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Construction, Realization and Validation of a Low-Cost Driving-Simulator and a Renault ZOE Data Interface

Konstruktion, Realisierung und Validierung eines Low-
Cost Fahrsimulators und eines Renault ZOE Daten-
Interface

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Abstract

The objective of this bachelor thesis is the adaptation of a low-budget driving simulator, to a recently developed driving simulator software BeamNG.research. This simulator is made as a close resemblance to the battery electric vehicle Renault ZOE. The thesis primarily focuses on all hardware aspects of the simulator. A market analysis compares already used and common solutions and hardware as base for the development of a concept.

Based on a requirement and feature analysis, a simulator with primarily computer gaming hardware is build and reconfigured from typical race car ergonomics to a more fitting compact car appeal. This requires the construction of several steel adaptor frames during the realization. A four-display setup is also realized, with three 55" UHD TVs (180 degree FOV) and a fourth 10" HD display as designated driver display. In parallel, a data interface for tapping into the ZOEs CAN-Busses is selected. And a new concept, the CanSee of the CanZE community is recreated and adapted. The first iteration of the simulator setup as well as a prove of concept for the CanSee is evaluated and tested. Several improvements follow the evaluation concluding the realization.

Both, the simulator setup and the data interface, showed promising results. The simulator could be used effectively during more than 60 hours of use in survey and provided all desired data. The CanSee data interface proved to more than a tool for validifying the simulator, but also as base for future development of energy interfaces.

Keywords

Electro Mobility – Driver-Vehicle Interaction – Battery Electric Vehicle – Renault ZOE – Driving Simulator – User-Energy Interaction – CAN-Bus Data Interface – OBD Logger

Kurzfassung

Ziel dieser Bachelorarbeit ist die Konzeption und Konstruktion eines Low-Budget Fahrsimulators für die erst kürzlich entwickelte Fahrsimulator Software BeamNG.research. Der Simulator soll in Referenz zu dem Elektro Auto Renault ZOE entwickelt werden. Die Arbeit fokussiert sich hauptsächlich auf die Hardware Aspekte des Simulators. Eine Marktanalyse fasst zuerst übliche Lösungen und Hardware zusammen, um dann später die Konzeption zu konkretisieren.

Ein Fahrsimulator aus Gaming Computer Hardware wird entworfen und modifiziert, sodass aus der ursprünglichen Rennauto-Ergonomie eine Kleinwagen-Ergonomie mit entsprechenden Abmessungen entsteht, ganz nach dem ZOE als Vorbild. Das erfordert die Konstruktion mehrerer, stählerner Adapterrahmen im Laufe der Realisierung. Um ein 180° FOV zu erreichen, werden drei 55" Fernseher als Display konfiguriert, mit einem vierten 10" Display als Driver Display zur gesonderten Instrumentendarstellung. Parallel dazu werden die Möglichkeiten der Datenerfassung im ZOE erschlossen. Die Entscheidung fällt auf ein gänzlich neues System, dem CanSee, ein Projekt der CanZE Community, welcher die beiden CAN-Busse des ZOE in der höchst möglichen Datenrate ausliest (d.h. mit der vollen Datenrate der CAN-Busse). Die erste Iteration des Fahrsimulators wird einer Evaluation unterzogen und die darin entdeckten, unzureichenden Features werden in einer zweiten Iteration als Verbesserungen realisiert. Der CanSee wird in einer Prove-of-Concept Version gebaut, wird erfolgreich getestet und erhält danach die nötigen Verbesserungen für einen dauerhaften Betrieb. Beide stellen sich als vielversprechend heraus; der Fahrsimulator lieferte solide Ergebnisse während der insgesamt mehr als 60 Stunden andauernden Evaluationsphase. Das CanSee Daten Interface stellte sich nicht nur als Werkzeug zur Validierung des Fahrsimulators heraus, sondern auch als Plattform zukünftiger Entwicklungen im Bereich der Energie-Anzeigen.

Schlüsselwörter

Elektromobilität – Fahrer-Fahrzeug-Interaktion – Elektro Auto – Renault ZOE – Fahrsimulator – Nutzer-Energie-Interaktion – CAN-Bus Daten Schnittstelle – OBD Logger

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1 Introduction

The successful and effective use of battery electric vehicles (BEV) is not only limited by their theoretical range in terms of electrical charge, but also depends on drivers' daily behavior. With their limited range, an advanced comprehension of energy consumption and an energy-efficient driving style is very important for the drivers (Franke, Neumann, Bühler, Cocron, & Krems, 2012). Persons, who are skilled in energy-efficient driving, seem to acquire their technical and strategic knowledge not only without system interaction (e.g. consulting experts), but also with system interaction through monitoring of energy interfaces and active testing of specific strategies (Franke, Arend, McIlroy, & Stanton, 2017).

This fact makes the development and testing of various new energy interfaces a priority task to further improve to usability of BEVs in increasing the driven range. This can be achieved by reducing the gap between the possible Technical Range (calculated by a BEV's on-board computer) and the subjective psychological range (Competent Range) a driver inhabits (Herrman, 2018). This can be visualized in following figure:

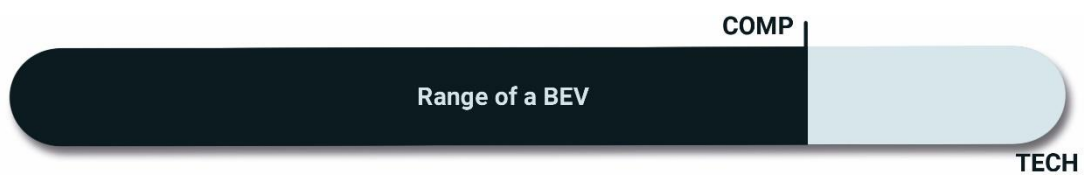


Figure 1: Range Limits of the Psychological Range: Technical Range (TECH) and Competent Range (COMP)¹

To ensure success and validity of developed energy interfaces in future projects, repetitive, cheap and save testing is necessary. Using a driving simulator is the first choice over driving in a real car. Driving simulators of all sizes, shapes and prizes are already available and in use. They conveniently reduce the risks for the participants, hence crashing the car or other accidents in the simulation will not hurt the driver in any physical way. The overhead time during an experiment can be reduced significantly, because no car must be driven to a designated test track including several participants for testing and survey, a simulator just needs to be set up once for a specific survey. Furthermore, legal issues can

¹ Based on (Franke, Neumann, Bühler, Cocron, & Krems, 2012) and (Herrman, 2018)

be put aside, for example a prototype of a driver interface isn't required to pass traffic and vehicle regulations in the driving simulator.

This results in a project deeply embedded in the Mixed Reality Context (Milgram, H., Utsumi, & Kishino, 1994) with aspects both in cognitive and physical ergonomics to be considered and evaluated.

2 Objectives

The objective is to build a driving simulator, which can be used by other projects to test energy interface prototypes. These interfaces will be used later in a Renault ZOE, a battery powered compact car. This makes the ZOE to a direct reference the simulator must stand up to, especially in physical measurements. For a quick amortization the construction costs must be low. A cheaper, but equally suited driving simulator, than the cheapest all-inclusive version on the market results in a great cost-value ratio and is therefore a main goal of this thesis. A high flexibility to simulate a wider range of different cars is attractive but would result in more compromises and more expensive construction costs. The close specialization on the ZOE makes it easier to construct and reduces costs while still achieving a high validity.

This project is closely connected to a previous bachelor thesis, which set the software basics in developing BeamNG.research, which not just simulates a virtual world and car, but also logs data like speed and energy consumption (Stieglitz, 2018). So, the result shouldn't just represent a close similarity to the ZOE's interior and ergonomics but also must run BeamNG.research.

After this simulator is in a testable condition, a solution is needed to compare not just the physical ergonomics and measurements between simulator and real car but also the generated data, like consumption, steering inputs or distance driven. To finally measure the validity of this simulator, a real-world scenario (test track, car and survey mission) needs to be reconstructed in the virtual simulator world. Both, real and virtual scenarios will be held and said data must be collected and compared afterwards. BeamNG.research already logs all viable values, but for the Renault ZOE a data interface must be constructed and integrated to collect the very same data as the simulation does.

3 Market Analysis

Next, we analyze the market regarding existing solutions. These solutions will be presented in terms of their basic working principals. Several bases will be listed and compared, making a differentiation between low-cost and high-cost models.

3.1 Simulator

The already developed simulation software BeamNG.research is a given (Stieglitz, 2018). A Windows based computer must be the core of the simulator (to run BeamNG.research). So, all peripheral hardware must be compatible with Windows, for e.g. the steering wheel needs to be connected and a Windows driver must be available.

3.1.1 Bases on the Market

The available simulator bases or platforms can be divided into complete sets, made for professional use like a driving school, and computer gaming platforms which are configured by the user. The gaming platforms are delivered in modules, e.g. a steering wheel made by a certain manufacturer and a seat platform made by a different company. On contrary, the professional platforms are rather built to suit a specific niche than for general gaming use.

Low-Cost / High-Cost

High-Cost bases are usually very limited in adaption, being delivered as a whole package even with a fix simulation software. These expensive platforms tend to have fewer teething problems and promise quick results. This comes with the negative costs of being tied to the specific company and its customer service for each change that needs to be done (Trautmann, 2019).

Low-Cost bases are almost all the time platforms built for computer gaming. Therefore, being dedicated to a wide range of customers. The products are rather kits than complete solutions, oftentimes compatible hardware is documented but must be obtained separately and from yet another manufacturer. The quality of the constructing ranges as well as the

prizes do. Though at the costs of more research and well-considered, time consuming picking of the platform modules, the built can be better suited for the task than a high-cost all in one solution. Some of the expensive solutions are even made from the cheaper gaming modules (see 3.1.2 Models / Comparison).

3.1.2 Models / Comparison

Four models were taken into comparison. All four fit into the given budget for this project. The Vogel simulator as a high-cost solution, the Fanatec RennSport Cockpit V2 (also used by Vogel), the RSeat RS1, a very robust and highly recommended platform in the gaming community and at last the FK Automotive Silverstone racing platform, a very cheap solution. All of those use the Fanatec force feedback steering wheel and pedals (4.1.2 Solution Concept), the Vogel by construction, with the others it was chosen for this project by recommendation by survey partners, the Universität Ulm and the Max-Planck-Gesellschaft Tübingen. Table 1 sets the candidates in close comparison by their key features in contrast to their prize.

Manufacturer	Vogel	Fanatec	RSeat	RK Automotive
Product name	Vogel Simulator ²	RennSport Cockpit V2 ³	RS1 ⁴	Silverstone racing ⁵
In separate modules configurable	No	Yes	Yes	Yes
Low profile	No	No	Yes	Yes
Seat included	Yes	No	No	Yes
Adjustability (Seat pedal distance /height, ...)	Middle	Middle	High	Low
Free use of software	No	Yes	Yes	Yes
Prize	25,000€⁶ (Estimation)	1000€	500€	170€

Table 1: Market Analysis Simulator Platform Comparison

3.2 Data Interface

The CAN-Bus or Controller Area Network is bus standard used and designed for the automotive branch. It is in use since the late 1980 and was invented by the Robert Bosch GmbH. In principle, it is a network allowing the equal communication between many controllers on a decentral base. The communication is done in packages, so called frames, with a 12bit unique header identification, the PID, followed by 8 bytes of data. For complex information, being too big for 8 bytes, an ISO-TP CAN frame is used where the data is partitioned onto several CAN frames. The ISO-TP CAN frame uses a different header and can only be read, when all sub frames have been received.

The market for serial data interfaces tapping in a car's bus system is wide and filled with reasonably up to date models. It ranges from sophisticated embedded modules which

²<https://www.springerfachmedien-muenchen.de/vogel-simulator-1795140.html>

³<https://www.fanatec.com/eu-en/racing-cockpits-simulators/rennsport-cockpit-v2-eu.html>

⁴<https://www.rseat-europe.com/RSeat-RS1-Simracing-Cockpit/Frame-Only-Black-cockpit-simulator>

⁵<https://www.fk-shop.de/en/Tuning/Sport-seats-belts/Racing-simulator-seats/FK-game-seat-Silverstone-racing-simulator-for-racing-games-black-green.html>

⁶ Displays, Soundsystem and computer already included

connect directly to several CAN busses, installed “under the hood” not visible for the driver semi-permanent installed. On the other side of the range are so called “OBD dongles” working plug and play with just a small ASIC chip connecting to the driver’s smartphone. Within the scope of this documentation, the notation “logger” will be equally treated as the denomination data interface.

3.2.1 Approaches

The first and biggest differentiation of all the solutions to make is the way they are connected to the car’s CAN bus. Professional interfaces are usually directly connected to the bus, therefore paneling of the car must be removed as well as splicing the car’s wiring harness by a technician. Those devices are made for applications like fleet management, so almost always a GSM module and sometimes an onboard GPS is provided. This results in way higher prices than the smaller consumer grade products. These use the OBD II port to plug in the CAN bus of the car, relaying the data via a Wi-Fi or a Bluetooth module for further processing for e.g. to a smartphone app.

3.2.2 Comparison of buyable Logger Solutions

The comparison of the different models by their key features can be best done by using the following Table 2Table 1. Additionally, a comparison of all accumulated costs of installing each logger solution is given in Table 3.

ELM based dongles weren’t included, the reasons for this decision can be found in 4.2.1 Hardware.

Manufacturer	M2M	Axotec	Freematics	UzL - ISP eRoller Projekt	IO Dynamics	CanZE
Logger Model	M2M Control C650 Starter ⁷	IGX 560 ⁸	ONE+ Model B ⁹	Odroid U3 + Arduino Uno + GSM-Module	IO Dynamics Logger	CanSee ¹⁰
Installation Materials	Mounting, Cables	Mounting, Cables	--	--	--	--
GPS Antenna	u-blox ANN-MB	u-blox ANN-MB	(Built in)	u-blox ANN-MB	(Built in)	(None)
SIM-Card	e.g. Telekom					(None)
Installation	Technician (25hrs)	Technician (25hrs)	Team Member (20hrs)	Team Member (20hrs)	Team Member (20hrs)	Team Member (20hrs)
CAN to USB Adaptor	PCAN-USB-Adaptor ¹¹	(Built in)	(Built in)	(Built in)	(Built in)	(Built in)

Table 2: Market Analysis and Features of Data Interfaces

⁷ https://www.m2mcontrol.de/de/produkte/M2M_Control_C650_Starter

⁸ <https://www.axotec.de/produkte/industrial-rpi-compatible-embedded-computer/industrial-rpi-compatible-lte-computer-igx-560-can.html>

⁹ <https://freematics.com/products/freematics-one-plus-model-b/>

¹⁰ <https://gitlab.com/jeroenmeijer/cansee/wikis/Hardware> (CanSee is just a building construction, not a product)

¹¹ <https://www.peak-system.com/PCAN-USB.199.0.html>

Manufacturer	M2M	Axotec	Freematics	UzL - ISP eRoller Projekt	IO Dynamics	CanZE
Logger Model	545€	500€ (Estimation)	138€	120€	150€ (Estimation)	40€
Installation Materials	80€	120€	--	--	--	--
GPS Antenna	30€	30€	--	30€	--	--
SIM-Card¹²	540€	540€	540€	540€	540€	--
Installation	625€	625€	200€	200€	200€	200€
CAN to USB Adaptor	180€	--	--	--	--	--
Sum	2000€	1815€	878€	890€	890€	240€

Table 3: Market Analysis Prizes Data Interfaces

¹² E.g. Telekom (2 GB Data for 3 yrs)

4 Requirements and Concept

This chapter will set the requirements of each part, the driving simulator and the data interface. The requirements will be derived from the results found in the market analysis and the objectives.

4.1 Simulator

The basic idea in the construction of this specific driving simulator lies on the principals of easy and cheap acquirement, using mostly entertainment hardware like TVs, Gaming Desktop computers and Gaming simulator platforms (see 2 Objectives).

4.1.1 Hardware

Displays

For a high immersion a 180 degree field of view (FOV) is necessary, so three displays with a reasonable size are required (Milgram, H., Utsumi, & Kishino, 1994). The distance between the windscreen of the Renault ZOE and the driver's eyes (seat in neutral position) can be measured with 106 cm. Assuming the display has the popular 55" diagonal, which resolves in 123 cm width, an angle of 60 degrees between each side-display to the center display creates a 180 degree FOV, see Figure 2.

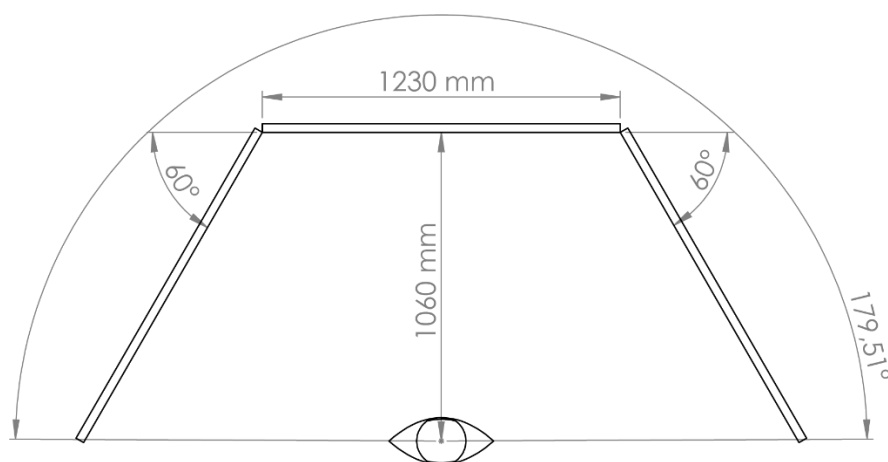


Figure 2: Concept FOV Driving Simulator

The framerate in BeamNG.research equals the log-rate, therefore a minimum set Hertz count is required (Stieglitz, 2018). For future applications and best graphic detail representation, a high resolution is needed. Two displays will be arranged angled to one center display touching each other on the angles. On that account the vertical housing of the LCD must be as slim as possible to keep the bezel at the lowest possible amount. The TVs must be mounted on a dedicated display stand, this implies the availability of a suiting Vesa wall mount on the backside.

The display requirements can be summarized as seen in Table 4.

Desktop Computer

BeamNG lists the following computer specifications for a resolution of 1920 x 1081 pixels as recommended. The connectivity and housing were added to the Table with the three-display setup and a nondestructive test environment in mind (see Table 5Table 3: Computer Requirements).

Platform Base

A sufficient platform, for mounting the pedal base, the force feedback steering wheel and the seat is needed. Furthermore, allowing for high adjustability of the said components to adapt to the measurements of the reference car, the ZOE. Last but not least, a mounting for the sound system is required.

The desired features are listed in Table 6Table 4: Platform Base RS1 Requirements and Features.

Force Feedback Wheelbase and Pedals

Steering a car in a simulator needs naturally a steering wheel as well as a set of pedals. Force feedback for the steering wheel is an elementary feature, because that feedback drivers are used in real cars must be copied, for e.g. if the front wheels are at an angle, they always try to return to their neutral position, which can be felt also in the steering wheel. The only active force feedback of a real car's pedals are low frequency vibrations and the ABS during its active state (strong brake pedal vibration). Most of the vibrations can be neglected, because as a BEV the ZOE has little to no motor vibrations, also tests showed, that there is no vibration during active ABS cycles. Therefore, a pedal force feedback is only an optional feature. The shifter is also just an optional feature because the simulated ZOE does

not have any gear modes beside D for forward driving and R for backwards as well as P for parking brakes. Until then, only surveys, which do require said gear modes can't be conducted. This means the simulated car will be always in D mode, so a shifter isn't needed.

Needed features are listed in Table 7Table 5: Wheelbase and Pedal Requirements and Features.

4.1.2 Solution Concept

Displays

Within the project there were already UHD flat screens of the brand Samsung successfully in use (parallel to this thesis two additional teams are developing features for driving simulator), which made the brand Samsung the first choice for the new three monitors. The model UE55NU8000T fulfilled all requirements but one, it has no DisplayPort jacks.

Important specifications of the Samsung UE55NU8000T:

Type	Requirement	Samsung UE55NU8000T
Resolution	4k / UHD / 3840 × 2160 pixels	3840 x 2160 pixels
Hertz	+ 40 Hertz	60 Hz LCD Panel
Size	55" diagonally	55" diagonally
Connectivity	HDMI 2.0 or higher, ideal DisplayPort	HDMI
Mounting	Vesa Wall Mount	Vesa Wall Mount
Housing	Vertical frame not thicker than 10mm	Vertical frame 6mm
Prize	<5000€	2400€ (3 x 800€)

Table 4: Display Requirements and Features

Computer

Following the requirements, the setup (listed in Table 5) was ordered. Although BeamNG gave only hardware requirements for only 1920 x 1080 pixels, even stronger hardware and

more reserves were chosen, resulting in a stronger setup. This was done, because the three displays will create a total resolution of three times UHD (11520 x 2160 pixels).

Important computer specifications:

Type	Requirement	Computer Specification
OS	Windows 7 Service Pack 1, Windows 8.1, Windows 10 (64-bit)	Windows 10 (64bit)
CPU	High-end Intel i5/i7 or equivalent AMD	Intel Core i7-8700K
RAM	8GB DDR3	32GB DDR4
GPU	Nvidia GTX 780 or equivalent	Nvidia GTX 1080 TI
DirectX	Version 11	Version 11 and 12
Connectivity	4x HDMI 2.0 or higher, ideal DisplayPort	1x HDMI. 3x DisplayPort
Housing	Plain, matte black	Plain, matte black

Table 5: Computer Requirements and Features

Platform Base

The RSeat RS1 uses the smallest frame but offers still a very high degree of modularity. Especially the front of the frame is low enough to not interfere with the displays, making it the most versatile base in terms of placement between the displays. Also, the research within the realm of PC simulator gaming emphasized the quality of the RS1 over the competition. This platform was ordered without a seat, because RSEAT always imitates seats of sports- and racecars, being also very pricy. An actual Renault ZOE should be imitated, therefore the high prize for a too deep seat pan of the RSEAT solutions wasn't acceptable. A different solution was found in buying the RK Automotive Silverstone simulator platform as well, including a plain and simple seat and still being cheaper combined as one RSEAT seat. This leaves the possibility of using the parts of the FK Automotive platform as spares or for augmentation of the RS1. However, an adapting frame needs to be constructed to fit the incompatible seat to the RS1 frame and rising the seating height. Specific features can be compared in Table 6.

Type	Requirement	RSeat RS1
Seating Position	Compactcar	Racecar
Seat Sliders	Yes	Yes
Gear Shifter Mount	Optional	Yes
Pedal Support	Yes	Yes, adjustable in 2 axes
Wheel Support	Yes, Gaming Standard Mount	Yes, height and angle adjustment
Buttkicker Mount	Optional	Yes
Seat included	No	No
Speaker Mount	Optional	Yes, for 5 speakers
Prize	<5000€	470€

Table 6: Platform Base RS1 Requirements and Features

All desired features, but one, are fulfilled, the seating position is very low, and the pedal base is rather high, this equals the typical seating condition in a racecar. Nevertheless, this can be solved by constructing several modifications.

Force Feedback Wheelbase and Pedals

Type	Requirement	Fanatec ClubSport: Wheel Base V2.5, Pedal V3 inverted and Steering Wheel Universal Hub ¹³
Available as Set	Preferable	No, all 3 separately bought
Force Feedback	Wheel Yes, Pedals Optional	Yes, both
Mounting	Gaming Standard Mount	Gaming Standard Mount
Connectivity	USB	USB
Prize	<5000€	1500€

Table 7: Wheelbase and Pedal Requirements and Features

¹³ <https://www.fanatec.com/eu-en/wheel-bases/clubsport-wheel-base-v2-5.html>
<https://www.fanatec.com/eu-en/pedals/clubsport-pedals-v3-inverted-eu.html>
<https://www.fanatec.com/eu-en/steering-wheels/clubsport-steering-wheel-universal-hub-for-xbox-one-eu.html>

4.2 Data Interface

All the devices brought up by the market analysis featured a relatively high price, with no guaranty of open code or hardware for this project to modify and adapt to the needs. With the exception; a small community, formed around the mobile app CanZE, published very good results with a self-made low-cost architecture (named CanSee) alongside with a rough sketch and completely open source code.

4.2.1 Hardware

The ZOE has three CAN-Busses, the Multi Media CAN-Bus, the Main CAN-Bus and the Power Train CAN-Bus. Each one inhabits a different Baud rate, as well as a different package size. For example the Power Train CAN-Bus has the highest Baud rate, connecting the most important modules, but with less individual packages and smaller package sizes, in comparison the Multi Media CAN-Bus has the lowest BAUD rate, sending a wide variety of packages with a bigger load to modules like the radio tuner or the dashboard display. In the ZOE the Power Train CAN-Bus is connected to the Main CAN-Bus via the Electric Vehicle Computer (EVC), therefore it's data can be also obtained over the Main CAN-Bus only. Those two CAN-Busses are connected to the On Board Diagnosis II (OBD-II) Hub, which has the main function of forwarding their packages through to a connector located in the interior of the car. In the case of the ZOE this connector can be found under the dashboard display, the place which was known in earlier days as the ashtray.

To process the data generated by the car and being available through the OBD-II connector specific packages must be sent to a smartphone or tablet, this will analyze and interpret the incoming data and visualize it for the driver. The smartphone or tablet must be connected wireless. So, in concept the task of a data interface is to receive CAN frames from to different CAN-Busses via the OBD-II port, buffer it and relay it either with Bluetooth or Wi-Fi as shown in Figure 18: Schematic Data Interface CanSee.

Prior to this project there had been several studies in the IMIS using cheap ELM based OBD dongles. These are commonly available on the market, most of them are even cheaper Asian copies. Their basic function is forward successively a single CAN package to the built in Bluetooth module and sending it typically to a smartphone. It turned out, that these devices have a high latency, around one second. They are limited to transmit packages only every

second. This slow data rate proved in the past project as a big hindrance, therefore all ELM bases dongles were singled out.

4.2.2 Features

The features were derived from the market analysis and the experiences with similar hardware in the development team. First of all, the new architecture couldn't be another black box, making changes and improvements impossible, which means the new solution must be freely programmable with open source code. Furthermore, the hardware should be modular to a certain degree, it must be possible to add a GPS in the future. A module capable of both Bluetooth and Wi-Fi is needed, as well as a serial USB interface for development and debugging.

4.2.3 Concept

The results published by the CanZE developers looked very promising, especially the logging speed. With the provided open source firmware the first results should be visible by just plugging in the data interface and connecting it to an Android device with the CanZE app installed. Also, the core controller, an Espressif ESP32 is known for a wide variety of additional modules like card reader and GPS modules on the market. So, the decision was made, to rebuild a CanSee data interface and start testing. If it proves insufficient the risk, due to extremely low prize, was minimal, leaving still the option to fall back to a commercial solution, having additional experience collected.

5 Realization

In the realization phase the construction of the whole driving simulator and all alterations are documented, the concepts from the chapter before and improvements, which surfaced after the evaluation, are included.

Secondly the built of the data interface in his first “prove of concept” stage as well as in his final iteration is documented by drafts and photos.

5.1 Simulator

This chapter describes the assembly of the driving Simulator, including the configuration of the TVs, the graphics setting chosen in BeamNG.research and the construction of several augmentations for the frame, HIDs and display stands.



Figure 3: Side View Seat Platform 2nd Iteration

The fully modified platform with all HID's is shown in Figure 3 and Figure 4.



Figure 4: Isometric View Seat Platform 2nd Iteration

5.1.1 Display Integration

All three 55" displays possess only HDMI ports, the graphics card on the contrary has several DisplayPorts but only one HDMI port. To connect all the displays, two adaptors²⁰ were ordered. These adaptors (DisplayPort plug to HDMI jack) are active, converting the signal with an internal logic to the different protocol, hence passive adaptors support UHD only up to 30 FPS and not the required 60 FPS (Table 2: Display Requirements). The front display is connected directly to the HDMI port, the two side displays via the adaptors. This ensures that the latency is symmetrical, for e.g. the car is leaving a dark tunnel, driving into bright light settings, the center display uses no adaptor and therefore has the least latency, so the bright surrounding is first visible on the center display and milliseconds after on the side displays. This is perfectly fine, because in reality it's the same. If the left side display would have a shorter latency than the other, the picture would brighten up on the left first and retarded the right one would light up too. This isn't coherent to the real experience and could therefore disturb the immersion.

In the settings of the computers operating system (OS; Windows 10), all three monitors are set to their native resolution (3840 x 2160 pixels each, 11520 x 2160 pixels all together). Unfortunately, the computer isn't capable of running BeamNG.research at this resolution above the required 40 FPS. Therefore, an exception on the OS setting was made to run BeamNG.research at three times Full HD (4720 x 1080 pixels in total), which runs on acceptable 50-60 FPS.

5.1.2 Seat Base Construction

The RS1 frame came without any seat. The second simulator platform built by FK Automotive bought, came with the designated seat. FK Automotive and RSeat are not compatible, so an adaptor frame was constructed. This adaptor has to secure a sturdy connection between seat and platform, furthermore it needs to rise the seat a specific height above the platform's fake car flooring. The FK Automotive seat has its mounting beneath the seating surface, facing downwards. It consists out of four bolts threaded by M8.

²⁰https://www.amazon.de/Club-3D-DisplayPort-Aktiver-Adapter/dp/B017BQ8I54/ref=sr_1_5?ie=UTF8&qid=1538707525&sr=8-5&keywords=displayport%2Bhdmi%2Badapter%2B4k%2B60hz

Seats on the on the RS1 platform have these bolts sideways, therefore the provided seat mounts are useless in this specific case.

First Iteration

As base material naturally steel was chosen to ensure the necessary strength. To achieve the height, 80 x 40 mm rectangular tubing is mounted at the ends to the RS1 seat sliders by four M8 screws. On top two 10 x 40 mm solid steel bars were welded onto the rectangle tubing. These were drilled to four times for another set of M8 screws to connect the seat. Finishing touches were a sanding to smooth the edges and the welds as well as a matte black color coating.

Second Iteration

The first iteration proved to be too short (see 1.1 Results), but satisfied in every other aspect. So, two pieces of flat steel (50 x 5 mm) were cut to mount between the RS1 seat sliders and the adaptor frame from the first iteration. All bores were countersunk to ensure, that no screwhead interferes with the with the adaptor or the sliders. A CAD capture (Figure 5) shows the adaptor frame, without seat or base.

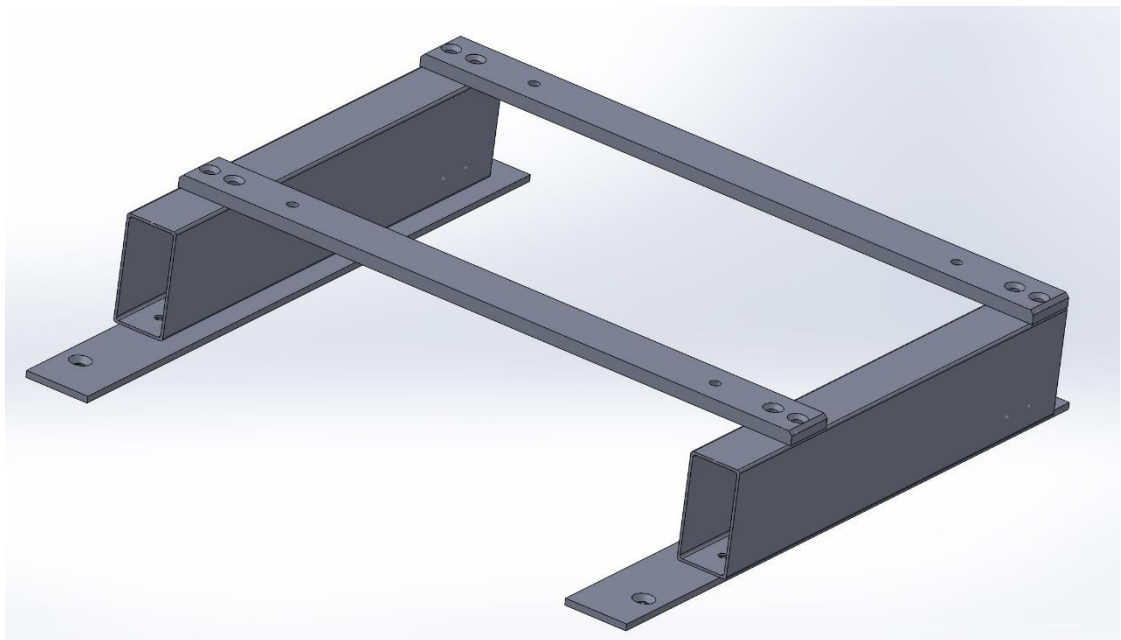


Figure 5: Seat Adaptor 2nd Iteration

5.1.3 Display Stand Improvement

The three TV displays are mounted on a display stand²¹. The stand is made from three similar modules, each one for mounting a single display. At both angles, the side modules are connected to the front/middle stand with a flat joint chain (like an oversized bicycle chain) (see Figure 6).



Figure 6: Display Stand Product Photo²²

Despite of the specification the manufacture provides, it wasn't possible to configure it to the planned angle (Figure 2Figure 1: Concept FOV Driving Simulator); the stand proved to be too small and instable. The following improvements were made:

Display Stand Legs

²¹ <https://www.playseatstore.de/tv-stand-pro-3s.html>

²² https://www.playseatstore.de/media/catalog/product/cache/29/image/114a0a6f9f719457f2705d708065bb8f/p/1/playseat_-tv-stand-pro-3s-1.jpg

Only the middle module inherited two legs, the side ones had each just one leg and relied on the stability of the chain. So, two additional legs were made for the empty leg slots in the side modules.



Figure 7: Two additional Display Stand Legs

Rectangular 60 x 30mm steel tubing was cut to the same length as the original legs. Bores were added on the top and threaded for M6 screws. Now the copied legs can be mounted in the same position with the same manner as the original ones. As feet, a pair of metal shelf brackets were mounted through their slot bores with screws and M6 threading in the leg. As follow up, the legs were finished with a black matte lacquer paint (see Figure 7).

Display Stand Chain

The original chain is too short to achieve a 60 degree angle between the modules, so the chain links were reconstructed in CAD and copied from 30 x 4mm flat steel, as seen in Figure 8.



Figure 8: Display Stand Chain Construction

The two required 8mm diameter bores were made and all nine pieces were rounded to achieve a similar look to the original ones. To separate the two chain rows 10mm aluminum tubing was cut into 50mm long pieces. The chain links got also a matte black lacquer coating and were mounted on the modules with 60mm M8 screws, shown in Figure 9.

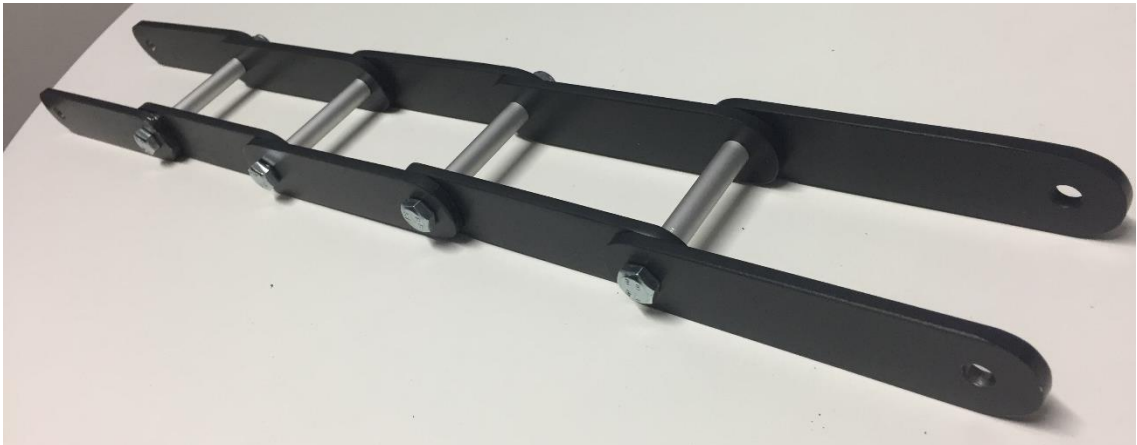


Figure 9: Display Stand duplicated Chain

5.1.4 Steering Wheel Integration

The ZOE uses a modified Renault Clio IV steering wheel, the only differentiation is a lower flat part, instead of a full circle (this is probably due to the inability of a height adjustment of the ZOE seat, hence the big battery compartment beneath the floor). A close comparison can be seen in Figure 10. Used ZOE steering wheels are quite rare and not often sold; therefore, a Clio IV wheel was bought instead.



Figure 10: Steering Wheel Comparison (ZOE left, Clio IV right)

The cover of the airbag in the center of the steering wheel can't be acquired without an armed airbag as customers can't identify if a replacement comes with or without the necessary airbag. An armed airbag can't be used as cover built into the driving simulator, because it's a safety hazard. So, a dummy was made out of Styrofoam and painted black afterwards.



Figure 11: Steering Wheel rear View

Firstly, the back panel was removed (Figure 11). The steering wheel bushing was cut away to achieve a flat surface to mount the wheel to the Fanatec universal hub. The latter provides enough mounting bores. When working on this steering wheel, an adequate cooling must be provided while cutting and grinding as it is manufactured out of an easily flammable aluminum/magnesium alloy. Four M4 bores were drilled and threaded for mounting on the hub (Figure 12).



Figure 12: Steering Wheel Threading

The steering wheel has four buttons to control the cruise control. These had to be connected to the hub for various uses, like starting events in the simulator. The Fanatec Universal Hub is essentially a refactored Xbox controller (Endor AG, 2019), therefore various buttons can be connected to the circuit board. These must pull down the signal wire to ground. Renault reduced the amount of wires by using determined resistors in row with the buttons on the steering wheel. Only two wires were exit the steering wheel, the buttons are coded by their resistor. To use the Renault buttons the resistors were removed with a soldering iron (see Figure 13) and new, individual wires were added.

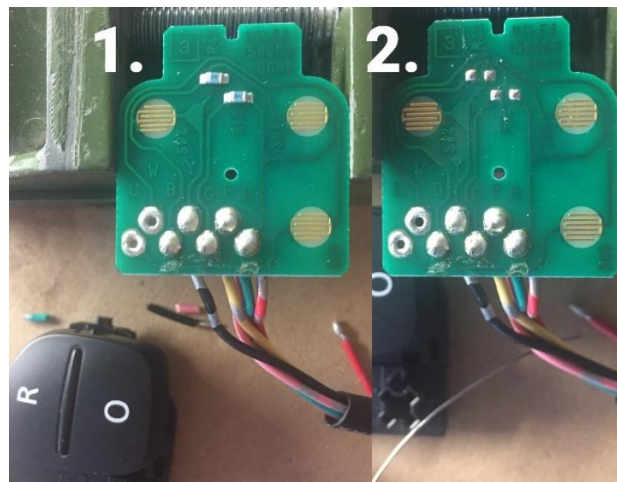


Figure 13: Steering Wheel Circuit Board right

To use the left circuit board properly, it needs to be bridged on two contacts as shown in Figure 14.

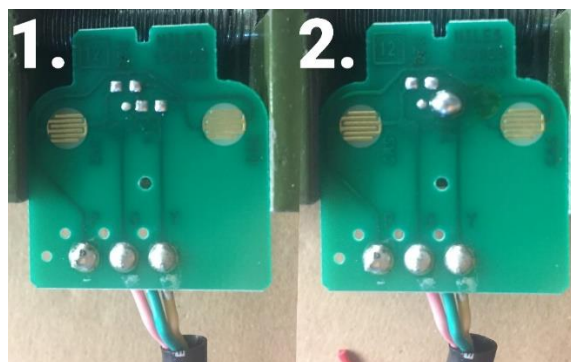


Figure 14: Steering Wheel Circuit Board left

The fully mounted steering wheel can be seen in Figure 16.

5.1.5 Driver Display Integration

The evaluation showed that the use of the 55" center display wouldn't provide a feasible representation of the car's driver display, including gauges. Therefore, a display reassembling the driver display of the ZOE (230 x 40 mm) was recreated at the same position in respect to the steering wheel, for the visualization of the speedometer, SoC, etc.

As display, a 10" IPS panel Full HD (1920 x 1080 pixels) with HDMI was chosen. It turned out, that the housing was too thick and too large to fit behind the steering wheel without obstructing the drivers view (see Figure 15). The display was disassembled and a smaller housing around the existing panel was constructed. By changing the position of the assembly screws, removing the speakers and constructing a separate housing for the LVDS converter board, the required reduction was possible. The original housing can be sized by 325 x 205 x 15mm, the new one measures 302 x 192 x 14mm.



Figure 15: Driver Display not modified

The frame was printed with the 3D printer and had to be printed in two parts hence the small measurements of the print bed. The backside is cut out of 8mm plywood to achieve a high resistance against torsion without adding to much thickness. The holes for mounting accessories in the front of the Fanatec wheel base were taken as measurement and transferred to the backplate. The separate LVDS converter board housing was mounted on the left upper corner on the backside of the backplate (see Figure 4) to make access for the power and HDMI plug still possible.

To mount the display, first the backplate must be screwed to the wheel base with M6 countersunk screws, then the front frame with the glued in IPS panel is screwed in with four M3 hex screws right beside the corners. Finally, the 40pin video cable needs to be plugged into the converter board and the board housing is screwed into the backside. The mounted driver display can be seen in Figure 16 and Figure 3. The driver display is connected to the computer with the use of an HDMI to DisplayPort adaptor (same as the side displays).

The software SimHub²³ was installed, it is built for adding peripherals to simulation games and supports BeamNG. This software reads in game variables, as speed, revolutions per minute, lights, etc., in real-time and allows to display this data in simple visualizations. The workgroup, developing parallel at the simulator used this tool to mockup several gauges and indicators. They also remodeled the exact gauges and background being used in the ZOE. Therefore, all cockpit gauges and signal lights in BeamNG.research were deleted from the car model and replaced by a representation visualized with SimHub on the 10" driver display.



Figure 16: Steering Wheel and Driver Display modified / mounted

²³ <https://www.simhubdash.com/>

5.1.6 Pedal Base Readjustment



Figure 17: Pedal Mounting Platform

The mounting platform provided by the RS1 platform (see Figure 17) is, when compared to the ZOE, around 100mm too high. To reduce the height, the full adjustment assembly was removed, leaving only two slots, 8mm in width. The pedal base itself is built from aluminum and steel and can be used entirely without a platform / frame. This made it possible to connect the pedal base, with the help of an adaptor plate, directly to the frame. The adaptor was built from 30 x 310 x 5mm flat steel, with two pairs of bores, 8mm in diameter, for the base and the slots in the platform. The pedal base rests on the front speaker mount (see Figure 3), so the possibility of changing its angle is lost, but the distance adjustment between the seat and the pedals is still possible.

5.2 Data Interface

Following the instructions²⁴ posted by the CanZE group, the electronic parts were ordered. Some parts differ to the original instruction, for e.g. the LEDs were left out, others weren't available, so equal suited ones replaced them. The specific parts are listed in Table 86.

²⁴ <https://gitlab.com/jeroenmeijer/cansee/wikis/Hardware>

The original CanZE plans include nothing more than the schematics (no housing, etc.). For the first iteration a proof of concept design was made, without a housing, to further reduce efforts and costs. After testing the interface successfully, necessary additions were made and documented in 5.2.2 Housing.

5.2.1 Serial Interface Construction

The interface was built with the following modules and functions. Figure 18 shows an overview of all technical components.

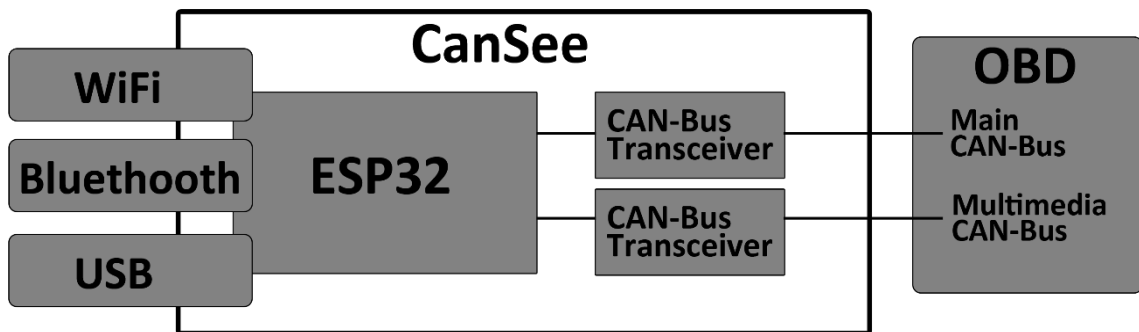


Figure 18: Schematic Data Interface CanSee

ESP32

The ESP32, produced by Espressif and embedded in a Dev Board by Himalaya, is the core microcontroller of the interface. It buffers all incoming CAN frames, assembles the longer ISO-TP CAN frames and forwards them by request via Bluetooth or Wi-Fi to a connected smartphone or tablet. In addition, a computer can be connected via USB to manual request frames or configure specific setting, which is also an important way for debugging.

CAN Transceiver

The CAN Transceivers convert the incoming bit stream into 8 byte CAN frames, headed by the PID (Microchip Technology Inc., 2007). This task could also be done by the ESP32 itself, but the parallel conversion, processing and forwarding the data would result into a high computation and scheduling load (Meijer, 2018). The use of the transceivers offers a relieve, allowing the interface to keep up with all incoming CAN-Bus data at full speed.

Voltage Regulator

Since OBD-II standard 12V DC is conveniently available through the OBD-II jack itself, the operating voltage of the Dev Board is 5V, which implies the use of a fixed voltage regulator to reduce the voltage.

OBD-II Connector Plug

To reduce further costs, an unused ELM OBD-II dongle has been acquired from a previous project. This dongle was disassembled to reuse its OBD-II connector plug for this project.

Type	Product Name	Specifications
Microcontroller	HIMALAYA Matrix-Core V2 Wireless Dev Board ESP-WROOM-32	Datasheet ESP32 ²⁵ and Schematics Dev Board ²⁶
CAN Transceiver	Waveshare SN65HVD230 CAN Board	Datasheet and Schematics ²⁷
Step-Down Voltage Regulator	Pololu Step-Down D24V10F5	Input: 5-36V Output: 5V, up to 1A ²⁸

Table 8: List of Interface Components

The assembly was done by soldering the necessary connections according to the provided schematics²⁴. Unfortunately, the Dev Board has no dedicated 3.3V supply pin, which is needed to run the two CAN transceivers. The ESP32 needs 3.3V as well, so the appropriate voltage regulator was tracked down on the circuit board and an extra wire was soldered on to supply the transceivers as well, this can be seen in Figure 19.

²⁵ https://ecksteinimg.de/Datasheet/esp_wroom_32_datasheet_en.pdf

²⁶ <https://ecksteinimg.de/Datasheet/HL01005/MatrixCoreV2%20Schematic.pdf>

²⁷ <http://ecksteinimg.de/Produkt/WS83004/SN65HVD230-CAN-Board.7z>

²⁸ <http://ecksteinimg.de/Datasheet/Pololu/PO2831.pdf>

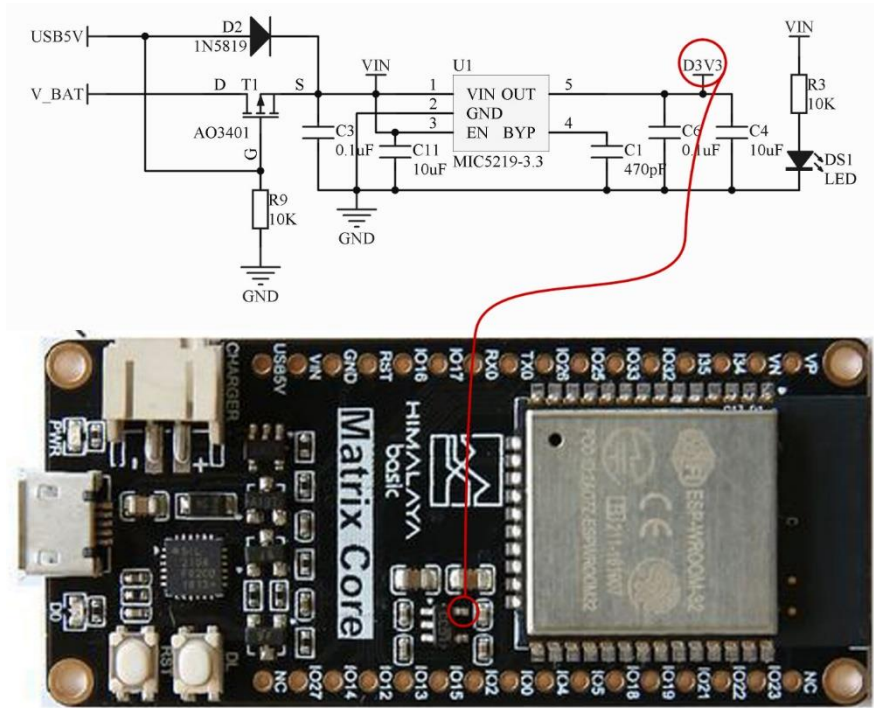


Figure 19: Data Interface 3.3V DC Supply Pin

Although, the CanZE schematic suggests the use of four status and debug LEDs, they were deemed unnecessary and rather distracting than helpful during test drives. Figure 20 shows a photo of the Interface connected to the ZOE.



Figure 20: Data Interface without Housing plugged into the ZOE

5.2.2 Housing

After successfully testing the data interface (see 6.2 Data Interface), a housing for the interface was constructed to make handling easier and reduce the imminent risk of shortcutting the OBD-II jack of the ZOE. The iterations of the housing were constructed with the use of CAD and fabricated with a 3D printer (Anet A8). The used filament for all prints was PLA. The housing was constructed as box in the form of a cuboid, embedding the OBD-II jack. The housing was kept as small as possible and square-cut to reduce print times and profile.

Version V1

Version V1 was constructed as one-part box (see Figure 21), all modules had to be inserted through the opening of the OBD-II plug. The opening was dimensioned 0.2mm smaller than the OBD-II plug to keep it in place with a friction fitting. On the opposite site a small opening was left to access the micro USB port of the ESP for debugging and programming.

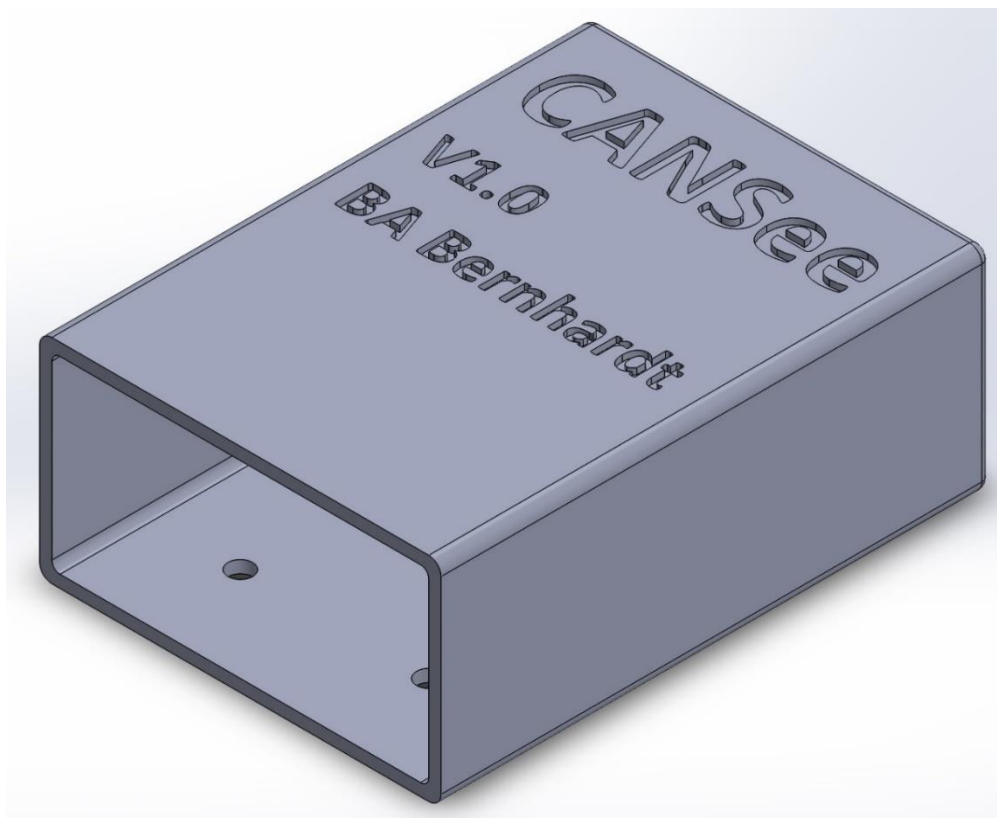


Figure 21: Housing Data Interface V1 Isometric View

Version V3

After several sketches the final version V3.3 was built to split in two parts. The lower part has mounting posts to screw the Dev Board into place. The opening for the plug was constructed with several rims and cut-outs with the dimensions of the connector. Therefore, the plug is clicked in place and locked by its original latches.

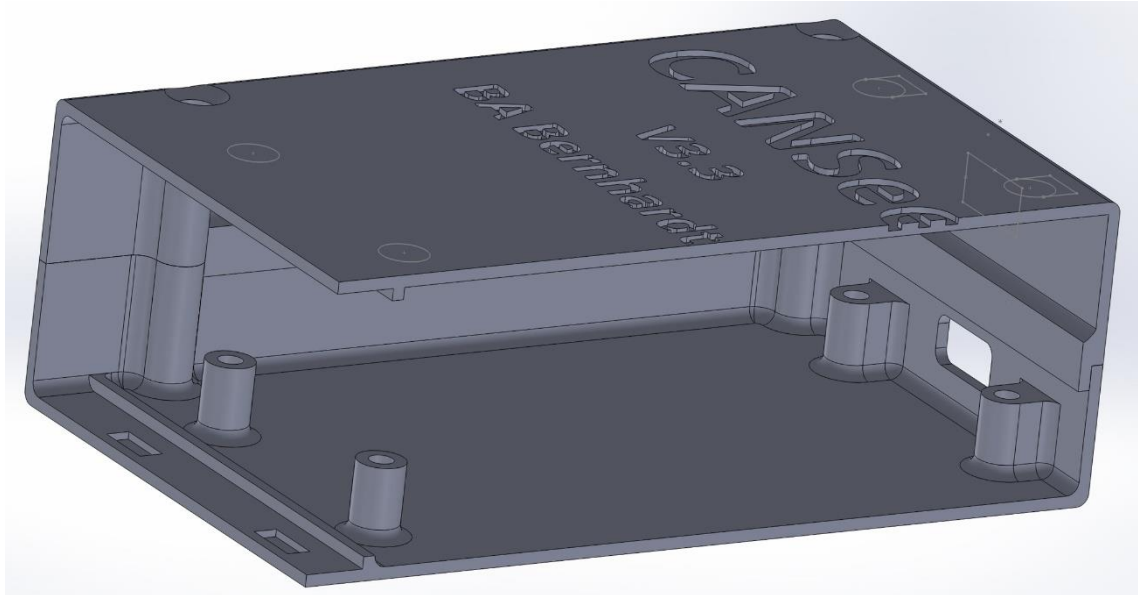


Figure 22: Housing Data Interface V3.3 sectioned

Figure 22 shows a cross section of the two parts already connected, the smaller hole is for the micro USB plug. After assembly, two 3mm bore holes in the upper part were drilled to reach the hard reset and set button on the circuit board beneath. Figure 23 shows a photo of the final and fully assembled data interface.

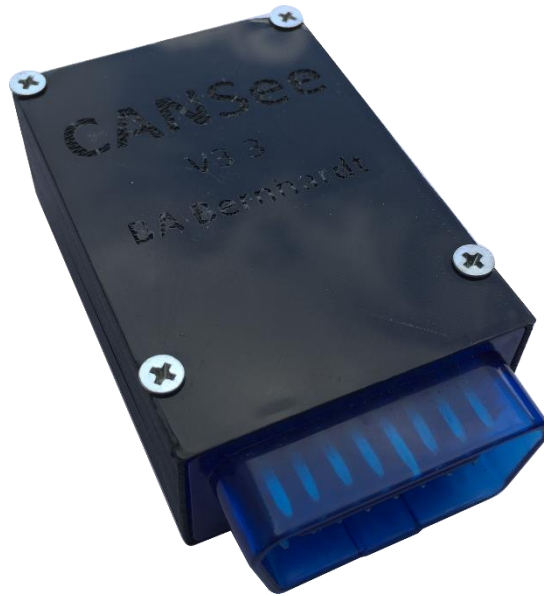


Figure 23: Photo of V3.3 Data Interface

5.2.3 Configuration / Implementation

The firmware for the CanSee was acquired and uploaded, via a special Espressif driver kit, with the Arduino suit. In the beginning the base settings must be made by setting designated flags with the help of a serial monitor over the USB connection to a computer. Best results were made with following flags:

```
17
18 nxxx,config: set EEPROM configuration
19 n100,0101000001
20 =====
21 100 Set the flags configuration as hex as ssbbwwlldd (0101000001)
22   ss: Serial over USB
23     01 for on
24   bb: Bluetooth
25     01 for on
26   ww: WiFi
27     00 for off
28   ll: Use leds
29     00 for off
30   dd: Debug
31     01: show CANbus receive free CAN_frame_std
32 =====
33
```

Figure 24: Configuration Flags Data Interface

Wi-Fi will work better than Bluetooth, because all iOS devices won't accept the interface as a Bluetooth peripheral. This dictates the use of websockets, which are not implemented yet (see also 7.2 Prospects).

6 Evaluation

In this phase, the constructed components (as documented in 5 Realization) are tested and evaluated. This provides important feedback for future improvements and ensuring the validity. The driving simulator and the data interface ran each through two iterations, separated by a formative evaluation to reveal necessary improvements, which should be addressed in the second iteration.

6.1 Simulator

In the first iteration, the driving simulator had the three 55" TV displays, the Clio IV steering wheel and only the first version of the Seat Base Construction was installed. This means, the 5.1.2 Seat Base Construction 2nd iteration, the 5.1.5 Driver Display Iintegration and 5.1.6 Pedal Base Readjustment weren't made yet. At the same time as this evaluation, two additional studies were made, using the driving simulator. A shared questionnaire and experimental procedure were developed in union with the parallel workgroups.

6.1.1 Goals

The goal was the acquisition of the Physical Presence (Makransky, Lilleholt, & Aaby, 2017) felt during the time in the simulator. This will provide an acknowledged and commonly used score to compare the constructed simulator to different driving simulators or applications with a high user immersion. And secondly to survey specific aspects of the driving experience. The latter will provide a, to this simulator, specific feedback with possibility of adding personal opinions and suggestions.

6.1.2 Method

All items were designed for a Likert-type scale (1-6), with 1: strongly disagree to 6: strongly agree (more details in the Appendix: Fragebogen). The questionnaire is made of two main parts: the first deals with the aspect of the Physical Presence and the second is dedicated to the driving experience. The participants of survey were acquired with the help of a Universität zu Lübeck mailing list. Each candidate got an individual appointment. Firstly,

the test persons were introduced by a moderator and filled in the first part of the questionnaire. Then the participant sat into the driving simulator, followed by the demand of the moderator to set up the seat as he would in a real car. When ready, different driving tasks were presented to the participant through the simulator scenario. After finishing the driving phase, the participant was asked to leave the simulator and fill in the rest of the questionnaire.

Part One: Physical Presence

Presence is an important psychological construct which helps to understand the human-computer interaction (Makransky, Lilleholt, & Aaby, 2017). The Multimodal Presence Scale is a compound of three dimensions, namely the physical, the social and the self-presence. The original questionnaire dedicates five items to each of those dimensions. In this project, the social dimension can't be surveyed, as there is none social interaction in the scenario. The self-presence dimension does not apply to the chosen scenario, too; it would describe the experiences the subjects have to their own selves (Makransky, Lilleholt, & Aaby, 2017). Hence there are no avatars or visible digital recreations of human hands in the cockpit, steering the car. The physical dimension (or the Physical Experience) involves the interaction a test person is experiencing during driving in the simulator. The items are:

Label	Item	Area attribute
01	The virtual environment seemed real to me. <i>Die virtuelle Umgebung erschien mir real.</i>	Physical realism
02	I had a sense of acting in the virtual environment seemed consistent with my experiences in the real world. <i>Ich hatte das Gefühl, in der virtuellen Umgebung zu agieren, anstatt etwas von außen zu kontrollieren.</i>	Not aware of physical mediation
03	My experience in the virtual environment seemed consistent with my experiences in the real world. <i>Mein Erleben in der virtuellen Umgebung erschien konsistent mit meinem Erleben in der realen Welt.</i>	Physical realism
04	While I was in the virtual environment, I had a sense of "being there". <i>Während ich in der virtuellen Umgebung war, hatte ich ein Gefühl des "Dort-seins".</i>	Sense of being in the virtual environment
05	I was completely captivated by the virtual world. <i>Ich war komplett gefesselt von der virtuellen Welt.</i>	Not paying attention to the real environment

Table 9: Physical Presence Scale Items (Makransky, Lilleholt, & Aaby, 2017)

These five items already were translated and validated in German by Volkmann T. (Volkmann, Wessel, Jochems, & Franke, 2018).

Part Two: Specific Driving Experience

Additional five items were constructed to survey certain aspects of the simulator, which weren't covered by the physical Presence yet. Those allow for more feedback to the base settings of the simulator hardware, like pro chosen pedal distance or the steering wheel position.

Label	Item	Area attribute
06	Within the driving simulator I had the same seating experience like in a real car. <i>Ich hatte im Fahrsimulator das gleiche Sitzgefühl wie in einem echten Auto.</i>	Seating experience
07	Within the driving simulator the seating position was like in a real car. (Distances / positioning of the steering & pedals) <i>Die Sitzposition im Fahrsimulator war wie in einem echten Auto (Abstände bzw. Positionierung Lenkrad & Pedale).</i>	Seating position (distances / positions)
08	The accelerator pedal was as easy to dose as in a real car. <i>Das Gaspedal (Fahrpedal) war genauso gut dosierbar wie in einem echten Auto.</i>	Controllability accelerator pedal
09	The brake pedal was as easy to dose as in a real car. <i>Das Bremspedal (Fahrpedal) war genauso gut dosierbar wie in einem echten Auto.</i>	Controllability brake pedal
10	The control of the steering wheel was the same as in a real car. <i>Die Lenkradsteuerung war genauso gut wie in einem echten Auto.</i>	Quality steering wheel control

Table 10: Specific Driving Experience Items

Part Three: Miscellaneous Data

As already mentioned, the two parallel studies had several items as well, those weren't designed for this thesis, but some items can be taken to retrieve a general understanding.

Label	Item	Area attribute
11	How many kilometers did you drive cars in total? <i>Wie viele Kilometer sind Sie grob geschätzt bereits insgesamt mit Autos gefahren? (unabhängig von oben genannten Fahrzeugtypen)?</i>	Driving experience
12	How old are you? <i>Alter?</i>	Personal
13	How many years are you driving cars? <i>Wie lange fahren Sie bereits insgesamt Autos (x Jahre und y Monate)? (unabhängig von oben genannten Fahrzeugtyp)?</i>	Driving experience
14	Set seat distance to pedals. ²⁹	Personal
15	What is your gender? <i>Geschlecht?</i>	Personal

Table 11: Miscellaneous Data Items

²⁹ Measured and documented by the moderator

6.1.3 Results

In total 22 test persons participated (19 female), with an average age of $M = 23.3$ yrs (Standard Deviation (SD) = 6.0). The average total kilometers (driven in a real car) amount to $M = 65,730$ km with a SD = 206,873 km, with an average driving experience of $M = 6.4$ yrs (SD = 5.8).

The subjects needed between 50 – 70 minutes to master all tasks in the driving simulator. The results of the Physical Presence and the specific driving Experience are visualized in Table 12 below.

Label	Item /Area attribute	Result	
01-05	Physical Presence	M = 3.26	(SD = 0.45) ³⁰
06	Seating experience	M = 3.45	(P ₂₅ = 3.00; P ₇₅ = 4.00)
07	Seating position (distances / positions)	M = 3.55	(P ₂₅ = 3.00; P ₇₅ = 4.00)
08	Controllability accelerator pedal	M = 3.36	(P ₂₅ = 2.25; P ₇₅ = 4.00)
09	Controllability brake pedal	M = 3.82	(P ₂₅ = 3.00; P ₇₅ = 4.75)
10	Quality steering wheel control	M = 3.00	(P ₂₅ = 2.00; P ₇₅ = 4.00)

Table 12: Driving Simulator Survey Results

6.1.4 Qualitative Feedback

Within the questionnaire, a free text field was reserved for suggestions and complains. In conclusion, the participants had problems to read the speedometer embedded in the digital car cockpit due to pixilation and bad graphic detail. Also, the maximum distance between pedals and seat couldn't be set big enough for taller persons, this resulted in an unsuited seating positions with the steering wheel touching the knees of participants lager than 1.8 m.

³⁰ As reference: simple Virtual Reality application $M = 3.15-3.54$ (Volkman, Wessel, Jochems, & Franke, 2018)

6.1.5 Discussion

The results according the Presence score are very promising, particularly in regard that this low-cost simulator achieved already a higher score than an application which is using a modern VR-Headset (Volkman, Wessel, Jochems, & Franke, 2018).

The seating experience didn't met the requirements. To find a solution, the reference car's interior measurements were taken again into consideration and the measurement, which is the farthest off, is the height of the pedals above the car flooring. In the ZOE the pedals are only 15 cm above the flooring, were as the lowest setting of the simulator platform only about 25 cm. Therefore, a modification was needed to lower the pedals (5.1.6 Pedal Base Readjustment).

The too small seating distance (Item 07) was not acceptable. During testing, the slider positions of the seat were measured (Item 15). Just one test person used the smallest setting, the average setting chosen was $M = 95.5$ cm (min: 87 cm; max: 100) most importantly a setting over 98 cm was chosen by 10 out of 22 participants. This sets the need of offsetting the seat by about 9 cm (5.1.2 Seat Base Construction 2nd Iteration).

The quality of the steering control was deemed to low (Item 10); this could be due to the high tolerances of the setscrews and bores provided by RSeat, which results in too much slack and vertical steering wheel wobble. The screws were immediately change from M8 cylindrical hex heads to countersunk hex heads. The conical head sets deeper into the bore and therefore negating any slack and wobble. Furthermore, the force feedback of the Fanatec steering wheel had to be fine tweaked.

At last, the problem of the pixilated and hardly visible speedometer (and all driver display meters) had to be improved. Neither the BeamNG.research details, nor the resolution can be set higher. This sets the need for a dedicated and additional display, located at the same position, where the ZOE's driver display is and measuring similar in width and height (5.1.5 Driver Display Integration).

6.2 Data Interface

In this chapter the constructed data interface was tested in the ZOE. It must be tested if the CanSee data interface works at all. If this is the case, the test is to be extended to check that

all the claimed features are fulfilled. Only the base functions can be tested without the CAN-Bus connected. That is why several test drives in different conditions were made with the ZOE.

To validate the first prove of concept state, the data interface was plugged into the OBD-II port without a housing and connected to the CanZE app installed on an Android device. All the traffic between the interface and the app was monitored with a serial monitor on a laptop. The data visualized by the app had a very low latency, and after finding a stable configuration, the interface ran flawless. Using it without a proper housing turned out to be very cumbersome, hence the risk of a shorting the circuit was very high due to the open circuit boards.

After the designing and construction of an appropriate housing (see 5.2.2 Housing), more in-depth tests were made, beginning with a test drive (about 80 km in total). During this drive, all requested CAN frames were logged and saved on a connected laptop. The data was later sorted and analyzed.

As reference the PID 130 (hex)³¹ was chosen. It stores the current axis torque, the position of the brake and acceleration pedal and the required tongue. Especially both pedals can be triggered very conveniently, and changes can be recognized, even while the vehicle is not moving.

Frame ID	Frames sent per Minute	Average Rate
All	3243	51.3 Frames/sec
130	328	5.5 Frames/sec

Table 13: Evaluation Data Interface

In total, 391 unique PIDs can be requested with the help of the serial monitor, but only 10 – 30 unique PIDs are needed for future use (Stahl, 2018). The data rate surpasses the rate of both, the Axotec IGX 560 and M2M Control C650 data interfaces (Goedker & G6rges, 2019).

³¹ https://github.com/fesch/CanZE/blob/master/app/src/main/assets/_Fields.csv
 See also 3.2 Data Interface for a PID explanation
 For an explanation see also 5.2.1 Serial Interface Construction

Small changes like the sending the complete CAN frame buffer (stored in the ESP RAM) in timed intervals instead of requests as well as adding an additional timestamp to all CAN frames was possible. This fulfills requirement of being able to modify the code.

7 Summary

In the beginning a cost-efficient driving simulator, that uses the Renault ZOE BEV as a direct reference, was set as the objective. At the same time the need of a tool, which logs specific driving related data, for e.g. speed or SOC, was formulated to compare and validate the simulator to the real car. In the market analysis several simulator platform bases were found and set into comparison. It turned out, that professional driving simulator manufacturers already are using computer gaming hardware, the exact same hardware is if separately bought, much cheaper. The possibilities of collecting data from the Renault ZOE were researched, which led to the use of a logger reading the Main CAN-Bus and the Multimedia CAN-Bus through the OBD-II port of the car. The solutions found in the market analysis range from simple ELM based dongles to complex modules featuring GSM, GPS and memory slots constructed for professional fleet management. With the data gathered in the previous chapters, requirements were set, and the decision was made, which concept would be the best fitting solution. The RSeat RS1 Platform was selected alongside with a list of necessary improvements to its frame, like the adaptation of the RK Automotive seat. Also, the requirements for the displays were set and fitting products were bought. To select the best data interface to read the CAN-Bus, a prioritization of the features was made, with open source code and the ability for easy adaptation as the most important features. The CanSee solutions differed from the rest, because it wasn't a product, rather a building documentation of a prototype. It was chosen, because of the very good results (documented by CanZE) paired with the lowest assembly price of a solution.

During the realization the RS1 platform got many improvements and was assembled with the displays and the force feedback HIDs to a working simulator. Several adaptor frames, made from steel and elaborate adjustments of all, hardware and software settings, were needed to be ready for its first survey with participants. The data interface was built in an easy "proof-of-concept" version and was able to read all required ZOE CAN frames, with a higher speed than all other solutions. After the construction of a housing for all circuit boards of the CanSee, more in depth testing and logging during several test drives with the ZOE the solution proved to be sufficient. After the evaluation of the driving simulator and the testing of the data interface, necessary improvements had been made. Now, that both are in their 2nd iteration, a conclusion can be made. At first, all results will be summarized

and after this, a small glimpse into the possible future of the simulator and the data interface will be given with the prospects.

7.1 Results

In the project objectives a complete driving simulator, built after the Renault ZOE, was claimed. As well as a device, which is able to log the same data BeamNG.research already provides. Within this bachelor thesis the required simulator was conceptualized, followed by the complete construction. It proved to be capable during the evaluation phase of this and two other projects during the same time with over 60 participants, which equals to more than 60 hours of driving. The results had been promising, a rehearsal of the features and the overall construction was possible and allowed for further improvements. The results were also published in the form of a poster on the 3rd Kongress der Verkehrspsychologie 2019.

The overall costs stayed as in the objectives claimed beneath the costs of the Vogel simulator, despite of using better hardware, like higher resolution and diameter displays.

A solution in the form of an OBD-II data interface was found for collecting data in the highest possible frequency (the logging frequency equals both ZOE CAN frequencies). This solution proved to be faster, more versatile and much cheaper, as its competitors, but it is missing additional features, necessary for the long-term use like a separate GPS or a GSM module. Also, in the line of this project the final evaluation of the simulator in comparing both logged data was not possible.

7.2 Prospects

As previously mentioned, the final comparison between the Renault ZOE and the simulator needs to be done, to verify the validity of the constructed driving simulator. The project team works already on a recreation of a real-world test track, found and recorded during the last test drive with the data logger. Also, the Styrofoam airbag cover of the steering wheel needs to be replaced with a more durable, 3D printed version. A live review of a Vogel simulator added a buttkicker, a seatbelt and a dashboard to the wish list. In long term use

the reduced resolution (below the native 3 x UHD) isn't acceptable, newer graphics cards, like the Nvidia GTX 2080, seem to be promising, but must be first closer evaluated.

The data interface, despite of the lack of extra features, aroused interest, because it can easily replace older, more limited logger solutions and has the unique feature of open source software, higher computation capabilities and unmatched logging speed. In fact, it is not only going to be a tool to validate the simulator, but also is already in use by another student project for a prototype energy interface within the ZOE. The plans of adding a GSM and GPS module were dropped, because it would exceed the price of the Freematics logger, which already has all those features, based on the same ESP32 platform and doesn't need to be assembled. Still, a version of the CanSee with built in SD-Card slot and a separate "record button" for simple data collection during driving is in planning for several ZOE's.

Glossary

The following terms will be explained by meaning. It should be noted that there are sometimes different definitions in different contexts.

ZOE	BEV of the manufacturer Renault Model: Z.E. R90 41kWh used in testing and as reference.
CanZE	Community driven and developed Android and iOS app, which processes CAN frames from various data interfaces. Built for the ZOE.
CanSee	Data interface form the CanZE community for the ZOE, published in January 2019.
BAUD	Common measure of symbols per second, therefore speed measure in the context of this work.
iOS	Operating system for Apple smartphones and tablets.
Android	Operating system for various smartphones and tablets.

Abbreviations

CAN	Controller Area Network (BUS system used in cars)
BEV	Battery Electric Vehicle (purely battery powered car)
CAD	Computer Aided Design (creation of virtual 3D models)
FOV	Field of View (referred to users)
OS	Operating System (Module of a von Neumann style computer)
CPU	Central Processing Unit (Module of a von Neumann style computer)
GPU	Graphic Processing Unit (Module of a von Neumann style computer)
RAM	Random Access Memory (Module of a von Neumann style computer)
Dev Board	Development Board (circuit board designed around a controller, making access to I/O Ports of the controller easier, also programming interface)
PLA	Polylactic Acid (thermoplastic polyester, used as 3D printer filament)
FPS	Frames Per Second
LVDS	Low Voltage Differential Signaling (Signal standard used to transmit display signals)
HID	Human Interface Device (Pedals, Steering Wheel, ...)
IPS	In-Plane Switching (Display technology, like Active Matrix LCDs)
ASIC	Application-Specific Integrated Circuit (chip designed to do only a specific task)
SoC	State of Charge (level of charge of an electric battery)

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Sources


- Endor AG. (10. July 2019). *fanatec.com*. Von <https://www.fanatec.com/eu-en/steering-wheels/clubsport-steering-wheel-universal-hub-for-xbox-one-eu.html> abgerufen
- Franke, T., Arend, M., McIlroy, R., & Stanton, N. (2017). Ecodriving in hybrid electric vehicles--Exploring challenges for user-energy interaction. In *Applied ergonomics* (S. 33-45).
- Franke, T., Günther, M., Trantow, M., Rauh, N., & Krems, J. F. (2015). Range comfort zone of electric vehicle users – concept and assessment. *IET Intelligent Transport Systems*, 9(7), S. 740-745.
- Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J. F. (2012). Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers. *Applied Psychology*, (S. 368-391).
- Goedker, M., & Görge, D. (25. March 2019). Datarate of the CanSee in Comparison to Axotec and M2M. (L. Bernhardt, Interviewer)
- Herrman, D. (2018). *Development of a web-based Eco-Driving Assistance System for Electric Busses Based on Visualisations Intergrated in Operational Processes*. Universität zu Lübeck IMIS Library.
- Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the Multimodal Presence Scale for virtual reality. In *Computers in Human Behavior* (S. 276-285).
- Meijer, J. (28. December 2018). *canze.fisch.lu*. Von <https://canze.fisch.lu/a-diy-canze-dongle/> abgerufen
- Microchip Technology Inc. (12. August 2007). *microchip.com*. Von <http://ww1.microchip.com/downloads/en/devicedoc/21667e.pdf> abgerufen
- Milgram, P., H., T. A., Utsumi, F., & Kishino. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. In *SPIE Vol. 2351-34, Telem manipulator and Telepresence Technologies*.
- Stahl, J. (11. July 2018). Action-integrated range visualization in electric buses to support system trust and range-related situation models. Universität zu Lübeck IMIS Library.
- Stieglitz, P. (2018). Development of the software BeamNG to a driving simulation environment for researchers on the field of user-energy-interaction (Bachelor Thesis). Universität zu Lübeck IMIS Library.
- Trautmann, M. (April 2019). Interview Experiences in using a Vogel Simulator in a driving school. (L. Bernhardt, Interviewer)
- Volkman, T., Wessel, D., Jochems, N., & Franke, T. (2018). German Translation of the Multimodal Presence Scale. In *Mensch und Computer 2018 – Tagungsband*. Dresden: Gesellschaft für Informatik e. V.

Software

Adobe Creation of drafts.	Photoshop CS5	12.0
Google Inc. Creation of survey sheets and project planning.	Google Docs	May 2019
Microsoft Corp. (2018) Evaluation of survey.	Microsoft Excel 365 ProPlus	1906
Microsoft Corp. (2018) Creation of this documentation.	Microsoft Word 365 ProPlus	1906
Dassault Systèmes Construction of all models and skechting.	SOLIDWORKS Premium	2015
Simplify3D (2016) Slicing of 3D models and print preparations.	Simplify3D	3.1.1
Arduino.cc (2019) Programming and uploading firmware to the ESP32	Arduino	1.8.9
Sourceforge (2019) Monitoring serial data streams and logging.	Realterm	3.0.0.30
SimHub (2019) Realtime visualization of BeamNG data in form of various gauges.	SimHub	V6.8.2

Appendix

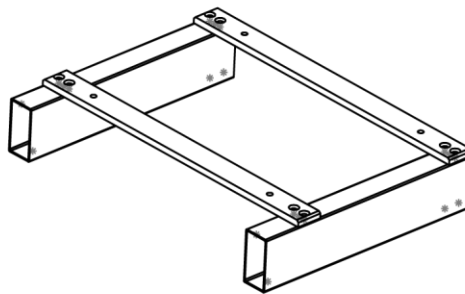
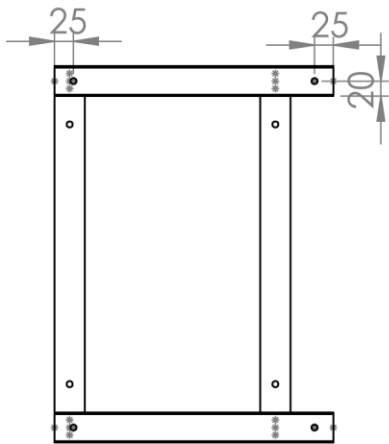
Survey – Questionnaire

 Kurzfragebogen Fahrerlebnis & Fahrgefühl im IMIS-Fahrsimulator						
Datum: _____ Uhrzeit: _____						
Wie haben Sie die virtuelle Umgebung (also die Fahrsimulation) erlebt?						
Bitte geben Sie den Grad Ihrer Zustimmung zu folgenden Aussagen an.						
01	Die virtuelle Umgebung erschien mir real.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	Ich hatte das Gefühl, in der virtuellen Umgebung zu agieren, anstatt etwas von außen zu kontrollieren.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
03	Mein Erleben in der virtuellen Umgebung erschien konsistent mit meinem Erleben in der realen Welt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
04	Während ich in der virtuellen Umgebung war, hatte ich ein Gefühl des "Dort-seins".	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
05	Ich war komplett gefesselt von der virtuellen Welt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wie nah kam das Fahrgefühl im Fahrsimulator an das Fahren eines echten Autos heran?						
Bitte geben Sie den Grad Ihrer Zustimmung zu folgenden Aussagen an.						
06	Ich hatte im Fahrsimulator das gleiche Sitzgefühl wie in einem echten Auto.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
07	Die Sitzposition im Fahrsimulator war wie in einem echten Auto (Abstände bzw. Positionierung Lenkrad & Pedale).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
08	Das Gaspedal (Fahrpedal) war genauso gut dosierbar wie in einem echten Auto.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
09	Das Bremspedal (Fahrpedal) war genauso gut dosierbar wie in einem echten Auto.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Die Lenkradsteuerung war genauso gut wie in einem echten Auto.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Haben Sie noch Anmerkungen zu dem Fahrerlebnis & Fahrgefühl?						
<ul style="list-style-type: none"> Fallen Ihnen Verbesserungsvorschläge für die Sitzposition, Lenkrad- und Pedalanordnung ein? Wurden Sie von Teilen des Simulators derart eingeschränkt, dass Sie in ihrer Aufgabenerledigung behindert wurden? 						
<hr/>						
Vielen Dank für Ihre Teilnahme an der Fahrsimulator-Studie!						

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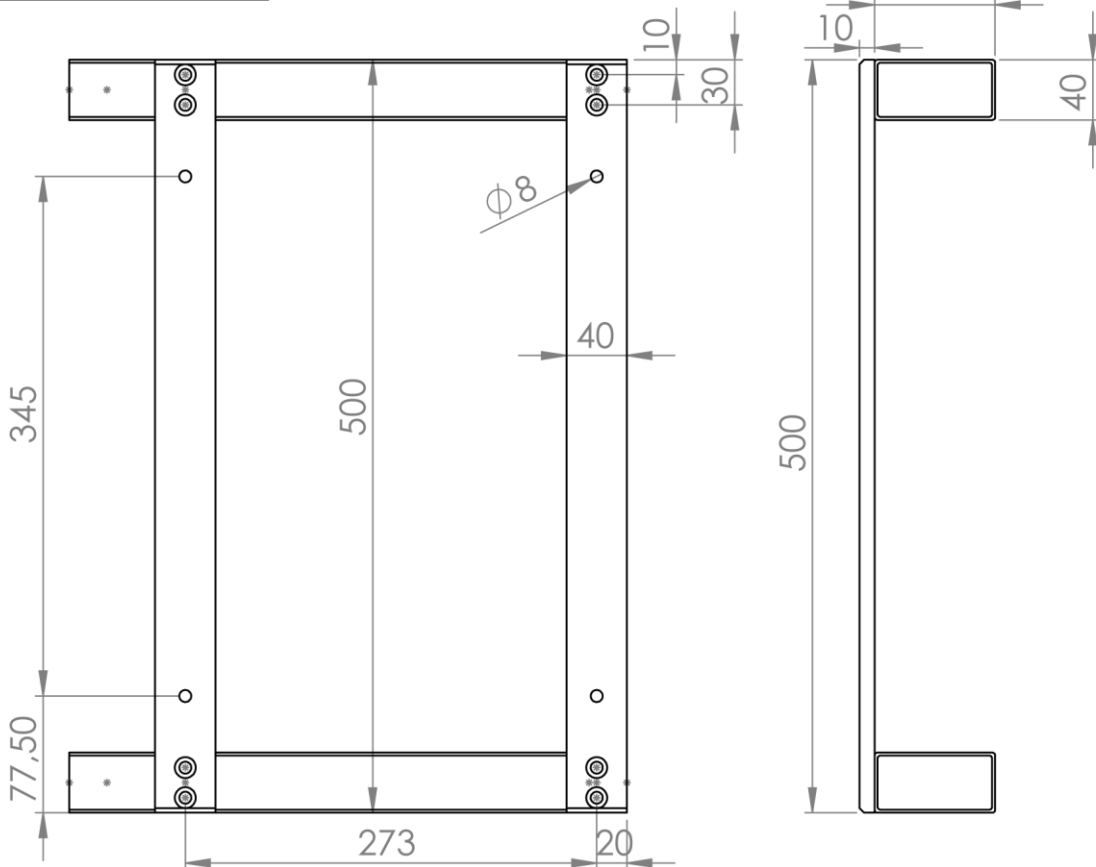
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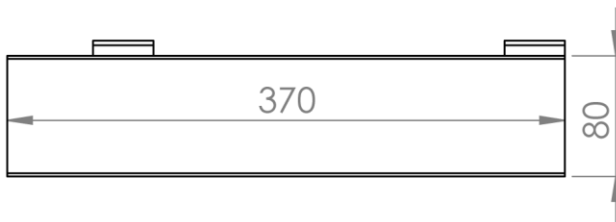
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ENTGRATEN
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ZEICHNUNG NICHT SKALIEREN

ÄNDERUNG

Lukas Bernhardt

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GEZEICHNET			
GEPRÜFT			
GENEHMIGT			
PRODUKTION			
QUALITÄT			

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**Basis für
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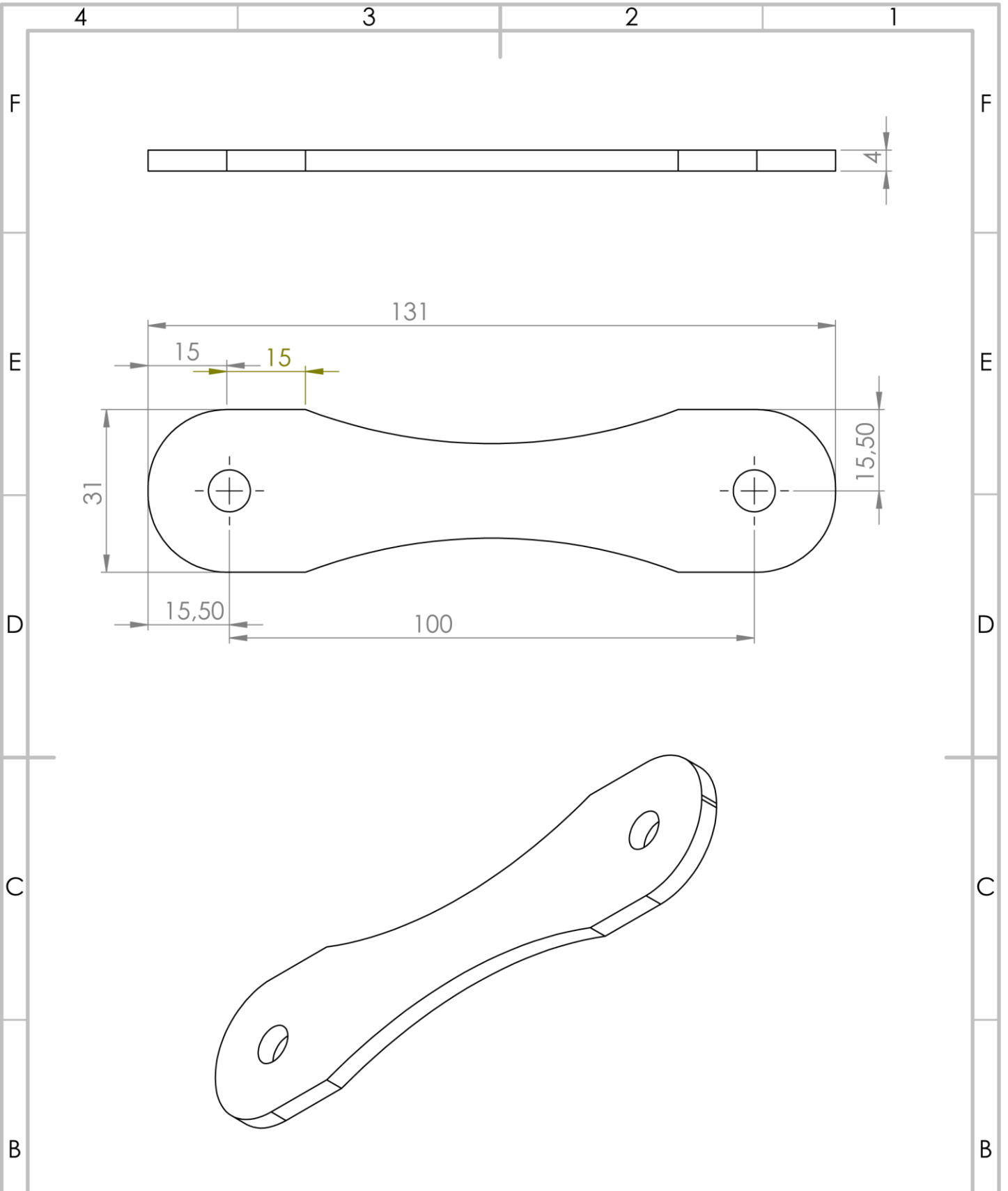
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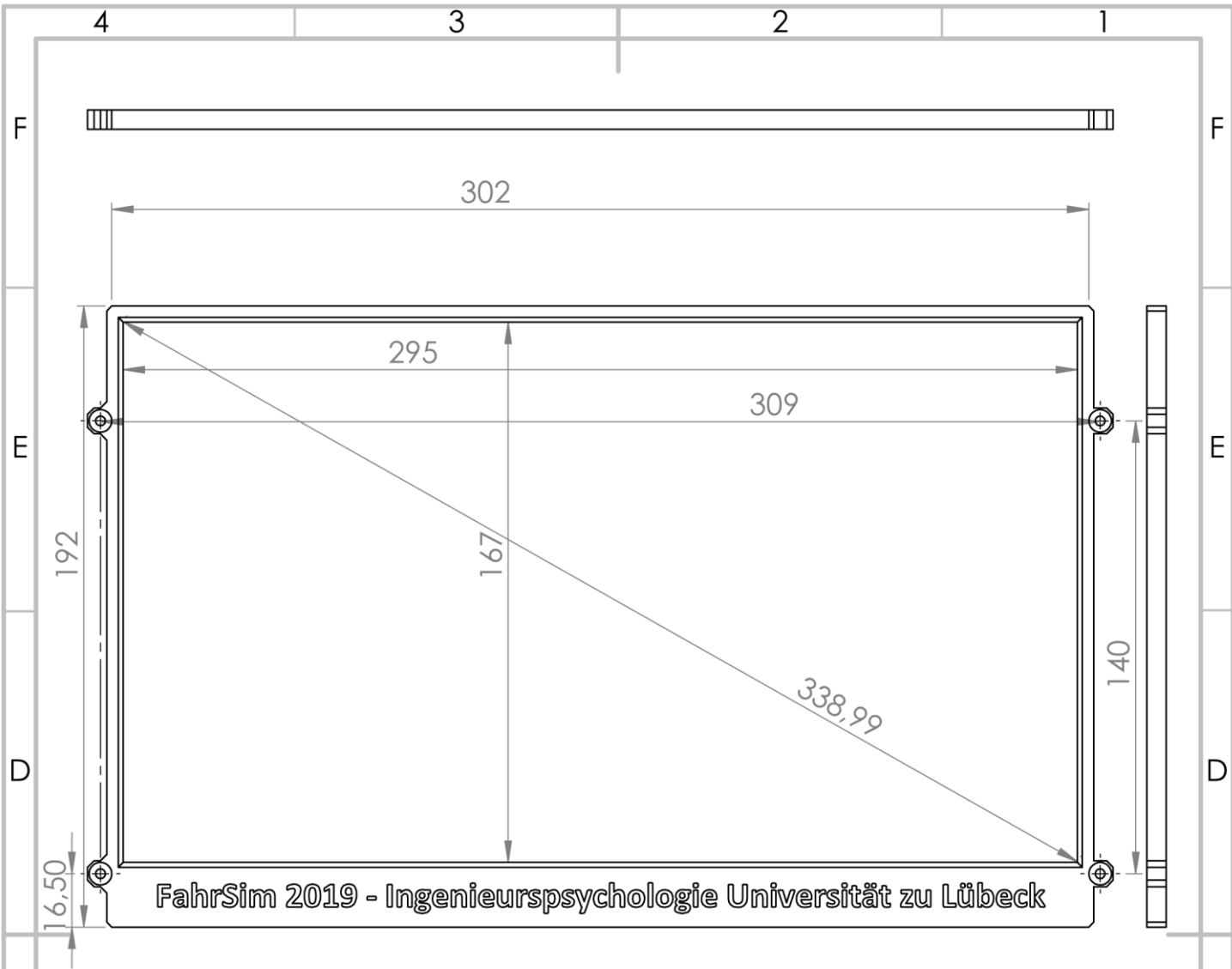
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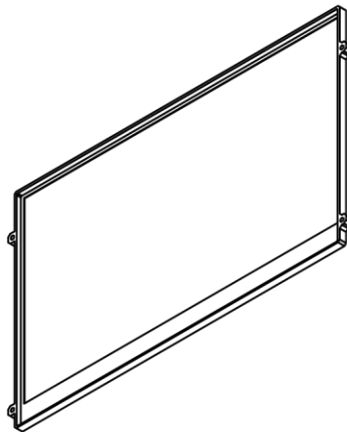
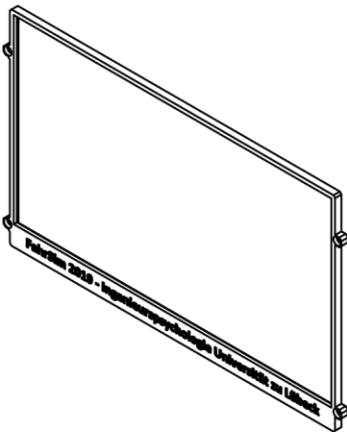
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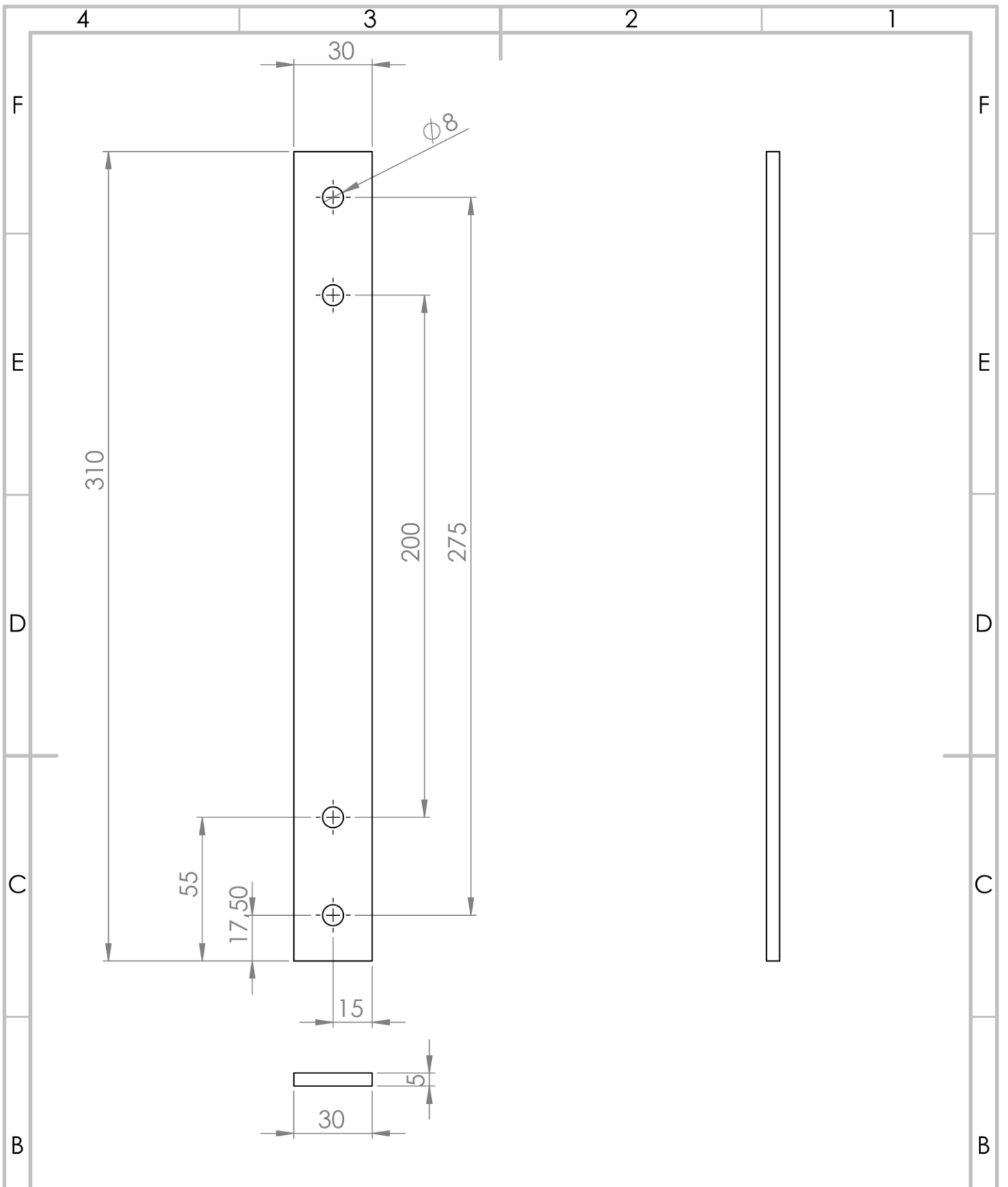
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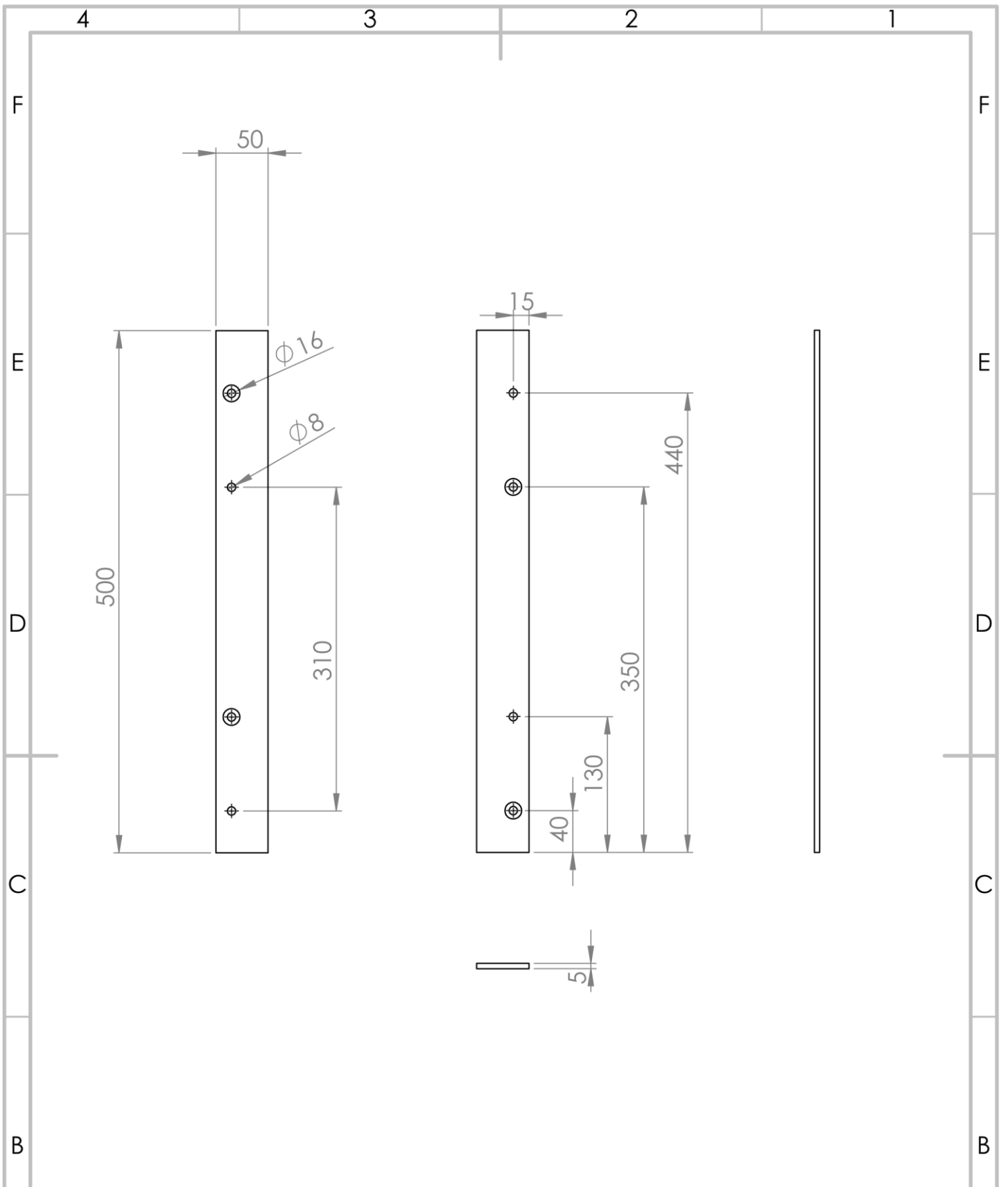
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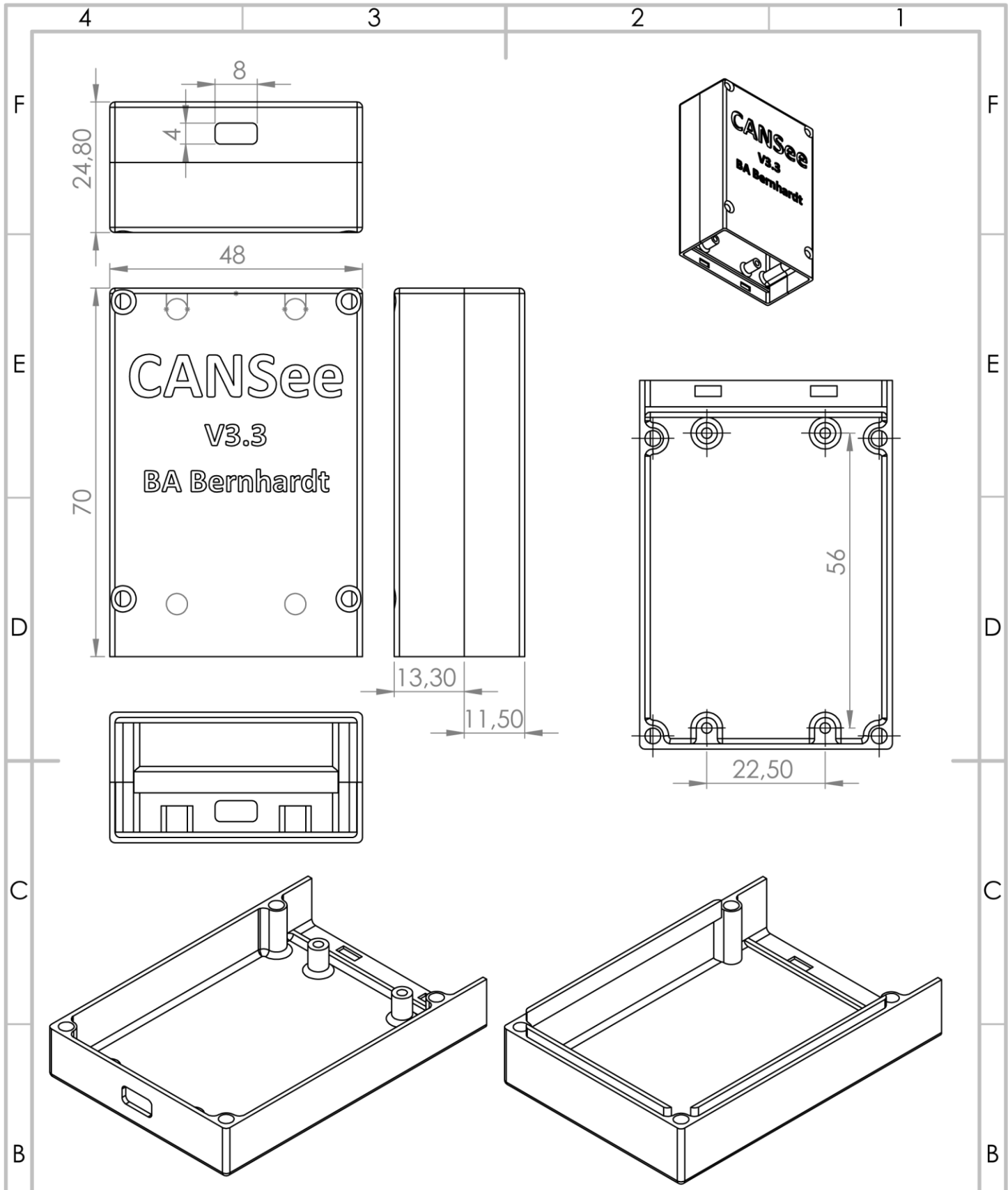
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GENEHMIGT				
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WERKSTOFF: ZEICHNUNGSNR. 67

Gehäuse Cansee V3.3

GEWICHT: MASSSTAB: 1:1 BLATT 1 VON 1

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Erklärung

Ich versichere an Eides statt, die vorliegende Arbeit selbstständig verfasst und nur die angegebenen Quellen benutzt zu haben.

Lübeck, den 16. Juli 2019

Unterschrift des Studierenden