially if the driver normally is allowed to drive faster vehicles. Therefore, it is suggested to raise the speed limit of L6e vehicles to 50 or 55 kph, which allows the driver to flow

in normal city traffic on single lane roads without being a traffic obstacle. To pursue a car sharing option for the EU-LIVE L6e vehicle - allowing an electronic derestriction and upgrade into an L7e vehicle with an increased power output and a higher top speed - the approval regulations for vehicles and potentially for drivers' licence need to be adapted. They need to allow for one physical vehicle with one registration but two different performance characteristics that allows it to be driven with different drivers' licences. The electronic derestriction could be done with the user identification in the vehicle via an identification chip in the drivers' licence, a separate identification card or a biometric matching of the driver, for example via his fingerprint.

The permissible maximum speed of 90 kph for L7e vehicle seems sufficient as it allows driving on inner city expressways, which in Germany often have speed limits of 80 kph, or short distances on the right-hand lanes of motorways without being a traffic obstacle.

4 DISSEMINATION, EXPLOITATION AND STANDARDISATION

The design contest has been advertised to design schools and their students as well as to young professionals across Europe. It has been further advertised on various design websites, such as Car Body Design, creating high awareness of the design contest itself but also for the whole project. This becomes apparent by participants' nations. With over 90 participants and participating teams, not only from Europe, but also from Australia, India, Indonesia, Russia, South Korea, the United States and others, the EU-LIVE project has been promoted around the world. During the design contest's running time, the traffic on the EU-LIVE website increased significantly. Today, the design contest and its results are still a major element on the project's website with its own tab for quick access.

The results of the design contest and the subsequent development of the virtual prototype have also been part of both newsletters published by the EU-LIVE consortium and several news reports on the website. The results of the virtual prototype development will further be published in additional news reports and a section in another newsletter.

This deliverable itself is public and will be published on the EU-LIVE website. The results of the development will be openly accessible. Additionally, it is planned to present the results of the development process on conferences, such as the Aachen Colloquium, where results will be published as part of the conference proceedings documents. The ongoing development of the L6e concept will also be part of a PhD-thesis at the Institute for Automotive Engineering (ika) RWTH Aachen University.

Furthermore, the concept is a proof that the modular architecture approach of the EU-LIVE project is applicable to L category vehicles other than scooters and comparable concepts.

5 INTEROPERABILITY

The key element of the interoperability of the L6e vehicle is the integration of the modular powertrain, which has been integrated in various combinations to all three EU-LIVE vehicles. As shown in the feasibility study, the market for BEV L6e and L7e vehicles is relatively small, compared to passenger cars and small commercial vehicles as well as for the L1e to L5e categories. Only with the integration of a cross-platform powertrain, it seems possible to produce a cost-effective L6e vehicle.

The type approval regulations however enable manufacturers to design an L6e vehicle that is, with small changes, also applicable to the L7e category. The simulations of the L6e vehicle have already been performed for such a scenario. In case of a further development, this option should be investigated.

As the vehicle concept is strongly different to the other two EU-LIVE vehicles, it has not been possible to carry over relevant chassis or interior components from the prototype vehicles. Nevertheless, the interior and electrics/electronics, which would be designed during an additional development phase, should adapt components such as displays or the final HVAC directly from the L5e vehicle.

The winning open wheel concept of the design contest did not allow to adopt the rear swing arm of the original suspension concept, but required an adaptation of a double wishbone axle at the rear. With a different exterior design and the extrusion profile frame, a modular body architecture for L6e and L7e vehicles seems possible.

6 CONCLUSION

Within the tasks 4.1.0 and 4.1.5, the virtual L6e vehicle has successfully been developed. Based on the results of a design contest, a concept vehicle has been created, simulated and its feasibility been analysed.

In the first development phase of the L6e vehicle, the EU-LIVE open innovation design contest has been offered to students and young professionals around the world. The call to develop a radically new battery-electric L6e vehicle has been answered by over 90 participants. To receive such a high feedback, 46 design schools and additional design platforms were contacted and leaflets sent out to promote the contest itself and to create a high awareness of the whole project. With participants from Europe, Australia, India, Indonesia, Russia, South Korea, the United States and others, the promotion reached much further than the contacted design schools in Europe might suggest. Due to the high variety of submitted concepts, the jury of prestigious designers and engineers had the opportunity to select three exceptional winners during the two-stage design contest.

The winning concept of the design contest, a modular open-wheel vehicle with a one+one seating layout, has been used as a development basis for the new L6e concept. Considering the exterior shape, first, a new seating layout has been selected, comparing different arrangements in respect to comfort and usability. Second, a package plan and a simplified CAD model have been developed, integrating the EU-LIVE modular powertrain. To estimate the full potential of the new concept, the CAD model has been complemented with suspension and interior components and a newly designed body structure, allowing for a more comprehensive analysis of the vehicle. Based on an additional weight estimation on assembly level and the suspension model, a multi-body simulation (MBS) has been performed, to secure a safe driving behaviour. Furthermore, a computational fluid dynamics simulation (CFD) analysed the vehicle's aerodynamic efficiency. The MBS has been performed for 45 kph, the permissible maximum speed for L6e vehicles, and normal road speeds, facilitating an optional development of the concept as an L7e vehicle. In all performed driving manoeuvres of the MBS, the vehicle showed a safe and stable behaviour at all speeds. In the CFD analysis, the L6e vehicle showed a low sensitivity to different yaw angles and a weighted drag coefficient of 0.457, which is comparable to other small open-wheel vehicles.

The development of the L6e concept has been completed with a feasibility study, analyzing the market and technical potential of the vehicle and an analysis of the needs for changes to homologation requirements and regulations. Due to a preliminary research of the regulation requirements, the technical feasibility of the vehicle is given. The analysis showed however that the market volume of battery-electric L6e and L7e vehicles is relatively small and that a successful production of the EU-LIVE L6e concept requires a good market strategy besides a simple sale to consumers and business customers.

For a future development beyond this project, the vehicle should be designed in detail, with the creation of more detailed interior concept. In this step, the required common parts strategy could be analyzed in detail, allowing for a reliable statement regarding the future sales price and potential sales volume.

With the successful integration of the EU-LIVE powertrain into a radically different vehicle, compared to the L3e and L5e concepts, the ambition to demonstrate the actual transferability has been achieved. It proves that it is possible to create a modular powertrain that is applicable to a wide range of L category vehicles and with that, answers one key research questions of the overall project.

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A. APPENDIX

A.1 FAQ of the design contest

> Who can submit?

- Students of industrial design, transportation design, engineering as well as other relevant fields
- Professional designers and experts in relevant fields

> How do I submit my design?

- Fill in your information and upload your design. No prior registration is necessary.

> What do I have to submit?

- One pdf-file with a maximum of 5 pages and a size of no more than 10 mb

> What are we looking for?

- Sketches of your vehicle
- A minimum of 2 and a maximum of 5 pictures
- At least two different perspectives (desired perspective: three-quarter front)

> What will be required during the redesign phase?

- Originating from the jury's feedback you might be asked to adapt your design to package components or to meet demands for better series production. In order to prepare your design for the virtual prototype, you will be assisted by professional 3D engineers.

> What is the L6e-category?

- A L6e-(B) vehicle is a small (l ≤ 3 m, w ≤ 1.5 m, h ≤ 2.5m) light quadric-mobile with a maximum power of 6 kW and an enclosed passenger compartment which is accessible from a maximum of three sides. It has 4 wheels, a top speed ≤ 45 kph and a mass in running order ≤ 425 kg (excl. Battery).
- For further information see the regulation of the EU: L-category vehicle EU type-approval legislation

> Are there any restrictions to participate?

- There is an age limitation: you must be 18 by the date of submitting your design concept and at least be of legal age in your country of origin.

> Can we participate as a team?

- Yes, you can participate as an individual or as a team.
- As a team: please add all team member names to your sketches and inform us via email concerning all members including their contact information

> Is there any charge?

- No, there is no charge at any stage of the design contest.

> What/Who is EU-LIVE? And what are its objectives?

- The EU-LIVE project is being carried out by an international consortium with comprehensive expertise in the areas connected with mobility and automotive development. It represents a promising mix of leading industrial companies and knowledge centres perfectly able to respond to the future challenges of urban mobility. The consortium consists of major European manufacturers of passenger cars and L-category vehicles, Tier 1 suppliers of components and sub-systems, SMEs and research centres specialized in mobility and the automotive sector. The know-how of this interdisciplinary think-tank, which covers the complete value chain of vehicle design, development and production, ensures the sustainable market exploitation of the project results.

> Who stands behind the EU-LIVE project?

- For more information please click here: Partners

> How does EU-LIVE handle intellectual property?

- Before submitting your designs, you have to agree to the rules and procedures of the EU-LIVE design contest. The intellectual property remains with the contender(s), however, the participant(s) allow EU-LIVE and its members the use, publication and re-utilisation of his/their designs for marketing, publishing, development and other unspecified uses without further notification. The contender(s) further agree to be named and their designs to be displayed on the EU-LIVE website as well as in official documents linked to EU-LIVE and EU-LIVE members' projects without further compensation. Marketing, publication, development, etc. includes advertising, scientific papers, dissertations and further undisclosed uses. However, the designer(s) have to be named as the owner and creator of the intellectual property at any time.

A.2 Evaluation sheet

Design Contest | Judging Criteria

Main Requirements / Sub Requirements	Sub Score	Main Score	TOTAL Score
			0,20 / 1
Fulfilment of the requirements			
USABILITY		3/15	
Driver visibility	1		
Manoeuvrability	1		
Space utilization (Expliot Parking Spaces)	1		
COMFORT		3/15	
Entrance concept (Alternitive Door (optional))	1		
Modularity (interior, storage space)	1		
Weather protection / All Year Usability	1		
SAFETY		3/15	
Space for crash elements (frontal impact)	1		
Supporting Structure	1		
Design supports Lightweight structure (target weight 425 kg)	1		
DIMENSIONS		4/20	
length ≤ 2.5M	1		
width ≤ 1.5M	1		
hight ≤ 1.9M	1		
Package design supports dimensions	1		
Originality of the design		5/25	
Creativity	1		
Style	1		
Innovativeness	1		
Uniqueness	1		
"want to have" feeling	1		
Quality of the design		4/20	
Proportion and shape	1		
Aesthetic appeal	1		
Level of elaboration	1		
Design function	1		
Technical feasibility		2/10	
Complexity of the shape	1		
Use of available components and systems	1		

A.3 List of the contacted design schools

Design School	Country
FH Joanneum – Industrial Design Department	Austria
FH OÖ Studienbetriebs GmbH	Austria
Universität für angewandte Kunst Wien (Industrial Design)	Austria
Universität für künstlerische und industrielle Gestaltung Linz	Austria
Privatuniversität der Kreativwirtschaft	Austria
Fachhochschule Salzburg GmbH – Design/Produktmanagement	Austria
New Design University – Department E-Mobility & Energy	Austria
Lahti University of Applied Sciences – Institute of Design and Fine Arts	Finland
Creapole	France
Espera Sbarro	France
ISD France	France
Strate College	France
Hochschule für Gestaltung (Offenbach)	Germany
Hochschule für Technik und Wirtschaft Berlin – Industrial Design	Germany
Institut für Designforschung der Hochschule Darmstadt	Germany
Braunschweig University of Art	Germany
Pforzheim School of Design	Germany
Coventry University – School of Art and Design	Great Britain
Royal College of Art of England	Great Britain
University of Huddersfield – School of Design and Technology	Great Britain
University of Northumbria at Newcastle	Great Britain
University of Wales Trinity Saint David	Great Britain
Moholy-Nagy University of Art and Design	Hungary
Facoltà di Architettura “Ludovico Quaroni” Sapienza	Italy
Facoltà di Architettura “Luigi Vanvitelli”	Italy
Florance Design Academy	Italy
Istituto di Arte Applicata e Design	Italy

Design School	Country
Istituto Europeo di Design	Italy/Spain
Istituto Superiore di scienza dell’automobile	Italy
POLI.Design – Transportation & Automobile Design	Italy
Politecnico di Torino – facoltà Architettura	Italy
Politecnico di Milano – Scuola del Design	Italy
Scuola Italiana Design – PST GALILEO scpa	Italy
Scuola Politecnica di Design	Italy
Design Academy Eindhoven	Netherlands
TU Delft – Delft University of Technology	Netherlands
Academy of Fine Arts and Design in Bratislava	Slovakia
Elisava – Barcelona School of Design and Engineering	Spain
Escuela Universitaria de Ingeniería Tecnica	Spain
Mondragon University – Engineering Faculty	Spain
Universitat Politècnica de València	Spain
Eco2 Vehicle Design Center (KTH)	Sweden
Chalmers University of Technology	Sweden
Umeå Institute of Design	Sweden
Art Center College of Design	United States

A.4 Fact sheet of the design contest

EU-LIVE
EFFICIENT URBAN
LIGHT VEHICLES

THE BRIEF

Future urban mobility calls for more space for people and less space for cars as well as for environmentally compatible vehicle concepts, saving resources and minimizing local noise and air pollutant emissions. Motor vehicles in the Light (L-) Category already offer an interesting complementary solution to public transport, walking and cycling. Yet, at present, L-category vehicles are still not sufficiently attractive to end users. EU-LIVE will provide a comprehensive solution, which covers a range of three different L-category vehicles (L3e, L5e and L6e). The design contest is the foundation for the L6e-category. Your concept will serve as the sound basis for the virtual prototype. Send us your sketches of a fresh and unconventional car and submit your concept until February 14, 2016.

THE AWARD

The winning concept will be further developed into a virtual prototype targeting the L6e category. It will consist a package plan, a simplified CAD model (which will be built by professional 3D engineers) and a corresponding multi-body and aerodynamics simulation model. Moreover it will be used for a feasibility study.

Furthermore, a prize money of € 6000 for the first 3 winners will be awarded (first: € 3000, second: € 2000, third: € 1000)

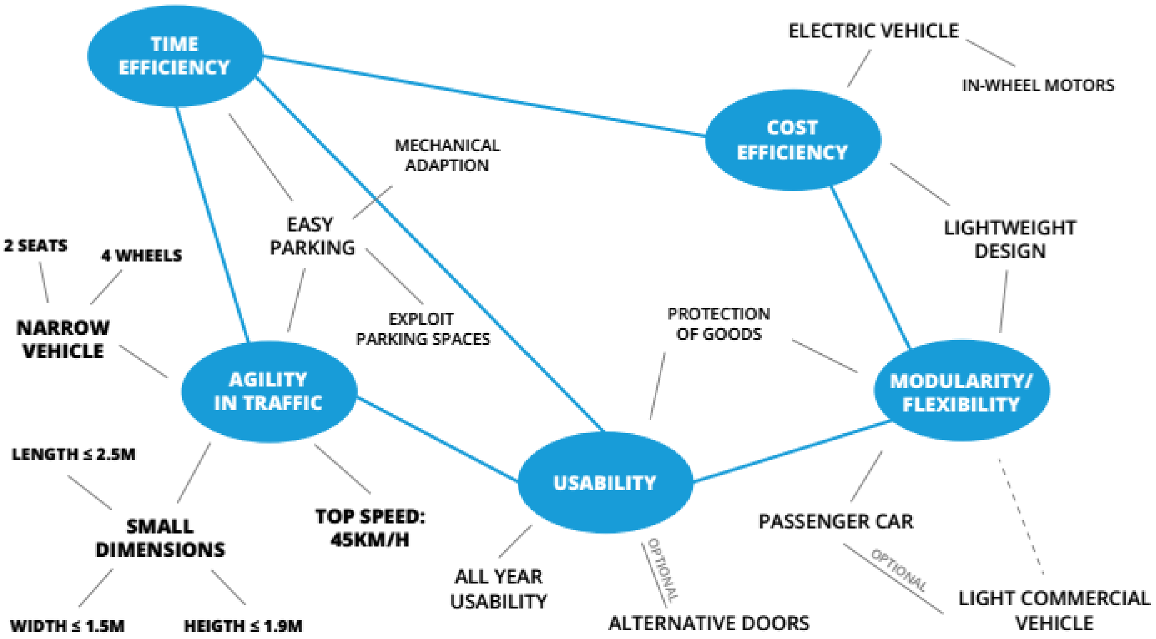
THE TIME TABLE

- **Applications Phase**
  November 30, 2015 – February 14, 2016
- **Notification of Winners**
  February 29, 2016
- **Redesign Phase**
  February 29 – March 30, 2016
- **Official Announcement Winners**
  April 18, 2016

JURY MEMBERS

- Damien Basset
- Lutz Eckstein
- Thomas Fournier
- Lutz Fügener
- Rüdiger Heim
- Daniel Huber
- Werner Rom

THE REQUIREMENTS



Hard facts

- Dimensions:
  - Length: ≤ 2.5 m
  - Width: ≤ 1.5 m
  - Height: ≤ 1.9 m
- 4 Wheels
- 2 Seats

Soft facts

Make up your mind and design a fresh and unconventional ultra-light vehicle concept for two passengers. The small but modular electric vehicle for future mega-cities shall use in-wheel motors and be designed for a top speed of 45 kilometres per hour. Your concept covers the needs of individual transportation on the first hand, but also could meet the requirements for business solutions. Keep in mind that car sharing gets more important and could be a future use case.

Our findings show that users have a strong need for safe, usable L-category vehicles which are easy to park and allow a convenient transport of the typical everyday goods. Regardless of the vehicle's top speed, safety always takes a high priority and the protection of the passengers should not be neglected. Your body design offers all weather usability and an optional alternative door or entrance concept allows accessibility by at least one and a maximum of three sides. Providing comfort mobility, easy parking and storage space will also serve the customers' needs.

THE JUDGING PROCESS

The jury members were selected and nominated carefully in respective to their previous work and their expertise in the EU-LIVE project. For the design contest we choose 4 designers, 3 from the EU-LIVE consortium (Peugeot Scooter, PSA Peugeot Citroën and Spirit Design) and 1 external expert from the Pforzheim University. To cover the technical perspective 3 engineers from the EU-LIVE consortium have been selected (Forschungsgesellschaft Kraftfahrwesen mbH Aachen, Fraunhofer Institute for Structural Durability and Virtual Vehicle). All members of the jury are listed below.

How will the jury rate my design?

- Fulfilment of the requirements 35 %
- Originality of the design 35 %
- Quality of the design 15 %
- Opportunity for series production readiness 15%

ANY QUESTIONS?

Please contact the Design Contest Team via email:
designcontest@eu-live.eu

A.5 Conditions of participants

Conditions of Participants

RESPONSIBILITIES OF THE CONTENDERS:

1. It is understood and agreed that each and every contender agreed to the following rules and procedures of the EU-LIVE design contest before submitting his/her designs.
2. The EU-LIVE Design Contest is open to participants of all countries. Participants must be 18 years old and at least the age of majority in their home country at the day of the first submission.

   “EU-LIVE” hereinafter refers to the EU project “Efficient Urban Light Vehicles (EU-LIVE)“ under Grant Agreement No. 653203 as well as – where applicable – any or all of its project members.
3. The submitted designs must be the idea and the intellectual property of the submitting contender(s) and must not infringe industrial and/or intellectual property rights or copyrights or any rights of any third person. If claims are asserted against EU-LIVE due to the violation of industrial and/or intellectual property rights or copyrights or any rights or if such claims are expected by EU-LIVE, EU-LIVE informs the contender(s) of this without delay and in writing as soon as it gains knowledge of it. The contender(s) shall, upon first demand, indemnify EU-LIVE and hold EU-LIVE harmless from and against any and all liability or claims of third parties based on the infringement of industrial and/or intellectual property rights or copyrights or any rights of third parties by designs submitted by the contender(s).

   The above indemnification shall not apply if the claim is based on EU-LIVE’s intentional breach of duties.
4. The contender(s) must not use registered trademarks and logos in their work without written permission of the trademark holder. This also includes logos, brand marks, and the like of EU-LIVE and his partners. If EU-LIVE and his partners request the contender(s) to use brand logos or any other such at a later date, the contender(s) will explicitly be asked to.
5. The intellectual property remains with the contender(s); however, the participant(s) allow EU-LIVE and its members the use, publication and re-utilisation of his/their designs for marketing, publishing, development and other unspecified uses without further notification. The contender(s) further agree to be named and their designs to be displayed on the EULIVE website as well as in official documents linked to EU-LIVE and EU-LIVE members’ projects without compensation. Marketing, publication, development, etc. includes advertising, scientific papers, dissertations and further undisclosed uses. However the contender(s) has to be named as the owner and creator of the intellectual property at any time.
6. The contender(s) hereby grant to EU-LIVE for all known and unknown types of use the exclusive transferable right to use, to copy, to revise and to exploit (including the right to sublicense) the submitted design without limitation in time, manner or place subject to these terms and conditions. Covered by the grant of rights are particularly but not exclusively the following rights: the right to full and partial duplication, distribution and publishing, the right to edit and other transformation of the designs and evaluation of these arrangements for all types of use permitted under these rules, the right to full and partial make available to the public, the lecture and demonstration rights by third parties (e.g. presentations at conferences), the right of communication to the public, in particular through the use of video, audio and data carriers (e.g. presentation of 3D designs in videos), the archiving rights, the advertising or merchandising rights, the right to title use and title change, the printing rights.
7. By participating in the design contest, no entitlement for compensation arises.
8. The submitted designs must not have been previously submitted to other competitions or be linked to other competitions in any other way.

9. The submitted designs may only be further published by the contender(s) after April 18, 2016. This applies regardless of the participation in the redesign phase or the elimination after the application phase.
10. The contender(s) shall submit one pdf with sketches. If the contender(s) would like to update his work, he shall simply submit his work again via the EU-LIVE website. If EU-LIVE receive several designs, they will consider only the latest submission.
11. EU-LIVE will only consider completely filled registration forms. This includes all personal data that is not marked as optional, a short description of the submitted work and a pdf with a minimum of two and a maximum of five sketches and a file size of no more than 10 mb.
12. To contact the contender(s) at a later date, EU-LIVE stores the first and last name and email address of each contender permanently. Each participant may at any time request the deletion of data by email.
13. Selected entries to the design contest will be presented on the EU-LIVE website. The contender's forename and surname will be published along his sketches. By participating in the design contest, the contender(s) do not gain the right to claim for publication.

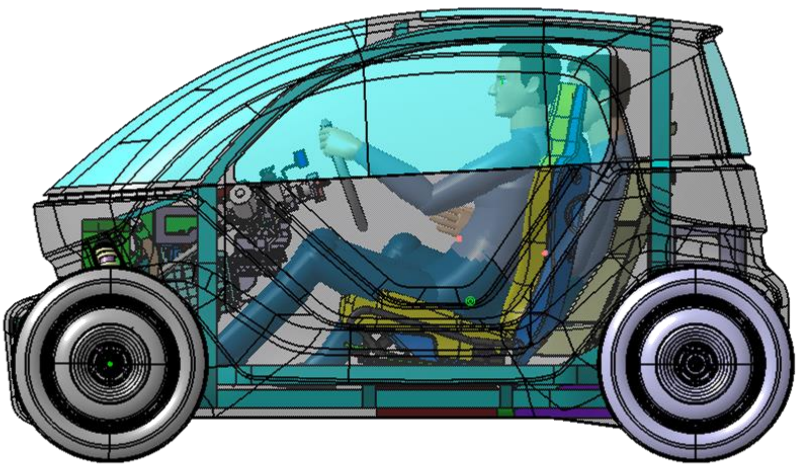
LIABILITIES:

1. EU-LIVE, its jury and its members reserve themselves the right to reject any designs at any time without giving reasons. Their decisions are binding and final. EU-LIVE, its members and its jury are not liable for any errors of EU-LIVE members or the EU-LIVE jury.
2. EU-LIVE and its partners are not responsible for loss, delay, misdirection or any other such events that may occur to or during the submission of you work.

CLOSING CONDITIONS:

1. The laws of Belgium shall apply (excluding its conflict of law rules and the Convention on Contracts for the International Sale of Goods). The courts of Brussels, Belgium shall have exclusive jurisdictions over all disputes arising from and in connection with the EU-LIVE Design Contest.
2. Should any of these provisions become invalid, illegal or unenforceable, it shall not affect the validity of the remaining provisions. In such a case, a valid and practicable provision shall apply which comes as close as possible to the intended purpose of the original provision. The same applies if these terms prove to be incomplete.

A.6 Vehicle datasheet



Vehicle Type		Technical Specification	
Segment	L6e, light quadicycle	Target Weight (Curb)	425 kg +75 kg + Battery
Seats	2 (M95th)	Target Weight (Design)	425 kg + 185 kg + Battery
Exterior dimensions		Battery Capacity	5.3 kWh
Length	2500 mm	C-S-Area	1.64 m^2
Width	1500 mm	Max. Velocity	45 km/h
Height	1430 mm	Electric Motor cont. Power	2*3 kW (legislative limited)
Wheelbase	1850 mm		
Front Track	1345 mm	Driven Wheels	Rear
Rear Track	1345 mm	Front Axle	Double Wishbone
Interior dimensions		Rear Axlte	Double Wishbone
Headroom Driver	1000 mm	Front Tires	125 R16
Headroom Co-Driver	980 mm	Rear Tires	125 R16
Shoulder Room Fr.	> 975 mm	Turning Circle	< 8m
Shoulder Room Rr.	> 975 mm		

B. ABBREVIATIONS AND DEFINITIONS

Term	Definition
B2B	Business-to-Business
B2C	Business-to-Consumer
BEV	Battery Electric Vehicle
CAD	Computer-aided design
CFD	Computational Fluid Dynamics
DCDC	Direct current to direct current converter
DLR	German Aerospace Center
DOW	Description of Work
GA	Grand Agreement
IWM	In-Wheel Motor
L6e	A light quadicycle with four wheel, a permissible top speed of 45 kph, two seats and a kerb weight of 425 kg excluding the battery
MBS	Multi-body systems simulation
OEM	Original Equipment Manufacturer
PDU	Power Distribution Unit
PHEV	Plug-In Hybrid Electric Vehicle
PSA	Peugeot Société Anonyme
PTC	Positive Temperature Coefficient
SgRP	Seating Reference Point
TBD	To be dated
USP	Unique Selling Proposition