

# Bachelor Degree Project



## ANALYSIS OF VEHICLE ERGONOMICS USING A DRIVING TEST ROUTINE IN THE DHM TOOL IPS IMMA

Bachelor degree project in Product  
Design Engineering  
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## Assurance of own work

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*I hereby confirm that for all the material included in this report which is not mine own, I have reported a source and that I have not – for obtaining credits – included any material that I have earlier obtained credits within my academic studies.*

A handwritten signature in black ink, appearing to read 'Javier Romera Orengo', with a circled '4' below it.

*Javier Romera Orengo*

## Abstract

The objective of this project is to develop a driving test using a Digital Human Modeling tool (DHM), specifically IPS IMMA, which will allow the evaluation of the ergonomics of the interior of vehicles as currently demanded by the automotive companies. Thus, improving both the design and the design process. This will involve a study of the driving and the tasks carried out by a real person to end up programming them in the DHM software. Based on this study an interface is suggested that guides engineers or ergonomists to design their own driving tests and enable them to evaluate their own designs without a high specialization in DHM tools and software.

Taking into account the already present autonomous cars and their future development, the conceptual design of a two positions steering wheel (autonomous/manual driving) will be introduced as an example to be added in the driving test. This example is intended to show how DHM tools can be used to evaluate different designs solutions in early stages of the product development process.

This project will be a contribution to one of the sections of the ADOPTIVE project carried out at the University of Skövde and in collaboration with Swedish automotive companies.

**Keywords:** CAE; Autonomous driving; Ergonomics; Driving test; Manikin; Steering-wheel; Digital Human Modeling; DHM;

## **Preface**

This work was carried out during the spring semester of 2020.

Development and Design at the University of Skövde, Sweden.

I would like to thank Erik Brolin and Aitor Iriondo Pascual for the support they have always offered me when carrying out this project.

Skövde, 17<sup>th</sup> August of 2020  
Javier Romera Orengo

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## 1 Introduction

Nowadays, and especially in the world of design, virtual tools play a fundamental role in the creation of new projects. The use of CAD, CAE or CAM tools is essential for the development and viability of projects, since they facilitate the task, reduce time, effort and costs and can generate models and simulations of the final product and its production processes (Högberg et al., 2019). CAE makes use of previously created virtual models in simulations of different processes and user interactions, such as the interior of a vehicle, without having to build physical models for testing (Yang et al., 2002).

In the automobile industry, there is a trend towards autonomous driving (Kun et al., 2016). Although there are already some autonomous vehicles circulating in the cities, their presence is scarce and their level of autonomy is still developing (Boston Consulting Group, 2018). Autonomous driving will mean a change in the design and design process of future vehicles. As Ralph Gilles (Fiat Chrysler Global Head of Design) says about the Chrysler Portal autonomous vehicle, "the interior has become the new battleground of car design" ("Review," n.d.). Given that these are products designed for human beings, ergonomics has a great importance in this sector. The reconfiguration of the interior of the vehicles, how they will be designed, and how the user will adapt to it are aspects that needs to be considered in future design projects.

Therefore, this project will study the possibility and facilities offered by CAE software that, through Digital Human Modelling (DHM) tools, facilitate the implementation of ergonomics, and its evaluation, in current and future vehicle designs. After a detailed study of the driving actions in a real circuit and a simulation of these actions in the IPS IMMA software an interface, to be able to more automatically generate simulations, will be suggested. This interface would guide engineers and ergonomists not specialized in DHM tools to generate their own custom driving tests to evaluate different designs ergonomically and to facilitate the choice of the best solution.

### 1.1 IPS IMMA and ADOPTIVE

For the development of this project, the IPS IMMA software has been a fundamental working tool. This software has been developed by experts in mathematics, ergonomics and engineering. It was developed to cover the need of companies for a simple and efficient software to verify the requirements of ergonomics in the manufacturing process. It is a software in constant development that creates demonstration versions for research projects and test new functions to meet new needs (Hanson et al., 2019).

IPS stands for Industrial Path Solutions and IMMA stands for Intelligently Moving Manikin ("IPS IMMA –Fraunhofer-Chalmers Centre," n.d.). Although the program was originally developed to identify musculoskeletal problems automatically in the tasks of assembly line operators in the automotive industry, its functions also allow it to be used to evaluate the interior of vehicles through

the use of manikins. The IPS IMMA software will be further explained in section 2.3.2 IPS IMMA.

The ADOPTIVE research project at the University of Skövde, Sweden, aims to develop a DHM tool that will allow partner companies to perform virtual driving tests to evaluate interior design and improve the vehicle design process (Brolin, E., 2019). Partner companies consists of Swedish automotive industry (Volvo Car Corporation, CEVT, Scania CV and Volvo Technology AB) covering both cars and trucks. The project is also supported by Fraunhofer-Chalmers Research Centre for Industrial Mathematics (FCC). The ADOPTIVE consortium is based on previous successful projects related to vehicle design and product development. Virtual Driver (VD) and Virtual Driver Ergonomics (VDE) which focused on the evaluation of driver posture and ergonomics in a sitting position. This was key to the development of the DHM based test procedure (Figure 1.1)(Högberg et al., 2019). ADOPTIVE will focus on automating the driving tasks that the automotive industry will introduce into the software through an interface to facilitate evaluations of the vehicles in early design phases.



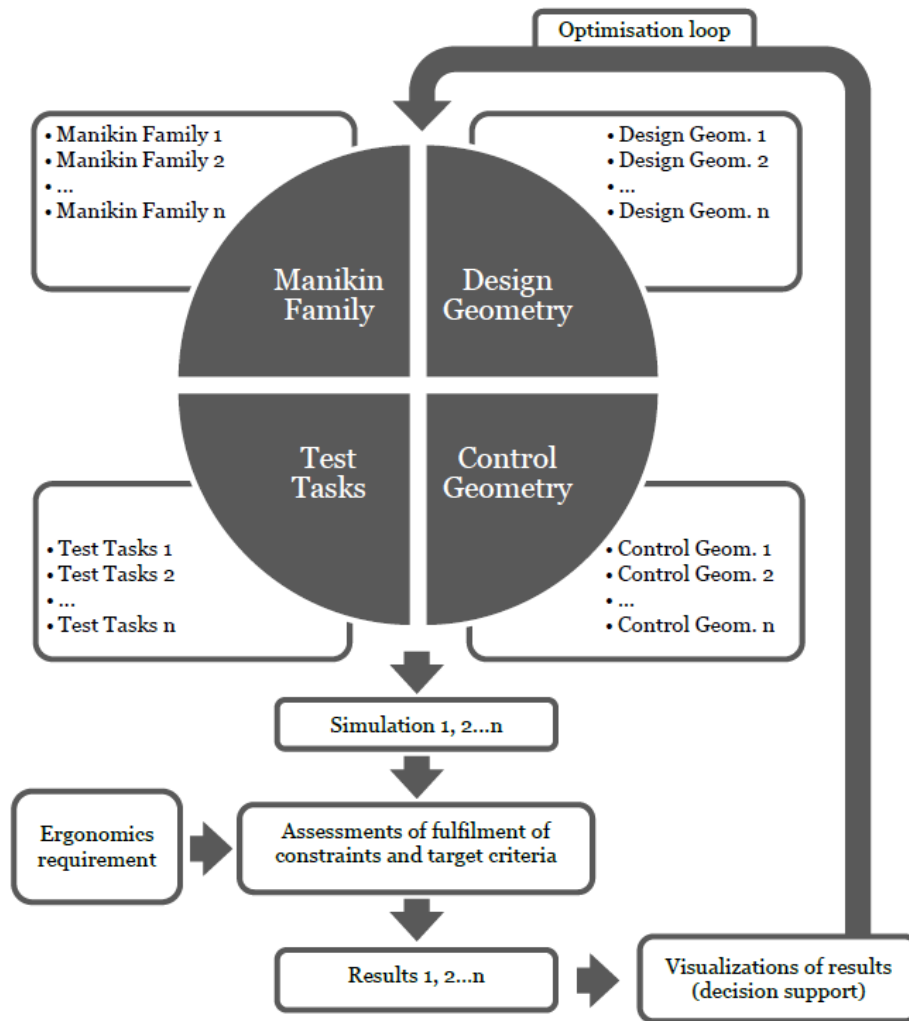


Figure 1.1 Structure of the main components of a DHM based test procedure.

### 1.2 Mission statement.

The objective of this project will be to study how DHM tools can be used to evaluate the ergonomics of the interior designs of current and future vehicles simulating driving sequences.

The aim will be to identify suitable actions to generate a driving test simulation and realising such simulations, while at the same time evaluating how these simulations could be generated more automatically. Thus, making it possible to quickly change between the different test tasks in the DHM based test procedure (Figure 1.1). In this way, information can be obtained from the studies carried out to improve the design as well as the design process, i.e. the use and functionality of the DHM tool. To evaluate the final result, a two-position steering wheel (for autonomous and manual driving) will be designed in parallel. The steering wheel design will be studied within the simulations created to carry out the driving test simulation in order to evaluate the possibilities to change

between different design geometries in the DHM based test procedure (Figure 1.1). Both parts will conclude in an interface where the future user of the DHM tool will be able to generate a driving test and evaluate the ergonomics of the different designs while driving.

### **1.3 Limitations**

The limitations will be mainly given by the software itself. While the analysis and study of the tasks and sub-tasks to be performed by the driver can be done in great depth, it will be the functionality to program those tasks that will mainly limit the result. That is why developing and programming precise and detailed tasks will be one of the main challenges.

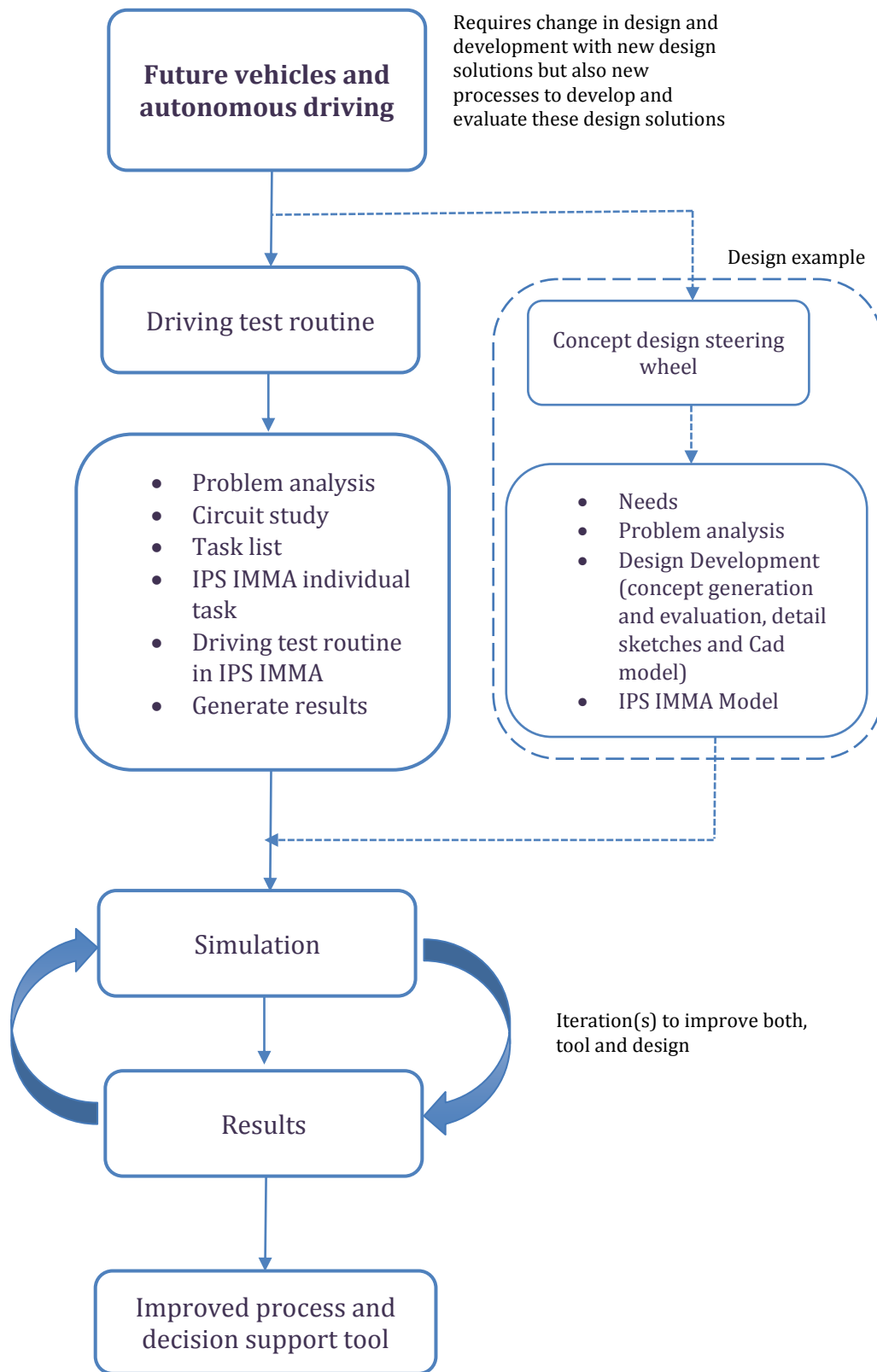
On the other hand, but without going too deep, the concept design of the steering wheel will be limited by needs during driving and the specification list of requirements.

### **1.4 Stakeholders**

The main stakeholder would be the ADOPTIVE project of the University of Skövde who will be able to use this project to advance their research. Thus, the following and immediate interested parties are the partners and automotive companies associated with the project. Researchers and engineers or ergonomists from collaborating industry partners, representing actual or potential end users of DHM tools, who will evaluate ergonomics in vehicle design are additional stakeholders. Also, the final user of the designed product, driver and passengers in cars, trucks and busses, would also be affected by the results of the project.

### **1.5 Project implementation**

The project follows the process indicated in the figure 1.2. It has its point of origin in the development of future vehicles, this means taking into account, in a way, autonomous driving. The new type of vehicle requires changes in design with new innovative design solutions, but also new processes to develop and evaluate these design solutions. The main objective of the project is to study how DHM tools can be used to evaluate the ergonomics of the interior designs in early stages of design development. Although the main objective is based on the study of driving there are two clearly differentiated sections. Even so, both sections conclude at the same point, supporting the basis of the project, the design is evaluated and the evaluation improves the design and consequently the design process. These parts are: the study of driving and creation of the test routines with DHM IMMA tool, and secondly, the development of a two-position steering wheel, to demonstrate the possibility of changing the design geometry and allow a good connection with the autonomous vehicles.



*Figure 1.2 Process Connection*

Section 1: Study of driving and the creation of test routines with the DHM IMMA tool.

- First, A circuit on which to conduct the driving test shall be proposed, and the test shall be sufficiently large to form a representative sample of the driving.
- The tasks to be carried out by the user as an active and passive driver will be detailed in all cases for subsequent simulation in the DHM IMMA tool.
- It will be required a familiarization with the program for its correct use.
- A driving routine will be created for subsequent testing in the IMMA tool.
- Go to the creation of driving test routines in the DHM IMMA tool and collect test information.
- Join the generated tasks and the design of the new steering wheel to obtain a final result
- Create a flow process for a Lua-script that automatically generates the task in the IMMA tool

## Section 2: Concept design of the two-position steering wheel

- Benchmarking to obtain a set of data on the driver's needs to adapt them to the new design of the steering wheel concept. These needs are expressed by means of a list of specifications
- Generate various design concepts through brainstorming.
- Evaluate through a Pugh matrix the sketches and obtain the best design for their development
- Development of the design
- Obtain a 3D design and export it to IPS IMMA

Once all this content has been developed, the results obtained will be analysed, the model of the new steering wheel will be imported and tested in a simulation in IPS IMMA. The steering wheel will serve as an example of the possibility to easily and quickly change designs for driving evaluations, which as explained below, is one of the basic advantages of using the DHM tool for evaluating design ergonomics.

The completion point of these two parts is the generation of driving routines by means of an interface. This will be a demonstration of what the end user, ergonomists and engineers, will use. It should be made clear that this project is not about creating a steering wheel for later improvement. The development of the steering wheel is just an example to be used in the process. Once the results are obtained, the conclusions, final control and proposal will be made for improvement for the process of creating the driving test.

## 2 Prestudy

For the development of this project, information has been collected on which to base further research. The main topics investigated are: driving, autonomous driving, CAE software as a tool for the design process and ergonomics within the automotive industry.

### 2.1 Driving as the center of the study.

Driving is a complex task that requires both coordination and concentration at a greater or lesser level. Users must feel comfortable with the environment such as the interior of the vehicle. Not all designs are the same, and therefore a study of the ergonomics in each design must be made for the correct adaptation of the driver and users. Although design changes in vehicles are gradual and progressive, any design is studied in detail to ensure optimal driving. Therefore, the performance and behaviour of users behind the wheel, as Carsten and Jamson (2011) say, is the subject of study in simulators and is increasing.

#### 2.1.1 Autonomous driving.

Today, driving has great technological advances that facilitate the task of drivers (autopilot, assisted speed, adaptive cruise control, etc.). These aids are considered to be tools of the first levels of autonomy listed below, but are far from the total autonomy of the vehicle.

For this reason, technology is being developed for autonomous driving of the vehicle itself, which is capable of reducing the number of errors, predicting actions and even accidents. Autonomous driving will make driving accessible to any user, due to age or disability, and will also facilitate the transport of supplies and parcels (Flämig, 2016). Possibly from the years 2022-2025 the autonomous vehicle can be massively marketed (Fagnant and Kockelman, 2015).

As Luettel et al. (2012) expose, the autonomous vehicles will bring several benefits: for the traffic allowing a better management of the traffic flow, for the environment, with a lower and more efficient fuel consumption and for the user, avoiding less accidents with collision avoidance systems and allowing to perform other activities than driving.

There are currently several car companies that are researching, developing or producing autonomous vehicles (Tesla, Volvo, Audi, Seat, Bmw, etc) but the different levels of autonomy must be defined beforehand. The scale of levels ("SAE International Releases Updated Visual Chart for Its 'Levels of Driving Automation' Standard for Self-Driving Vehicles," n.d.) was first published by the Society of Automotive Engineers (SAE) in 2014 as part of its report "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving System" and although the National Highway Traffic Safety Administration (NHTSA) created its own scale of autonomy in 2013, it was this first one that has been adopted as a world reference.

The levels that are ordered from lowest to highest level of autonomy are:

- Level 0: No attendance
- Level 1: Assisted driving
- Level 2: Partial automation
- Level 3: Conditional autonomy

- Level 4: High autonomy
- Level 5: Full autonomy

As can be seen, it can be differentiated into two blocks, from level 0 to 2 and from level 3 to 5, in which the driver may or may not release the steering wheel at some moment during driving. Currently there are vehicles on the market that reach levels 3, and a large number of prototypes or concept cars for level 4 and 5 of autonomy, examples are Volvo 360c Concept, BMW Vision next 100, Mercedes Benz f 015 luxury, and all models of Tesla. At these levels the presence of the driver is necessary to a greater or lesser extent. In level 3 the driver is needed when driving is not in a controlled environment such as a highway, and in level 4 it is only needed when the on-board computer is not able to solve certain situations while for example driving in a metropolitan area. Research is underway and there are already prototypes for level 5, in which the steering wheel disappears and all driving is handed over to the vehicle itself (Volvo 360c, Google Waymo).

That is why the study of the interior ergonomics of the vehicles will be a very important point in the future, since the drivers will disappear and will have an enclosed space in which they will have to move around comfortably to perform other non-driving tasks as can be seen in prototypes such as the one in figure 2.1



*Figure 2.1 Interior of Volvo 360c*

## 2.2 CAE software in the automotive world.

For the development of this project it has been necessary to use a CAE software. CAE is the acronym for Computer Aided Engineering. CAE software is based on models previously created by CAD (Computer Aided Design) software, to carry out simulations and improve the design or design process. Later, once validated the final detailed design of the product it is possible to use a software CAM (Computer Aided Manufacturing) to optimize the manufacture by automated processes through the use of CNC machines (computer numerical control).

It is a very useful tool nowadays to optimize and validate products. As Vasiljević et al. (2018) maintain, the use of this type of software within the automotive industry is diverse and with several applications. The diversity and specialization of CAE software is huge. Every engineer calculation has some CAE software that helps to facilitate the task. Exercises such as structure calculations, analytical study of parts, calculation of aerodynamics, study of ergonomics, etc., are currently solved by engineers with CAE software such as ANSYS, SolidWorks, IPS, Inventor, NX, Catia, etc.

As supported by some authors, the use of CAE software in the automotive industry is highly beneficial (Högberg et al., 2019). It saves design time, and provides a better way to objectively check the model, and to test several models quickly by means of digital modifications without the need to create real physical models, which also reduces costs. This is how virtual laboratories appear, with online databases, accessible to everyone at all times, and which replace traditional physical testing laboratories that require specialized, bulky and expensive equipment opposed to software CAE (Reischl and Harris, 2013). In vehicle development, the use of CAE software, as explained by Vasiljević and et al. (2018), improves the coordination of the project, allowing the design team to quickly share and visualize technical documentation and simulations on different models. It allows at a minimum cost to study several designs or elements of the same design in different conditions. It is possible to find faults in the design at a very high level of detail.

It is also worth mentioning that testing with Virtual Reality (VR) designs and Gravity Sketch, ANSYS OPTIS (Wong, 2017) or HTC VIVE technology ("BMW uses the HTC Vive to design new vehicles," n.d.), is becoming more prevalent and plays a very important role (Laizerowitch and Reyes, 2019). Even so, they currently combine basic physical models with augmented reality technology as shown in Figure 2.2, which allows them to obtain a vision of where all the interior elements of the vehicle will be and whether they are accessible at first glance.





*Figure 2.2 OPTIS VR lets Bentley Motors conduct ergonomic tests on virtual vehicle models*

The aim is to increase the efficiency of the design and design process by using these software tools while minimizing resources. Although they are not perfect, they continue to be developed and to solve the problems that make it difficult to use a physical model as a study method.

### **2.3 Ergonomics in the automotive world.**

As mentioned by Bhise (2011) the application of Ergonomics helps to obtain functionally superior designs, helps to prevent costly redesigns and loss of time. Ergonomics helps to differentiate any design from an outstanding design. The figure of the driver takes special attention within the interior design of the vehicle. Ergonomics, as a science that studies the adaptations of the workplace, machine or tool, is applied inside the vehicle to ensure correct driving. The interior of the vehicle requires a detailed study to ensure that every user achieves optimum comfort. The driver's workspace (steering wheel, pedals, mirrors, gear shift, etc.) becomes an extension of the user. The sitting position becomes the fundamental study position, which with research such as that Dempster in the book *Space requirements of the seated operator* (1955) established the foundations for with the study of musculoskeletal angles and capable efforts of the human body.

As can be seen and as Marek and Siebertz (2014) say, it is necessary to know the users well in order to develop a good ergonomics evaluation method, beyond their personal tastes. Anthropometric diversity (body dimensions, physical constitution, cognitive skills) is contemplated by manufacturers, and products are designed for the majority, i.e. taking into account the different users in the population. In addition, each market has its own requirements for vehicle development, and although most are common, this is not always the case. That is why a tool that evaluates ergonomics while driving should be able to easily change both the user (manikin) and the evaluation model (design).



### 2.3.1 Digital Human Modelling (DHM).

For products where the end user is a human being, the use of DHM tools is essential. DHM tools encompasses and makes use of CAD and CAM. Already the object of analysis is a 3D model previously created in CAD software, which is displayed in relation to pre-set and sometimes configurable manikins (DHM) that can analyse ergonomics in simulations of manufacturing processes, CAM. These tools developed by experts in Mathematics, Ergonomics and Engineering use digital models of humans called manikins capable of interacting with the products digitally and evaluate the ergonomics in the virtual development process. The study of driving can be carried out by means of a simulation assisted by CAE software, since the entire population can be evaluated using families of mannequins, quickly and objectively by interacting with different models. As mentioned by Yang et al. (2019), it is important for the automotive industry to be able to perform long driving simulations and non-driving tasks (eating, texting, talking, relaxing, etc.). These activities will gain importance with the increasingly automated vehicles. For the development of the driving test based on a DHM tool, the structure proposed by Högberg et al. (2019) (figure 2.3) and will be a foundation for the conceptual solution proposed within the research project ADOPTIVE (Brolin, E., 2019). In this study and as mentioned previously, it will focus on two of the four sections proposed in the Structure of the main components of a DHM based test procedure: Test Tasks and Design Geometry.

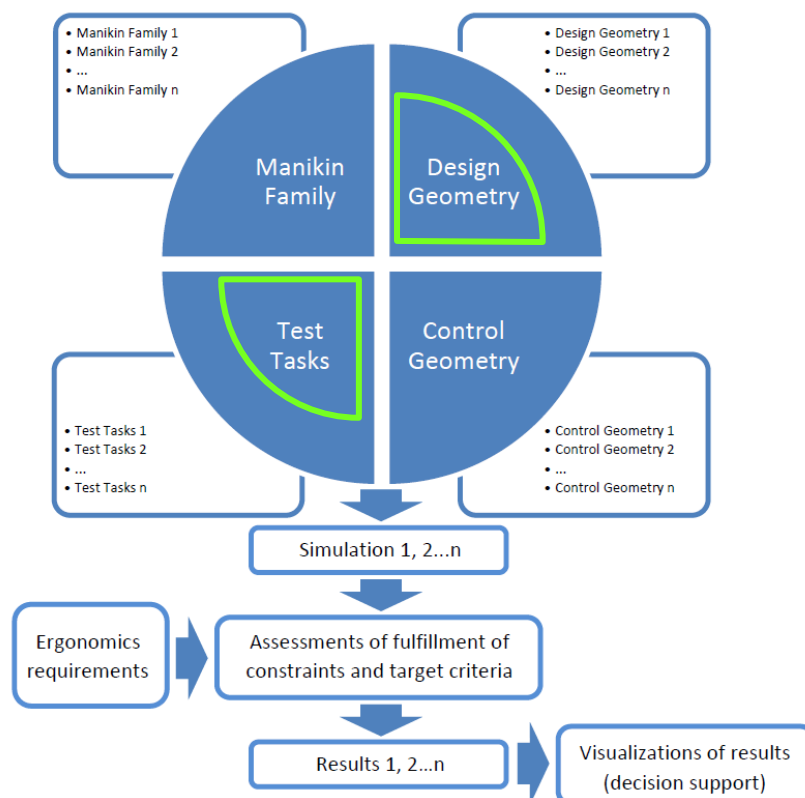


Figure 2.3 Structure of the main components of the DHM based test procedure(Högberg et al., 2019)

For Högberg et al. (2019) the driving test from the point of view of tasks would initially consist of primary tasks from an ergonomic point of view (changing gears, reaching the steering wheel, turning the wheel, looking at the rear-view mirror). At a more advanced level, the manikins would perform these primary tasks combined in a longer virtual test route. This would give the possibility to generate a standardised task list by the company, following the Lean Product Development (LPD) philosophy by studying the tasks of interest to the company and the possibility to use their own standards for evaluation. A personalized study in which only the aspects of interest for the company in particular appear, and not a generic analysis in which not everything is useful.

The demands of the automotive companies are that the driving tests be efficient and objective. The results must be the same or very similar regardless of who uses the tool. The tasks will be defined based on a study of a specific test circuit, and must be performed by the manikins to obtain a result. The result of the simulation should not change if the tasks do not change. The Design Geometry segment will be in charge of the different designs to be evaluated. Changing the design will mean that the manikins will perform the tasks with a new design and get new results.

Since the objective is to generate a driving test only one default manikin will be used in the first section Manikin Family. In the section Test Tasks, the tasks carried out by a human in a circuit representative of driving will be investigated, this section is developed in point 3.2 Driving routine creation in IPS IMMA. The Design Geometry section contains the different designs with which the manikins will have to interact, these will be the interior of the Volvo S90 and the two-position steering wheel obtained at the end of the design development, from point 3.1.7 CAD Model. Finally, the Control Geometry section will be those elements of the environment that are not changed between the simulations and consists of already defined geometries.

### **2.3.2 IPS IMMA.**

A DHM tool that meets the requirements described in the previous section is the IPS IMMA software, which will be used for the development of the virtual driving test of this project. IPS, which stands for Industrial Path Solutions and is a “mathematically based software tool for automatic verification of assembly feasibility, flexible component design, motion planning and optimization of multi-robot stations, and simulation of key surface treatment processes” (“Industrial Path Solutions–Fraunhofer-Chalmers Centre,” n.d.). The IPS software has several tools, including Path Planner, Cable Simulation, Robot Optimization, Virtual Paint, IBOFLOW and IMMA.

IPS Intelligently Moving Manikin (IMMA) is focused on optimizing the assembly of vehicles by planning routes managed by an ergonomics tool that allows to detect musculoskeletal and joint problems that could suffer the worker, represented here by a manikin or family of manikins. Also, due to the functions that the software has, it can be used in a satisfactory way for the driver-vehicle ergonomic study, being able to evaluate the interior design of the vehicle (“IPS IMMA – Centro Fraunhofer-Chalmers,” n.d.). Therefore, this software will be used to carry out the test drive of this project. Some of the functions and tools that

allow fast and objective assessments of driving test routines, and comparisons of different design scenarios(Hanson et al., 2019) are:

- Grip library: The library has different grips for the hands of the manikin that facilitate the simulations and the manipulation of the manikin.
- Editor sequence: When instructing the manikin, the sequence editor helps to organize the elements and actions involved in the simulation.
- Automatic evaluation of ergonomics: IPS-IMMA has several methods of evaluation of ergonomics and specific methods of evaluation. One example is the Rapid Upper Limb Assessment (RULA), which creates value for companies that have their own ergonomic evaluation methods, such as Scania with Scania Ergonomic Standard (SES). It also consists of analyses of forces and torsions at the joints of the manikins, as well as compression and shear forces of the spine, showing unsuitable actions according to the National Institute for Occupational Safety and Health (NIOSH).
- Vision analysis: the program can display the first-person view of the manikin on the screen, allowing for evaluation of the manikin's vision. This tool can be very useful when locating elements on the dashboard, and the correct visualization of the rear-view mirrors.
- Manikin family library: has a library of manikins updated with the anthropometric measurements of any population and the possibility of configuring families of manikins to the preferences of the company to focus on their target audience.

Therefore, these tools can also be used to specify ergonomic requirements (constraints and target criteria), by being able to carry out evaluations of the ergonomics in the design.

### 2.3.3 Advantages of using DHM.

As Högberg et al. (2019) mention the development of processes based on DHM tools follow the LPD philosophy. The Lean philosophy focuses on reducing waste and generating value for the customer, meaning "value is what the customer is willing to pay for". To do this, the design process is reviewed from the beginning, establishing a continuous flow called Value Stream Mapping (VSM) that reveals the links in the development chain that can be improved (Faulkner and Badurdeen, 2014). So, by implementing DHM tools in the early stages of design, costs can be reduced, in materials or in efficient processes, and safe but outdated procedures can be set aside. When applied to automotive design, cost reduction is shown in the possibility of analysing designs without the need for a physical real model/prototype, which involves investment of time, personnel and material. In virtual worlds and with a CAD model, these DHM tools can evaluate and compare different designs and make it easier for the engineer or ergonomist to make the right choice, helping engineers to ensure that the elements being designed meet user requirements relating to safety, ergonomics, user experience and other user-centred aspects (Högberg et al., 2019).

DHM tools also reduce the number of people needed to carry out ergonomic tests. These tools contain families of manikins that replace any human population covering any anthropometric model. So, if there are not enough real representatives or it makes the design development process more expensive and slower, this tool makes the task easier. It generates value for the company by

being able to select only specific groups of the population in which it is interested.

The ease, efficiency and objectivity of iteratively testing different designs is another advantage over traditional methods. With DHM tools the engineer or ergonomist takes control of the user, in this case represented by a manikin, being able to control the tasks that are the object of study. Even if the last check is done with the final physical model, the implementation of these tools in the early stages of the design process can help to reduce costs by preventing future user-product problems when performing the study prior to the physical creation of the product.

### 3 Generation of driving test routine and steering wheel design

This section describes the development of the driving test routine. Then, the conceptual design of the two-position steering wheel, following a methodology and attending to some requirements is developed and integrated in the driving test routine to obtain a final result.

#### 3.1 Driving test routine creation in IPS IMMA.

In this section, the necessary tasks will be created in IPS IMMA so that a driving test routine can be generated to evaluate the ergonomics of the interior vehicle design. For this purpose, the movements during driving in a proposed circuit will be studied in detail, and a flowchart will be generated that could be used to automate the simulation using Lua script (Skyrme et al., 2008). During this process the problems or limitations, of the IPS-IMMA tool, that have been found will be named in detail to be able to solve them in the future. The objective to follow is to obtain comparable results to evaluate different design proposals, regardless of who uses the tool or when.

The objective of simulating driving tasks as a human would do, as advocated by Högberg et al. (2019), is to take into account critical efforts and movements when evaluating different design proposals. To support quality and efficiency, DHM-based testing should have a functionality to easily evaluate and compare various proposals, following the LPD philosophy, generating stable and objective processes for companies. The simplified structure that have been suggested in previous literature (Högberg et al., 2019), and that this project will follow, for the realization of a DHM-based test is as follows:

Define manikin families → Define manikin tasks → Predict manikin movements → Visualize ergonomics assessment simulations → Results

##### 3.1.1 Circuit study

For the realization of this study the following circuit in the city of Skövde is proposed (figure 3.1). A circuit is chosen that is large enough to contemplate most actions during driving. From it, key points with the main tasks are identified and extracted, to be generated later in the software and to be able to reorganize them according to the needs of the final user (figure 3.2). Starting from a real circuit the study will be more accurate to the driving than generating the tasks separately. Performing a detailed study of real driving will serve to obtain useful information on how to perform the simulations. Taking into account all the actions that the driver has to do in real driving, the time or speed of the actions, the correct order, etc, will facilitate the creation of the simulations so that the manikin performs the tasks correctly in the software.

As mentioned above, this project is being developed to collaborate with the ADOPTIVE project, which is preceded by the VD and VDE projects. Findings from those projects showed the need to create a driving test on a real circuit. Therefore, the circuit proposed below was validated by a member of the ADOPTIVE project team to carry out the study of the tasks.



## Proposed circuit



Figure 3.1 Google Maps capture in Satellite view

## Key points with main tasks



Figure 3.2 Screenshot of Google Maps edited with keypoints

Following the numerical order of the key points, the main tasks to develop and take into account are:

- Adjust vehicle environment. (point 1) (not to be included in this study)
- Start vehicle (point 1) and go to point 2.
- Approach to the traffic light at point 2. (two options)
- Turn left to enter the lane at point 4.

- Acceleration in point 4.
- Bus stop, possible overtaking.
- Approach to roundabout incorporation.
- Incorporation to roundabout.
- Approach to roundabout exit.
- Take the roundabout exit to point 10.
- Turn left to get to point 12.
- Linear drive section.
- Turn left to get to point 13.
- Final point, arrival at destination, stop.

These tasks are a starting point for the detailed study of driving. The next step is to break these tasks down into sub-tasks, which are simpler tasks that can be carried out by a manikin.

### 3.1.2 Task list breakdown.

A breakdown of the actions and tasks that are necessary to carry out the driving in the most detailed way was made.

This structure was followed:

+Main task

-Subtasks

\_needs to perform the task

=target of the task

This detailed breakdown was performed throughout the circuit, at all key points and also for any task that the manikin has to perform in order to carry out a correct drive. The total number of tasks is listed in Appendix 1.

### 3.1.3 Simulation of individual tasks in IPS IMMA

To start generating tasks in IPS IMMA a default manikin is created, and the interior model of a Volvo S90 is imported. The manikin is adapted to the driving position using attach points. Those used for this study will be the balls of the feet, Hip-centre and Lower Back. To define the position, some of them will have to be defined as support where the manikin can take up forces: the balls of the feet and the hip.

Next step is to generate different types of grip, in this case, cylinders for the steering wheel and spherical for the gear shift:

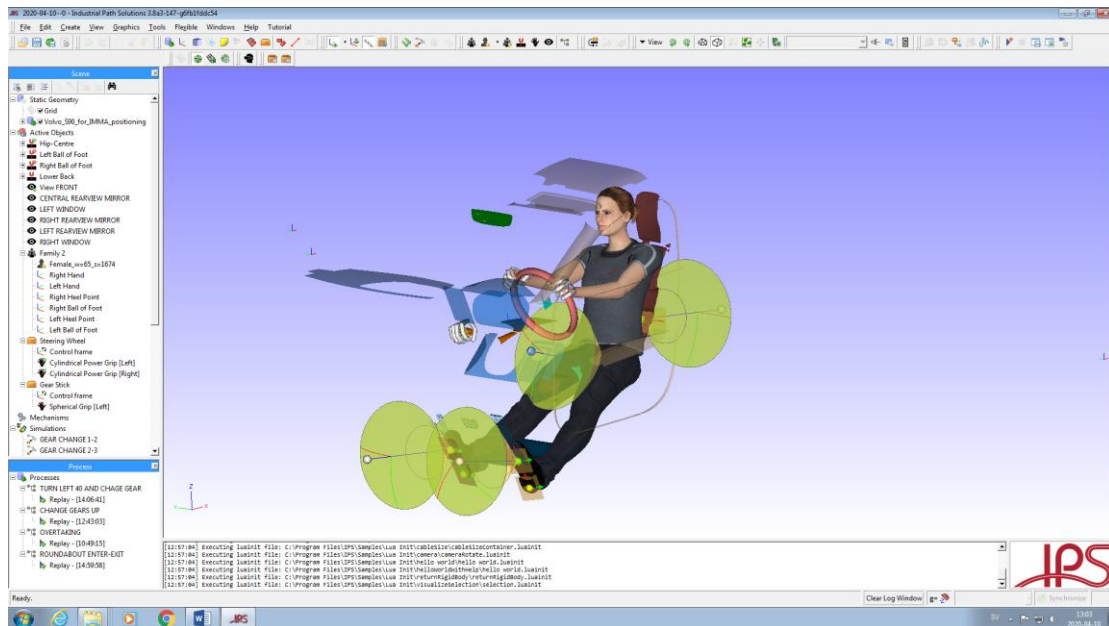


Figure 3.3 Completed sitting posture

Finally, in order to be able to generate the routine, the points of vision are placed via viewpoints. Those objects that will interact in the simulation, in this case the steering wheel and the gear shift, are made into rigid bodies.

To start generating final tasks in the "sequence of operations", it is necessary to first do the sub-tasks with "create motion". With this software tool it is possible to generate movements or controlled paths of the objects previously defined as a rigid body. To do this it is necessary to add one by one the positions through which the objects pass or adopt. For example: to turn the steering wheel, the steering wheel is selected, the "create motion" function is started, the steering wheel is turned to the desired final position and selected as a step. The program will generate a simulation of the rotation, in a smooth way, until the selected end position is reached. If another position is added within the same simulation, it will be taken to the new desired position where the object is and it will be selected as a new step.



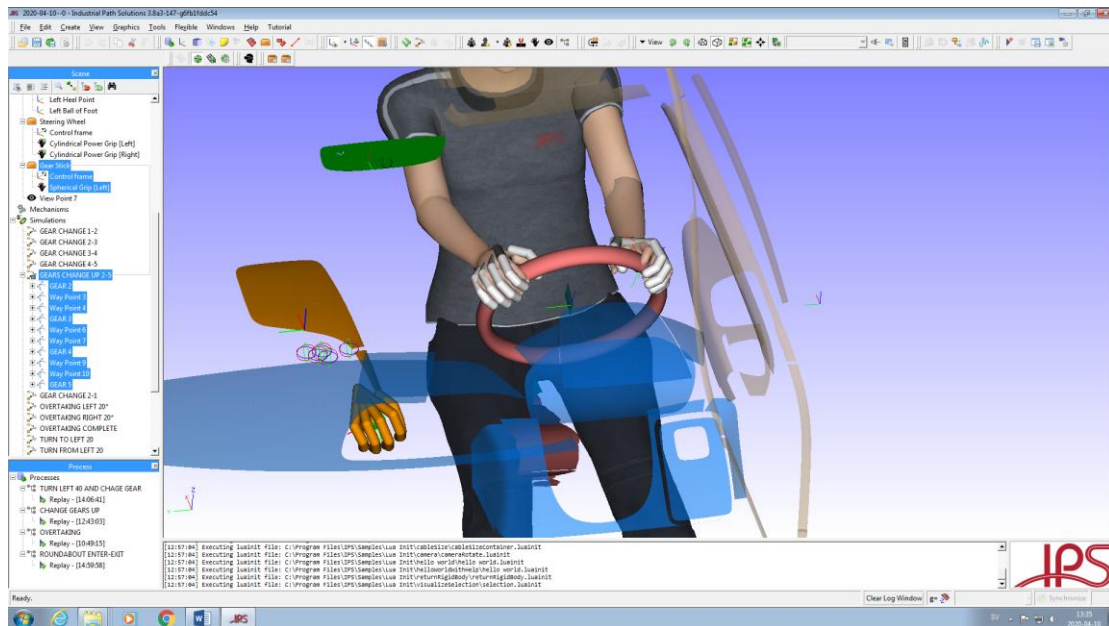


Figure 3.4 Completed “gear change” simulations

The tasks are created as detailed as possible, so that the study is always as accurate as possible. This will also require adjusting the speed of actions and delays for movements. Once the simulations have been created, the operation sequence is carried out. For this purpose, the manikin and the rigid bodies that will be used in the simulation are added. Actions of what to do with each of the operands are placed sequentially and correctly so that the whole simulation is continuous and real.

For example: To grab the gearshift, first release the steering wheel grip. And to turn the wheel again, you have to release the gearshift, grab the wheel and add the sub-task generated in the simulations. The beginning and end of the operation must be located and defined for the correct operation. It is also necessary to take into consideration the points of view and to take everything in such a way that it is fluid, considering the timing of each operation.

This means that the analysis previous to the driving has been detailed and meticulous so that the simulation is correct. To test the possibility of performing long simulations, an operation sequence was generated in which the manikin performs all the tasks necessary to enter and exit a roundabout. This means that previously created tasks, turns of different degrees and in different directions, gear changes and visualization operations were combined in the same simulation.

The operation sequence generated has been the following:

- Turn left 40 and change gear
- Change gears up
- Overtaking
- Roundabout enter-exit

### 3.1.4 Analysis and flowchart for creating a driving test routine




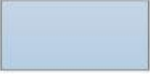

One of the problems that appears when doing the previously mentioned process is once a simulation is created, it cannot be fragmented. An example is steering wheel rotation. In real driving, turning has a beginning and an end in which the steering wheel ends in its initial position before the turn. If another action was

desired in the middle of the turn, it would not be possible, so it was necessary to create sub-tasks in which the turn is carried out, and another complementary one in which the turn is undone. This allowed to make a driving simulation more faithful to reality. Based on the analysis of the selected circuit a number of recurring tasks could be identified. These smaller tasks can in different ways be put together to generate longer driving sequences. The list of tasks needed for the study, has been the following:

- Gear Change 1-2
- Gear change 2-3
- Gear change 3-4
- Gear change 4-5
- Gear change up 2-5
- Gear change 2-1
- Overtaking left 20°
- Overtaking right 20°
- Overtaking complete
- Turn to left 20°
- Turn from left 20°
- Turn to right 20°
- Turn from right 20°
- Turn to left 40°
- Turn from left 40°
- Turn to right 40°
- Turn from right 40°
- Turn left and back 40°
- Turn right and back 40°

Although in the circuit almost all the turns are to the left, the analysis was carried out in a symmetrical way, all the necessary left turns in the circuit have their homologues in the right direction. In this way, future needs or demands are covered when generating a personalized test by the companies and end users of the tool.

To automate the process of creating a simulation in the IMMA tool the idea is to generate an interface in which the user is guided and asked to enter relevant data to create a simulation. Such interface, if kept relatively simple can be generated through Lua-script code that executes the interface and handles the input and generate a simulation as output. Before writing the code, a flow chart is developed. A flow chart is a tool used to facilitate the understanding of a process. A diagram visually describes all the steps that a task or process goes through. Within the flow diagrams there are different symbolic representations (ovals, rectangles, rhombuses, rhomboid, etc) that vary according to their meaning (terminal, process, decision, data input/output, etc.)

Symbol	Name	Function
	Start/end	An oval represents a start or end point
	Arrows	A line is a connector that shows relationships between the representative shapes
	Input/Output	A parallelogram represents input or output
	Process	A rectangle represents a process
	Decision	A diamond indicates a decision

*Figure 3.5 Flowchart Symbols*

The proposed flow chart for task generation is as follows:

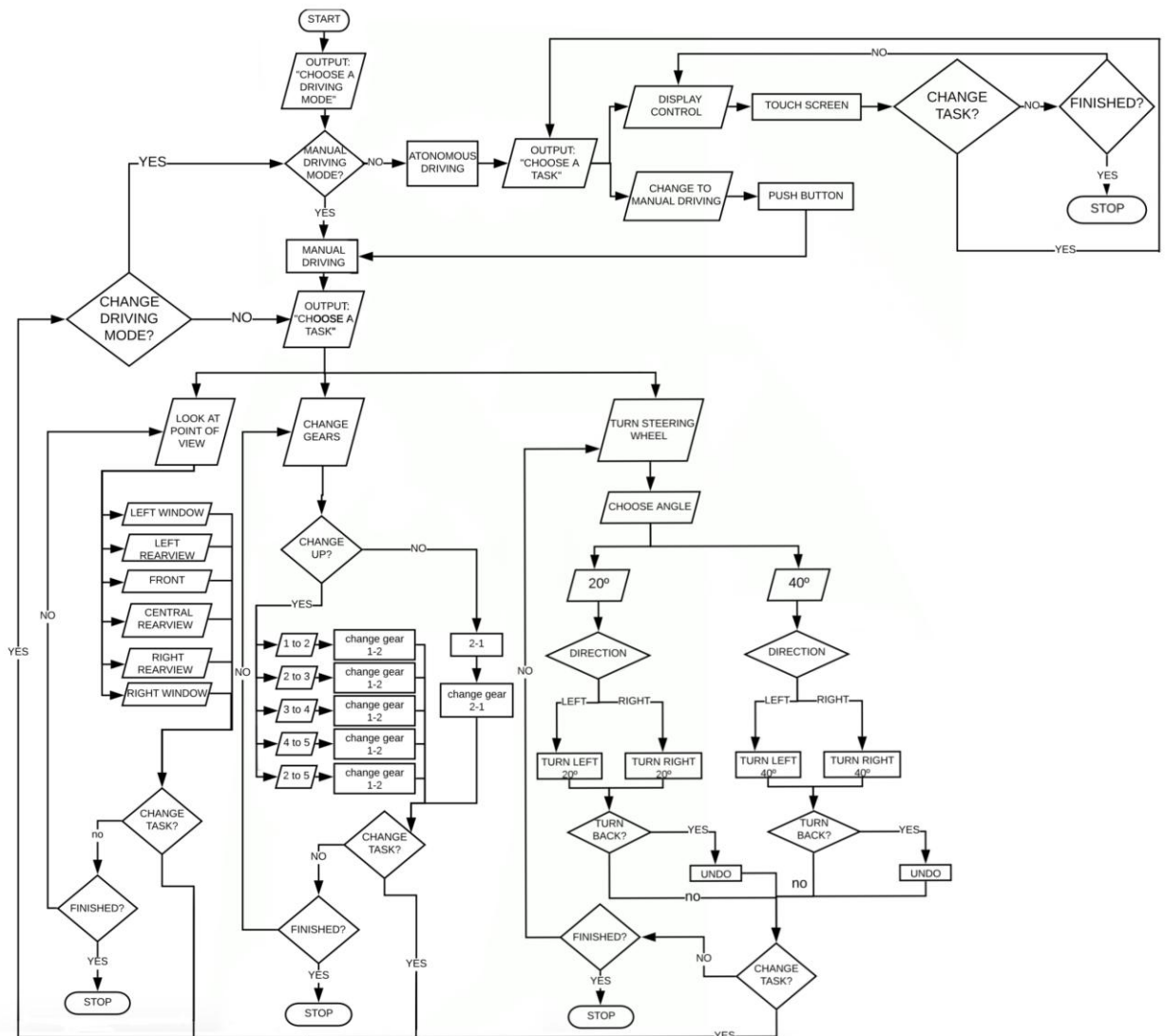


Figure 3.6 Flowchart to create the interface using Lua-script

As it is shown in the part of the choice of driving mode, the user is asked to introduce the first task. The tasks for driving manually are divided into three groups: looking at a point, changing gears, turning the wheel. Depending on the task, the user is asked to enter the corresponding data and concludes with the three options: a new command within the same task, change of task and finally, end the process.

In the case of autonomous driving only two tasks are presented, changing driving mode and touching the screen, since the vehicle in autonomous mode is controlled or configured entirely through the screen. In case the user wants to change to another driving mode in the middle of the simulation, the option is added after "new task". After completing each task, the previously created tasks will be added to the simulation. The study of the flowchart that was initially carried out can be found in the appendix 3: Flowcharts for driving tasks.

### 3.1.5 Interface for creating a driving test routine

The suggested flowchart could then be demonstrated with an interface generated through Lua-script code. The interface handles the input and is intended to generate a simulation as output but that part of the interface have not been finalized. The interface obtained and the process of a turn with the steering wheel are demonstrated in figure 3.7-3.12.

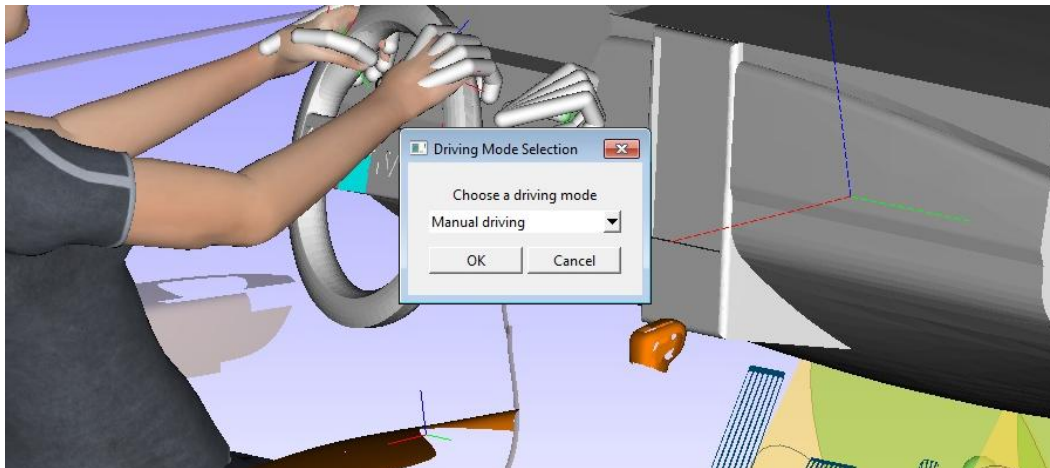


Figure 3.7 Start of the interface

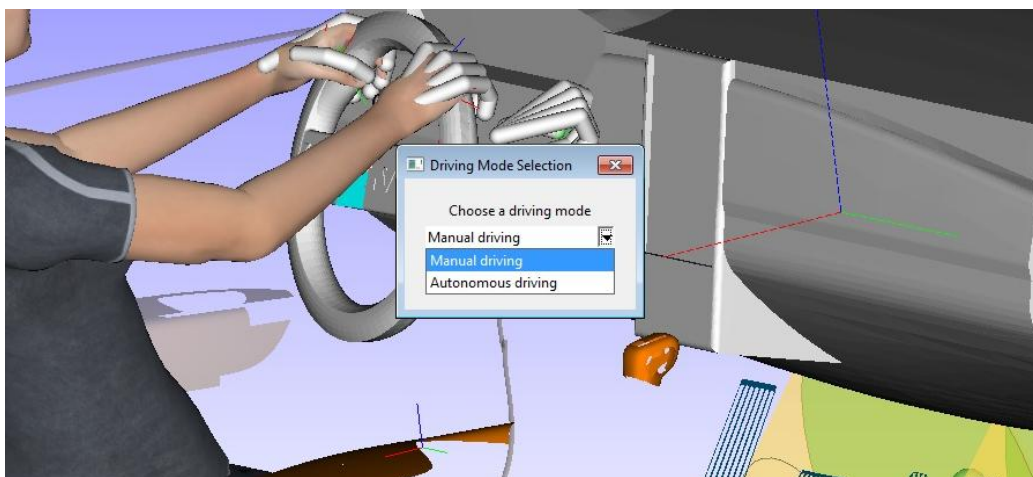
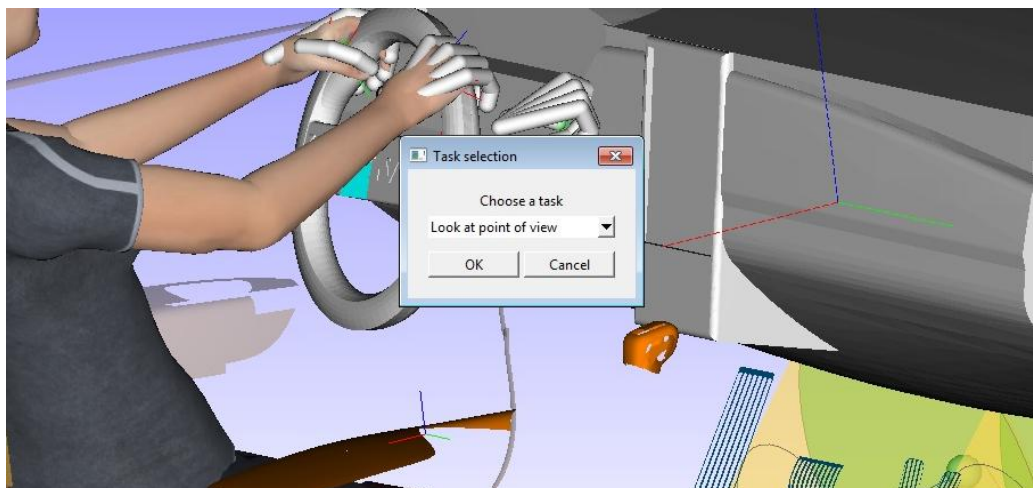
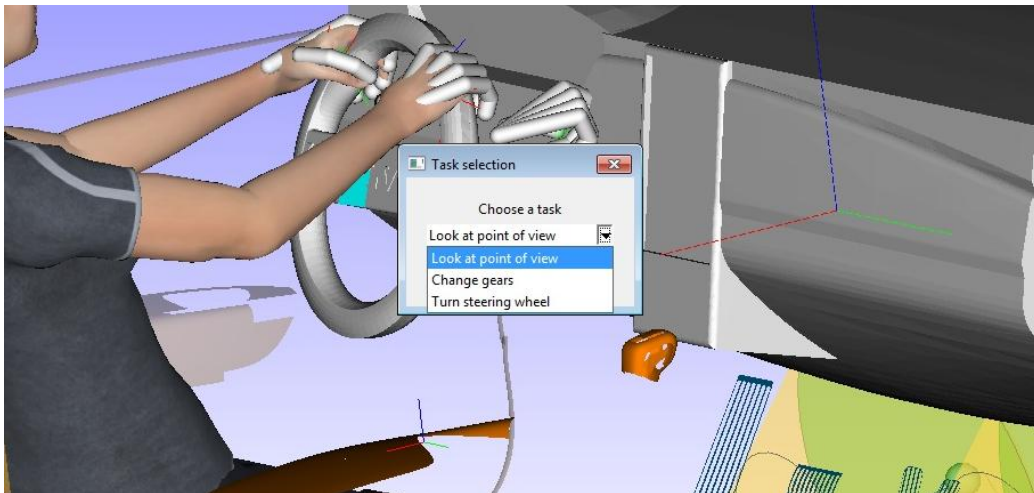


Figure 3.8 Drop-down list with driving modes

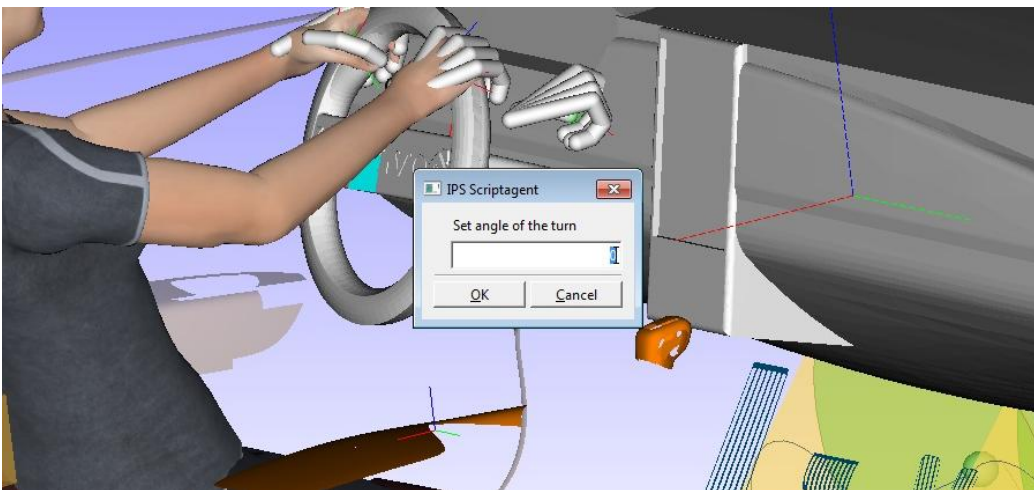




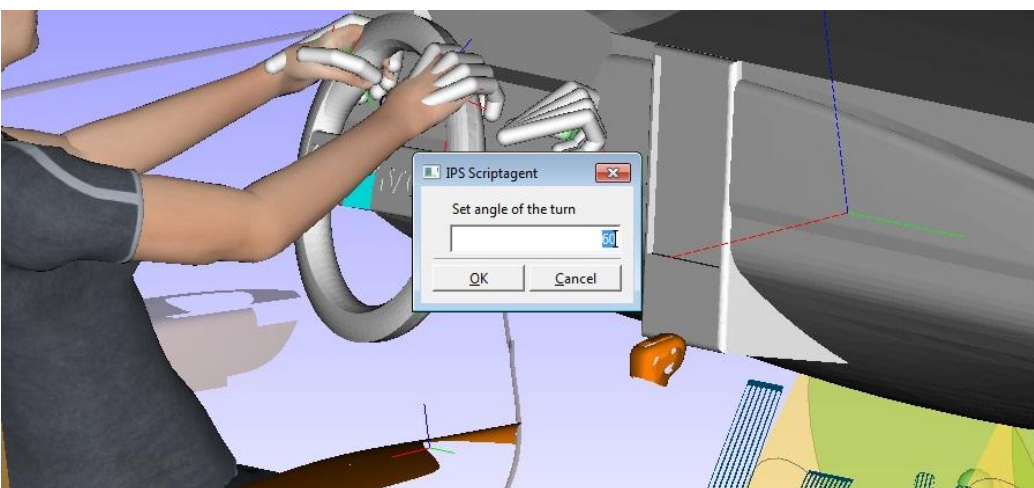
*Figure 3.9 Next window with tasks selection*



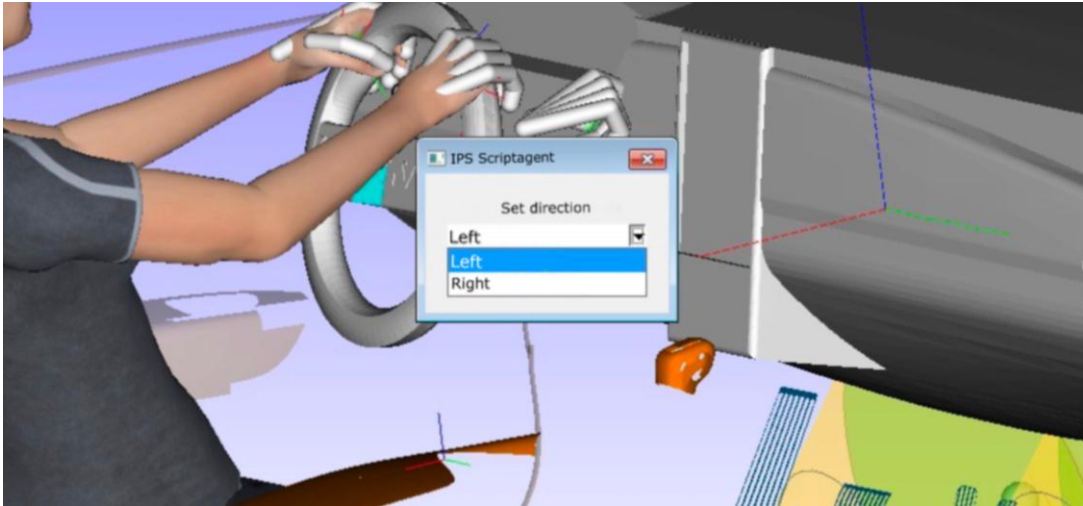
*Figure 3.10 Drop-down list with tasks options*



*Figure 3.11 Selected task: turn the steering wheel*



*Figure 3.12 Selecting the angle for the task*



*Figure 3.13 Selecting the direction for the task*

### **3.2 The steering wheel development.**

In this section, a conceptual model of a steering wheel for an autonomous vehicle will be developed. The intention of this design is to demonstrate the easy and quick replacement of the different CAD models to perform the driving test in the IPS IMMA. The development described in point 1.5 Project implementation and according to figure 3.14 will be followed. The process, based on the methodology proposed by French (1992), "The Anatomy of Design" shares some of the initial phases of the design process, but since this is only an example of use, the design process will not be complete. The aim will be to obtain a three-dimensional model, according to some requirements and specifications. The different stages will be refined from the sketch phase, through the development of details, to the 3D model and its import into IPS IMMA.



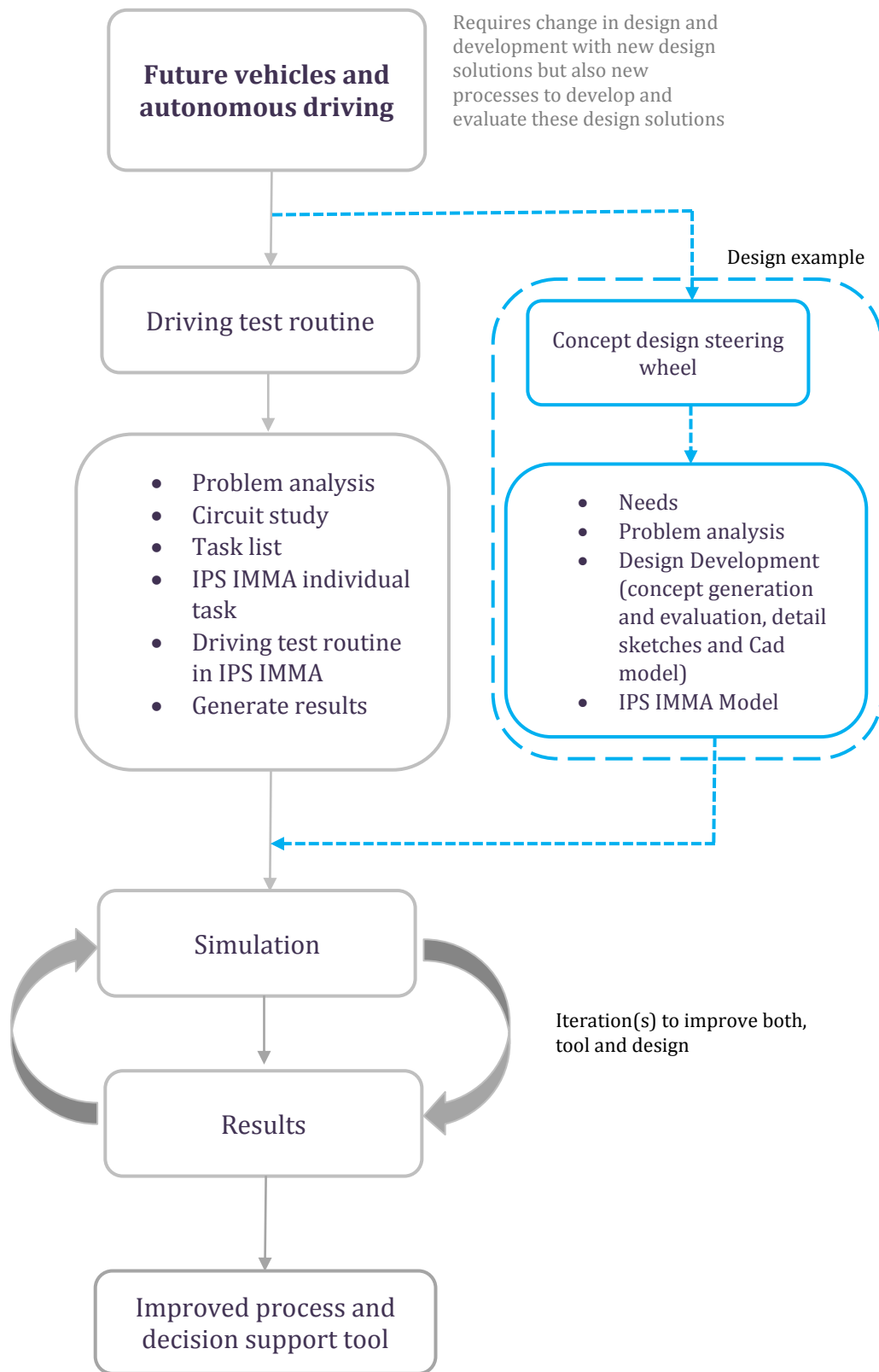


Figure 1.2 Process Connection

### 3.2.1 Needs.

The objective proposed for this part of the project will be to design a steering wheel for a high autonomy vehicle (level 4 of autonomy). The steering wheel will

only be necessary for those occasional situations in which the vehicle's on-board computer is not capable of solving some situation. Based on this concept, it is proposed that, for greater driver comfort inside the vehicle's cabin, the steering wheel should be integrated or hidden in the dashboard during autonomous driving, since it will spend most of the time in the background with no function. Examples of this type of retractable steering wheel are the steering wheels of the Vision Next 100 concept car that BMW released in 2016, the 2017 Nissan IMx, the Nissan IDS, the three Volkswagen ID, ID Buzz and ID Crozz, Volvo C26, among others.



*Figure 3.15 Volkswagen ID Crozz Steering Wheel*

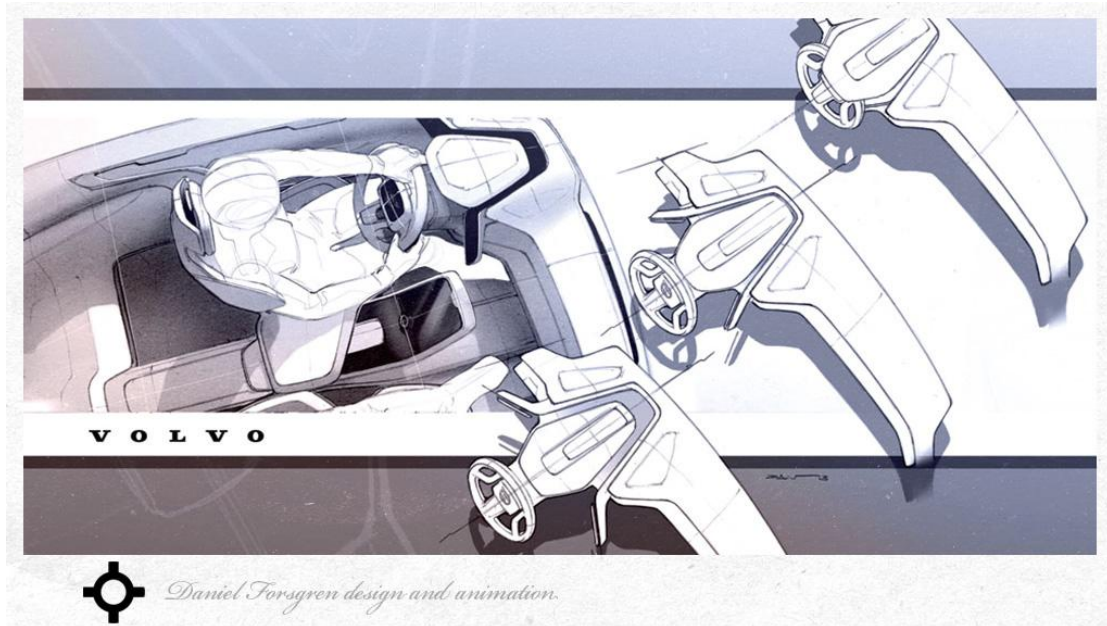


*Figure 3.16 Nissan IDS steering wheel (autonomous-manual position)*





*Figure 3.17 BMW Vision Next 100 Steering Wheel (autonomous-manual position)*



*Figure 3.18 Volvo C26 Steering wheel*

In 2015, Volvo launched its Volvo C 26 concept car, which had an ejection steering wheel designed for a manual and autonomous driving vehicle. The design of the steering wheel remained almost unchanged from current Volvo models, very similar to the Volvo s90 steering wheel. When the vehicle goes into autonomous mode, the steering wheel is retracted, integrated into the dashboard, and the interior of the vehicle is reconfigured for greater comfort and freedom of users. This follows the description by Marek and Siebertz (2014), which maintain that in automotive design, designs normally evolve from a reconfiguration or slight alteration of a previous product. Since the model that has been worked with to create the routines in IPS IMMA has been a Volvo, and one of the main partners of the ADOPTIVE project is Volvo Cars, the conceptual design of the new steering wheel will be a steering wheel for a future Volvo car, and as described by Marek and Siebertz (2014), it will have to maintain a relationship with its predecessors.

### 3.2.2 Problem analysis and statement

Establishing a list with measurable specifications serves to set a goal, meeting the specifications will result in meeting the associated needs of customers. For the list of specifications of the steering wheel, a market study or evaluative comparison has been carried out on the steering wheels of concept cars that some firms indicate as future autonomous. The specifications and their metrics are shown in Table 1 below. Some specifications are based on the market study carried out, which can be found in Appendix 4. Others, such as number 3, Ergonomic shape/grip, are based on technical standards for quality assurance in industrial and scientific products, such as DIN standards. Specifically, DIN 33 402-2 (“Antropometria y Ergonomia - ERGONOMIA-Y,” n.d.) was used to determine the size of the grip.

While numbers 1 to 6 are requirements, numbers 7 and 8 represent hopes or aspirations.

#	Needs	Metric		
		Not ok	Good	Better
1	Dashboard integration/retractable	Does not integrate	Integrates	Almost disappears
2	Grip points	2 handles	>360 <sup>o</sup> grip	Grip 360 <sup>o</sup>
3	Ergonomic shape/grip	Grip size of <5 % and >95 % of the adult population	50 %	Adjustable grip size
4	Brand loyalty (logo/appearance)	Does not appear	Is identified with the brand	Logo appears
5	Easy driving mode change	Complex	Releasing 1 hand	Without releasing hands
6	Simplicity (number of mechanisms and buttons)	Too many buttons	Current model	Configurable buttons
7	Screen on the steering wheel	No screen	Display	Touch screen
8	Futuristic aspect	Old-fashioned	Current	Future

*Table 1. Specifications and metrics*

### 3.2.3 Conceptual design

The next point is to perform a brainstorming to generate different designs and evaluate them according to the specifications. As a result of the concept generation, 8 designs were obtained (figures from 3.19 to 3.22). In the sketches the main characteristics of each design are defined (bonuses, dashboard integration, fixed parts):



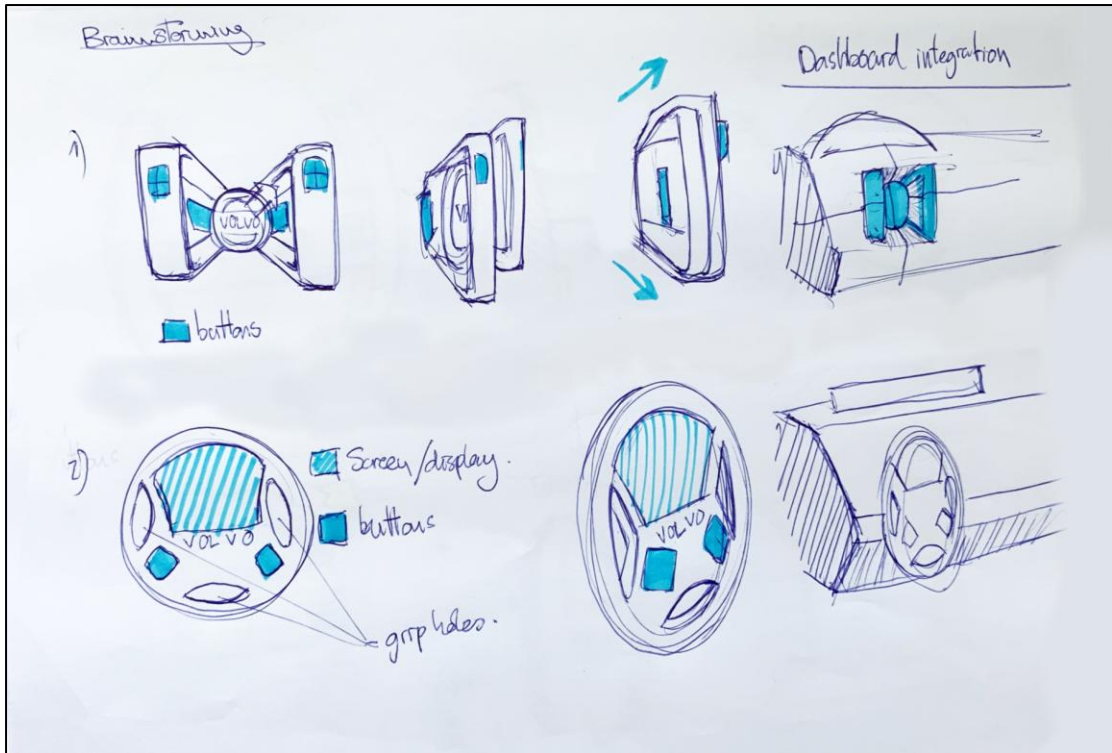


Figure 3.19 Concepts 1 and 2

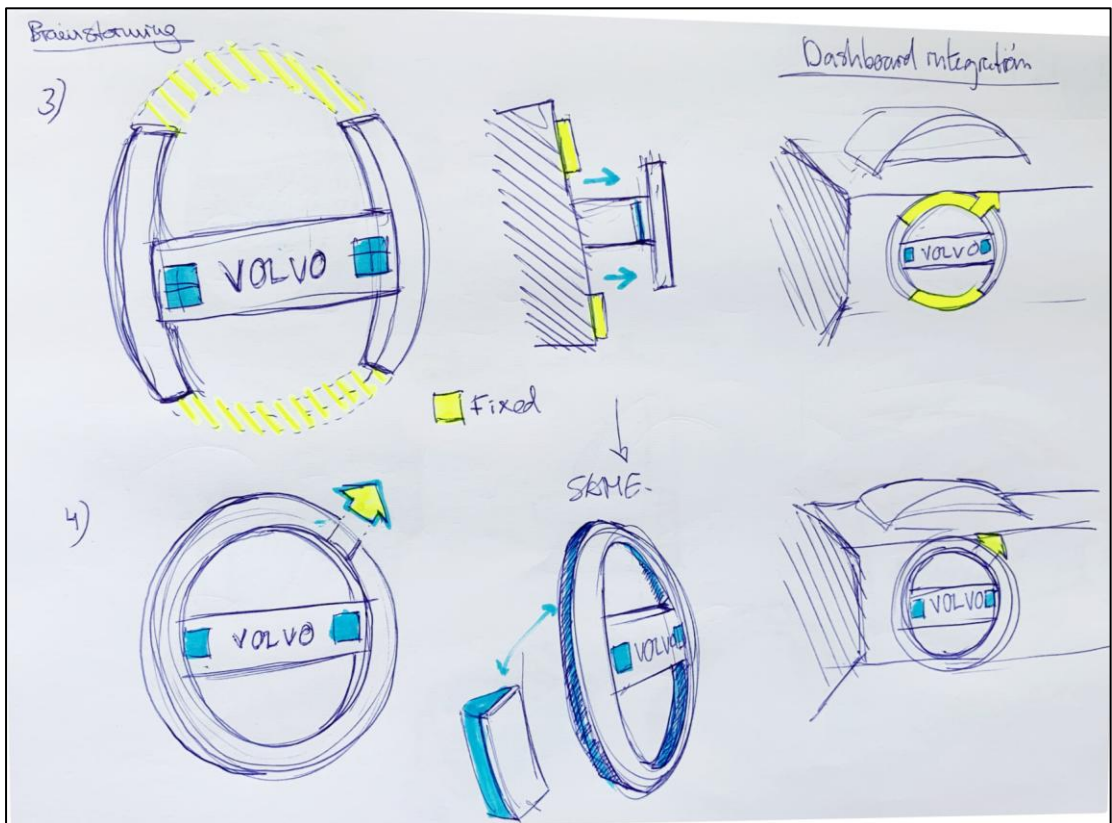


Figure 3.20 Concepts 3 and 4

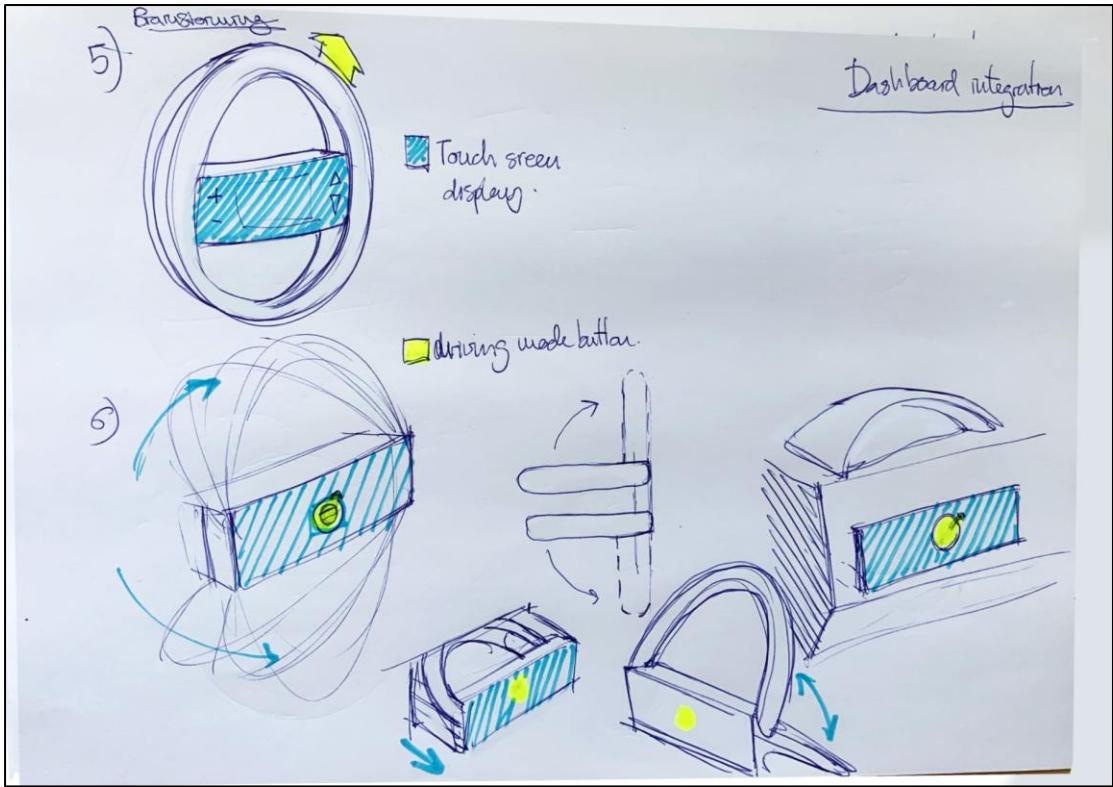


Figure 3.21 Concepts 5 and 6

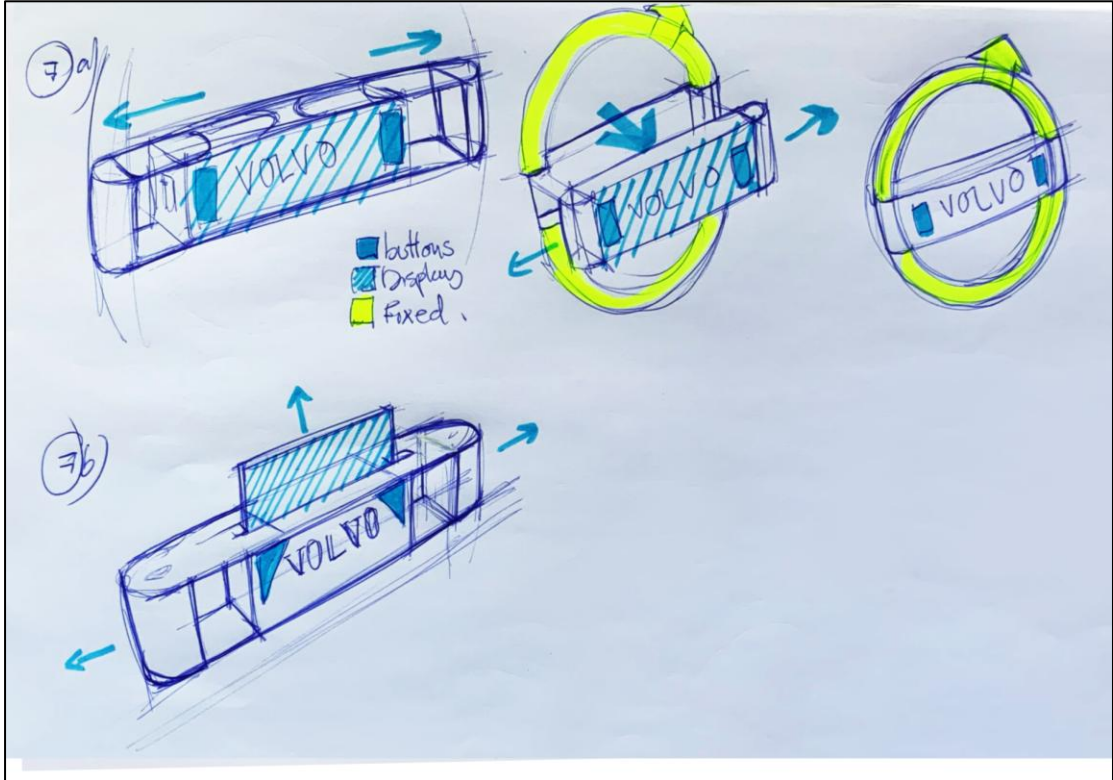


Figure 3.22 Concepts 7 and 8



### 3.2.4 Concept evaluation.

To select the best option, an evaluation of the designs is made in a Pugh matrix (Table 2). A Pugh matrix is a widely used method in design for the objective evaluation of various design options in a quantitative way (“Decision-matrix method,” 2020). The reference model was the Volvo C26 steering wheel (figure 3.18):

	Reference	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8
Retractable	0	0	0	0	0	0	0	0	0
Integrated in the dashboard	0	1	0	1	1	1	1	1	1
Ergonomic shape	0	-1	0	-1	0	0	0	-1	-1
Brand loyalty (logo/appearance)	0	-1	0	0	1	1	0	0	0
Easy driving mode change	0	0	0	0	0	0	0	0	0
Simplicity (number of mechanisms and buttons)	0	1	1	1	1	1	-1	1	1
Sum of +'s		2	1	2	3	3	1	2	2
Sum of 0's		2	5	3	3	3	4	3	3
Sum of -'s		2	0	1	0	0	1	1	1
Net score		0	1	1	3	3	0	1	1
Ranking		3	2	2	1	1	3	2	2

Table 2. Pugh's Decision-matrix.

The selected designs are design 4 and design 5. Since a single example model is sufficient to demonstrate the easy comparison of designs within IPS IMMA, and both designs are very similar, design 4 is chosen. As has been observed in the simulations of the driving tasks in IPS IMMA, one of the needs is the grip at different points of the steering wheel for the turning of 90°, which the design 5 does not facilitate.

### 3.2.5 Representation of the sketches

The next step is to define the concept a little more and this was done on the Volvo design concept. The next step is to further define the concept of the design 4. The parts of the steering wheel, the change of driving mode, the integration into the dashboard, and finally, if necessary in the future, possible relations with the instrument panel, and a provisional design of the buttons will be defined.

The steering wheel in its autonomous position is integrated into the dashboard, forming the current Volvo logo. Given its geometry, the adaptation to the steering wheel function is simple. By pressing a button, the arrow at the top right of the logo, the ring or circumference of the rest of the logo, expands to the natural position of a steering wheel inside the passenger compartment, Figure 3.23.

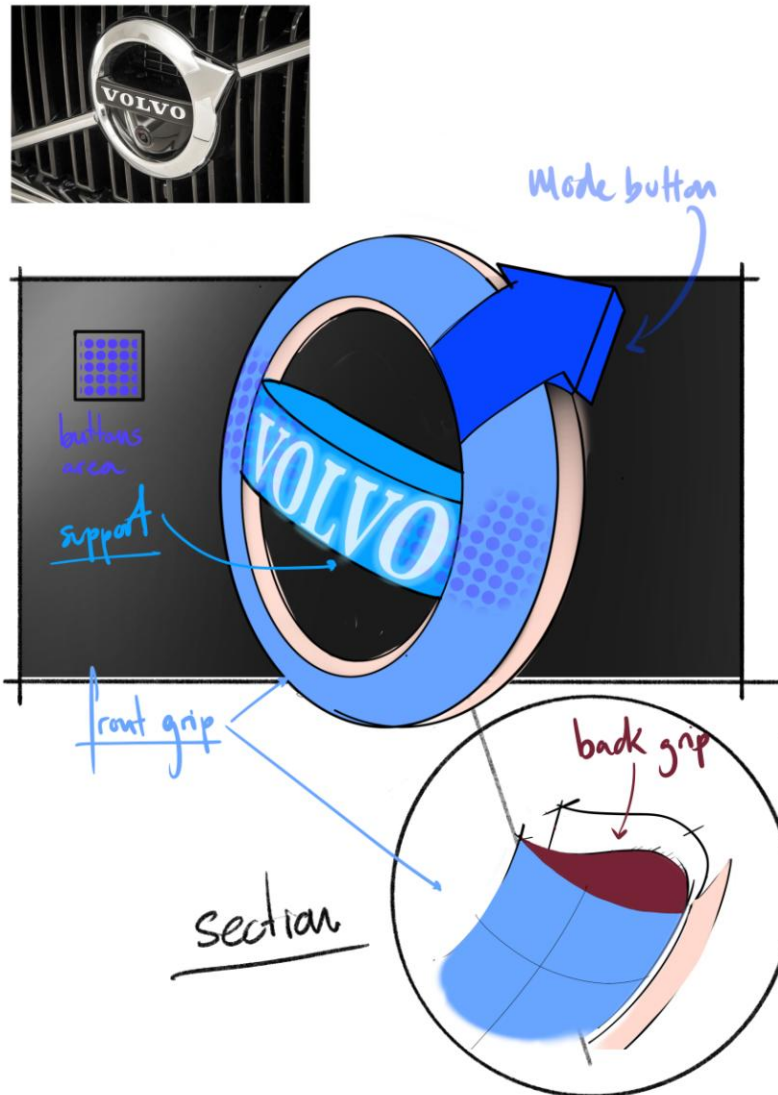


Figure 3.23 Volvo Idea Sketch

The following sketches define the movement and functioning of the steering wheel. As can be seen in the sketches, when the steering wheel switches to manual driving, it comes out perpendicular to the plane of the dashboard. The arrow button, which is part of the logo, stays integrated into the dashboard so that it does not get in the way of the steering wheel's grip.

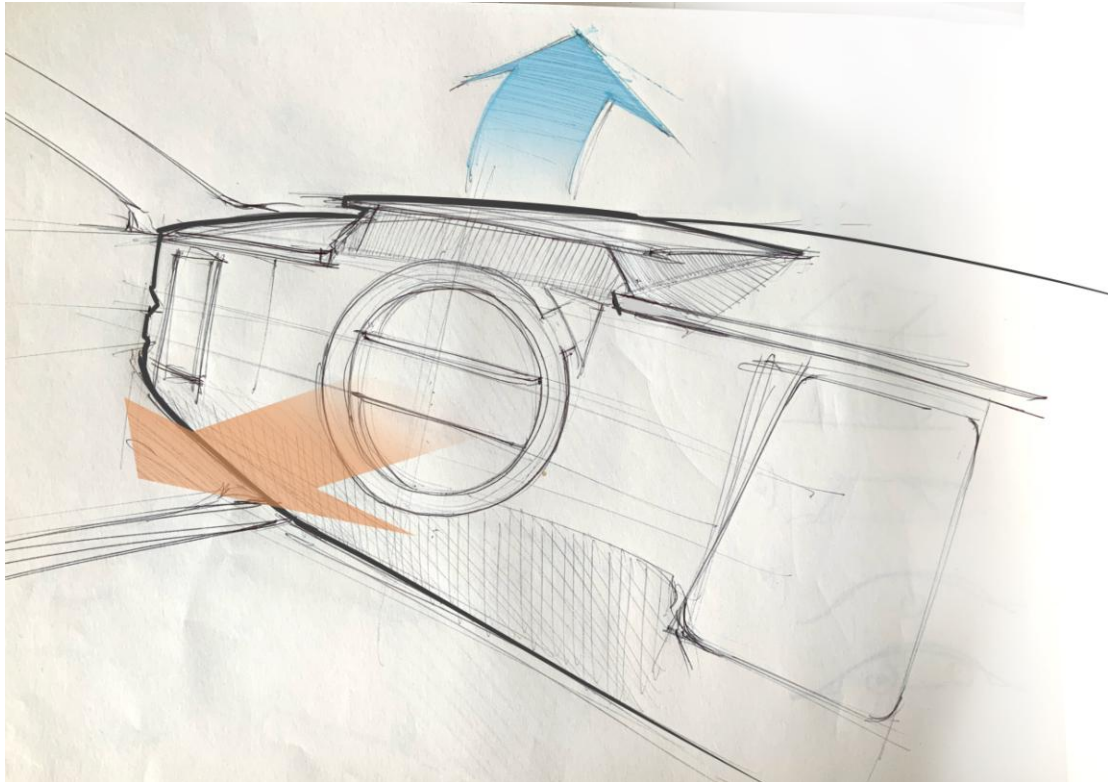


Figure 3.24 Direction of movement 1

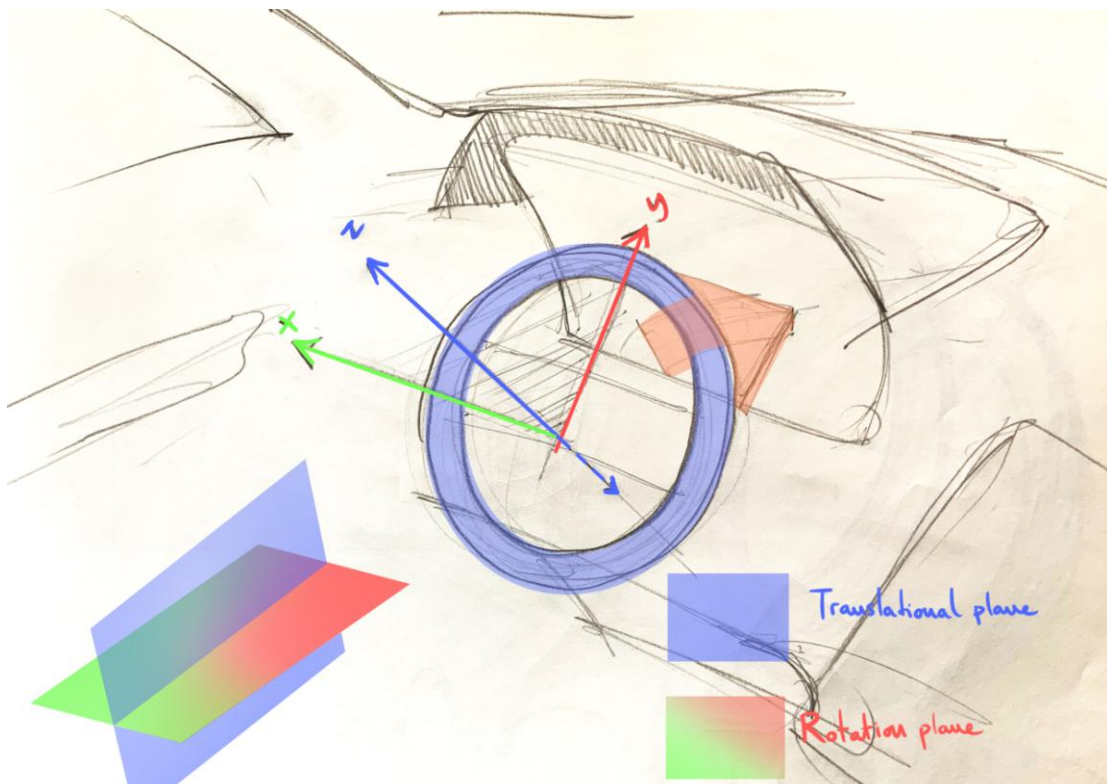


Figure 3.25 Direction of movements 2

Since the buttons are not needed within the objective of section 3.2, a quick and provisional design of how they could be developed is proposed (FIGURE 3.27). Perhaps, for a detailed product design in the future, the best option would be

touch screen buttons as some of the examples in the market study (Nissan and BMW). In these examples, it was suggested that the number of buttons on the current Volvo steering wheels should be maintained as a design specification. The position of the buttons will be to show only that although they are not developed, they are contemplated in the design.

Depending on the current Volvo models, the steering wheel consists of some functions such as

- Cruise control
- Adaptive Cruise Control
- Speed limiter
- Distance Alert
- Pilot assistance

These functions take up a total of 14 buttons (6 per hand or thumb). (Figure 3.26)



Figure 3.26 Volvo S90 2020 buttons

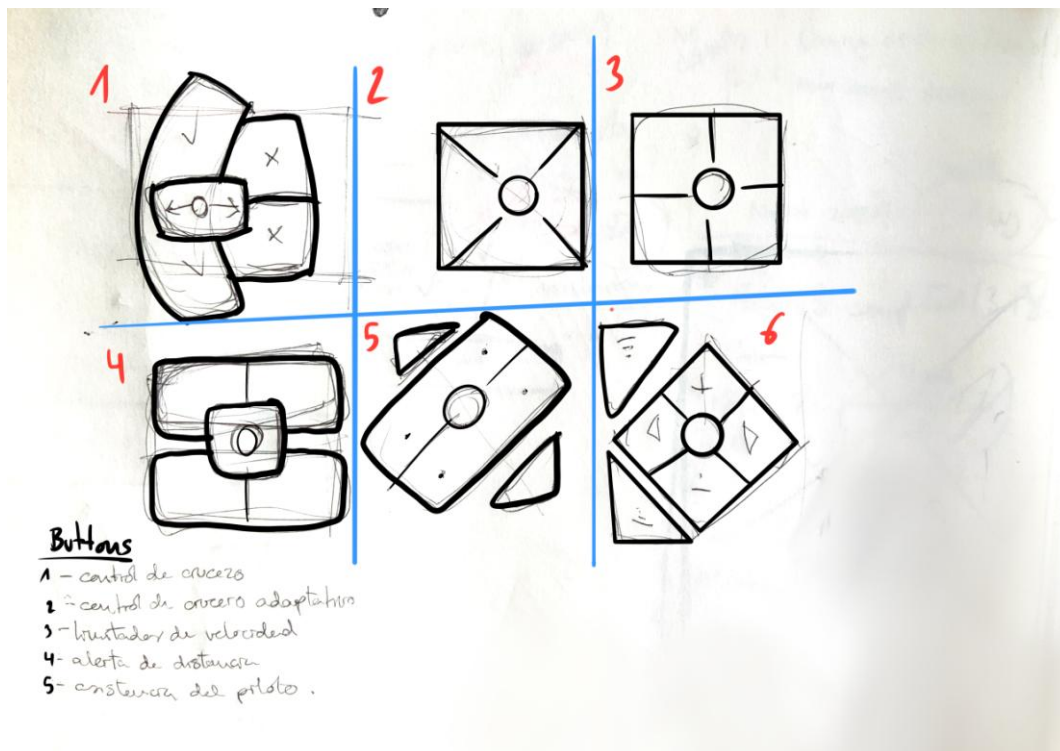


Figure 3.27 Brainstorming of the button configuration.



Since during autonomous driving the vehicle control is displayed on the central screen, it is also proposed to integrate into the design the idea that the instrument panel is hidden while driving autonomously. So the different ways in which the instrument panel could be hidden were studied (Figure 3.28). Since this concept was not considered from the beginning, and only the design of the steering wheel and not the dashboard was considered, it will not be further developed in the following stages of this Project.

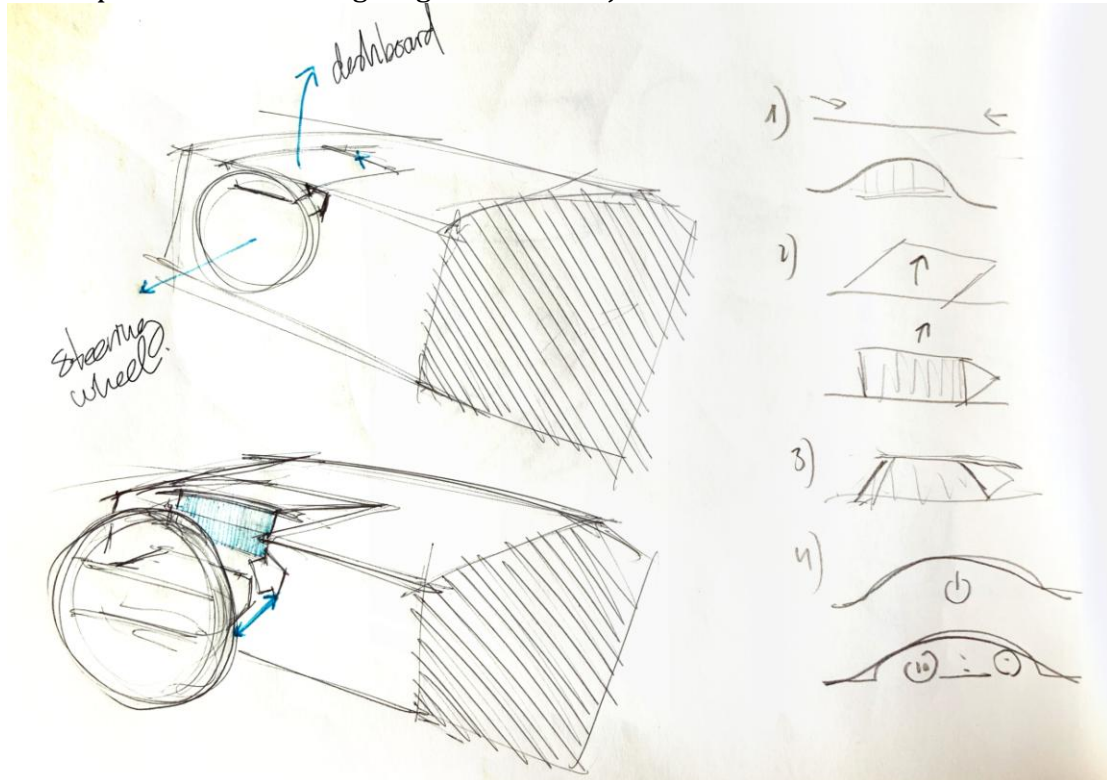


Figure 3.28 Brainstorming instrument panel hiding

### 3.2.6 Selected Sketches.

Once the concept has been defined, a more precise sketching phase is carried out, which brings the sketch closer to reality. The lines represent volumes for a better understanding and tries to get closer to the final design.

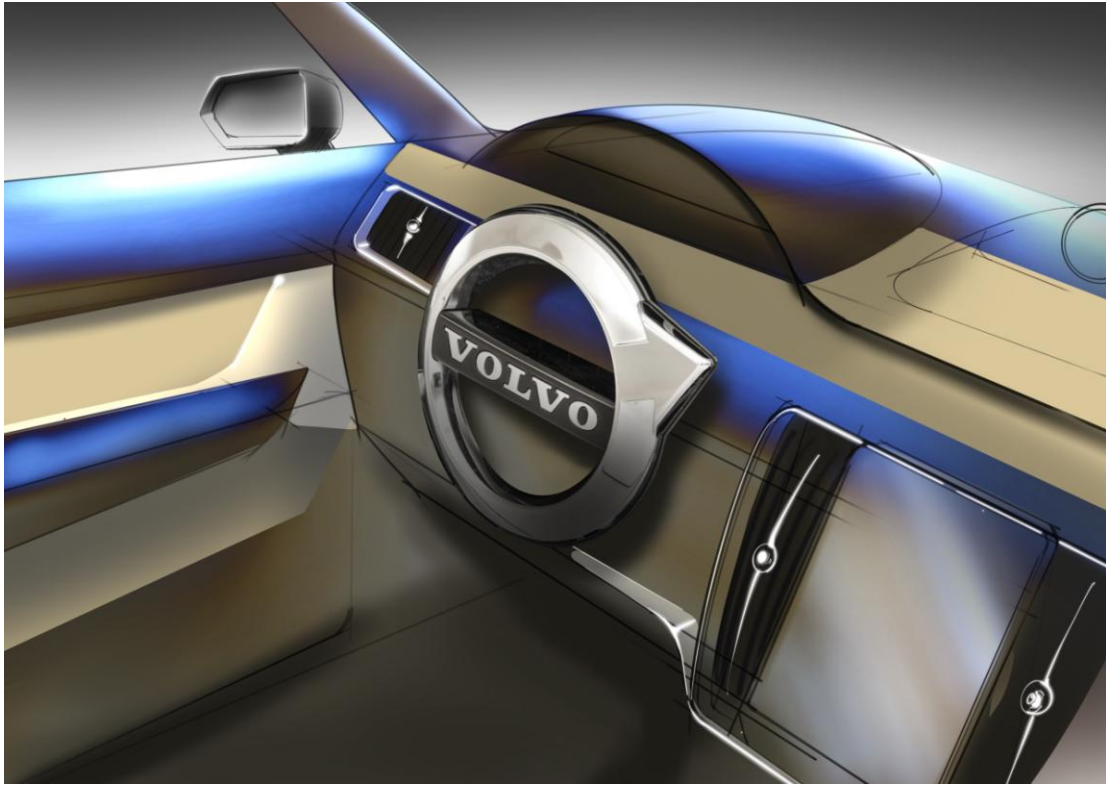


Figure 3.29 CMF Sketch (color, material and finish) 1

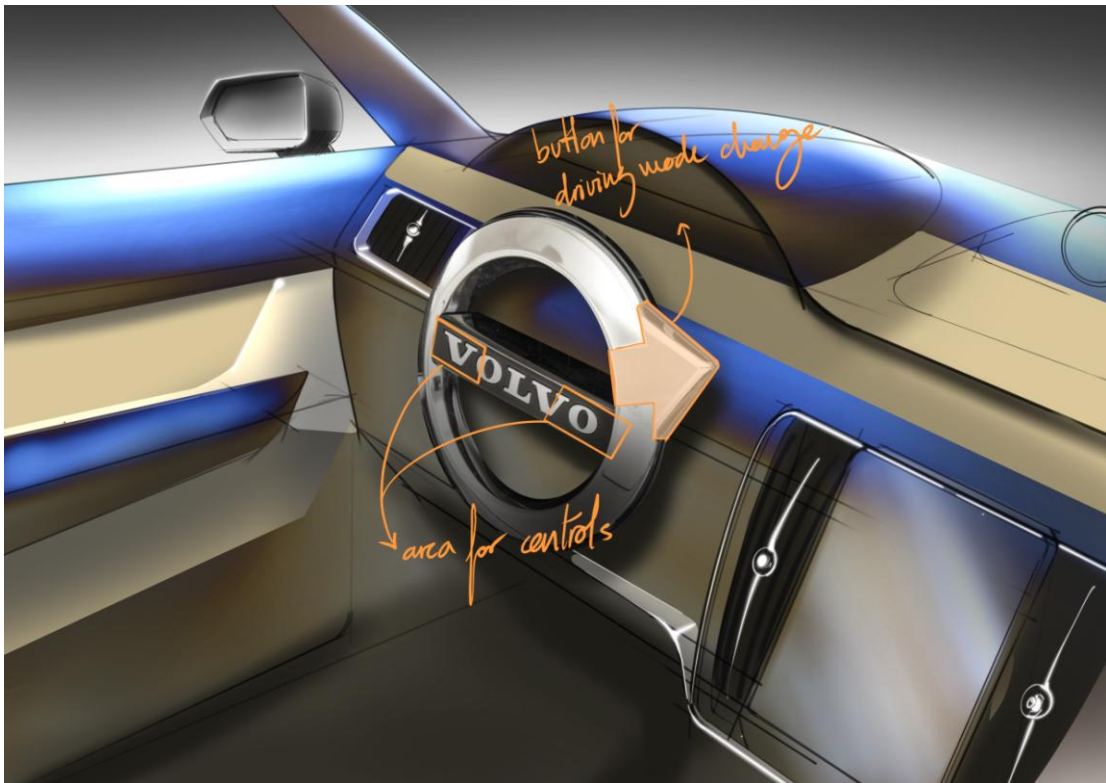


Figure 3.30 CMF Sketch (color, material and finish) 2

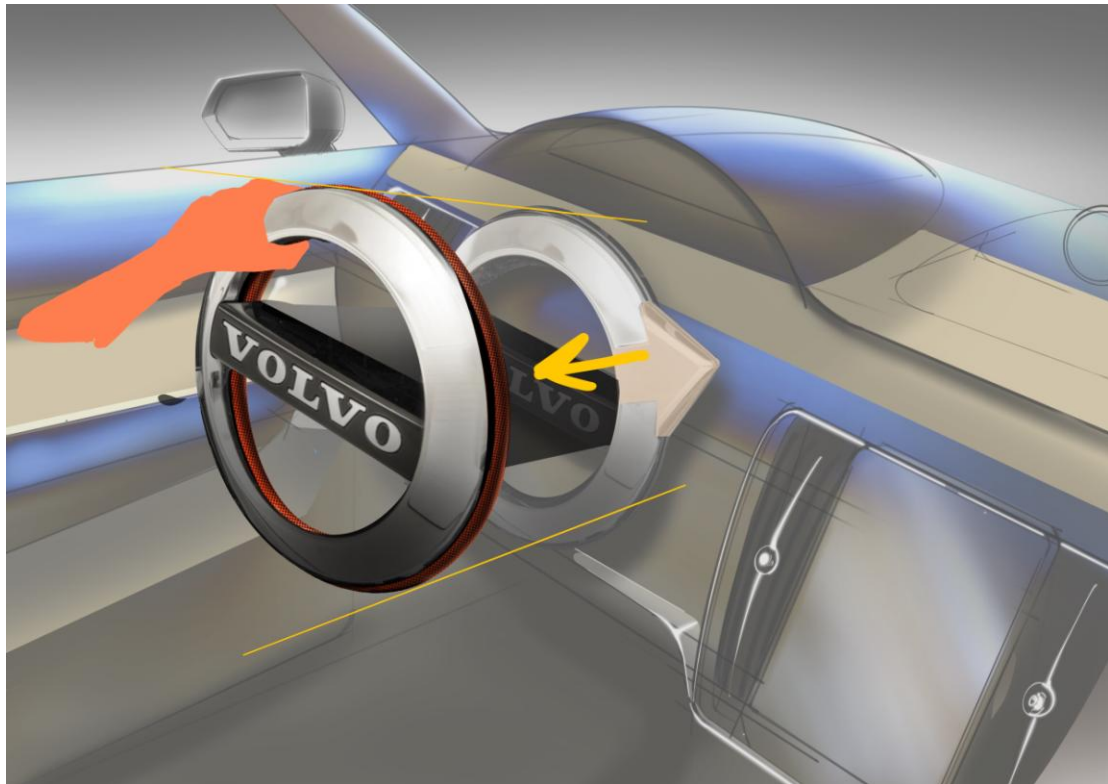


Figure 3.31 CMF Sketch (color, material and finish) 3

### 3.2.7 Development of details

In this phase of the design, measurements are taken and the paper sketches become volumes in a 3D software. Now the steering wheel is defined in more detail and how it is integrated into the dashboard.

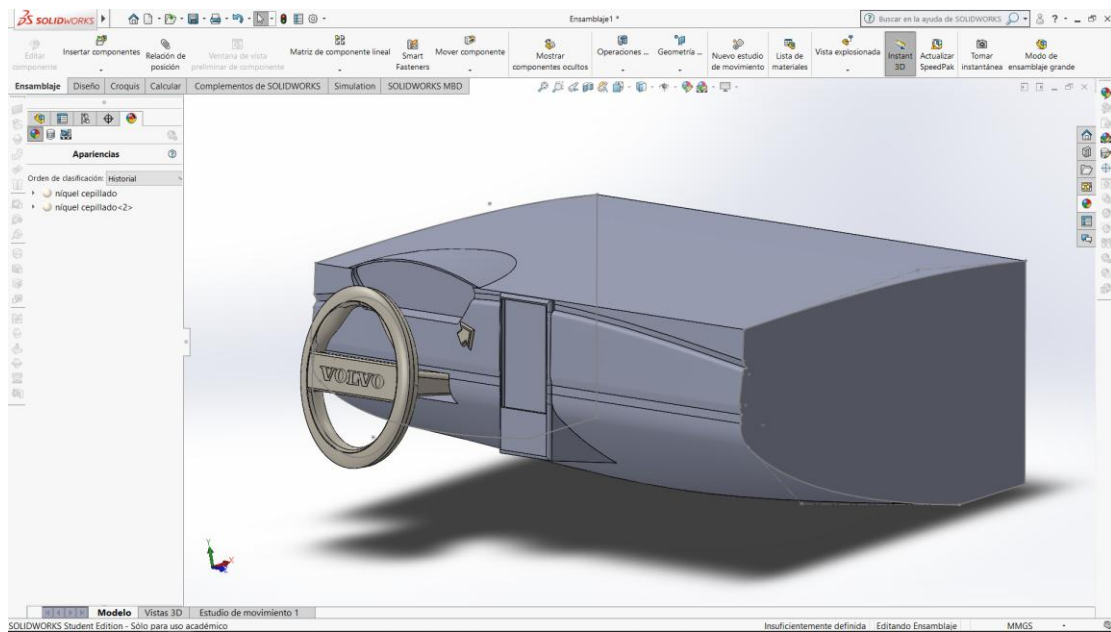


Figure 3.32 3D model of the steering wheel and the dashboard



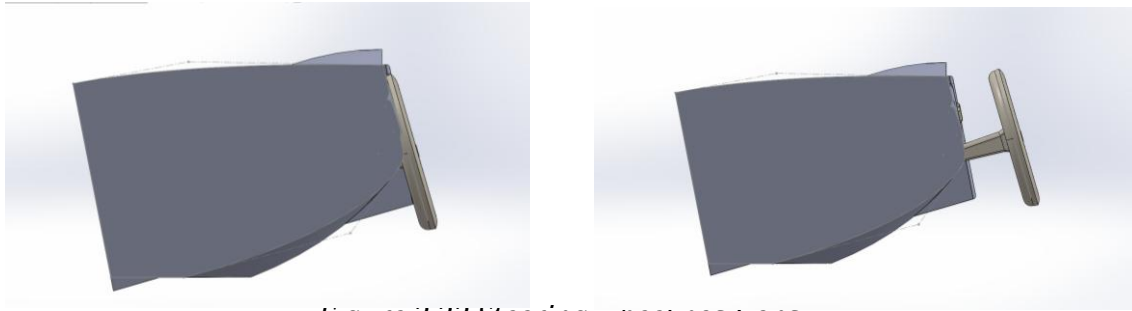


Figure 3.33 Steering wheel positions

### 3.2.8 CAD model

The selected design is modelled in the SolidWorks software (Dassault Systèmes, 2020) to produce a 3D model. In this way, it is possible to define in detail, ensure that the design is volumetrically correct and export it to IPS.

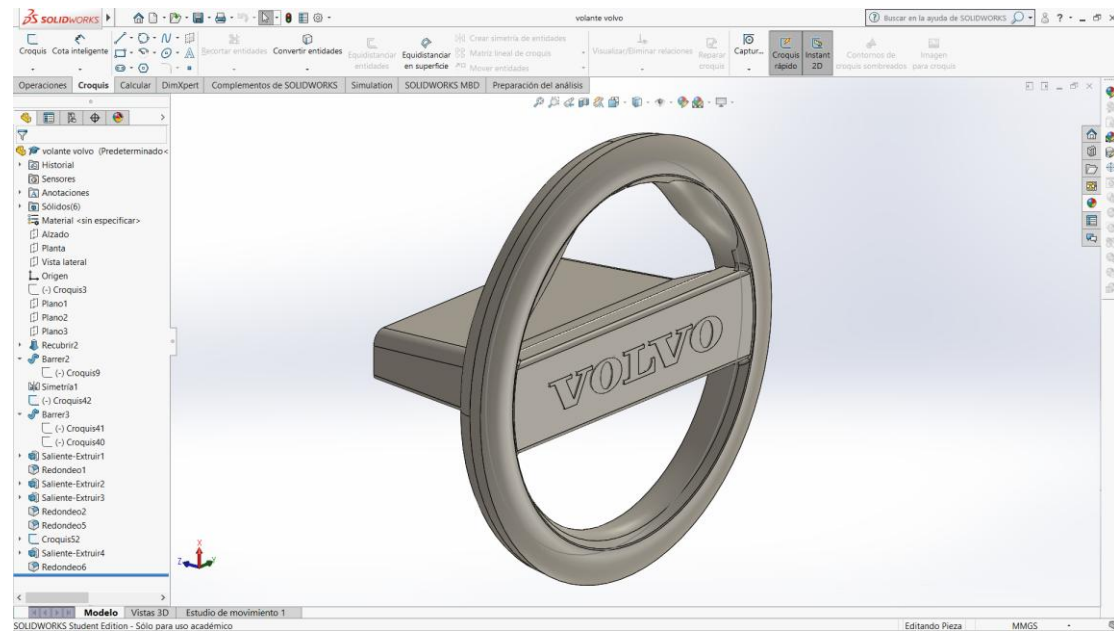


Figure 3.34 3D model of the steering wheel 1

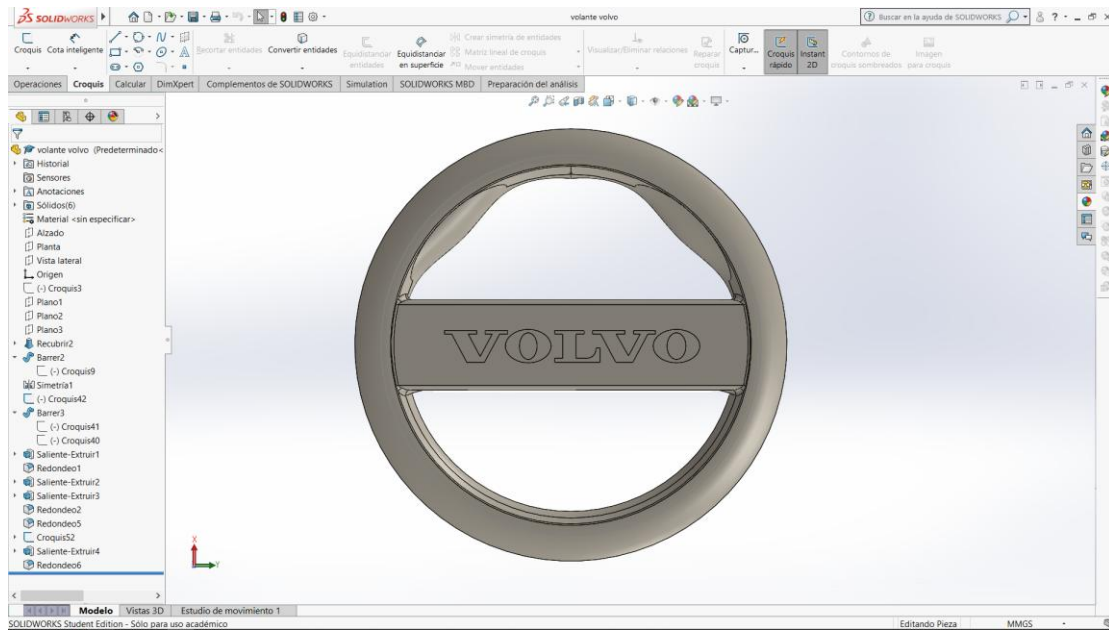


Figure 3.35 3D model of the steering wheel 2

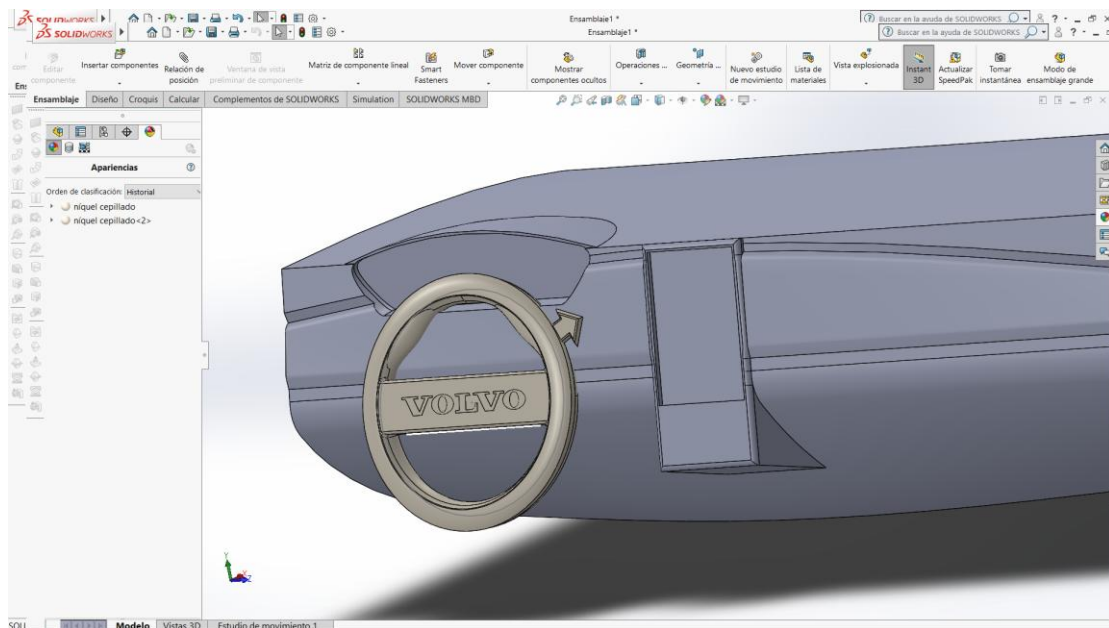


Figure 3.36 3D model of the steering wheel 3

To check the retractable function, the steering wheel is assembled in the dashboard and the inclination of the steering column is adjusted. At this stage of the design, renders can be generated that present the design in a photorealistic way, applying materials and lights. This way, it is possible to differentiate between what could be a brushed metal for the front grip and the arrow (so that they are integrated), the rubbery material for the back grip, the chrome of the letters, the glossy plastic of the front part of the support and the black metal of the back part of the support.



*Figure 3.37 Final aspect 1*



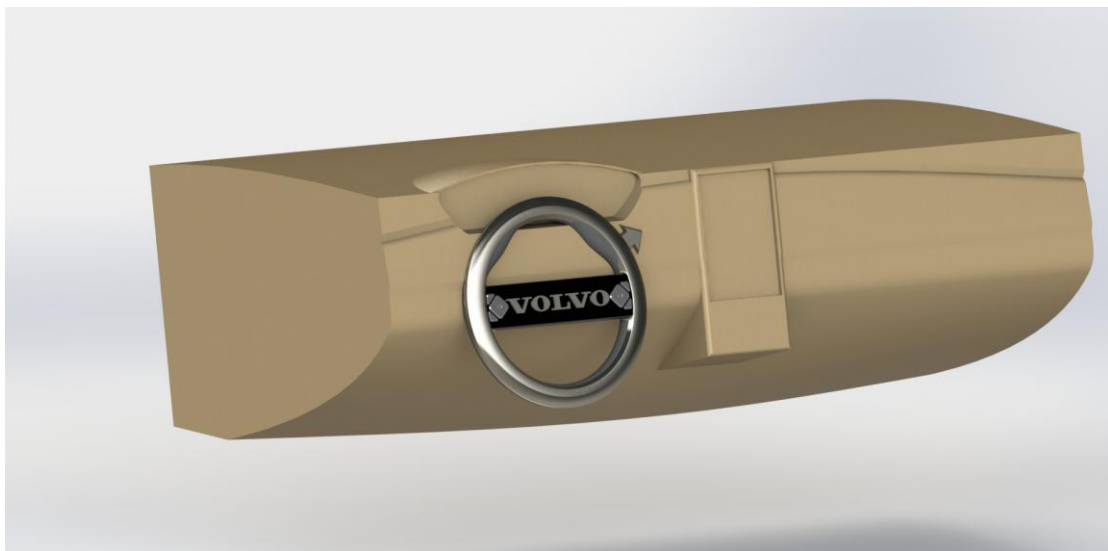
*Figure 3.38 Final aspect 2*



*Figure 3.39 Button detail*



*Figure 3.40 Final render 1*



*Figure 3.41 Final render 2*

### **3.2.9 IPS IMMA Model**

This section describes the process of importing into the IPS IMMA software. The model created in SolidWorks was imported into IPS IMMA software as a 3D model in .igs format, to test the new design. After the import it was necessary to scale the model from millimetres to meters as the import function did not take this into account. Then it was only necessary to move and rotate the steering wheel to the desired position by two simple operations.

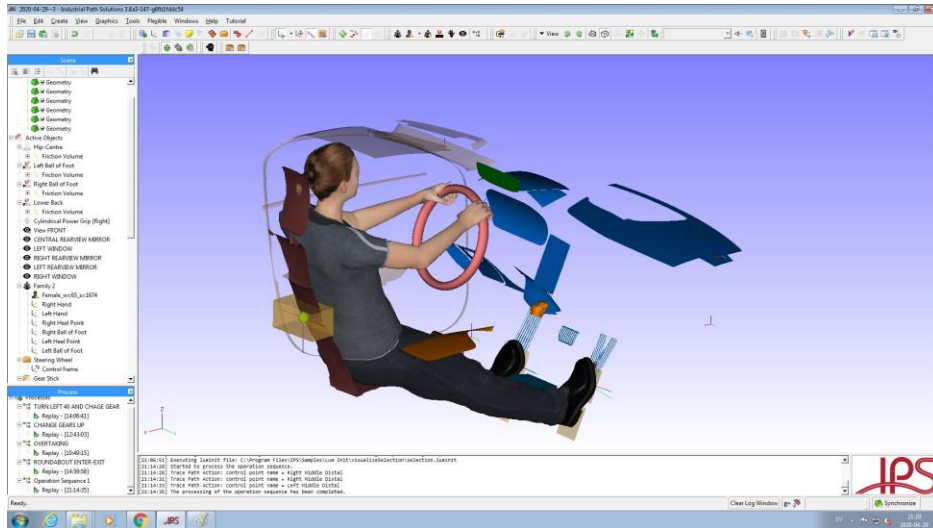


Figure 3.42 Volvo S90 model in IPS IMMA

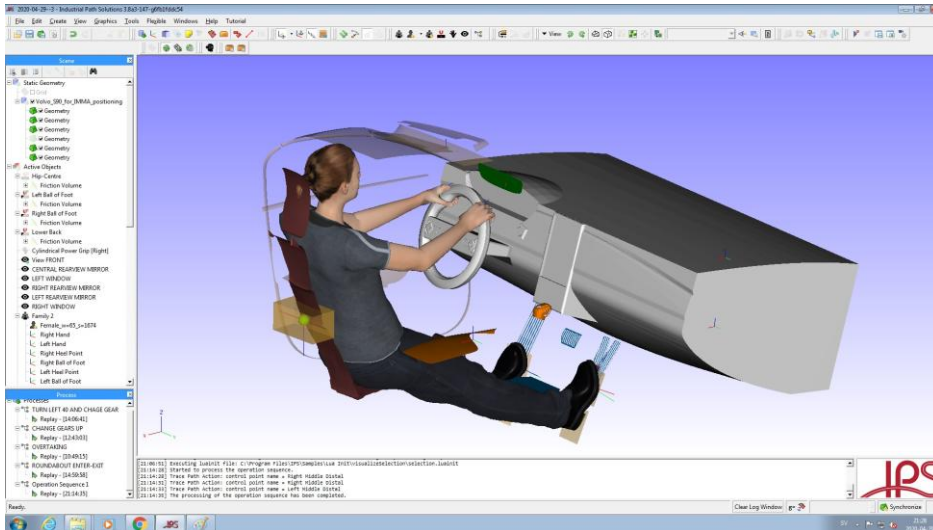


Figure 3.43 New autonomous steering wheel model in IPS IMMA

As can be seen, the objective is successfully accomplished and the manikin only needs a new grip, for the new steering wheel object, and to adapt the old simulations to the new design. With the new steering wheel having additional functionality a simulation visualising the change of driving mode was also added.

## 4 Final results

This section shows the results obtained from the interface for semi-automatically generate driving tasks and from the simulation with the two-position steering wheel.

### 4.1 Interface to semi-automatically generate driving tasks

The final result obtained is an interface. In it, the different options appear ordered, that by means of the selection and the introduction of data, generates the driving tasks for the manikin to carry them out. As can be seen in figure 4.1, the interface starts with the selection of the driving mode and continues to ask for the data of the task that the user wants to simulate, in this case, turning the steering wheel from  $60^{\circ}$ . The interface follows the flowchart elaborated in point 3.1.5 allowing the total personalization of the task by the user. The interface allows the elaboration of driving routines as long as the user wants and through simple steps that do not require a specialization in the software.



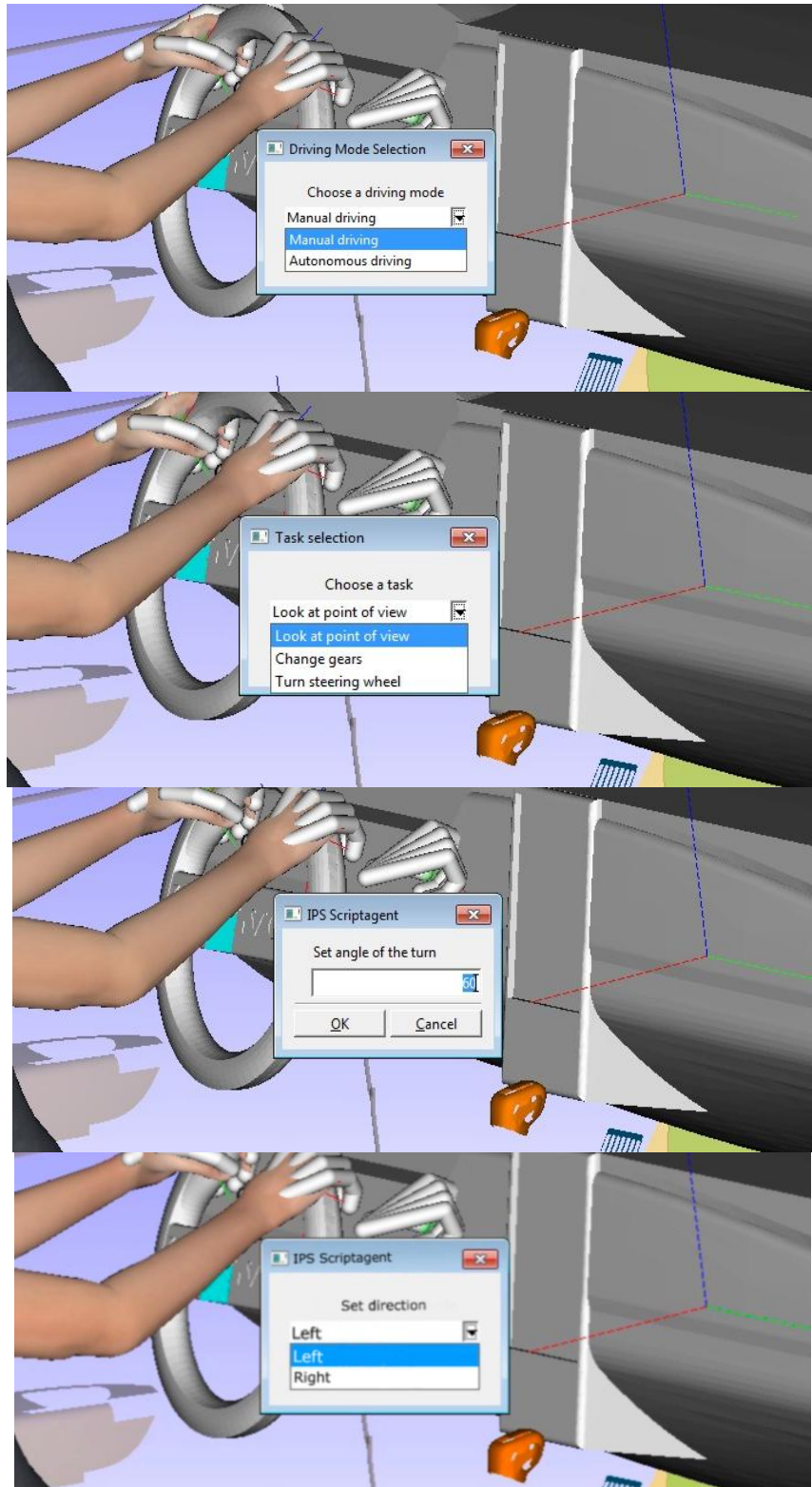
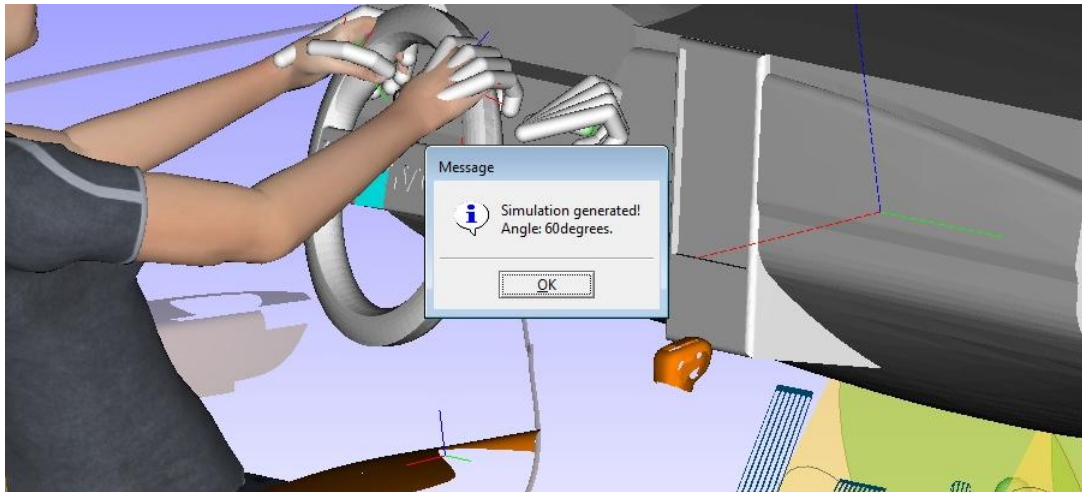


Figure 4.1 Driving routine generation

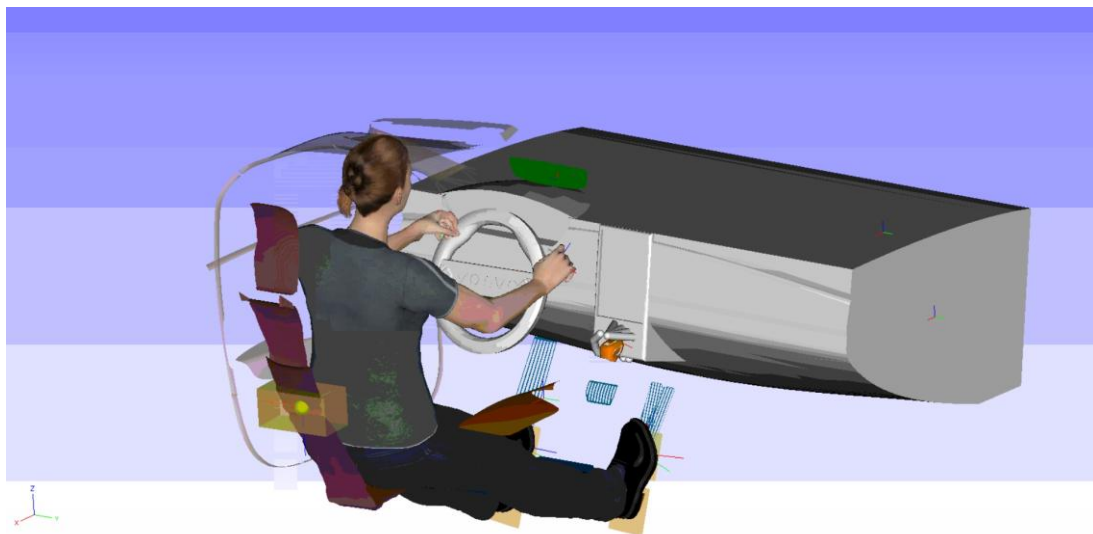


*Figure 4.2 Final confirmation message*

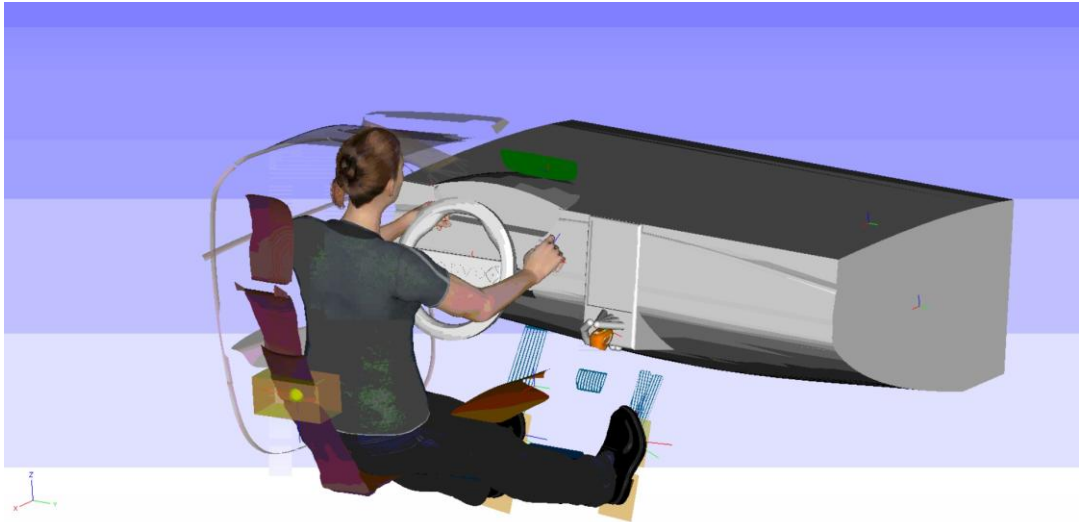
Once followed the steps indicated in point 3.1.6 the final result is a window verifying the task generated through the interface to be simulated.

#### **4.2 Simulation with new steering wheel model in IPS IMMA**

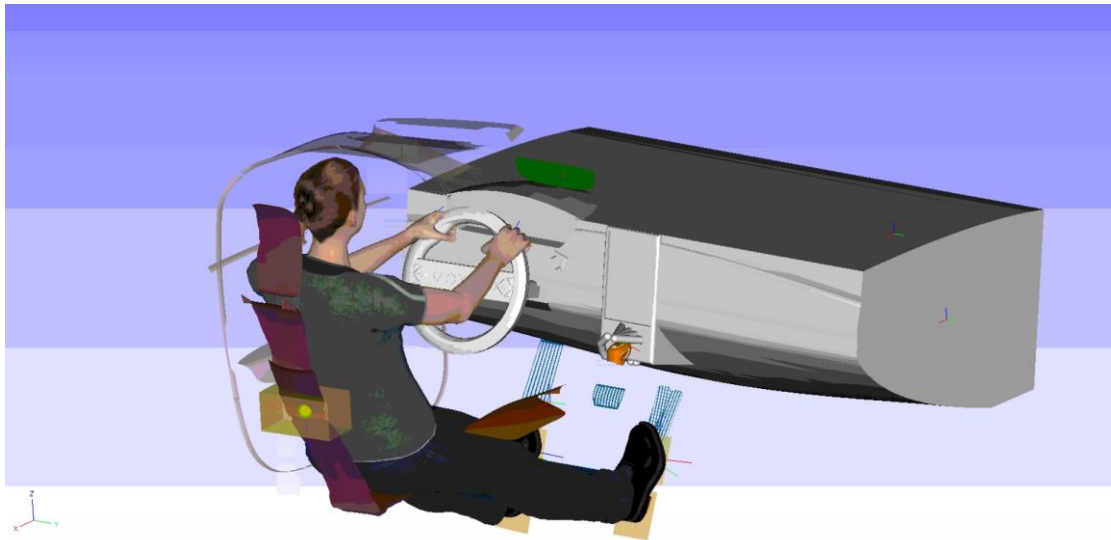
The result obtained here is a two-position steering wheel for a level 4 autonomous vehicle, which has been exported to the IPS IMMA software, demonstrating the ease that these software provide for the comparison of different designs. Since in the list of necessary tasks for the driving broken down in the point 3.1.3 the autonomous function of the vehicle is not contemplated, a simulation was added in which the steering wheel changes position from an autonomous driving to a manual driving (figures from 4.3 to 4.5). The model was linked to the simulations created for the driving test with the definition of a new grip of the manikin. The design created is then ready for possible evaluation through the software.



*Figure 4.3 Manikin pressing the button to change driving mode*



*Figure 4.4 Operation of the handwheel from the autonomous to the manual position*



*Figure 4.5 Final manual driving position with new steering wheel*

## 5 Discussion and conclusion

Once the project was completed, and having an overview of the project, some aspects could have been done differently. During the development of the project, and because of the time constraints involved in a degree project, some tasks overlapped. Leaving the design of the steering wheel until the end could have speeded up the development of the project and allowed to go a little deeper into the driving test part. It would also have been beneficial not to focus so much on the development of the steering wheel as on the evaluation of various steering wheels to support the motivation of the project.

Knowing how to use the software a few weeks earlier, could have helped to understand its operation and limitations, and could have given more time to plan the development of the tasks for the interface flowchart in another more efficient way.

Having said this and taking into account the objectives defined at the beginning, it can be concluded that these have been achieved in the first instance: an interface to generate driving tests in a DHM tool and the conceptual design of a two-position steering wheel.

The method followed has allowed to fulfil the objective that independently of who performs the test or when, the results must be the same or very similar. The generation of the test through a guided interface with previously generated tasks, prevents the user to perform the test by customizing or changing factors that alter the result. The software will be able to evaluate the ergonomics of the test generated in function of the design to be evaluated and the routine created through the interface, eliminating the subjectivity of the final user.

Even so, the success is not total, since due to the limitations found some tasks are not totally faithful to reality. Also, because the knowledge about IPS software and Lua-Script programming is very basic, both simulations and flowchart for the interface can be improved. This project can serve as a starting point to reach a bigger and more efficient goal.

One limitation to be considered is that this project has not studied real people driving. The tasks required to perform driving on such a circuit were analysed, which may have limited the different ways of performing the tasks, as well as their diversity for study. For the future, a study of real people driving should be included.

Taking into account the movement of the feet and some more interactions such as using turning indicators are factors that could have been taken into account with a deep knowledge of the tool. Some simulations would have been quite faithful to reality, although these factors do not influence much in the purpose of the project. An advantage for the future is that the study of the driving on the proposed circuit was done before knowing the limitations of the software, and therefore contemplates a detailed study of the actions of the feet for speed and gear changes, as well as the hands for the use of the indicators.

Thus, this project can be used to further develop a tool that generates extensive and detailed driving simulations to evaluate vehicle interior designs and the design process. A recommendation of improvement for the driving test, would be a Preview Window of the task list that is generated for the test, so the user could have a global vision of the test at all times.

Since one of the biggest problems is the correct positioning of the manikin in the vehicle, as mentioned Högberg et al. (2019), the next step would be for the

manikin to recognize the environment and set itself in the driving position. While recognizing the environment can be a highly problematic task in programming, a more realistic solution might be to generate a pre-test driving interface that asks the user to identify only the necessary elements of the vehicle to perform the test, and the program will place the manikin in the optimal position (with user correction freedom). The solution would be a sort of selection of magnetic points where the manikin would be dropped and positioned correctly. These elements could be: pedals, seat (back and mid-hip area), steering wheel, gear shift, mirrors. Once the manikin has been positioned, check that everything has been correctly defined and positioned. This would save a lot of time and the manikin would be configured to perform the driving test.

Another future investigation, after having made this project, could be to define the degrees of freedom of the components of the design, that is, that the CAD model of the interior of the vehicle contributes information of the included elements:

- Possible positions of the seat. This way, it could be possible to adjust automatically to different manikins without having to modify the environment every time the manikin is changed.
- Degree of freedom from other moving objects. Gear shift lever, steering wheel, pedals, etc.

All these automations are still within the LPD philosophy. After having placed the manikin, and having carried out the driving test, the functions of strength studies and ergonomics evaluations should be easy to execute.

To conclude, since the autonomous vehicles will become "self-driving cabs", in which they can perform tasks that are currently limited, the user's mobility inside the future autonomous models will be worth studying, and therefore will pose new challenges for the tool.

## 6 Recommendations

Once the study is completed, suggested recommendations are

- Improve some functions of the IPS IMMA software, on the one hand the facility to place the manikin in the sitting position is not always easy.
- Another aspect to improve would be to add one more option to the grips library, in which there would be one that does not respond to any regular geometry.
- Add a grip or hand task to push buttons. In the example of the steering wheel, as in any model, there are buttons on the dashboard, which are used while driving. This option would be very interesting when it comes to identifying range problems in the design.
- The Sequence Editor Window could be improved, in aspect, being able to zoom and condense the tasks to avoid excessive scrolling, and the option to add and remove tasks without error, having to redo everything.
- Solve the options of the grip during the sequence to be able to generate a turn of 90 degrees releasing and grabbing the steering wheel in two different points in the same turn.
- A hand simulation option for detailed study of your ergonomics when using steering wheel functions could be an interesting option. It may not be necessary for the rest of the manikin or that it complies with the same restrictions as the body of the manikin, a separate window like the one in the vision study where you can see the hands in detail, generate your simulations there and not interfere with a simulation involving the whole body.



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## Appendix

### Appendix 1: Task list breakdown

#### . Breakdown of main tasks into sub-tasks

0. Adjust vehicle environment. (point 1) (not to be included in this study)
  - +Adjust seat
    - Set driving distance
      - \_Adjustment lever reach, under seat.
        - =Correct steering range, pedals and arm extension.
    - Adjust seat height
      - \_Height adjustment lever, seat side.
        - =Correct viewing height, pedals and steering range
    - Adjust seat back
      - \_Tilt adjustment lever range, seat side
        - =Correct backrest tilt, steering range.
  - +Adjust interior mirror
    - Adjust mirror reflection angle.
      - \_Reach the mirror, in the ceiling central part.
        - =Correct view to the rear through the central mirror.
  - +Left rear-view mirror adjustment
    - Adjust mirror reflection angle.
      - Reach for the mirror controls, left door.
        - =Correct side-rear view through the left rearview mirror.
  - +Right-hand mirror adjustment
    - Adjust mirror reflection angle.
      - Reach for the mirror controls, left door.
        - =Correct side-rear view through the right-hand mirror.

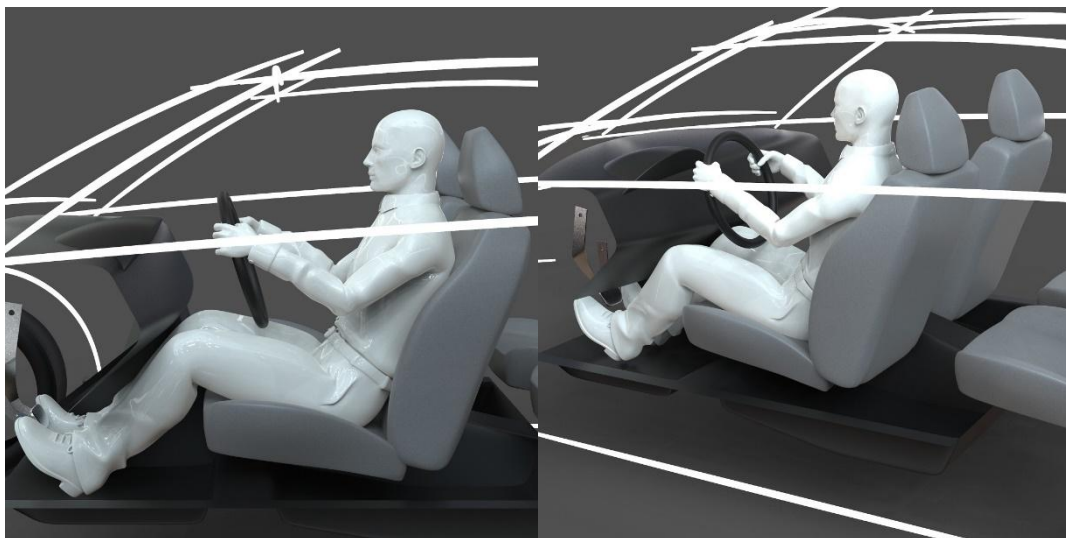


Figure 3.1 Driving position 1 (dp1)

1. Start vehicle (point 1) and drive to point 2.

+Insert key in ignition switch

-Scope of contact with the right turnkey

\_Contact range and possibility of wrist rotation.

+Remove handbrake

-Hand brake range with the right hand

possibility \_Hand brake range with hand, button range with thumb and  
to press button and stretch right arm.

+Enter gear

-Pedal and gearshift range

release the \_press the clutch pedal, change gear, press the accelerator,  
clutch, return to dp1.

=Correct range set, steering wheel, gear lever and pedals

2. Approach to the traffic light at point 2. (two options)

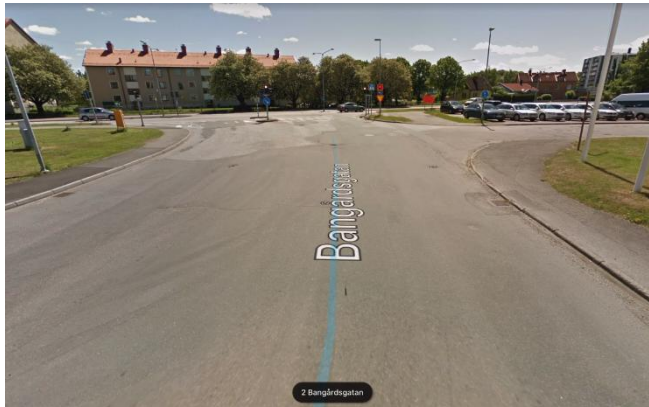


Figure 3.2 Key Point 2. Google Maps capture in Streetview

+Enter gear (up)

-Pedal range and shift lever

\_press the clutch pedal, shift gears, press the accelerator.

=Correct range set: steering wheel, lever and pedals.

Option 1: red light.

+Enter gear (lower).

-Pedal range and gearshift lever

gear, \_press brake pedal, release brake, press clutch pedal, change  
release clutch, press brake pedal, return to dp1.

=Correct range: steering wheel, lever and pedals.

Option 2: green light.

+Reduce speed

-Pedal range

\_lift foot off the accelerator

=Correct joint range: handwheel and pedals.

3. Turn left to enter the lane at point 4.

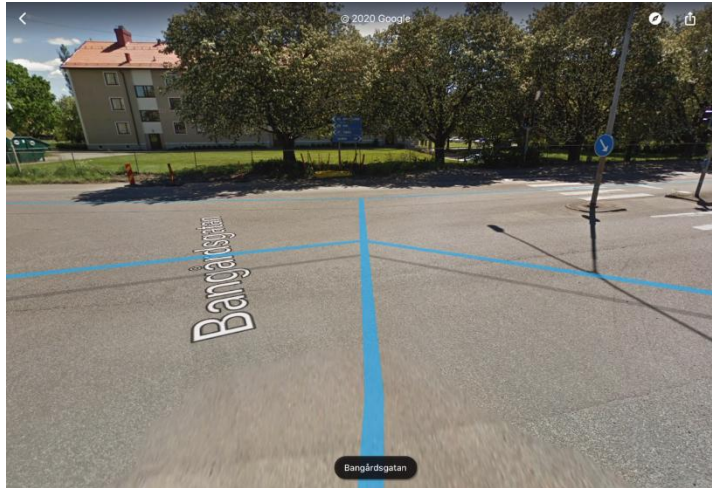


Figure 3.3 Key Point 3. Google Maps capture in Streetview

+ Left turn

-Turn signal.

\_Change the position of the turn signal lever (input direction),  
dp1.

back to

=Correct range of the turn signal lever and steering

wheel.

-View of the environment.

\_Head and eye turn

=Correct view of the environment and check points of  
(point 1 of the dashboard sketch), steering wheel  
range.

view,

and pedals

-Turn the steering wheel.

\_Turn 90° to the left. (input radio) (input time), turn to dp1.

=Correct steering range during the turn

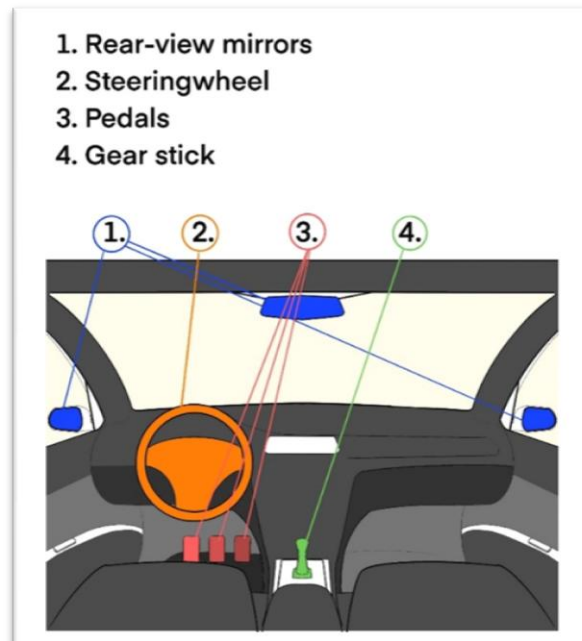


Figure 3.4 Croquis salpicadero

4. Acceleration in point 4.





Figure 3.5 Key Point 4. Google Maps capture in Streetview

+Incorporation into rail

-Vision of the environment.

\_Turn of the head and eyes

=Correct view of the environment and check points of view (point 1 of the dashboard sketch).

+Enter gear (up)

-Pedal range and gearshift

\_press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1.

=Correct range set: steering wheel, lever and pedals.

5. Bus stop, possible overtaking. (double continuous line)



Figure 3.6 Key Point 5. Google Maps capture in Streetview

+Overtaking

-Turn signal.

\_Turn indicator lever change (input direction), back to dp1.

=Correct range of turn signal lever and steering wheel.

-View of the surroundings.

\_Head and eye turn

view, =Correct view of the environment and check points of (point 1 of the dashboard sketch).  
 -Steering wheel.  
 X<sup>0</sup> to \_Turn X<sup>0</sup> to the left. (input radio) (input time), turn to dp1, Turn the right. (input radio) (input time), turn to dp1.  
 =Correct steering wheel reach during the turn

6. Approach to incorporation of roundabout.



Figure 3.7 Key Point 6. Google Maps capture in Streetview

+Enter gear (lower)  
 -Pedal range and gearshift  
 \_press the brake pedal, press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1.  
 =Correct range: steering wheel, lever and pedals.  
 +Steering wheel.  
 \_ Turn X<sup>0</sup> to the right. (input radio) (input time).  
 =Correct range of the steering wheel during the turn

\*(possible stop due to yield signal)\*

7. Incorporation to roundabout.



Figure 3.8 Key Point 7. Google Maps capture in Streetview

- +Turn the steering wheel.
  - \_ Turn left  $X^0$ . (input radio) (input time).
    - =Correct steering wheel reach during turning
- +Vision of the environment.
  - Turn of the head and eyes
    - =Correct view of the environment and check points of view, (point 1 of the dashboard sketch).

8. Approach to roundabout exit.



Figure 3.9 Key Point 8. Google Maps capture in Streetview

- +Exit lane approach
  - Turn signal.
    - \_Turn indicator lever change (input direction), back to dp1.
      - =Correct range of turn signal lever and steering wheel.

9. Take the roundabout exit to key point 10.



Figure 3.10 Key Point 9. Google Maps capture in Streetview

- +Vision of the environment.
  - \_Turn of the head and eyes
    - =Correct view of the environment and check points of view, (point 1 of the dashboard sketch).

- +Steering wheel.
  - \_ Turn from  $X^0$  to the right. (input radio) (input time).
    - =Correct range of the steering wheel during the turn
- +Enter gear (up)
  - Pedal range and gearshift
    - \_press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1.
      - =Correct range set: steering wheel, lever and pedals.

\*(possible stop for pedestrian crossing)

10. Turn left to get to point 12.



*Figure 3.11 Key Point 10. Google Maps capture in Streetview*

- +Aproximation to change direction
  - Turn signal.
    - \_Turn indicator lever change (input direction), back to dp1.
      - =Correct range of turn signal lever and steering wheel.
- +View of the environment.
  - \_Head and eye turn
    - =Correct view of the environment and check points of view, (point 1 of the dashboard sketch).
- +Enter gear (lower)
  - Pedal range and gearshift
    - \_press the brake pedal, press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1.
      - =Correct range: steering wheel, lever and pedals.

\*(possible to yield)\*

- +Steering wheel.
  - \_ Turn de $90^0$  on the right. (input radio) (input time).
    - =Correct steering wheel range during the turn.

11. Linear drive section.





Figure 3.12 Key Point 11. Google Maps capture in Streetview

+Enter gear (up)

-Pedal range and gearshift lever

release the \_press the clutch pedal, change gear, press the accelerator, clutch, return to dp1.

=Correct range set: steering wheel, lever and pedals.

## 12. Turn left to get to point 13.

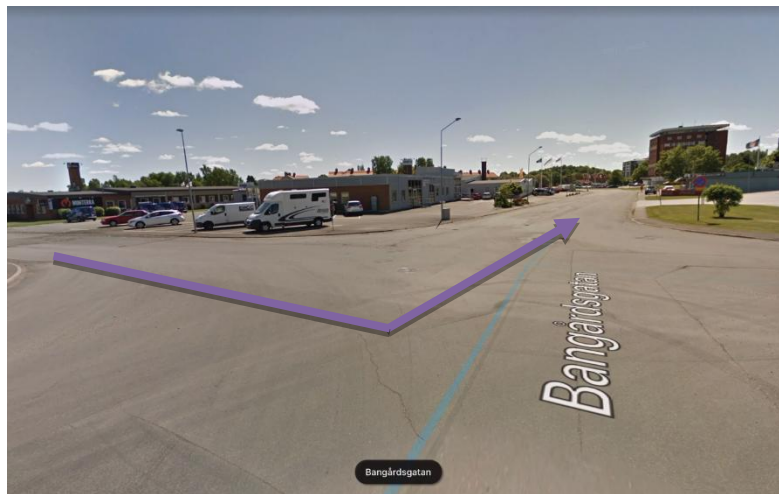


Figure 3.13 Key Point 12. Google Maps capture in Streetview

+Approach change of direction

-Turn signal.

\_Turn indicator lever change (input direction), back to dp1.

=Correct range of turn signal lever and steering wheel.

+View of the environment.

\_Head and eye turn

=Correct view of the environment and check points of view, the dashboard sketch).

(point 1 of

+Enter gear (lower)

-Pedal range and gearshift

the \_press the brake pedal, press the clutch pedal, change gear, press accelerator, release the clutch, return to dp1.

=Correct range: steering wheel, lever and pedals.

\*(possible to yield)

+Steering wheel.

- \_ Turn de90<sup>0</sup> on the right. (input radio) (input time).  
=Correct steering range during the turn

+Enter gear (up)

- Pedal range and gearshift lever
    - \_press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1.
- =Correct range set: steering wheel, lever and pedals.

### 13. Punto final, llegada a destino, parada, estacionamiento.



Figure 3.13 Key Point 13. Google Maps capture in Streetview

+Enter gear (lower) and stop

- Pedal range and gearshift
    - \_press the brake pedal, press the clutch pedal, change gear, press the accelerator, release the clutch, return to dp1. (repeat until neutral).  
Press the brake.
- =Correct range: steering wheel, lever and pedals.

+Putting on the handbrake

- Hand brake range with the right hand
  - \_Brake range with hand, button with thumb and possibility to push button and pull with right arm.

#### 4. Possible specific operations

4.1 Passing through a speed bump

4.2 Overcoming an obstacle

4.3 Adaptation to poor road conditions

4.4 Emergency braking

4.5 Using the functions of the steering wheel

4.5.1 Indicators

4.5.2 Headlighting



- 4.5.3 Horn
- 4.5.4 Radio Utilities
- 4.6 Interacting with console options (A/C, GPS, radio...)

## Appendix 2: Generation of individual tasks in the detailed IPS IMMA

To start generating last tasks in IPS a default manikin is created, and the interior model of the Volvo S90 will be used.

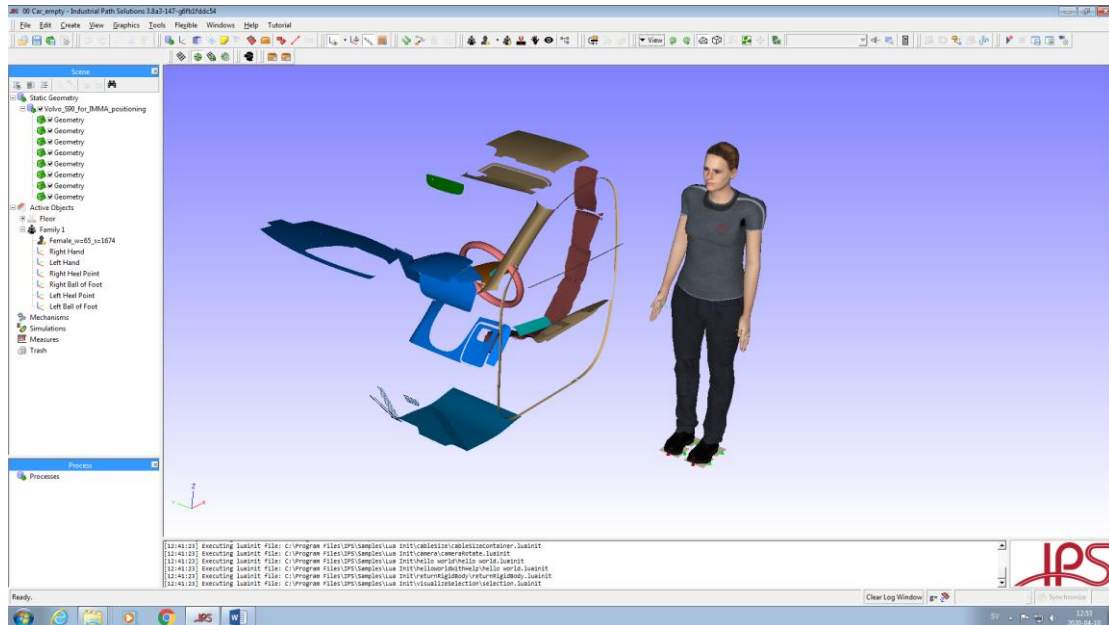


Figure x.x Starting point. Default manikin and interior model of the Volvo S90

The manikin is then adapted to the driving position using the attach points. Those used for this study will be the balls of the feet, Hip-centre and Lower Back. To define the position, some of them will have to be defined as support. The balls of the feet and the hip:

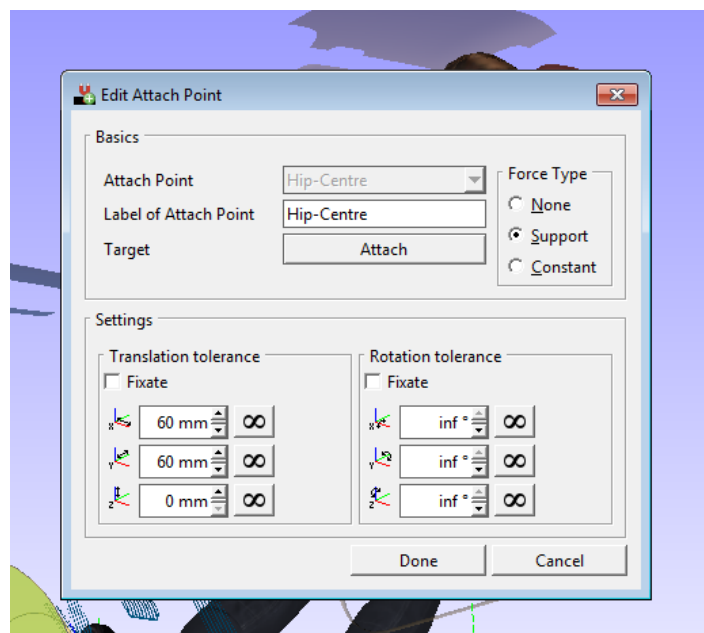


Figure x.x Defining the hip center attach point as support

Next are the types of grip, cylinders for the steering wheel and spherical for the gear shift:

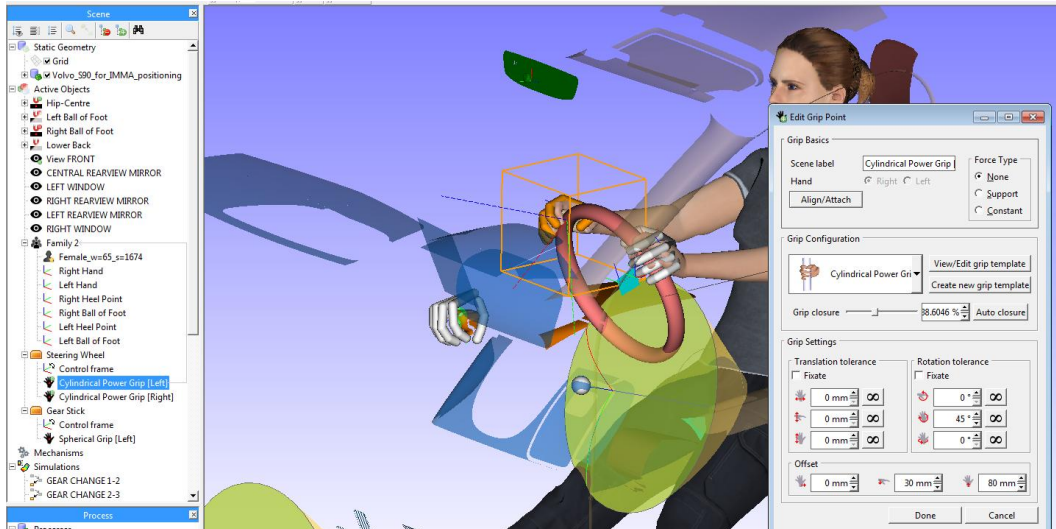


Figure x.x Defining the cylindrical right grip.

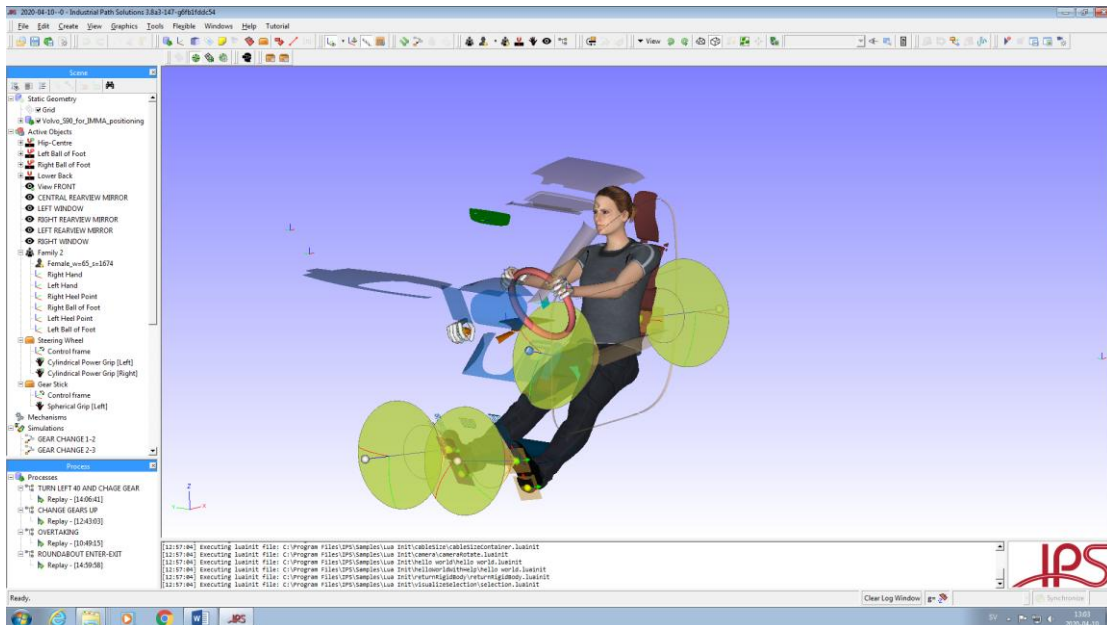


Figure x.x Completed sitting posture

Finally, in order to be able to generate the routine, the points of vision are placed, and those objects that will interact in the simulation, in this case the steering wheel and the gear shift, become rigid bodies.

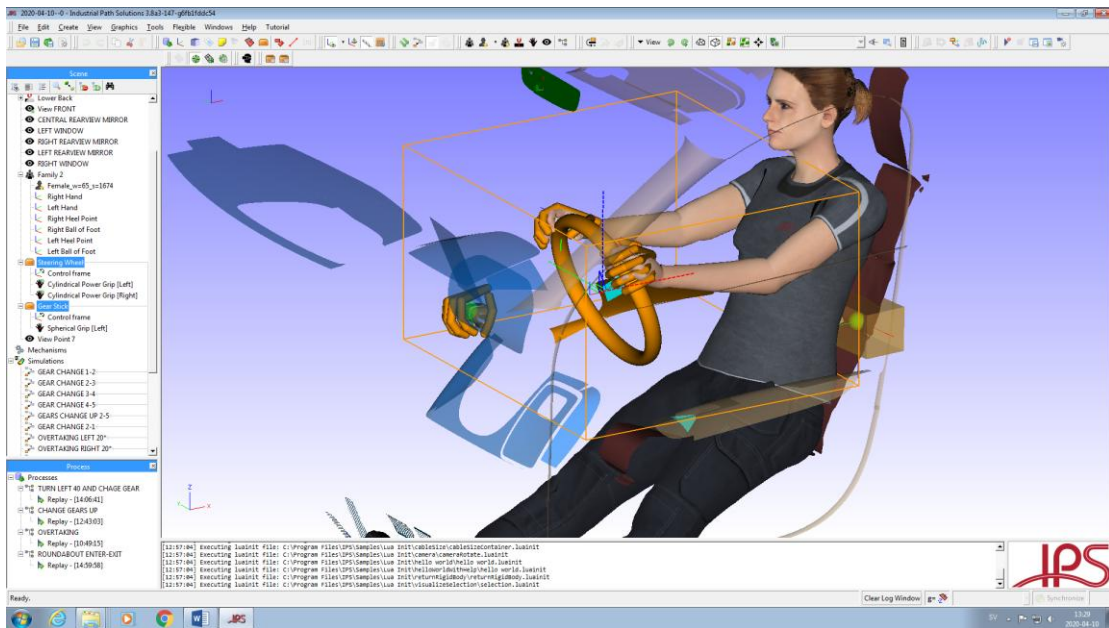


Figure x.x Completed sitting posture

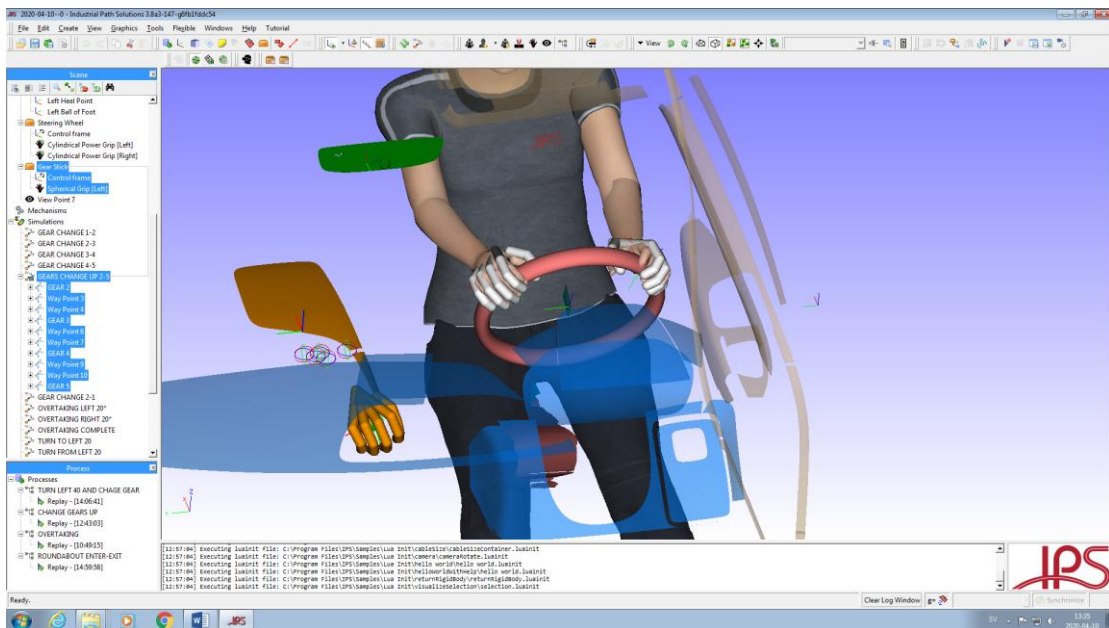
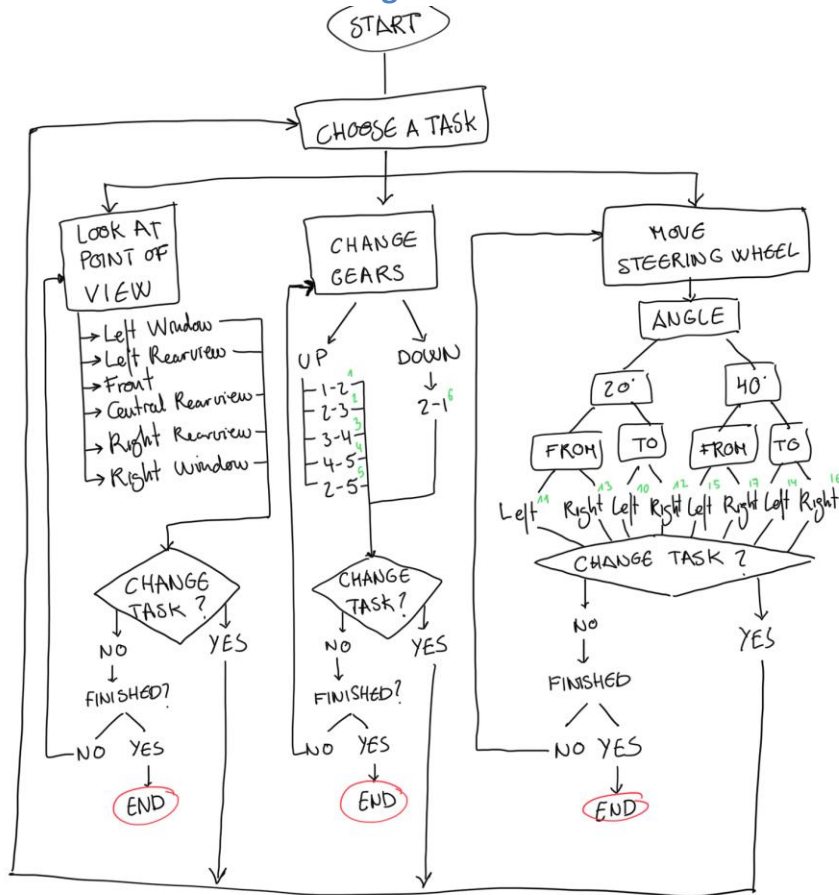


Figure x.x Completed "gear change" simulations

### Appendix 3: Flowcharts for driving tasks.



### CURRENT SIMULATIONS

1. GEAR CHANGE 1-2
2. GEAR CHANGE 2-3
3. GEAR CHANGE 3-4
4. GEAR CHANGE 4-5
5. GEAR CHANGE 2-5
6. GEAR CHANGE 2-1
7. OVERTAKING LEFT 20°
8. OVERTAKING RIGHT 20°
9. OVERTAKING COMPLETE
10. TURN TO LEFT 20°
11. TURN FROM LEFT 20°
12. TURN TO RIGHT 20°
13. TURN FROM RIGHT 20°
14. TURN TO LEFT 40°
15. TURN FROM LEFT 40°
16. TURN LEFT AND BACK 40°
17. TURN RIGHT AND BACK 40°
18. ROUNDABOUT COMPLETE.



**+PROBLEM.**  
 - How to look at one point on turn?  
 • Is it necessary?

Figure x.x



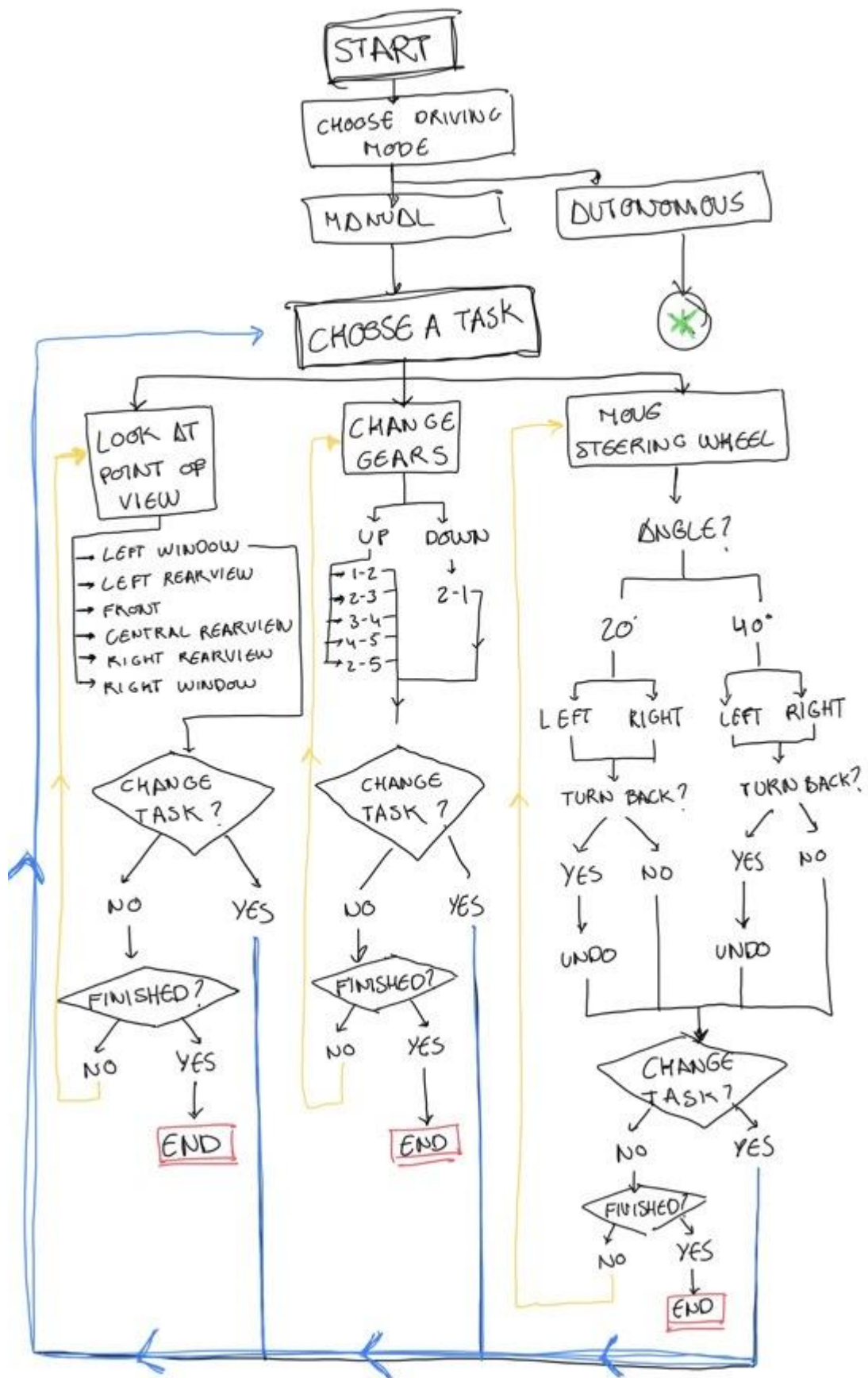
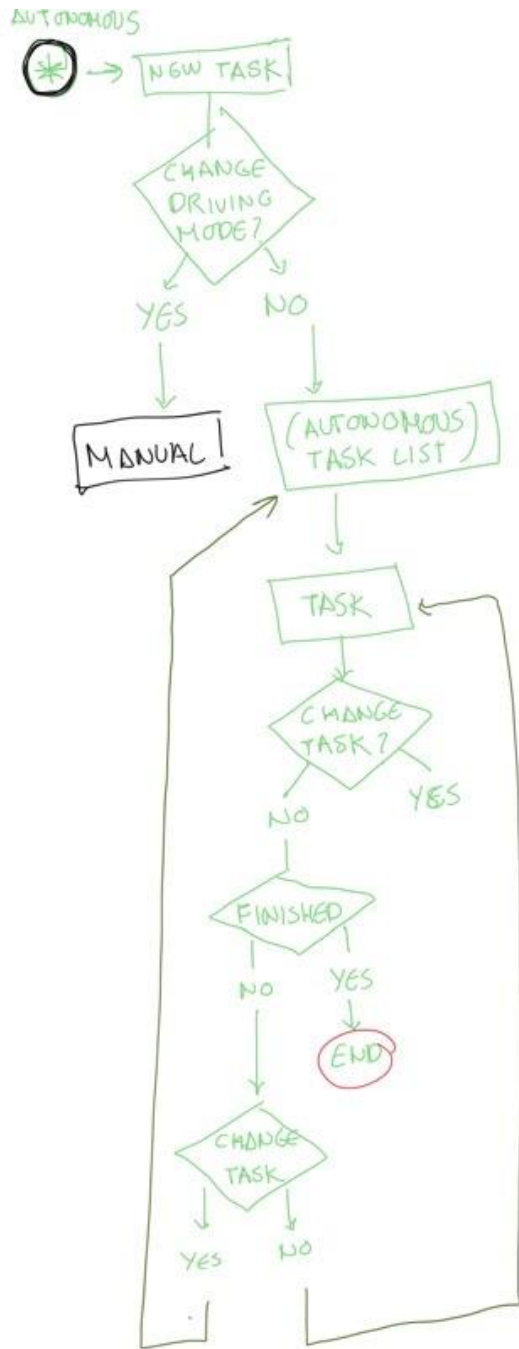


Figure x.x





\* CHANGE DRIVING MODE  
 WHEN YOU FINISHED WITH ONE.  
 e.g: Being manual task, finish, and then  
 change to autonomous mode.

Figure x.x

## Appendix 4: Market study.

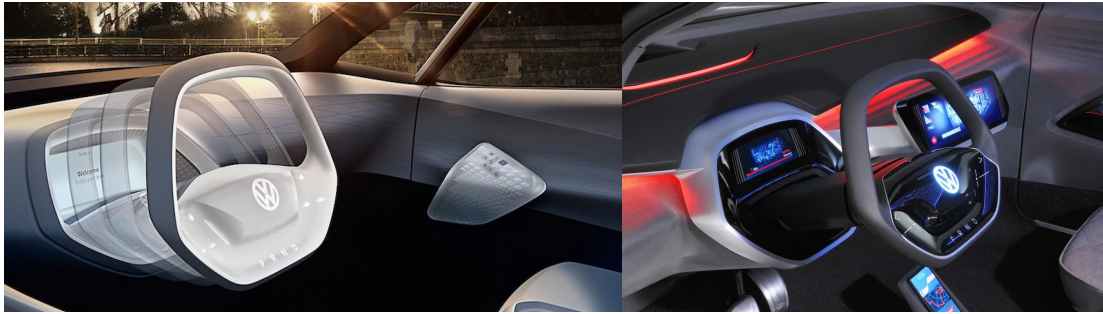


Figure 3.14 Volkswagen ID Crozz Steering Wheel

Simplicity/Comfort
<ul style="list-style-type: none"> <li>• Gears: indicated by easily accessible buttons</li> <li>• Steering wheel handling: less than 360°</li> <li>• Number of buttons: minimum. Only those required</li> <li>• Ejection mode: simple. Press and hold the logo on the steering wheel for 3 seconds.</li> </ul>
Adjustment between parts
<ul style="list-style-type: none"> <li>• Retractable: Yes</li> <li>• Extraction system: simple</li> </ul>
Appearance
<ul style="list-style-type: none"> <li>• Dashboard integrated: Yes</li> <li>• Includes brand logo: Yes</li> <li>• Mechanism: simple</li> </ul>
Ergonomics
<ul style="list-style-type: none"> <li>• Ergonomic design: Yes</li> <li>• Customization in relation to the user's physical characteristics: Yes. Possibility to adjust the dashboard removal distance</li> <li>• Non-slip grip. Avoiding hand slippage while driving</li> </ul>
Range
<ul style="list-style-type: none"> <li>• Appearance: futuristic, lights, glass and metal</li> </ul>



Figure 3.15 Nissan IDS steering wheel

Simplicity/Comfort
<ul style="list-style-type: none"> <li>Gears: located on the left side of the steering wheel. The location of the gears can be complicated</li> </ul>
<ul style="list-style-type: none"> <li>Steering wheel handling: two grips.</li> </ul>
<ul style="list-style-type: none"> <li>Number of buttons: minimum. Only those required</li> </ul>
<ul style="list-style-type: none"> <li>Ejecution mode: non-ejecutable, Reconfiguration by pressing a "PD Commander" button.</li> </ul>
<ul style="list-style-type: none"> <li>In autonomous driving, the steering wheel is replaced by a screen</li> </ul>
Fitting between parts
<ul style="list-style-type: none"> <li>Retractable: Yes.</li> </ul>
<ul style="list-style-type: none"> <li>Extraction system: complex</li> </ul>
Appearance
<ul style="list-style-type: none"> <li>Dashboard integrated: Yes, hidden mode.</li> </ul>
<ul style="list-style-type: none"> <li>Includes brand logo: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Mechanism: complex. Many moving parts.</li> </ul>
<ul style="list-style-type: none"> <li>Design: complex. The steering wheel includes the control panel</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip: provides elegant look</li> </ul>
Ergonomics
<ul style="list-style-type: none"> <li>Ergonomic design: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Personalization in relation to the physical characteristics of the user: No.</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip: provides a better grip. Avoids slipping of the hands while driving</li> </ul>
Range
<ul style="list-style-type: none"> <li>Appearance: futuristic, lights, glass and metal</li> </ul>



Figure 3.16 BMW Vision Next 100 Steering Wheel

Simplicity/Comfort
<ul style="list-style-type: none"> <li>Gears: touch screen buttons</li> </ul>
<ul style="list-style-type: none"> <li>Steering wheel handling: two grips</li> </ul>
<ul style="list-style-type: none"> <li>Number of buttons: minimum. Only those required</li> </ul>
<ul style="list-style-type: none"> <li>Eject mode: Press the logo on the steering wheel.</li> </ul>
Adjustment between parts
<ul style="list-style-type: none"> <li>Retractable: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Extraction system: complex</li> </ul>
Appearance
<ul style="list-style-type: none"> <li>Dashboard integrated: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Includes brand logo: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Design: simple. Not many elements</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip: provides elegant look</li> </ul>
Ergonomics
<ul style="list-style-type: none"> <li>Ergonomic design: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Personalization in relation to the physical characteristics of the user: No.</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip: provides a better grip. Avoids slipping of the hands while driving</li> </ul>
Range
<ul style="list-style-type: none"> <li>Appearance: current-futurist</li> </ul>

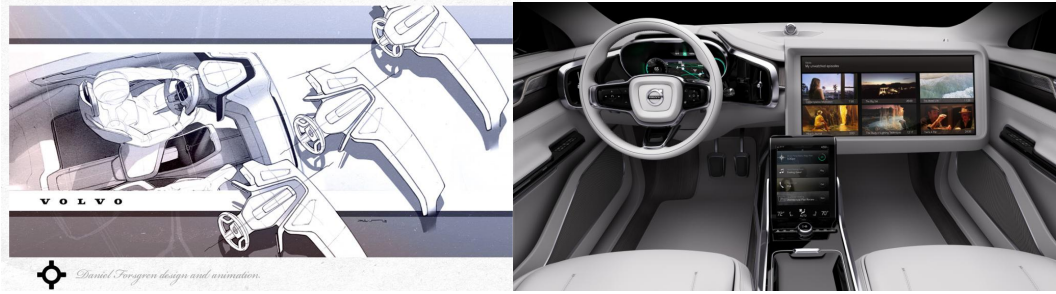


Figure 3.17 Volvo C26 Steering wheel

Simplicity/Comfort
<ul style="list-style-type: none"> <li>Gears: indicated by easily accessible buttons</li> </ul>
<ul style="list-style-type: none"> <li>Steering wheel handling: complete 360°</li> </ul>
<ul style="list-style-type: none"> <li>Number of buttons: minimum. Only those required</li> </ul>
<ul style="list-style-type: none"> <li>Ejection mode: simple. Hold the "Autopilot" button at the rear left of the steering wheel.</li> </ul>
Adjustment between parts
<ul style="list-style-type: none"> <li>Retractable: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Extraction system: simple</li> </ul>
Appearance
<ul style="list-style-type: none"> <li>Dashboard integrated: No</li> </ul>
<ul style="list-style-type: none"> <li>Includes brand logo: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Design: simple.</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip: provides elegant look</li> </ul>
Ergonomics
<ul style="list-style-type: none"> <li>Ergonomic design: Yes</li> </ul>
<ul style="list-style-type: none"> <li>Personalization in relation to the physical characteristics of the user: Yes. Possibility to adjust the dashboard removal distance, depending on the selected mode; driving, creating or relaxing</li> </ul>
<ul style="list-style-type: none"> <li>Upholstered grip. Avoid slipping of the hands while driving</li> </ul>
Range
<ul style="list-style-type: none"> <li>Appearance: Current.</li> </ul>