CHALMERS
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Instructor's workplace for driver's education buses

Development and integration of a modularized concept

Master's thesis in Product Development

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Cover:
Front and side view of instructor's workplace concept mounted in Volvo bus

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Abstract

Incremental customer adaptations and add-ons to existing products are commonplace in the vehicular industry today. In part due to shorter development cycles and an increasing demand for higher performance. In part due to global market demand for customization and product variation. The effects of such customized add-ons to an existing Volvo city bus model were investigated in this paper while developing an instructor's workplace module. Customer specific requirements were incorporated into the design concept while taking into consideration governing regulations as well as end user needs.

The customer, a Belgian transportation company, wanted to extend their bus fleet and needed a number of vehicles that had certain additional equipment for the instructor to use during driver's education. The instructor's workplace was expected to be detachable and a review of current Belgian regulations revealed that the instructor's workplace in many respects needed to function as a secondary driving position.

Designing the workplace included using common product development methods as well as topology optimization and ergonomic heuristics. The outcome was a digital mockup of the final instructor's workplace concept that fulfilled the presented requirements.

Keywords: instructor's workplace concept, city bus, Volvo 8900, driver's education

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Armin Fatic, Miguel Huezo Martinez
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Acronyms

C - Constraint
CAD – Computer Aided Design
CN - Customer Need
FR - Functional Requirement
H-point - Hip reference point of a seat
OC - Optimization Criteria
ROM - Range of Motion
SC - Selection Criteria
SRP - Seat Reference Point

1 Introduction

This first section of the thesis places the subject matter into a greater context by introducing the main problem that is solved and the stakeholders involved in the process. The project starting point and the outcome expectations and delimitations are the main take away for the reader.

1.1 Background

Benteler Engineering Services is a consultant firm with more than 50 years of experience, spanning over many industries. The company offers engineering services along the whole product development process. The roots of the company lie within the automotive industry, making it suitable for companies such as Volvo Buses to acquire their services. Volvo Buses is part of the Volvo Group, and is one of the leading bus manufacturers in the world. The company operates in a global market and also has manufacturing capabilities in different parts of the world (Volvo Buses, 2015).

During 2013 Volvo Buses received an inquiry for 250 low-entry, city buses from a public transport organization in Belgium. The inquiry specified that of the 250 buses, 10 were to be fitted with a set of functions which duplicate certain driver controls in a secondary position next to the driver. The secondary driving position would act as a workplace for the instructor during driving lessons. It is worth noting that the customer also wished to be able to dismantle the add-on equipment, in order to have the bus available for regular traffic when needed. Since no currently available product is able to fulfill the requirements, Volvo Buses decided to pursue investigating what effects an add-on solution would have on the offered bus product. Being a mode of public transportation, buses are subject to strict EU regulations but also to international standards and national Belgian laws and have to fulfill certain requirements in order to be considered legal road vehicles.

The instructor's workplace module was developed by two students from Chalmers University of technology as a Master's thesis with support from Benteler Engineering Services AB.

1.2 Purpose

The main task of this project is to investigate how a driving instructor's workplace can be developed and integrated as a module that can be mounted onto city bus 8900. The final concept solution will be delivered as a Digital mockup (DMU) concept of the workplace module that fulfils the requirements stated by governing EU and Belgian legislation while also accommodating customer requirements and user expectations.

1.3 Scope

In order to conclude the project in the given time frame some delimitations are made.

1. Investigation will not be concerned with the rear part of the bus. Only the front part of the bus that was specified in the inquiry will be investigated for the extent of changes needed.
2. Development of the electrical systems will not be addressed in this project.

3. Finite element analysis will not be performed on mechanical parts of the bus. It is assumed that the parts will not change significantly from the original design.
4. Neither evaluation nor development will be made of the seat. It is assumed that the standard driver's seat with seat belt available in the current Volvo bus will be used.
5. No development of solutions will be made for the rear-view system. The standard mirrors used in the current bus will be investigated.
6. New solutions for the pedal system will not be developed. Evaluation of existing products from suppliers will be made to find a suitable solution.
7. Detailed development of the control panel and its components will be limited to finding the necessary functions and choosing a suitable layout.
8. No thorough investigation of materials or manufacturing methods will be conducted. Already present and commonly used materials and methods are assumed to be sufficient.

1.4 Objective

During the development of the instructor's module certain questions about the design will need to be answered.

1. How can we assure that the module fulfils the requirements put by the governments and customer and to what degree?
2. How can we incorporate topology optimization in product development projects?
3. Can a camera system replace mirrors for the instructor?
4. What is the extent of changes required in the bus, and what parts are affected?

2 Theory

This chapter lays out the theoretical foundation for the following sections by elaborating on the related fields of study that will be consulted during the development process.

2.1 Type of project

Knowing what type of development project is to be undertaken is useful when deciding on the level of resource commitment that will be required in the project. A project classification based on the degree of change represented by the project is suggested by Wheelwright & Clark (1992). One such project class is the incremental or derivative project, which is characterized by little to no process or product change and involves only enhancements or add-ons to the current solution. Extending the use of an existing product the project will be less resource intensive when compared to a complete platform overhaul. Since the scope and issues are different for different project types, the requirements for success will also vary significantly.

The main difference and benefit of a derivative project, when compared to a new platform project, is the range of performance dimensions that need to be accounted for in the front end planning. Since parameters on all levels are stated from the outset in a derivative project there is less need for creativity and initiative (Wheelwright & Clark 1992).

2.2 Product architecture

According to Ulrich & Eppinger (2012), the product architecture defines the assignment of functional elements to physical building blocks. The purpose of this definition is to establish the functions and physical element interfaces that make up the final product in a schematic overview, before reducing them to specific technologies. Functions are described with functional elements and correspond to operations and transformations performed. Physical elements can be parts, components and subassemblies that implement the product's functions. The physical elements are further organized into physical building blocks called chunks or modules. Algeddawy & Elmaraghy (2013) state that the main reason for grouping elements into modules is to manage the interactions among them. The objective is to minimize interactions between modules and maximize connections within them.

A pertinent characteristic of the product architecture is the level of modularity that is assigned to the chunks. In a highly modular architecture, each chunk implements only a single or very few functional elements and interactions between chunks are well defined and fundamental to primary functions of the product. The polar opposite of a modular architecture is an integral architecture. The main difference being that single chunks implement numerous functional elements and that the interactions between chunks are poorly defined. It is rare that products exhibit either one quality entirely. Instead the architecture modularity is relatively defined with regard to a comparable product. The most common type of modular architecture is a slot-modular architecture. It is characterized by interfaces that are unique for each chunk and do not allow for chunks to be interchanged (Ulrich & Eppinger, 2012).

The product architecture will commonly emerge during concept development through informal sketches, diagrams and early prototypes and is further developed in the system level design stage. As development progresses, the decisions which produce the product architecture, will also allow for detailed design of product components to be carried out simultaneously. The level of completion is determined by the maturity reached of the basic product technology in either stage.

Ulrich & Eppinger (2012) suggest a four step method to structure the decision process of creating the product architecture.

1. Create schematic of product and identify critical physical or functional components
2. Cluster elements either through geometric integration (chunking) or function sharing
3. Create rough geometric layout
4. Identify fundamental and incidental interactions
    a. fundamental- physical interfaces
    b. incidental - because of geometric arrangement of chunks

Similar heuristic methods are offered by others, including using a design structure matrix (DSM) as a starting point in achieving an adequate level of granularity to the product architecture (Algeddawy & Elmaraghy, 2013).

An integral architecture allows designers to exploit secondary properties to implement multiple functions using a single physical element. For example, a product's housing can be designed to also carry structural loads in order to eliminate the extra size and mass of a separate frame and enclosure. This practice is called function sharing and allows for redundancies to be eliminated while also allowing for geometric nesting of components to minimize the occupied volume and material used. Component integration is a strategy for minimization of the number of parts and thus reduces manufacturing cost (Ulrich & Eppinger, 2012).

2.3 Design for assembly

There are well established benefits to incorporating design for assembly (DFA) in the development process, among others, DFA can improve assembly ease and reduce assembly time. The principles of DFA are considered a subset of the more overarching design for manufacturing (DFM) and focus attention on managing assembly cost through reduction of parts count, manufacturing complexity and support costs (Ulrich & Eppinger, 2012). Current methods are commonly implemented in the embodiment design phase, overlooking the opportunity to incorporate DFA in the conceptual design phase, even though it implies increased cost through forced additional iterations of the design (Stone, McAdams, & Kayyalethekkel, 2004).

Stone, McAdams, & Kayyalethekkel (2004) propose a product architecture-based approach to DFA in the conceptual phase. By generating solutions to modules separately the outcome will be a concept with fewer number of parts than the theoretical number of parts produced by a post-conceptual DFA method. The idea is that once a functional model has been expressed in a common language of functional basis, sub-functions can be clustered to define the modular product architecture (Stone, McAdams, & Kayyalethekkel, 2004). This offers the benefits of early implementation of DFA while using a similar methodology to product architecture as presented by Ulrich & Eppinger (2012).

2.4 Topology optimization

In recent years, an important tool called topology optimization has spread throughout the mechanical design disciplines. It is a mathematical method used to find the optimal distribution of material and voids within a design domain, for a prescribed objective and set of limitations. The quantities that normally limit the optimization in structures are stresses, displacements or the geometry (Christensen & Klarbring, 2009).

2.4.1 Topology optimization in Product development

In today's competitive markets, there is a need to refine the classical product development process in order to release products faster, but also to improve important aspect of the product. The automotive industry and the aerospace industry have been in the forefront of using topology optimization methods to lower the weight of existing parts, thanks to stricter emission laws.

A general description of the structural development process is presented by Kirsch (1993). He identifies four different stages.

- *Formulation of functional requirements:* What is the use of the product? Normally established in the beginning of the project.
- *Conceptual design stage*: Deals with the overall planning of a system to serve its purpose. Selection of the overall topology and type of structure are some of the decisions made by the engineer in the conceptual design phase.
- *Optimization:* Within the selected concept there may be many different possible designs that satisfy the functional requirements, a traditional *iterative-intuitive* procedure may be employed to choose the optimal design.
- *Detailing:* After completing the optimization phase, other factors come in to play. This can be anything from the decision of manufacturing process to the decision of what colour to use.

Although the process is concerned with the development of structures, it is not difficult to identify similar phases in the product development process proposed by Ulrich & Eppinger (2012). More specific conceptual design phase heuristics can be found in both process models. The traditional *iterative-intuitive* procedure in step three is described by Christensen & Klarbring (2002) as follows.

1. A specific design is suggested.
2. Requirements based on the function are investigated. (Analysis and testing)
3. If these are not satisfied, e.g. stress levels are too large, a new design must be suggested.
   Even if the requirements are satisfied the design may still not be optimal, which makes the proposition of a new design valid.
4. The new design is brought back to step 2

It can be seen that this procedure is not far off from the design-build-test process proposed by Ulrich and Eppinger (2012). Normally computer based methods are used for the realisation of step three, e.g. FEM or Multi-body Dynamics. Christensen & Klarbring (2009) argue that these methods help in analysing the product or structure with greater confidence, and make every step more effective. However, they also argue that it does not lead to a basic change of the strategy.

Topology optimization is a different strategy from the iterative-intuitive procedure. Here a mathematical optimization problem is formulated, and the requirements transformed into functions that act as constraints. The concept that is "as good as possible" is then given a precise mathematical form. For this to work, a basic requirement is that the constraints used are measurable in mathematical form. This is not a problem for mechanical constraints, which cannot be said for aesthetic ones.

2.4.2 Examples of topology optimization

Sudin et al (2014) show in their paper how a new lighter concept for a brake pedal was achieved using topology optimisation. The final concept was 22% lighter compared to the existing pedal, without sacrificing its performance. Olason & Tidman (2010) investigated the potential use of topology optimization in the product development process of Saab Microwave systems. They concluded that it was possible to introduce topology optimization in the early stages of the process. In the early concept generation stage, the method should be used to develop stable and efficient structures early in the PD process.

Norberg & Lövgren (2011) use topology optimization to find the optimal topology of beams and rods to achieve high stiffness in the front structure of a Volvo car, for improved ride and handling. They also recommend using topology optimization early in the design process, not to get direct realisable concepts, but to have a clear view of load paths and a good understanding of the structure under load.

Stangl, et al (2013), present a methodology for consideration of uncertainties in the topology optimization. When using optimisation tools the results primarily depend on the requirements defined by future operating conditions. Normally in the early design stages these requirements are uncertain. It is also common for the product developer to use a deterministic approach assuming all input parameters can be determined exactly. The consequence of this being that the resulting design might not be optimal. Stangl et al (2013) also present some recommendations to be used when working with topology optimization.

The definition of the boundary conditions and load case of a static FE model for a dynamic system should represent the extreme positions with the maximum load. (Worst-case-analysis) Local changes of the boundary conditions for different load cases must be avoided and should always represent the nominal position of the dynamic system.

Rough meshed FE-models should be optimized, since these allow a check up if the selected boundary conditions are appropriate. If the model is reasonable, a high mesh density is required to guarantee a sufficient detail resolution of the optimized structure. Prevent adverse forms by using the "minimum member size control" as constraint for the topology optimisation especially when using a very detailed mesh. This allows the resulting structures to be suitable for manufacturing, (Stangl et al, 2013)

2.5 Ergonomics

Ergonomics is a multidisciplinary science that incorporates knowledge of the human body and mind from many different fields such as, psychology, anthropometry, biomechanics and physiology to name a few. It involves understanding human characteristics, limitations and capabilities when designing machines that people use. In essence, ergonomic design is the application of this knowledge to the development of machines or devices that fit the human body and the human cognitive abilities.

One important aspect of ergonomics is to place focus on the human as the center of the system being designed. In many situations the user and the system cooperate in a specific environment to achieve a given goal. There are several advantages to implementing ergonomics early in the development phase. The international standard ISO 13407:1999 list the following advantages.

The developed systems:
• are easier to understand and use, thus reducing training and support costs;
• improve user satisfaction and reduce discomfort and stress;
• improve user productivity and operational efficiency of organisations;
• improve product quality, and provide a competitive advantage.
It is important to early in the development phase break down the ergonomic requirements imposed on the system in order to reap the benefits and avoid costly changes in later stages. The requirements can be found by exploring the user, the tasks to be performed by the user and the environment the system will be used in.

2.5.1 Human capabilities and characteristics

Human capabilities can be divided into two areas, physical capabilities and information-processing capabilities (Bhise, 2011)

2.5.1.1 Physical capabilities

Anthropometrics is the study of the different measures of the human body, i.e. size, proportions and shapes of different body parts. These measurements are affected by certain factors genetics, plasticity, different ancestry and different ethnic groups. Anthropometrics is useful when designing a system to fit the intended users. Biomechanics is the simplification of the human body into a mechanical system. It allows for the exploration of the ability of humans to exert force. Work-related loadings are defined to consist of posture, forces and time (Sandom & Harvey, 2004).

2.5.1.2 Digital Human Modeling

Ergonomic analysis tools are increasingly integrated into the 3D computer aided design (CAD) environments, most notably in large industry sectors producing complex products like the automotive industry. The software tools have been specifically designed to simulate working postures and related actions using human representations called manikins in the CAD environment. Such models can be adapted to anthropometric specification in terms of gender, size and other parameters, in order to investigate whether the bounding extremes of human population are able to work in the proposed environment without potential hazard to their health. Besides analysing space and reach to create comfortable working environments, the human modeling tools can be used to analyze the field of vision a human would have in a particular position (Berlin & Adams, 2014). By creating a virtual representation of the vision, it is possible to see if certain objects will obstruct the view of the user and determine if alternative positions need to be considered.

The manikin allows for faster extensive ergonomic testing of design alternatives, securing the best choice for a workplace with low ergonomic risks, without increasing the product development time or cost significantly. (Berlin & Adams, 2014)

2.5.1.3 Information-processing capabilities

Information-processing, commonly known as cognitive capabilities, are concerned with the mental processes such as perception, memory, reasoning and motor response, and how they affect the interaction with other humans and with other parts of the system (Simonsen, 2014). Humans are constantly over showered with different information from the surrounding environment and therefore it is of importance to know how humans process this information. There are many different types of models for the human information process. One of the most modern and complete model of the human information process is the one developed by Wickens.

The model visualises the process of information in three distinct phases. Perceptual encoding, processing and responding. Sensory stimuli enters the sensory register where the information is processed into a form that the perceptual processes within the brain can understand. The processed information is then transmitted from the perception stage to the working memory. The working memory interacts with the long term memory to develop our perception of the environment. Finally a response to the perceptions is determined, information about the executed response is also sent through the feedback loop. The model also takes into consideration the attentional resources needed in the different phases.

2.5.2 Automotive Ergonomics

The automotive industry is a very competitive industry, the automakers are pressured to design the “right” product right from the start. This means that implementing ergonomics in the development phase is essential to develop products that not only are mechanically good, but ergonomically good.

2.5.2.1 Driving

During driving the driver is constantly being bombarded with information from the senses. This information is processed to make decisions about which actions to perform. The predominant input of information is the visual sense. It is therefore important to know the limitations of human visual capabilities. Bhise (2012) lists eight of the commonly considered capabilities used when driving.

1. Detection of objects
2. Perception and identification of colors
3. Difference in luminance
4. Equality of appearance
5. Difference in colors
6. Recognition of details or object recognition.
7. Depth perception
8. Accommodation

2.5.2.2 The aspect of time

The amount of time a driver needs to perform a task is important when designing the vehicle human-machine interface. Performing a task usually means that the driver takes their eyes off of the road. For example, to read the speed from an analog speedometer with a moving pointer takes approximately 0.5-1.2 s (Bhise, 2012). Looking at the rear view mirrors to view the vehicles behind takes 0.8 -2s. In more complex tasks, such as changing the radio frequency or changing the temperature on the climate control, the driver takes two to four glances where each glance is about 1s long. A vehicle traveling at a speed of 100 km/h moves 28 m in one second. Hence, it is important when designing vehicle equipment, that the driver can perform necessary actions with glances no longer than 1.5 s (Bhise, 2012).

2.5.2.3 Displays & Controls

The way information ispresented in vehicles is very important. The controls and displays are the interface between the human and the machine.When designing the driver interface there are some considerations to keep in mind:

1. Drivers will prefer to minimize their mental and physical efforts in using controls and displays.
2. People will prefer to not use what they do not understand.
3. Study the user population, user characteristics and the variability among the users in the population.
4. Study the usage conditions and driving situations when the controls and displays are used.

These conditions and situations will provide an insight into the driver's informational needs, time constraints and environmental conditions needed to design controls and displays (Bhise, 2012). With these considerations in mind there are a few characteristics of good controls and displays.
Characteristics of a good control

1. A driver should be able to operate the control quickly with minimal mental and physical effort.
2. Minimal number of eye glances should be needed to complete the desired control operation.
3. Any control activation should require minimal hand/finger movements.

Characteristics of a good visual display.

1. The driver should be able to read and understand the display quickly with minimal mental and physical effort.
2. The driver should be able to acquire the necessary information from a visual display in a few short eye glances.
3. The driver should not require any gross body movements to obtain needed information.

2.6 Regulations

The UNECE (United Nations Economic Commision for Europe) is a legislative organ established to regulate agreements and conventions in order to integrate national laws in the EU (UNECE, 2015). The reasoning behind this has been to reduce the differences between the EU member states, but the organisation has subsequently made an impact globally as well. The UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) has produced numerous regulations for transportation and motor vehicles that harmonize national regulations. These standards have been negotiated and agreed upon by government representatives and set precedence in the countries that accede to them.

Such centralized national regulations are intended to simplify border crossings and have established a framework for coherent transportation infrastructure. They have also made previously separate markets become more integrated and the homologation process has become a tool for the extension of global trade, by creating mutually recognized vehicle approval systems (UNECE, 2015). Each UNECE member country can however still have unique additions to the agreements, meaning that there can be noticeable discrepancies between countries or regions of countries in specific cases.

The laws that govern complementary driving education vehicle equipment in the Flemish part of Belgium are defined in the Royal Decree of 2004. This regulatory document states in detail what control functions the driving instructor must have at their disposal during lessons and also the field of vision that has to be provided in buses for education purposes. Dual control pedals and the prescribed field of view in figure 1 are just some examples of the legal requirements and the most significant ones can be found in the requirements specification in appendix A

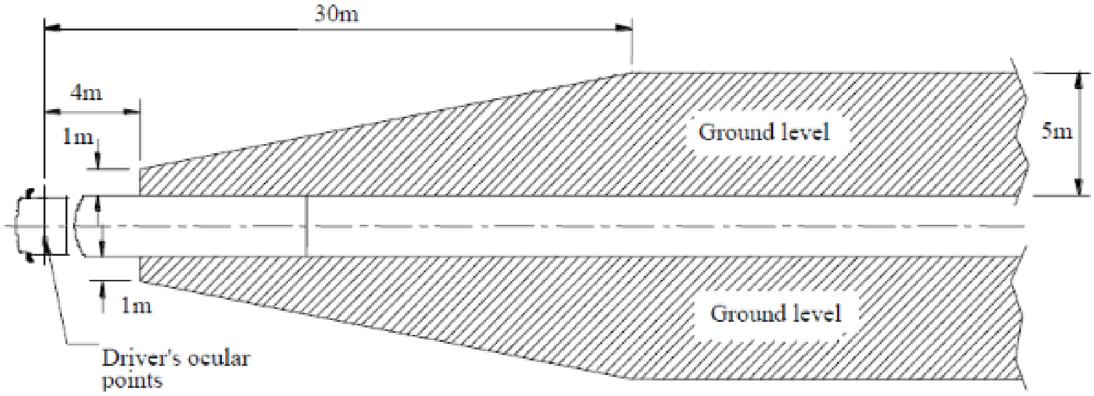

Figure 1: Legally required area of vision.

3. Method

The methods and theory presented in this chapter were used to support decisions in finding answers to the previously posed questions. They made up the framework for information gathering and interpretation as well as the main sequential phases of the development process. The generic product development process, as outlined in Ulrich and Eppinger (2012), was used as a foundation and then adapted to suit the needs of this particular project.

3.1 Planning

According to Maylor (2010), some common causes of projects failing to succeed are failure to gain a shared understanding of the outcome, failure to recognise requirements of a key customer group and lack of user involvement. To manage these risks project management methods such as work breakdown structure, Gantt chart, stakeholder analysis and risks were considered. The project direction was guided by the mission statement in appendix B, which further expanded on the details and the project framework. These methods assured that there was a good control of the project outcome and that the major project stakeholders had been considered.

Developing the instructor’s workplace concept was considered to be an add-on project to the current bus model. This meant that the solution needed to function within the greater context of the bus system with respect to safety and usability. It was therefore imperative to find information on what the physical constraints were of the designated design space and what changes could be afforded in the bus in order to determine how the development effort would be structured.

Product architecture and concepts solutions were developed in the concept development stage. The stages following the conceptual development constituted design on two levels. The system level design phase defined the reference positions and dimensions of the product architecture’s internal chunks, mainly based on vision analysis. In the detailed design phase, the interactions between the chunks and the bus were addressed in terms of final placement and attaching structures. Focus was placed on the intricacies of each component and a more precise description of the attachment type and the changes required in the bus structure were created.

3.2 Needs mapping

Once planning was concluded the first step was to get acquainted with the bus itself and the context in which buses operated. The project focused on laws that apply to the driver functions and the surrounding driving compartment within buses, particularly regulations concerning buses used by driving schools.

3.2.1 Literature review

The customer's requirement specification that was presented at the outset of the project was specific, but not complete to the level where it could sufficiently support the development of the product. The final product would only be useful to the customer if it could be certified according to regulations and thus become a legal road vehicle. This is why many of the customer requirements were found to be derived from laws in the target market, the Flemish province of Belgium. In order to establish a fundamental understanding of the governing bodies that control vehicle design, a thorough review of current regulations was conducted. This was done on multiple levels, firstly on an international level by researching the UNECE regulations and ISO standards for transportation vehicles. Secondly, Belgian laws concerning driving school buses were analyzed in order to get the specifications needed for the final product.

The main areas of interest were transportation vehicle related

1. driving education laws
2. field of vision laws
3. structural design regulations
4. ergonomic standards

This provided the necessary information to establish a mapping of requirements that would limit the solution space once concept development began.

3.2.2 Interviews and observations

While studying the legal and customer requirements it had been noted that not all important stakeholders were represented in the research. The driving instructors, who would be the ones using the product in the end, needed to be considered if the final solution was to be of good use to them. The Kano model (introduced by Prof. Noriaki Kano) shows how customer satisfaction varies with the three types of different needs, as seen in figure 2. These are the basic, the performance, and the delighter needs and can be found when gathering Voice of the Customer information. Different data collection methods are appropriate for different types of needs and not all types of needs will be equally clearly expressed by the user. It is therefore necessary to select data collection methods which can elicit all three types of needs (Karlsson, 2013).

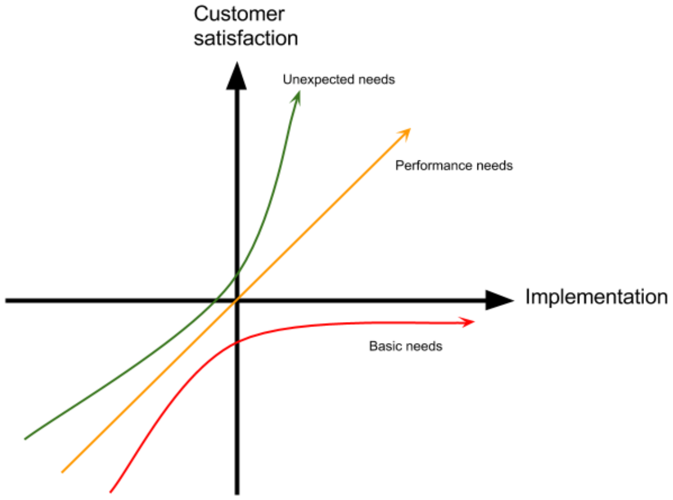

Figure 2: Kano model of satisfaction as function of needs type.

According to Stanton & Young (2004) interviews are not limited to any particular phase of the development and can be utilized in any situation where an individual's opinion or perspective is sought after. In order to capture the end user needs, bus driving schools were contacted and semi-structured interviews were performed with driving instructors. The information that would be retrieved was related to how driving lessons are conducted today, what the critical factors were and what, if any, control functions the instructor would be interested in having while teaching. Open-ended questions along with some mediating sketches and pictures were prepared beforehand to guide the four interviews conducted. Each interview lasted approximately an hour and the interview guide used can be found in appendix C. Working Only local driving schools were considered since it was assumed that driving instructors in other regions had similar needs.

After the interviews, the buses that the instructors used during lessons were visited where further discussion and observation could take place. To further elicit user needs, a ride along during a driving lesson was arranged. This observation in the user's occupational setting served as an additional source of information for identification of needs and problems in the current set up that the user might not have been aware of, or was unable to express. The information acquired could then be analyzed and combined with the already structured requirements in order to enhance the provided requirements specification and to ensure that no latent stakeholder needs were disregarded in the process.

3.2.3 Data interpretation

During bus driving lessons, instructors stated that they focused on the driving student's behaviour, the bus characteristics and the surrounding traffic environment. They would often sit in one of the first row passenger seats and observe and communicate instructions to the student from there. The level of supervision required was regarded to be lower for bus driver education than for first time students in personal vehicles. This emphasized that most bus driver students have extensive experience with the concepts of vehicles and road traffic.

Since education specific adaptations in buses is not something strictly regulated by Swedish law, add-ons, such as the ones required by Belgian law, were found to be rare and not something that bus manufacturers offered directly to customers. Instead driving schools and their instructors chose themselves what type of aids, if any, were retrofitted to the bus.

Some of the instructors expressed skepticism toward the usefulness of having additional technology and thought it would be distracting and counterproductive if the instructor performed tasks that the students were supposed to learn. Particularly concerning was the requirement for a warning sound that activated when the instructor intervened and used the dual brake pedal. The worry expressed was that this could make the student more stressed in a difficult traffic situation. Providing a mute switch for the brake sound was therefore identified as a delighting feature.

Most schools used coach buses and usually placed the instructor in the first row passenger seat. The schools that used city buses, the bus type referenced in this project, would either simply seat the instructor in the first row passenger seat or place an extra seat on a platform, in order to elevate the instructor to the driver's eye level.

During the observed driving lesson, some drawbacks of placing the instructor too far back and too high up became apparent. In order to keep track of the surrounding environment the instructor had to lean forward. With the instructor's seat placed far behind the driver the distance between the instructor and student acted as a physical barrier where the instructor on one hand tended to lean forward to communicate with the student. The instructors also confirmed that some students occasionally felt an urge to turn around and face the instructor to better interact, thus losing sight of the road ahead. As seen in figure 3, the restricted view and the distance from the driver imposed a straining posture on the driving instructor during the lesson.

Figure 3: Observed posture of driving instructor in coach bus.

To provide the instructor with the adequate vision all schools had added additional mirrors, but other than that there was little in the way of vehicle controlling or informing functionality from the instructor's position. Some schools had added brake functionality with a hand operated joystick. The joystick worked by activating a pneumatic cylinder that pushed on the brake pedal. The main complaints about this solution were that it was not possible to regulate the brake pressure; it was either full on or off. The second issue was that the hand control did not provide the same feeling and the instructors expressed that they would intuitively move their feet in anticipation before they realized that the brake was hand operated.

The exception to the rule was one school that had a factory customized control panel from which the instructor could control not only the brake, but also activate the horn, adjust the extra mirrors, activate the instructor's mirror heaters and also provided two power outlets for charging cell phones or tablets. The control panel furthermore provided the instructor with an area for taking notes and a lamp on a swan neck, which could light up the writing surface.

A small screen resided on the writing area on which information was displayed. The information was the current date and time, the temperature, the RPM, the gear and the speed. The display also had buttons which would switch between showing the information mentioned or show the image from a rearward facing camera mounted on the back of the bus, although this was rarely used.

This solution, shown in figure 4, was unique compared to what the other schools used and came very close to fulfilling the Belgian requirements. The instructor was pleased to work in this environment and expressed delight when talking about the writing surface on the control panel, which also had a storage compartment inside. Although most of the functions were never used it felt comforting to have them available and it made for a good workplace environment.

Figure 4: Control panel in driving school bus.

The information gathered needed to be interpreted in order to translate statements into product requirements and constraints. This was done by following the procedure described in Ulrich & Eppinger (2012) where information transcripts were parsed for relevant statements and then structured into categories and weighted by relative importance. The resulting specification was further refined and became the requirement specification found in appendix A, which was used to develop the instructor's workplace. Table 1 shows some of the most important control panel requirements that were discovered.

Table 1: Requirements and delighting features of control panel.

<table>
<tr><td>Control functions</td><td>Display information about</td></tr>
<tr><td>1. control low/high beam light
2. control front door, D1, state (open/closed)
3. control horn
4. control parking brake
5. control turn signal indicator lights
6. control hazard lights
7. mirror heaters</td><td>1. current speed
2. current gear
3. current RPM
4. turn signal indicator status
5. current temperature
6. current date and time
7. low/high beam light state
8. hazard lights state</td></tr>
<tr><td colspan="2">Additional and delighting features</td></tr>
<tr><td colspan="2">• Mute for alarm sound which informs student when instructor has used activated the brake pedal
• Space for radio with swan neck microphone and loudspeaker
• Perform security check function (activates lights)
• USB port for charging cell phone, tablet
• System active indicator
• Storage compartment in control panel
• Control mirror heater</td></tr>
</table>

3.2.4 Current bus study

Volvo produces buses in many different configurations and variants, but since the inquiry that this project was based on refers to a particular bus variant there was no need to consider any types other than the one specified. The bus in question was the 8900, which is defined as a short to medium range city or intercity travel vehicle (Volvo, 2015).

Notable for city buses is the low passenger entrance floor; meanwhile the driver is elevated on a platform to better see the surrounding environment while driving. The front part of the platform extends at an angle farther to the right to provide space for a step up to the driving compartment and claims a part of the entrance floor. The compartment was enclosed by a separating wall and a gate behind and to the right of the driver respectively. Both of which significantly limit the field of vision from any position in the passenger gangway behind the entrance floor. The driver gate therefore needed to be opened and kept out of the way when the bus was used for driving practice. The front passenger entrance consists of two doors that open inwards and take up some of the space on the entrance floor.

Since the instructor's workplace needed to fit within the above mentioned geometrical boundaries, the first part of concept development was used to define a virtual representation of the solution space. This illustrated the geometrical constraints that were used to determine the suitability of different concept solutions. Solutions contained within the green volume in figure 5 would be considered acceptable with regard to minimizing the changes made to the original bus. These factors were interpreted and included in the requirements specification in order to be accounted for in the placement of the instructor.

Figure 5: Available design space in the bus. Top view to the left, rear view to the right.

3.3 Concept development

Once the target specification had been established concept development could be started. Defining the system and its boundaries was essential if the concept generation results were to have appropriate interfaces and take advantage of early stage function sharing opportunities and synergetic effects. The concept solutions were then sought both internally, within the project team, as well as from external sources such as experts, literature and competitors. The sub-solutions were combined in a morphological matrix to maximize the solution space. To screen the generated concepts Pugh matrices and Kesselring matrices were used. Using these methods the goal of having 1-3 concepts that fulfilled the requirements after the concept development phase was achieved.

3.3.1 System definition

The instructor's workplace could have been designed as a system of its own, but since it would eventually need to interface with the higher level system of the bus, the workplace was modelled as a sub-system. This meant that the workplace module inherited the bus system requirements and needed to fulfil certifications which apply to buses from the start. Figure 6 shows a top level excerpt of the functional system diagram where the main function of the instructor's module was to "support the instructor during lessons".

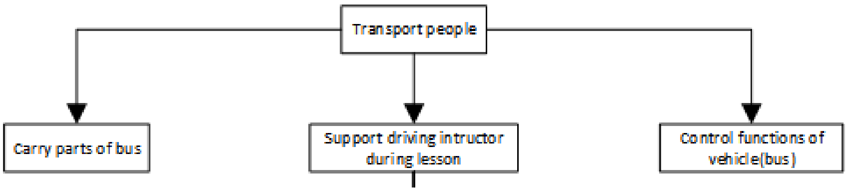

Figure 6: Top level functions of bus.

Within the instructor's module there were numerous functional requirements that the final product needed to fulfil. The development problem was analysed and decomposed into more manageable sub-functions that could be solved individually and then combined into total concept solutions. The previously established requirement specification influenced the decomposition since several parts had already been requested as functional requirements from both customer and users. Figure 7 shows the main functions of the module which were broken down further. A comprehensive functional decomposition that took the above mentioned factors into account can be found in appendix D.

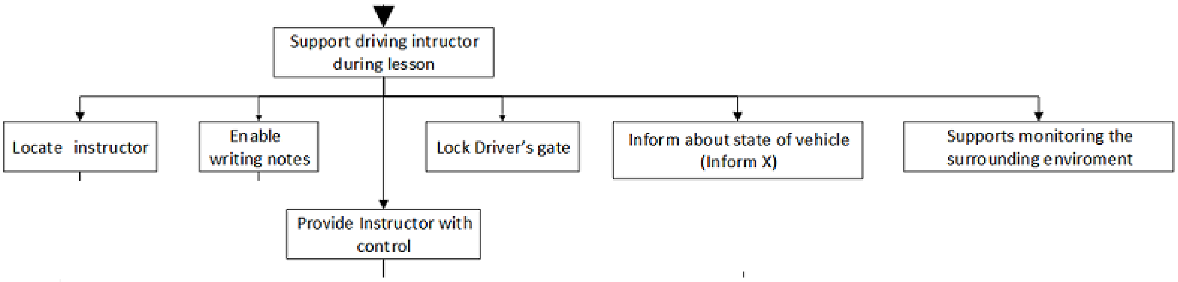

Figure 7: Instructor's workplace functional decomposition.

Some observations were made at this stage that simplified the development and resulted in an early idea of what the product architecture would become. The implication of having much of the system information at the outset of the project was that a high resolution product architecture could be developed early in the concept development phase and was improved and finalized in the system level phase.

3.3.2 Product architecture

Since it was supposed to be simple to attach and remove the instructor's workplace, it could be defined as a highly modular add-on with only few interfacing connections to the bus. An identification of the architecture revealed an approximate geometric layout, descriptions of the major chunks, and documentation of the key interactions among the chunks.

Following the product architecture and DFA methodologies of the theory chapter, top level functional elements that utilized similar functions or geometries were clustered together and those that had few interconnections were divided into separate chunks. The chunks, or modules, could be developed separately and in parallel since changes made to one part would not influence the others in a noticeable way.

Solutions that utilized electronic technologies, such as the control functions and inform functions could share a single micro-processing unit and were therefore physically grouped together. By including the writing area in the same enclosure as the electronic parts, these otherwise three different housing solutions were able to share a single enclosure that was called the control panel. The benefits of this early stage integration and function sharing were mainly cost savings from reduction of the number of parts, the assembly time, and the space and material used.

Similarly the solutions of the leftmost branch in figure 7, that located the instructor could be integrated with the pedal controls and take advantage of the attaching structural properties of a single platform for multiple elements.

But it was discovered that not all parts needed to be developed from scratch. Several functional requirements were already addressed by constraints to such an extent that only a single physical solution was possible. The seat, for instance, had to be the same as the one in the driving compartment and did not require any further development. These elements did however possess certain properties that influenced the other chunks of the instructor's module and needed to be explored further.

A design structure matrix was used to show the relationships between defined chunks that needed to be present in the final solution. Interactions were either purely physical attachments or incidental relations such as relative distances defined by constraints. The two options were denoted by 1,0 or 0,5 respectively in the matrix and interactions that were not scored had no relations.

Table 2 shows how for example the platform was connected to the instructor's seat and the dual command pedals, but not to the control panel or the driver gate. The driver gate was in fact only related to the aspect of vision because it could obstruct the view. Since it was not physically connected to any of the other elements, a solution could be chosen independently without the risk of creating any adverse effect on the other chunks. Similarly the control panel only needed to be positioned well in relation to the instructor seat, but was otherwise be developed on its own. The vision was an abstract concept that was mainly created to illustrate how most components were incidentally related to the placement of the seat reference point.

Table 2: Design structure matrix of relationships between main workplace chunks.

	Design Structure Matrix:						
		A	**B**	**C**	**D**	**E**	**F**
A	**Platform**	**X**	1,0	1,0	-	-	-
B	**Instructor seat (SRP)**	1,0	**X**	0,5	0,5	-	0,5
C	**Dual command**	1,0	0,5	**X**	-	-	-
D	**Control panel**	-	0,5	-	**X**	-	-
E	**Driver gate**	-	-	-	-	**X**	0,5
F	***Field of vision***	-	0,5	-	-	0,5	**X**

The ensuing development effort was focused on the platform and the control panel while the gate, dual command and seat were examined for feasible solutions. Since the platform was constrained by multiple criteria an optimizing approach was selected. The control panel would be the main interface between the user and the module development would rely heavily on the aspects of human factors and ergonomics for the process to arrive at a satisfactory concept solution. Figure 8 shows a mockup of the resulting product architecture that was used to illustrate the available space for the different solutions.

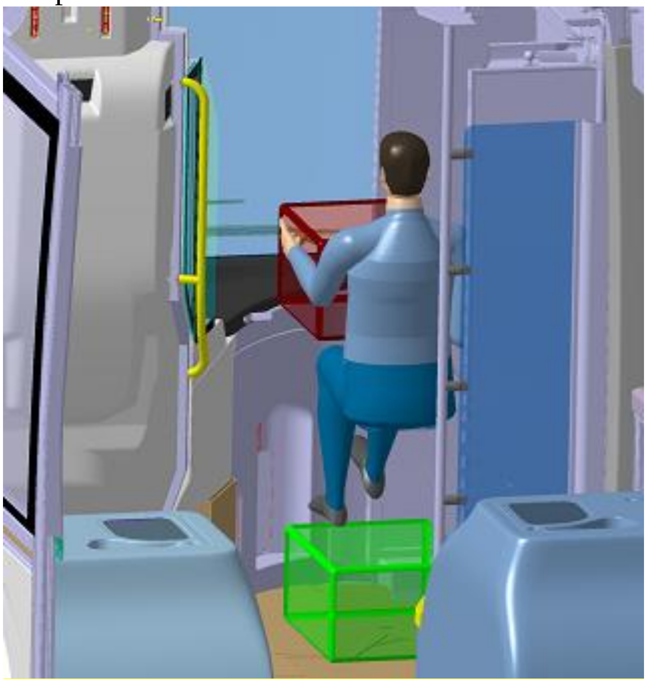

Figure 8: Platform and control panel product architecture.

3.3.3 Pedal supplier study

The dual command pedals were not part of the development process but rather chosen between from currently available technologies manufactured by different suppliers. The objective was to find a solution that allowed the instructor to control the driver brake and accelerator pedals from a secondary set of pedals. Besides the limited available space, another important selection factor was that the final solution would need to be simple enough to attach and detach without requiring any major changes to the bus. Secondary pedal suppliers were sought out and contacted to determine properties such as technology, size and price information, which could be used to find a suitable solution. The resulting alternatives were then compared and the best suited option was chosen based on the constraints of the project.

The initial assumption was that there would exist numerous suppliers with various technologies available, but it was discovered that two main types of technologies were prevalent on the market. While other types of solutions potentially exist, these were deemed satisfactory for the purposes of this project. The main difference between the two solutions was the way in which force was transferred from the secondary instructor pedals to the primary driver pedals. The first solution needed the instructor pedals to be placed in parallel to the driver pedals, because it used rigid rods to transfer the force. Since the bus middle console blocked the path between the pedals, this solution would only work if significant changes were made to the bus or a complicated countershaft solution was implemented. The solution was therefore deemed infeasible.

The second solution, commonly found in training vehicles, was more flexible since it used cables that could be routed around the middle console. The cables allowed the instructor's pedals to be placed independently of the driver's pedals and were also simple to attach and detach when the equipment needed to be removed. The wired pedals solution was therefore used in the final concept and the final placement and attachment type were determined in the detailed design phase.

3.3.4 Driver gate solution

The purpose of the driver gate is to provide assault protection for the driver. Since the risk of assault is minimal during driving practice and the driver gate would interfere with the communication path between the student and instructor, the gate needed to be kept open and out of the way during driving lessons. If the gate was locked behind the instructor's seat, as seen in figure 9a, the locking mechanism would have to ensure that the gate posed no danger to the instructor in a crash.

The intention was to develop a locking function for this purpose. It was however noted that if the instructor wanted to look through the window behind the driver, the glass part of the gate could create unnecessary reflections, as seen in figure 9b. It was also concluded that during assembly of the instructor's module, the gate would have to be locked in place before the seat and would make fastening the seat to the platform awkward. In the end the simplest route was opted for since the gate hinges were clearly exposed and made it straightforward to remove the gate entirely before installing the instructor's module. This way the gate would not conceal the rear window, it would not pose a safety risk and there would be room to access the seat attachment during assembly.

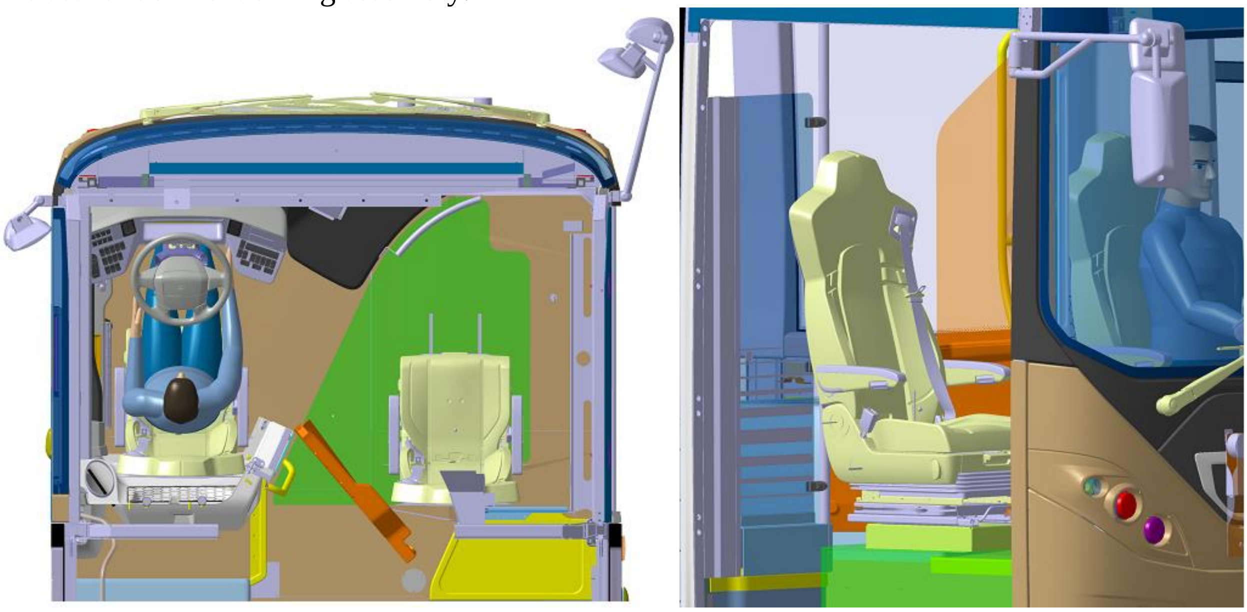

Figure 9: a)Top view of driver gate placement, b) gate obstructing view

3.3.5 Platform concept development

Keeping in mind the platform design space defined in the product architecture, a base structure was developed using topology optimization. The structure was then refined and developed into a platform concept using concept generation methodology.

3.3.5.1Topology Optimization Methodology

The topology optimization was performed with the recommendations in the theory section in mind. In order to do a topology optimization certain steps need to be performed (Olason & Tidman, 2010).

1. Formulate requirements and objectives
2. Set up design domain
3. Perform topology optimization
4. Realize concept
5. Analyze realized concept

Formulate requirements and objectives

In the first step the requirements and objective for the topology optimization were decided upon. After extensive study of the legal requirements, it was decided that the requirement for the optimized structure was to be able to withstand the pull test described in UNECE *Regulation No. 17.* During the test the seat and the corresponding anchorages are submitted to a pulling force equivalent to an acceleration of no less than 20g applied for 30ms in a direction imitating a frontal crash. Figure 10 shows the described acceleration as a function of time. From the figure it is seen that the minimum acceleration is 20g while the maximum is around 28g. In order to ensure that the structure of the platform coped, the maximum limit of 28g was chosen for the optimization.

In order to get an equivalent force that represented the 28g decceleration, the mass of the bodies involved had to be taken into account. During driving lessons the instructor was seated on the seat, which attached to the platform and in turn then attached to the bus. This mean that the bodies involved were the instructor, the seat and the platform.

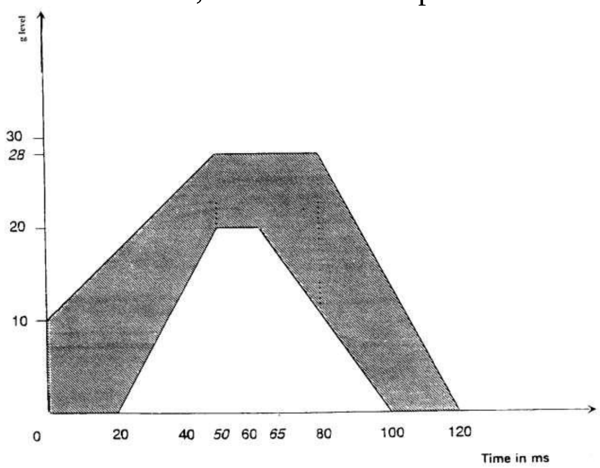

Figure 10: Acceleration loadings for crash simulation testing.

In order to get a force to analyse, the weights of the bodies were estimated. For the instructor the weight of a german 95:th percentile man was found to be 104 kg, in the CATIA V5 anthropometric library. Since the same seat as the driver's seat was used, the weight was 50 kg, as defined in the Volvo database. Lastly the weight of the final platform had to be estimated, it was estimated that the weight should not exceed 60 kg. While the true load in figure 10 was described as dynamic, the load case needed to be simplified by assuming a static load for the optimization analysis. The platform should withstand a static force of the weight of the bodies, which amounted to 214 kg in 28 g of acceleration which was calculated in equation (1).

$$F = ma \rightarrow F = 214 \cdot 28 \cdot 9.81 = 58781N \quad (1)$$

This calculated force was very high, but understandably so, since g forces in crash scenarios have been measured up to 28g (Mackay, M. 1992). The objective of the optimization was chosen to stiffen the structure as much as possible. The idea was that a stiffer structure would withstand the load better. Normally the weight of the structure can be of importance, to lower the fuel consumption. In this case the bus will most likely never be used with maximum passenger capacity during driver's training and therefore the weight was not be optimized.

Setup the design domain

The design domain chosen for the optimization was an important aspect considered early in the topology optimization process. It represented the design space where the topology optimization was supposed to find the optimum structure. At the start of the project little was known about where the seat would be put in relation to the whole design space. Product architecture showed that the seat position clearly affected the topology optimization since the load could be anywhere in the upper surface of the instructor's workplace design space (figure 5).

In order to evade this problem, the platform design domain was reduced to the green volume beneath the seat shown in figure 8. The argument was that by optimizing the reduced volume, the optimized structure would support the load regardless of where the seat was placed and the final position could be determined later without compromising the structural integrity of the design. The final platform would in the later stages be extended to take up the larger area in order to provide pedal attachments points and easy access to the driving compartment. The optimized structure would therefore be further reinforced by surrounding non optimized structures.

Perform topology optimization

In order to perform the topology optimization the FEMAP software was used. The design space was modeled in CATIA and imported into FEMAP as an IGES file. Constraints were set up and three different load cases were tested for the topology optimization in order to achieve a robust design. The load from the bodies was simplified as a point load above the volume, illustrated in figure 11. The main difference between the three load cases was in the direction of the forces. A force in the forward direction as in a front collision, a side force representing a side collision and a force in 45 degree angle representing an angled impact were used.

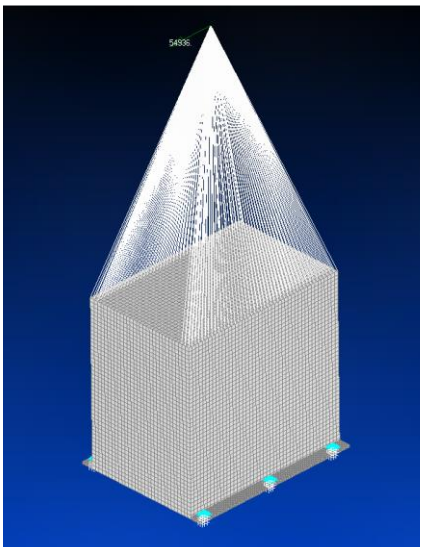

Figure 11: Design domain in optimization software with applied constraints and load.

Constraints were placed in three holes located in the lower part of the domain that matched the attachment to the seat. The resulting structures of the topology optimization for the three loading cases can be seen in figures 12 a) , b) and c).

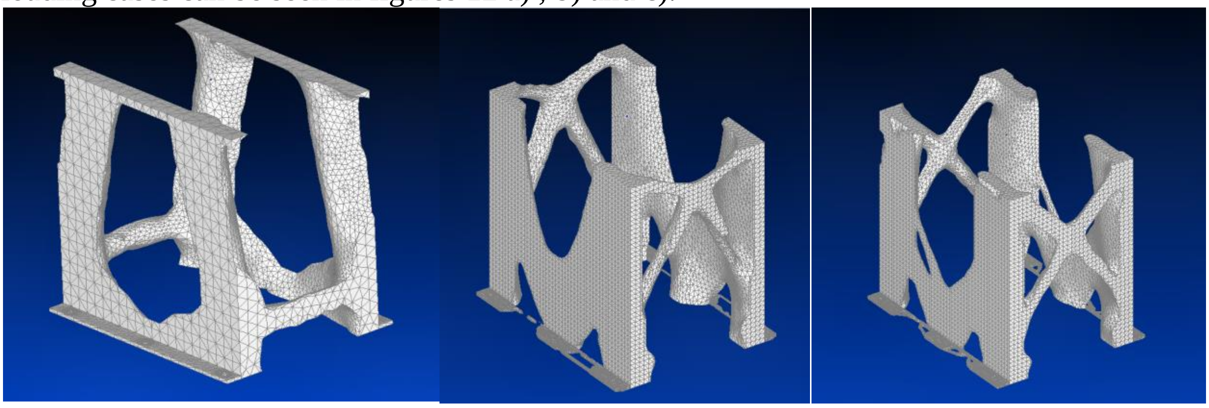

Figure 12: Optimization results a) Front impact force. b) Side impact force. c) 45 degree resultant force.

In order to get a robust design, the three structures had to be merged into a single structure to ensure that the final structure was the optimal for the three loading cases. The final merged structure was then used in the morphological matrix in order to produce different concepts.

3.3.5.2 Concept Generation

In order to have a fully working platform several concepts had to be developed. The concept combination table provided a systematic way of develop concepts from combinations of sub solutions. The starting point for the table was the function tree diagram found in appendix D, and explained in section 3.3.1 System definition. It was noted that only a portion of the tree was needed for the development of the platform.

The main function performed by the platform was to raise the seat to the same level of the driver's platform. This function could also be further decomposed as seen in the tree diagram in appendix D.

It can be seen that the platform function is decomposed to three sub functions which can be used to construct the concept combination table. The three sub functions are “Take up External load”, “Take up internal load” and “Fasten platform”. The resulting combination table is found in appendix E, with solutions to the respective sub functions. One important aspect to note is the use of the topology optimization result as the only solution to the function “Take up external load”. It was argued that the solution space for this function consisted of many different structures or topologies of material.

As explained in section 2.4.2 Examples of topology, it is recommended to use topology optimization early in the development process. Some reasons are to get an understanding of the load paths in the structure and to avoid getting not fully realisable concepts. Combining the optimized structure with the solutions for the other sub-problems meant that fully realisable concepts could be built, with an optimised structure that could withstand the external loads and constraints.

3.3.5.3 Concept Selection

The different concepts generated by the morphological table had to be evaluated, in order to find the concept that best fulfilled the requirements stated. The concepts were systematically evaluated using the Pugh and Kesselring matrices, found in appendix E. Criteria used for the matrices were based on the requirements found in appendix A. Using these methods the concepts generated were reduced from six down to one concept. Figure 13 shows the concept that best fulfilled the criteria set up in the beginning of the concept selection phase.

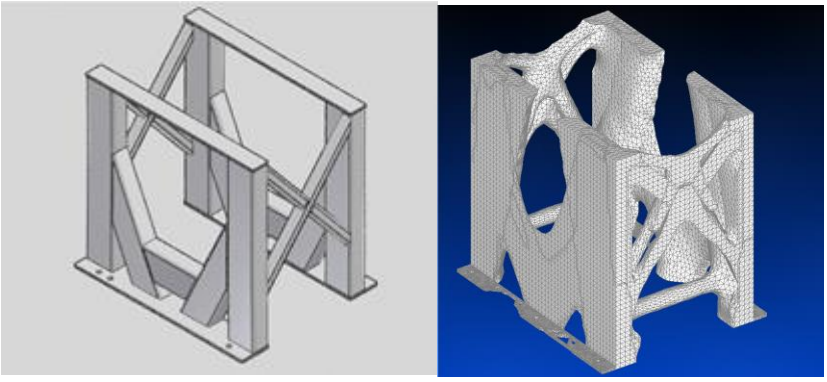

Figure 13: Selected platform solution.

The concept had a similar structure as the topology optimization result. Several benefits were identified to using square structural hollow sections, or square tubes for short, to realise the design. Square tubes are widely available and there are many different sizes to choose from. The manufacturing process was also considered relatively simple. The tubes only needed to be cut to the right length and then welded together. Since the tubes were common and manufactured according to standards the price was very low. The mechanical benefits that tubes had in smaller structures in and their resistance to buckling specifically made them a good choice for the platform design.

Bolts were used in order to attach the platform to the bus. This was the same method used in the current bus to attach the driver's seat to the driver's platform. It was therefore confirmed that bolts could withstand the resulting forces acting upon them. The use of the tubes also meant that the weight of the concept was kept within an acceptable range. Although there were lighter concepts using sheet metal for some parts, it was argued that in the tradeoff between weight and strength, strength was more important than weight. Since the platform was only going to be lifted out a couple of times a year, a reasonable weight under 50 kg was accepted.

3.3.6 Control panel concept development

The control panel was the second part of the instructor's workplace module that was developed. While analysing the function decomposition (appendix D) and the product architecture, it was established that some functional elements could be grouped physically into the control panel, represented by the red volume in figure 8. The control panel would have to include the functions "inform", "control" and "enable writing notes".

3.3.6.1 Concept Generation

The concept generation of the control panel was based on the opportunities of function sharing and integration of the three main functions of controlling, informing and support taking notes.

It was decided that the enclosure used to cluster the control and inform functions should implement two different functions. The enclosure should implement both the “carry parts” functions of the electrical components and the “enable writing notes” for the writing area.
This approach differed from the platform concept generation in that the functions solved were gathered from different branches of the function tree. It was possible since the interfaces had already been identified and it was determined that the control panel could be developed as a concept independent of the other physical components of the workplace. The concept generation table can be found in appendix E. From this table many different concepts were generated to be used in the evaluation phase.

3.3.6.2 Concept Selection

The generated concepts were evaluated and ranked using Pugh and Kesselring matrices found in appendix E. The concept that ranked highest was the “Replicator”, illustrated in figure 14.

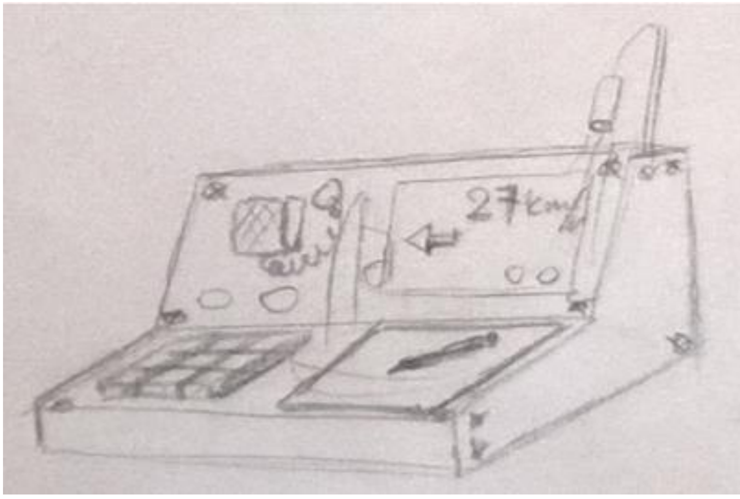

Figure 14: Illustration of Replicator concept.

The ranking was performed using ergonomic criterias together with criterias encompassing manufacturing and cost. The “Replicator” concept showed several advantages, mostly ergonomic. Ergonomic advantages can be afforded to the replicating nature of the concept. Being a smaller copy of the current driving compartment, it was argued that the driving instructor would feel the design more recognisable.

The layout was of course meerly of illustrative nature at this stage and would be further refined in the detail design phase. More specific advantages are explained in the detail design section of the control panel (3.5.2). The “Replicator” concept was also evaluated against other similar solutions made by competitors in order to make a competitive benchmarking. The evaluation showed that the concept, relative the competitive solutions, was slightly better according to the chosen criterias.

3.4 System level design

In this phase CAD models were used to perform the necessary field of vision analyses and the instructor's module packaging analysis.The method incorporated the fundamental aspects of the product architecture that was initiated in the concept development phase. The main task was to place the instructor's seat so that the instructor, once seated, fulfilled the legal field of vision requirements. The vision depended on both the SRP position and the mirror placement, which is why both elements needed to be considered in the study.

3.4.1 Vision and SRP placement study

The instructor's workplace implemented the same seat model as the driver's seat, as per the customer's request. The seat position, next to the driving compartment, was determined by taking into account the field of vision and the geometrical constraints of the available design space in the bus. It had already been established that the available space was significantly reduced by the bus geometry. Within the available space, the aspect of vision therefore became the deciding factor for placing the instructor's workplace components.

Firstly, driving instructors in Belgium are legally obliged to have a field of vision that is equivalent to that of the driver. Secondly, the instructor needed to have a sufficient overview of the student driver while also being provided with an ergonomically sound workplace. Since none of the factors could be completely disregarded the position of the instructor's seat was a tradeoff between them and the placement procedure needed to be done in an iterative manner.

A preliminary layout was created by placing manikin representations of the student and instructors in their respective anticipated positions. The instructor's seat was placed so that the SRP coincided with the instructor's hip point, which was then pulled as far back as possible, at the same height as the driver.

From there the instructor position was adjusted in the transversal direction to find a position where the instructor could see the surrounding environment, the student and have sufficient leg space and reach for the pedals. Once a suitable position had been chosen vision analysis could be done. The driver's vision was evaluated first to create a reference. Using the manikin eye points and the existing mirrors, the analysis results in figure 15 established that the driver fulfilled the legal requirements.

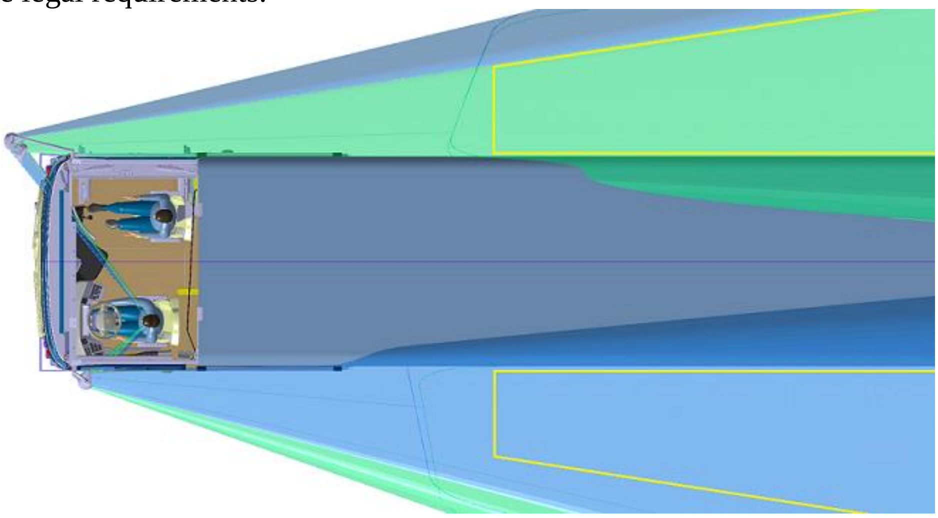

Figure 15: Legal vision requirements of driver.

Furthermore the additional results in figure 16 showed the impact of the obstructing elements. In figure 16 a) the green fields are visible and the blue are blocked. It was noted that the instructor created some obstruction, but it was not considered significant enough to warrant changing the position. Figure 16 b) was the result of a later performed analysis with the additional instructor mirrors added. The effect of additional mirrors became clear and placing the mirrors on top and below the current ones was the solution that blocked the field of view the least.

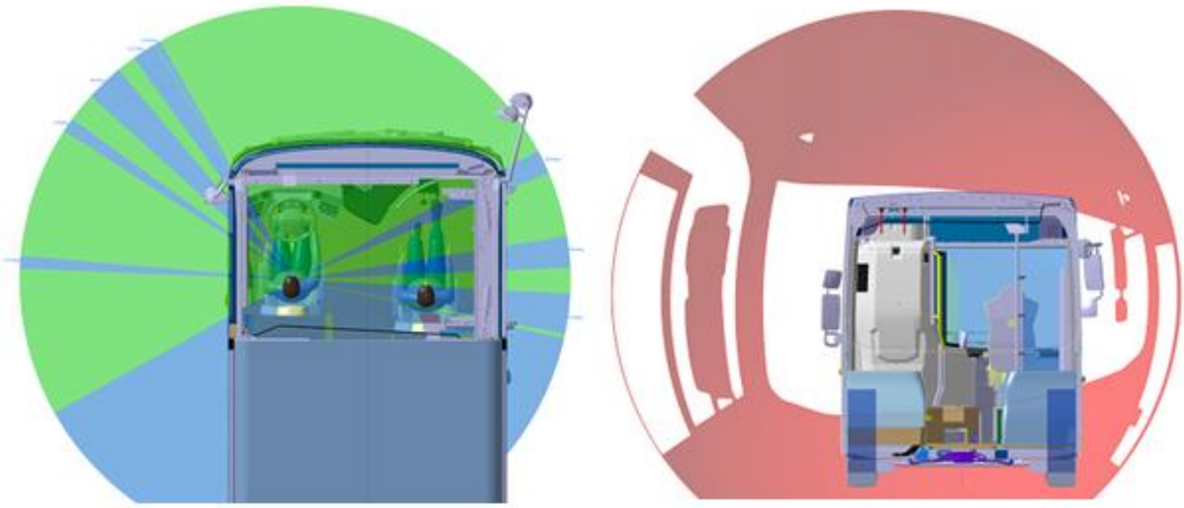

Figure 16: Field of vision of driver a) Top view with instructor obstruction. b) Rear view with additional mirrors.

The same analysis was then performed for the instructor in the chosen position. The instructor would of course need a set of mirrors, separate from the ones the driver used, to achieve the equivalent rearward vision. On the left hand side the best position for an instructor's mirror was simply to mount it above the regular driver mirror in order to minimize the number of additional components and the obstruction width of the drivers view. On the right hand side there were two options available that did not interfere with the driver's field of vision while they still provided the instructor with the required rear view.

Since the instructor was placed similarly to the driver, the first alternative was to replicate the mirror placement of the driver's left hand mirror. The instructor had to view this mirror through the entrance door. While this option did fulfill the legal requirements, as seen in figure 17 a), it also blocked the right side driver mirror unless it was lowered significantly. This lower placement, illustrated in figure 17 b), created a set of new issues such as designing new attachment points on the bus. The mirror also had to protrude more from the bus body than normally in order to avoid being bumped by the entrance door when it opened. Since this protrusion exceeded the allowed bus width and made it difficult to maneuver narrow roads without bumping the mirror this solution was scrapped.

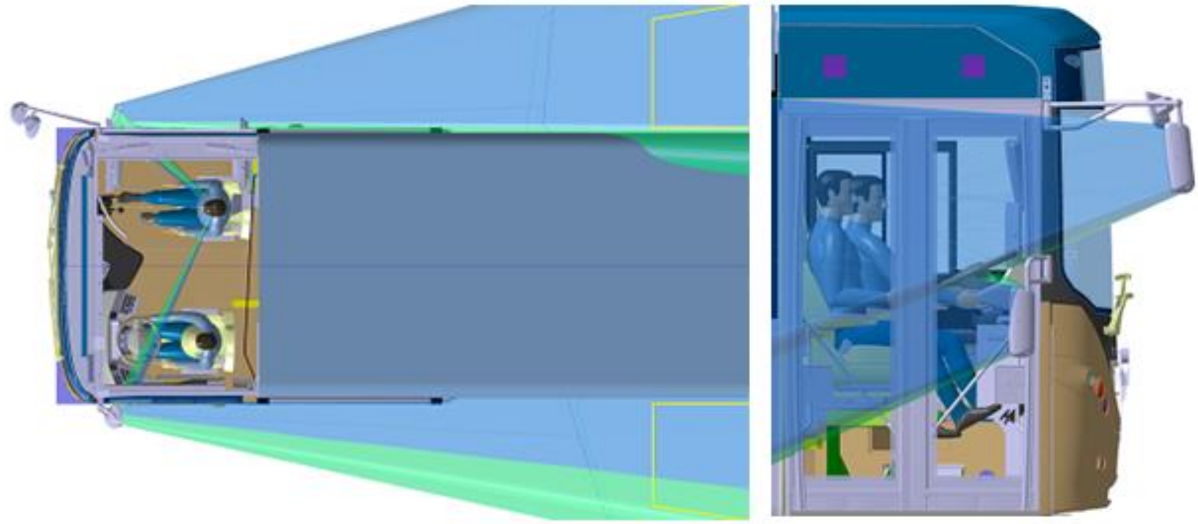

Figure 17: a) Instructor legal vision requirements. b) Lower mirror position.

The second option, which was also the final choice, was to mount an additional mirror below the driver's right hand mirror by extending the attaching arm. In the interest of reducing the obstructed vision for both student and instructor, it was noted that smaller mirrors could still pick up the required rear view area if the mirror surface radius of curvature was reduced. The results of the field of vision analysis in figure 18 showed that the left hand view was slightly obstructed by the driver. This could be solved by raising the instructor seat higher up than the driver seat, but the bus roof would potentially block the view and force the instructor into a poor posture, as had been observed in coach buses.

Other alternatives that were discussed were to implement a camera solution or additional mirrors that would compensate for the obstruction. In the end it was concluded that the instructor had sufficient vision and that adding more technology or mirrors would only be distracting. Finally the solution was also tested for the 5-95 percentile range of population by using different manikins and adjusting the SRP as seen in figure 19.

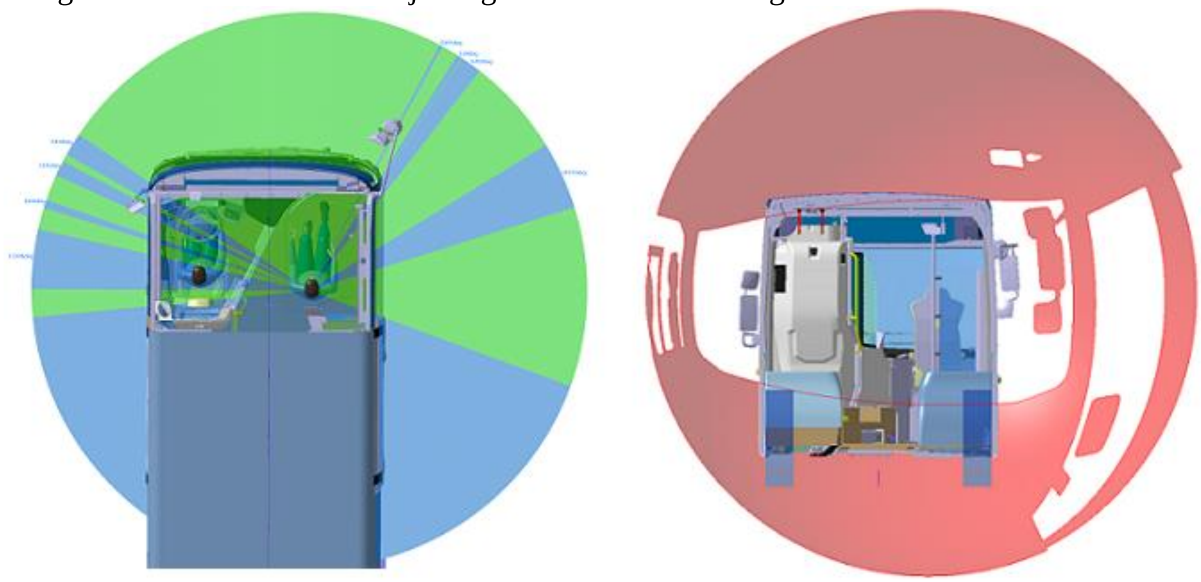

Figure 18: Field of vision of instructor a) Top view with driver obstruction. b) Rear view with additional mirrors.

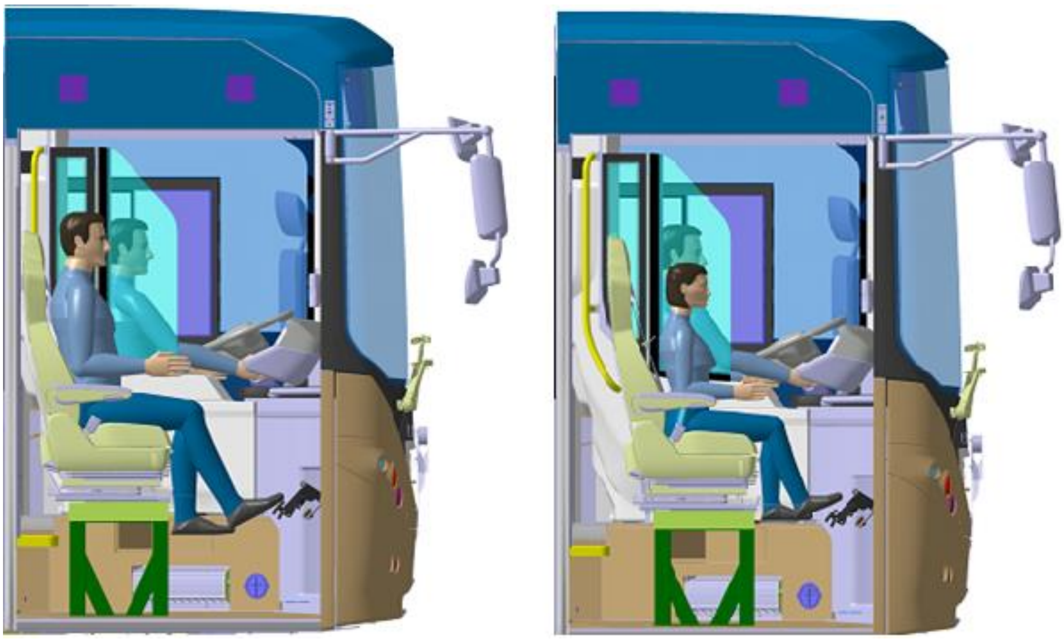

Figure 19: Mirror placement a) 95th percentile male. b)5th percentile female.

3.5 Detailed design

Since this project did not proceed into the physical testing and production phases but resulted in a DMU concept of the instructor's workplace, the detailed design phase focused on the intricacies of each component in the module. This involved a more precise description of the attachment positions in the bus, the type of attachments that were used and the changes required in the bus structure.

3.5.1 Platform detail design

Further details had to be designed for the platform in order to be able to fulfill the requirements. The main characteristics studied in the concept phase were the structure, the structural attachments and the structural elements. The resulting concept that was developed was one constructed of tubes and attached to the frame with bolts, illustrated in figure 20.

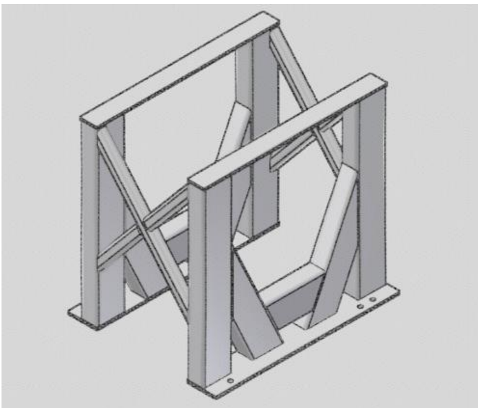

Figure 20: Winning platform concept.

The concept was designed using the topology optimization results as inspiration. The tube sizes were chosen in order to closer mimic the optimized topology. In order to finalize the design other aspects had to be taken into consideration.

3.5.1.1 Seat and platform interface

This interface between the seat and the platform was an important aspect. The platform had to withstand the pulling test described in the requirements. It was known that the structure was going to withstand the forces generated, but whether the interface was going to hold needed answering. This aspect was deliberately not taken in consideration in the topology analysis. The reason for this being that there already existed an interface capable of withstanding the test. Figure 21 shows the current interface found under the driver's seat

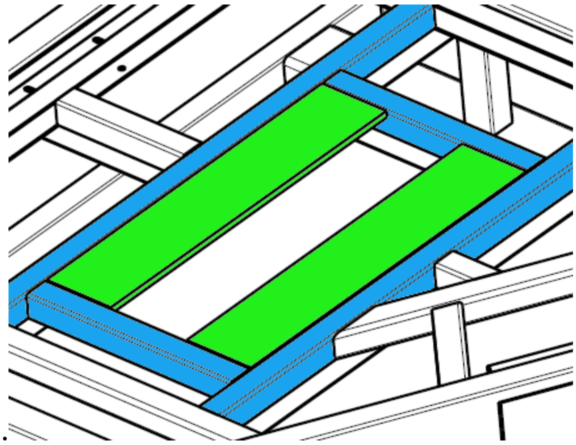

Figure 21: Driver's seat to platform interface.

The interface was implemented to the platform as is shown in figure 22. The next step was to choose the sizes of the tubes used for the structure. The current tube sizes used for the driver's platform were chosen. Although not the biggest problem, using the current sizes meant that the manufacturing of the frame could be facilitated by using parts already used in production.

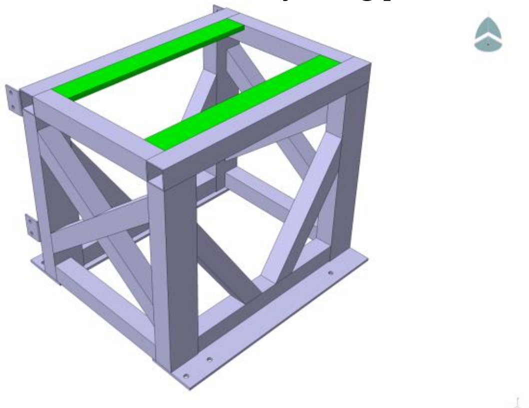

Figure 22: Instructor's seat to platform interface.

3.5.1.2 Total Platform design

As stated earlier in 3.4 System level design, the development would focus on the structure beneath the seat. Having a structure under the seat that withstanded the loads meant that the rest of the platform could be designed to support the current structure in other aspects. One aspect was the area covered by the platform. As was seen in figure 19, the concept only covered the small area beneath the seat which. In order to improve the area coverage two more structures were developed to fill and raise the area surrounding the seat. Figure 23 shows the structure used to fill the area between the driver’s platform and the instructor’s.

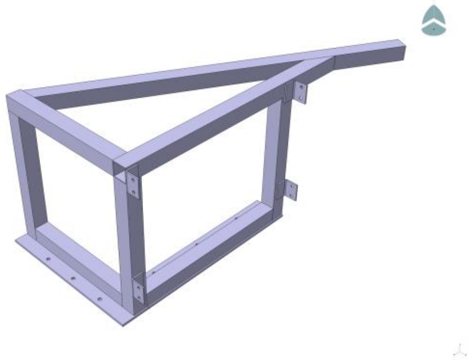

Figure 23: Support structure between driver's and instructor's platforms.

Figure 24 shows the structure used to fill in the area in front of the instructor’s seat. The figure also shows the attachment plate for the dual control pedals solution selected earlier.

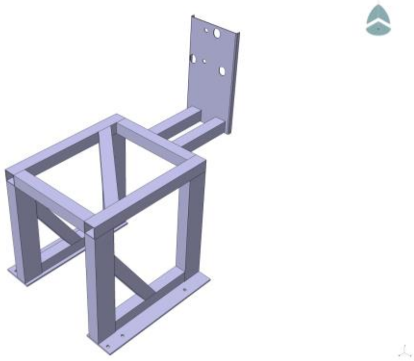

Figure 24: Leg space and pedal support structure.

It meant the platform was divided into three different sections. This brought several different advantages. Each one of the sections were small and light enough to be carried by one person during mounting and dismounting. It also meant that mounting the sections in the right order would facilitate the mounting of the final platform assembly, seen in figure 25.

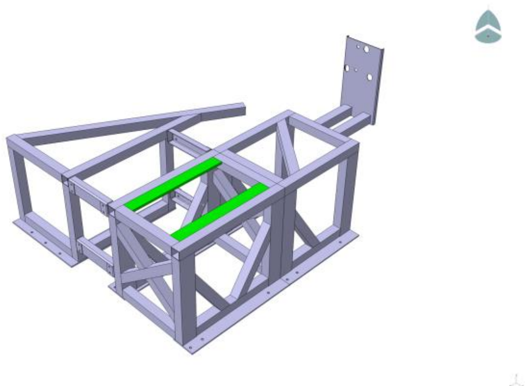

Figure 25: Complete platform design.

3.5.1.3 Platform to bus interface

One aspect that had to be taken into consideration was how the platform was to be attached to the bus. It was chosen to attach the platform the same way the driver’s seat is attached to the bus, using bolts. The structure underneath was changed so the transversal profiles were moved to fit the attachment points of the platform shown in figure 24. Weld nuts were welded on the profiles from below to be able to use the bolts.

The section of the platform between the instructor's seat and driver's platform was attached to the main platform bracket. Extra plates were welded in order to fill the void between the beams, and to be able to attach the section frame.

The floor area, to which the platform was installed, is normally the passenger entrance of the bus. The frame structure underneath the entrance was designed to withstand a distributed force in the gravitational direction. The structure was not designed to withstand forces created by a seat during deceleration or a crash and such analysis fell out of the scope of the project. It is therefore recommended to study the structure under the new loads in order to learn what changes are needed to be done.

3.5.2 Control panel detail design

From a cognitive ergonomics standpoint, the main purpose of introducing an instructor's module in an already information processing intensive workplace had to be to simplify and reduce the information flow, while providing a comfortable working environment. The control panel was considered the most interactive component of the instructor's workplace and needed to be designed in such a way that the instructors did not waste time or mental resources on looking for information, but that the information existed in the place and shape they expected it to be.

3.5.2.1 Ergonomic heuristics

One of the more prominent requirements when it came to control panel design thus became to mimic the driving compartment design as much as possible. It was assumed that the instructors had spent enough time in driving compartments to benefit from their ability to recognize placement and function of controls in a similarly designed environment. The second reason was the advantage of being able to reuse already developed component solutions which had been confirmed to fulfill physical and cognitive ergonomic requirements and thus saved on development time and cost.

This is the idea behind the replicator concept which tried to mimic the design of the driving compartment. Control panel solutions with a completely flat surface had to be positioned horizontally to support writing which produced an awkward viewing angle for the display. A folded design, on the other hand, allowed a horizontal surface for the writing area and an angled surface for the information display. The display surface angle was chosen to mimic the driver dashboard with a 60 degree inclination towards the user. Since the control panel was adjustable, the user could choose the final position of the writing surface and the viewing angle which suited them the best.

3.5.2.2 Final control panel layout

The placement of the information display and control buttons did not only affect the glance time but also the cognitive load which was why the layout was of utmost importance. The layout distributed user interface elements for the three main functions that had been integrated into the control panel design. The informing, controlling and writing surface elements. Since the user interface could be applied to all concept solutions, it was evaluated separately and then implemented in the final solution. Figure 26 shows the different considered layouts, where the red dashed line, the green solid line and the blue line illustrate the cluster placement of controlling, informing and the note taking functions respectively.

Since the instructor did not have a steering wheel implementing control levers for the indicators and beam lights was both impractical and non-functional, which is why the same buttons as the ones on the driver dashboard were chosen for all control functions.

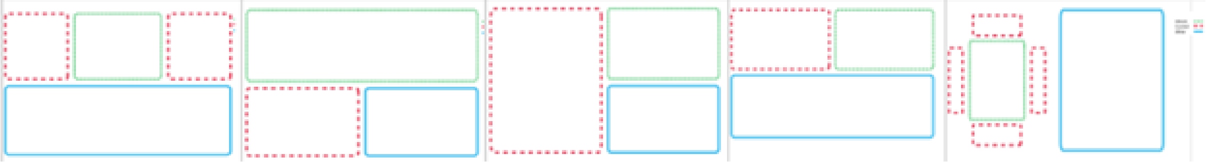

Figure 26: User interface concepts considered for final control panel layout.

The recurring theme of mimicking the driver dashboard was incorporated and of the five possible layouts in figure 26, the first layout had significant advantages over the other alternatives. The display was placed in the middle of the top surface so that the information could easily be glanced when needed without the user having to reposition their eyes to the side. Control buttons were then placed on each sides of the display. Buttons that usually resided on the left side of the driver dashboard were placed to the left of the instructor's display and those that were found on the right side were placed to the right. Table 3 shows the implemented button configuration.

Table 3: Control panel button configuration.

Left side buttons	Right side buttons
1. Left turn indicator signal 2. Right turn indicator signal 3. High beam/low beam 4. Control horn	1. Open/close door D1 2. Control parking brake 3. Control hazard lights 4. Control mirror heater

An additional benefit of the button separation was that buttons expected to be used during driving were clustered on the left side and those that should be used when stationary were placed on the right side. Clustering the buttons in this manner supported a simple workflow and would require minimal physical and mental effort from the instructor during lessons.

The buttons were placed on the upper surface to minimize the risk of accidentally activating any of the functions when leaning on the writing surface. It also freed up the complete horizontal surface for both left or right handed writing.

On the top most surface of the control panel, a light on a swan neck was placed so that it could be adjusted by the instructor to illuminate the writing surface during night time driving practice. This was a suitable position since it did not interfere with any of the other features while it was simple to reach and operate. A similarly designed microphone on a swan neck was placed on the same surface so that it was comfortable to use. A speaker was positioned below the right side buttons so that it could easily connect to the electronics of the radio. Two USB ports were also added on the left side below the buttons, which the instructors expressed could be useful to have in case they needed to charge their phone or tablet while working. Finally the required system active indicator light was placed next to the USB ports.

3.5.2.3 Control panel to bus interface

The control panel had a functional housing but needed to interface to the bus with an attachment that allowed it to be placed in a suitable position in front of the instructor. The ticket holder arm, which was sufficiently rigid, already supported rotational adjustments. A second adjustable locking lever was added to the back of the control panel which was attached to the ticket holder arm with steel tubing. The two rotational axes allowed the control panel to be easily adjusted for the instructor and could also be completely moved out of the way when the driver needed to enter or exit the driving compartment. The final control panel and attachment can be seen in figure 27 a) and the results of reach analysis in figure 27 b) showed that the control panel could be adjusted to well within the range of motion (ROM) of the instructor.

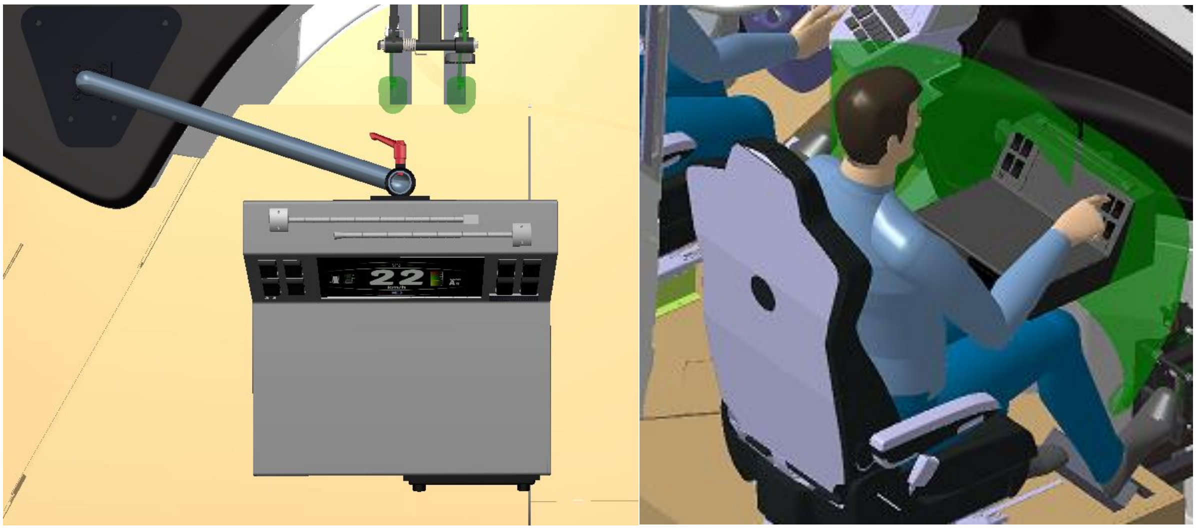

Figure 27: a) Control panel with attaching interface to bus. b) Reach analysis for instructor ROM.

4 Results

In this chapter the final outcome of the instructor's workplace concept development will be described in detail. Since the driver's gate was removed and the instructor's seat was the same as the driver's seat, the four remaining elements developed are presented as DMU illustrations of components and interfaces.

4.1 Platform

As shown in figure 28 a), the platform is divided into three sections mounted to the entrance structure of the bus. The sections are bolted to welded nuts in the entrance structure. The platform is then covered with plywood sheets to get the same aesthetic as the rest of the bus floor as can be seen in figure 28 b). A step is also mounted on the side of the platform in order to comfortably access the platform and the driver's compartment.

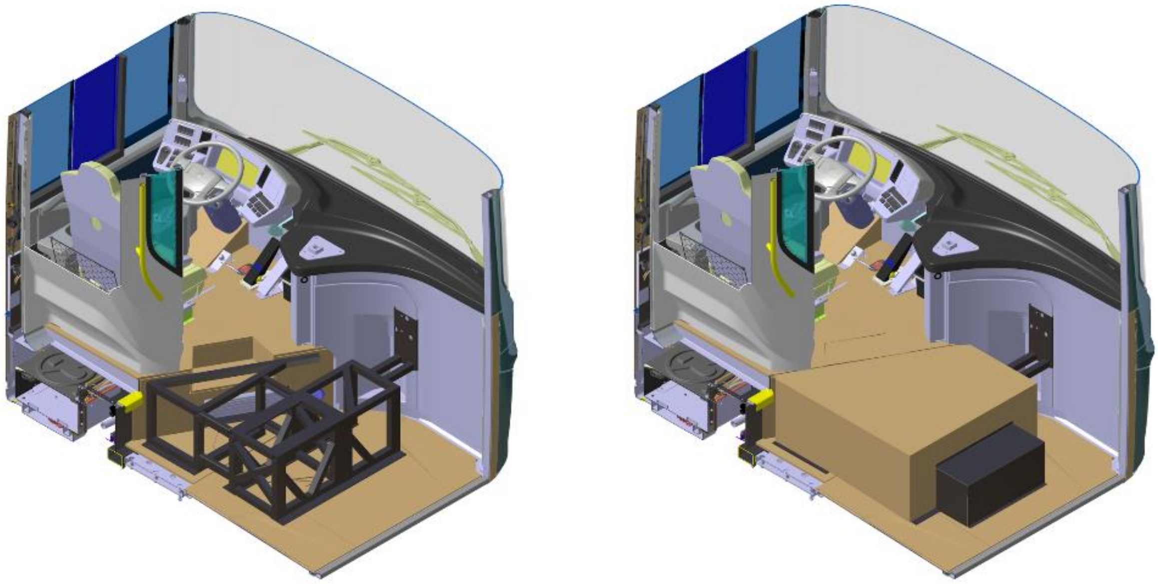

Figure 28: a) Platform structure sections. b) Plywood cover and step.

4.2 Pedals

The pedals are mounted on the attachment found in the front section of the platform as seen on figure 29 a). The design of the dual control pedals allows the inclination to be adjusted, which can be seen in the figure 29 b). The cables that connect the secondary pedals to the primary driver's pedals are routed through the interior front panel shown in figure 29 b). The wires are designed to go under the panels all the way to the steering wheel where they are drawn to the floor and connected to the driver's pedals. When not used the wires can be disconnected from the dual controls and stored in the space above the fire extinguisher, behind the panel. A small pressure sensor is retrofitted to the brake pedal and connects to the control panel to make the alerting sound. The simplest way to create a sound when the instructor activates the brake is to implement a small transducer, though a sound specifically designed for the purpose could yield a more positive effect with the student driver and induce less additional stress.

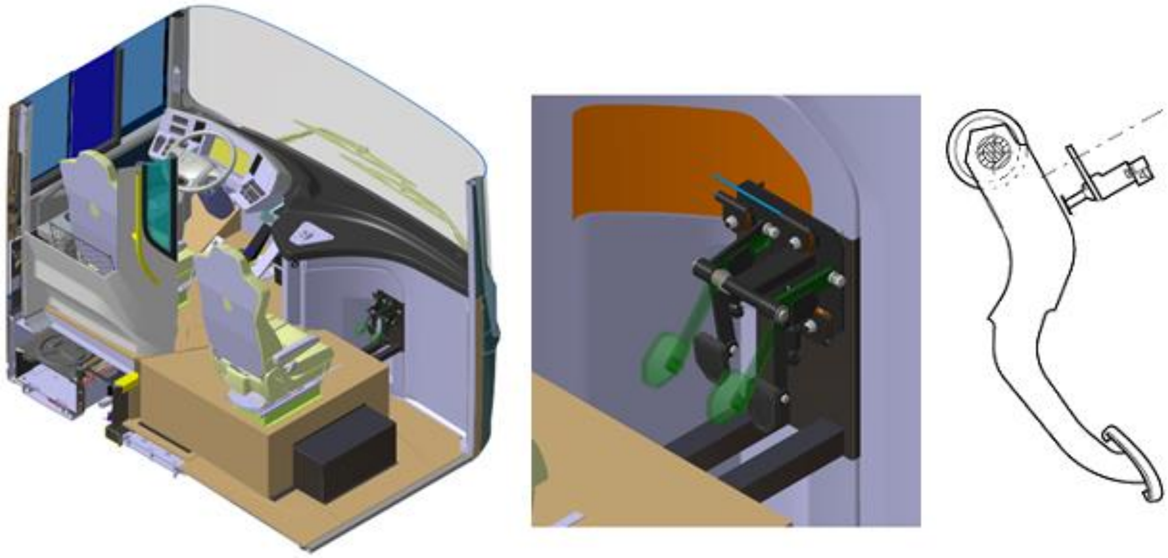

Figure 29: a) Pedals mounted on platform. b) Detailed pedal placement and wire burn through. c) Pressure sensor fitted to pedal.

In order to support the foot when using the pedal a heel support was design to be installed in front of the seat. The heel support allows the pedals to be used by both a 5th percentile female and a 95th male. Figure 30 a) and b) show the use of the heel support for different size of people.

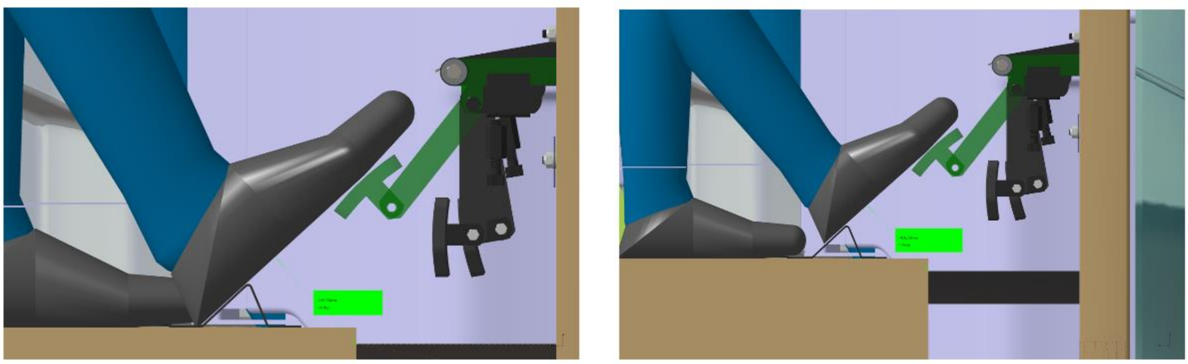

Figure 30: Pedal heel support ergonomics a) 95th percentiler male. b) 5th percentiler female.

4.3 Control Panel

The control panel is mounted on the current attachment used for the ticket holder so that the instructor can adjust the control panel to the desired position, as seen in figures 31 a) and b).

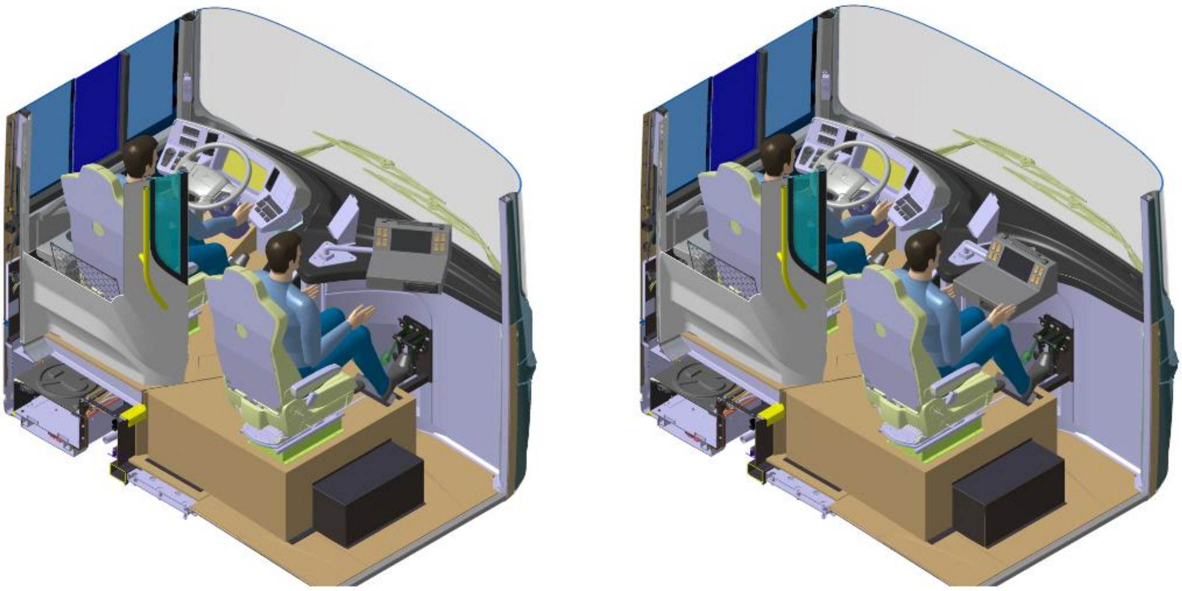

Figure 31: Control panel a) adjustable placement b) final position.

This way the control panel can be moved out of the way when the instructor or student boards the bus. The control panel is designed with a writing space for note taking during lessons and works equally well with tablet as with pen and paper thanks to the USB charging ports. The control panel was also equipped with a radio, swan neck microphone and light. Figure 32 shows the control panel from a closer range.

Figure 32: Final control panel design.

4.4 Mirrors

The mirrors are mounted on top of the current mirror attachments. The mirror on the right side is mounted beneath the driver’s mirror while the left side mirror is mounted above the driver’s mirror. The instructor’s mirrors used are smaller in size than the main driver’s mirrors, to reduce the obstructed view of both driver and instructor. The additional mirrors add approximately 200 mm to the height of the current mirrors, combining to a total height of approximately 570mm. Figure 33 shows the final placement and size of the mirrors seen from the rear and front.

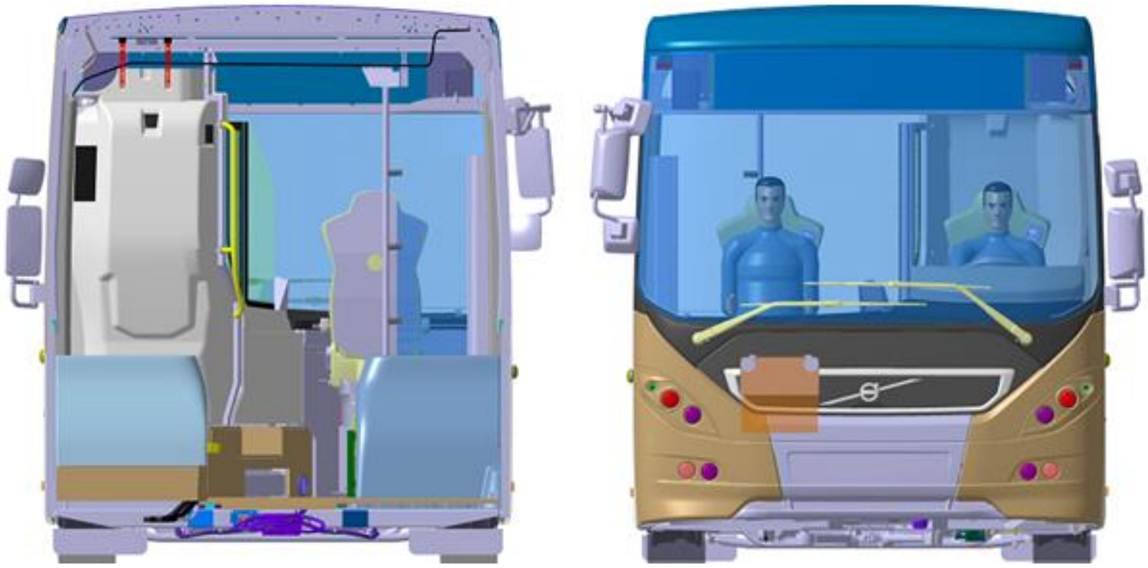

Figure 33: Instructor's mirrors size and placement. a) rear view b) front view.

4.5 Business case

After all components of the workplace concept were determined, some analysis could be made on the aptitude of this product for a wider market. a price estimate had to be calculated.

4.5.1 Assembly time

One of the earlier prerequisites for this product was the ability to remove it within a day so that the bus could resume regular transportation duties when needed. With all parts of the workplace defined, an estimation could be done for the time of assembly. A bill of materials was created for all the components included in the final concept. By approximating the time it would take to assemble each component a final assembly time was estimated as seen in appendix F. The estimations were based on time measurements for common procedures presented by Boothroyd, Dewhurst &Knight (2002). The results show that the total assembly time was roughly estimated to a quarter of an hour.

4.5.2 Cost estimation

The price estimate can be used to get a picture of how much the chosen solution could cost. The prices are gather from different internet sources. In order to facilitate the calculations certain simplification were made. The cost of the different frames was calculated using the weight of the frames times an estimated price per kilo steel. Same procedure was used for the plywood cost using the price per m^2 instead. The price of the dual control pedals were received from the manufacturer and of course the price varies with the amount of units ordered. For this particular case the price of one unit is used. The price of the control panel is estimated from the cost of the different parts used to build the control panel.

The total cost for the workplace amounts to 47 771 SEK, the calculations can be seen in appendix F. Assuming the price of a bus is around 1 million SEK the cost of the instructor's workplace would be around 5% of a bus price. The selling point being that the bus not only will be used for driver's education but can also be used in regular line traffic. Being able to offer additional functionality on current buses while not changing the old functionality and will improve customer satisfaction. In this project all of the buses exclusively used for driver's training were custom made for the customer. It is argued that manufacturing this way is less cost efficient than having a variant of the product ready to be offered to the customer.

4.5.3 Market opportunity

Since additional instructor equipment is not regulated on an international level, not many markets require it, but those that do should be explored further to evaluate the interest and potential for market extension of Volvo products. Especially since the users expressed a need for a designated place for instructors in driving education buses. The question is whether the customer can see the benefit of the solution and if it can be provided at an affordable rate for them. Thus, the market opportunity lies mainly with larger driving school companies that have the means to order customized vehicles or with public transport companies, like De Lijn in this case, that either have their own education needs or have the opportunity to rent out their buses to smaller driving schools.

5 Discussion

In this chapter we will highlight and discuss some topics of this project that we felt were interesting from a product development viewpoint. We will describe some of the challenges we faced and how they were solved.

5.1 Requirements management

One of the first decisions we had to make was how to approach the requirements for the project. The customer had already stated a list of requirements. The question that arose was whose needs the requirements reflected. We identified four different stakeholders which are shown in the stakeholder analysis in appendix B. The customer, in this case the public transportation organisation Deljin, was easily identified. Second stakeholder we could identify were the governing authorities and certifying bodies of the EU and Belgium. Lastly other stakeholders that could have potential input were the driving instructors and the students. Analysing the requirements from this viewpoint we could conclude that the requirements were mostly based on laws and regulations and the needs of the customer. No requirement could be identified to come directly from the end users of the system (instructors or students).
On the other hand the laws from the governing bodies could include the voice of the user in their requirements. I.e. the requirements could have been developed together with end users.
Customer requirements can be acquired in a number of different, equally satisfying ways with regard to constraints of time, cost or quality. We were then confronted with choosing between two situations.

We could choose to continue development with the existing requirements, and risk missing needs from end users. We felt this option could sacrifice the quality of the result too much.
We could also collect requirements from the end users, and risk taking too much time away from development. We felt this option improved the result and could be useful in future projects. On the other hand, there was a risk of not having enough time to develop the concepts as deep as we wanted to.

In the end, we chose to collect requirements from the end users by interviewing several bus driving instructors in the Gothenburg area. As was previously stated the end user, or driving instructors in this case, were keen to use new technology under the condition that it is integrated properly into the environment. Thorough data collection showed that development should not only resolve the physical aspects of customer and legal requirements but should shift focus on to facilitating the teaching experience. It should also not be forgotten that a key stakeholder in the driver education is the student. It is necessary to discern between the different groups in order in order to satisfy needs. Failure to meet user expectations could have a negative impact on the learning experience of the student or even worse, pose a safety risk.

The interviews also revealed some delighting functions, such as having the parking brake available on the control panel. These delighters were not found in legal requirements, but they are crucial in order for the end user to have a positive experience with the product. At this point it is also good to discuss the impact of including ergonomics early in the development process. Having in mind that ergonomics play a big role in the perceived usefulness of the system developed. Using ergonomic methods, it is possible to further enhance the experience for the end user in a positive direction.

5.2 Product architecture of derivative projects

Identifying the interfaces between the instructor's workplace and the bus was crucial for the structure of the development process. We recognized very early the benefits of having a clear idea of the product architecture and it worked particularly well in this case since it was an add-on project with clearly defined system boundaries. Instead of developing solutions to five different functions sequentially and identifying the interactions after the fact, the well-defined chunks allowed for development of fewer elements. And since the interactions were known the development could be done concurrently without the changes made propagating throughout the system and affecting other parts. This felt like we only developed what needed developing and we reached solution convergence very efficiently. It also naturally progressed into the other tools and methods we implemented like DFA and topology optimization.

5.3 Topology optimization in the development process

The use of such a complex method used in this kind of development project can be interesting to discuss. Were there any gains of using topology optimization? The method requires that a lot of time is spent on analysing loads and constraints in order to get robust results. Time that can be used for further analysis development and analysis instead. Also it requires a basic knowledge in the mathematical base the method use, in order to make proper interpretations.

One gain that we found was in the generation of concepts for the platform, a task that became more effective. We believe topology optimization helps in decreasing the solution space available during the concept generation phase. In our case we started to try coming up with as many different solutions to the structure problem, the consequence being that we had about 100 possible concepts we could generate from the different sub solutions. But by using topology optimization as the only solution for one structure sub problem, the solution space was decreased to about 25 possible concepts. This gave us the possibility to explore and understand more concepts that we normally would.

6 Conclusions and recommendations

Once the development was finished and the outcome deemed satisfactory, the questions posed in the beginning of the project could be answered.

1. How can we assure that the module fulfils the requirements put by the governments and customer and to what degree?
In this project it was assured that the product fulfils the requirements by doing extensive regulation-legal study and by interviewing lead user. By gathering needs from the lead users, and the situation the module will be used, robust requirements were specified. When having many different stakeholders, many times trade-offs have to be made between stakeholders needs. Having legal requirements can easily drive the focus of the development away from user needs. The argument being that legal requirements have priority over user needs, otherwise the product might not be allowed to be used and the customer would not be interested in procuring the product. In this project the customer was the public transport organisation De Lijn, understandably the focus for them is to have certified and approved training buses. In order to avoid the problem of focusing only on legal requirements in this project, lead user interviews and observations were made. The information gathered was used to identify, potential unexpected needs the users might have. Of course the importance of the legal requirements cannot be overlooked.

2. How can we incorporate topology optimization in product development projects?
The use of topology optimization is connected to the existence of a structure in the product. Incorporating topology optimization early in the process, preferably use the result from the analysis as input to the concept generation table. Doing this will decrease the solution space, and give possibility to explore the remaining concepts better. The method also works better when combining it with the product architecture. The architecture results in design domains attached to each one of the interfacing parts. The design domain can then be used as in input for the topology optimization. It also helps in studying the loads and on the constraints, in order to be able to get robust results from the study.

3. Can a camera system replace mirrors for the instructor?
At the moment there exist camera systems that can replace mirrors in buses. Different suppliers have developed system that can be integrated to the bus. Though certain aspects have to be considered before implementing the change. If a camera system is used, it will be more effective for both the student and the instructor to use the system. The concepts that exist for camera systems have screens mounted inside the bus, one product places a screen on each A-pillar. Using this concept gives both the driver and the instructor the same required sight. The issue of using camera systems is found in the legal requirements. Today the regulation for indirect vision ECE 46 requires mirrors to be used on buses. This means that the bus needs to have both mirrors and camera systems to be approved for driving. But there is work being done on updating the regulation in order to approve vehicles using only cameras for indirect vision. To conclude, yes camera systems can be used instead of mirrors, but not as of today. This implementation should be done in the future when the new regulations apply.

4. What is the extent of changes required in the bus, and what parts are affected?

In order to implement the proposed concept into bus 8900 certain changes are needed. With the help of the DMU models a list was composed showing what parts in the bus needed changing.

Front interior panel
Shown in figure 28 b), change is needed in the dashboard interior panel, just in front of the module pedals. The proposed idea is to design a hatch or a lid in the panel in order to easily hide the wire ends when the bus is used in line traffic but to still have them easily accessible for driving practice.

Ticket holder structure
The control panel attachment to the ticket holder needs to be redesigned to accommodate the bent steel tube arm better.

Mirrors
Using standard class 2 mirrors would work, but could block the sight unnecessarily much. In order to minimize the obstructed vision of both driver and instructor, smaller wide angle mirrors are proposed to be used in the final solution. Special sized mirrors with even smaller height and customized radius could also be investigated.

Front entrance floor structure
The entrance floor structure should be redesigned to withstand the forces acting upon it during certification testing. Attachment points for the platform should be set out. The transverse sheet profiles should be moved to achieve this.

Driver's gate.
In order to facilitate the mounting of the seat and the platform, the driver's gate door is proposed to be removed. The removal should only be done when the bus is used to train bus drivers.

6.1 Recommendations

This section will focus on the recommendation that can be considered in the future development of the driver's workplace module. First of all it is recommended to further analyse the mechanical properties of the front entrance structure since this component needs to pass certification testing. The structure should be analysed with FEM to see how it should be reinforced to withstand the acting forces.

The control panel should go through further ergonomic development in order to improve the perceived usefulness of the functions. Remembering that many instructors felt it was not particularly useful to have a control panel, it is important to find out what factors can be used to change their perspective. Further study is needed on the detailed level of the control panel with a larger sample to perform methods of link analysis and cognitive walkthrough. This could help design better button placements, but more importantly it could help find out if error barriers are needed and how they should be implemented to refrain the user from making mistakes that could jeopardize their safety. This is also where further user involvement could be useful for the embodiment.

It is also recommended that the workplace module, especially the platform and control panel arm are analysed in their behaviour during dynamic loading and crash scenarios. Information otherwise missed because of the simplifications made in this project, e.g. static linear FEM analysis to name one. To avoid eigen mode excitations in the instructor's workplace, special care needs to be taken with lower frequencies which are a common source of structural vibrations in buses. This analysis should give better understanding of how secure the workplace is and how it will behave during normal operation.

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Appendix A

Requirements specification

#	Part / Implemented Solution	**FR** / Non-FR **C**onstraint **S**election **C**riteria **O**ptimization **C**riteria	(DI) Driving Instructor (S) Student (WP) Workplace **Requirement / Metric**	**Level of importance**	**D**emand **W**ish	Belgian Royal Decree (BRD) **Justification**	**Evaluation**	**Units**	**Tolerance**	**Ideal**	**Metric**	**User need**
1	**1. Module**	***FR**	**Support (DI) during lesson**		D	User, Customer requirement						
2		C	(DI) is seated on entrance platform next to driver		D	Customer requirement	CAD					
3		SC	(WP) shall be removable so that buses can be put into normal operation		D	Customer requirement	CAD Packing ana	days	0-1 days	0,5 days		
4		SC	Components with less than 10% total obstruction of specified field of vision shall be disregarded		D	EU, Regulation 46	CAD		<10%			
5		SC	Writing area, controls and information unit are preferably integrated into one easily removable unit	4	W	Customer requirement						
6		C	(DI) rear view and imposed view to the sides fulfills legal requirements		D	EU regulation	CAD / CAVA					
7		Non-FR	(WP) conveys perception of vehicle and surrounding environment	4	W	User requirement	Objective					35
8		SC/Non-FR	Supports S. in focusing on driving (unobtrusive)	4	W	(Ergonomic) User requirement	Obj.(User test)				15	37
9		C	Expensive manufacturing methods are disregarded (3D printing, casting)		D	Manufacturability, cost	CAD					
10		C	Expensive materials are not considered (e.g. exotic alloys)		D	Manufacturability, cost	CAD					
11	**1.1 Platform system**	****FR**	**Locate (DI) in designated space**		D							
12	**1.1.1 3 Point Belt**	*****FR**	**Restrain (DI)**		D	EU regulation						
13		**C**	Equipped with seatbelt		D	EU regulation, BRD	CAD					
14	**1.1.2 Seat**	*****FR**	**Carry (DI) and define H-point**		D							38
15		C	Seat is identical to seat in driving compartment		D	Customer requirement	CAD					17
16	**1.1.3 Platform**	***FR	**Elevate and connect seat to bus frame** *Define anchoring positions*		D							
17		SC	Platform height is equivalent to or higher than driving compartment platform and includes a step		D	User requirement. Ergonomic access, overview	CAD	mm	>430			
18		SC	Horizontal distance in x-direction between H-points of driver's and (DI)'s seats	3,5	W	User requirement	CAD				2	10,9,12
19		SC	Horizontal distance in y-direction between H-points of driver's and (DI)'s seats	4	W	User requirement	CAD				3	11,9,12
20		SC	Vertical distance in z-direction between H-points of driver's and (DI)'s seats	4	W	User requirement	CAD				3	11,9,12
21		OC	(Forward blind spot) From occular point V_1 and V_2(ISO 16121-2) A Bar length equal to the width of the bus at a height of 1100 mm above ground and 300 mm infront shall be visible by direct and indirect view. X% of the bar length is seen.		D	ISO 16121-2 Safety standard for sight of busdrivers	CAD	%	90-100%	95%	4	13,14
22		SC	(View upwards)** To ensure sufficient view of traficlights,etc., a minimum clear angle of view above V1 shall be provided		D	ISO 16121-2 Safety standard for sight of busdrivers	CAD	degrees	12 deg-15deg		6	13
23	**1.1.3.1**	****FR	**Fasten Platform**		D	EU, Regulation 17	CAD					
24	**1.1.3.2**	****FR	**Take up Force**		D	EU, Regulation 17	Engineering evaluation					
25		OC	Anchorage must withstand longitudinal horizontal decceleration/acceleration no less than: 20g applied for 30ms, in direction of whole shell		D	EU, Regulation 17	Engineering eval	g(9.8 m/s^2) ms	20 30			
26		OC	Pulling force of 20*g*M where M = mseat+moccupant+mplatform		D	EU, Regulation 17		kg	mplatform			
27		C	Roof mounted components shall have radius of curvature no less than: Width of projecting parts not less than amount of downward projection		D	EU, Regulation 21		mm	>3.2			

28	**1.2 Note taking area**	**FR	**Support note taking**		D	Customer User wishes to take notes during lesson	CAD					15,39
29	**1.2.1**	*** FR	**Provide supporting surface**		D							
30		C	Size of designated note taking surface	3	W	Customer requirement, Accomodate paper or tablet	CAD	mm^2	A4-210x297 tab-272x189		11	
31			Storage compartment	2	W							
32	**1.2.2**	***FR	**Illuminate surface**		D							
33		SC	Spot light on swan-neck		D	Customer requirement	CAD	lux	>500 lux			
34												
35	**1.3 Control**	** FR	**Provide instructor with control**		D	BRD						1
36	**1.3.1 DC, Dual Control**	*** FR	**Control Speed**		D	BRD						16
37		SC	Dual control is separate from original bus control system	3	W	User (safety)	CAD					7
38		SC	Brake pedal is separate from bus brake system	3	W	User (safety)	CAD					8
39		C	Pedal use is optional	3	W	User requirement	CAD					4
40	**1.3.1.1 Accelerator pedal**	**** FR	**Transfer movement to main accelerator pedal**		D	BRD						3,16
41		SC	Accelerator pedal may be linked in a mechanical or other way	3	W	Customer requirement	Engineering evaluation					5
42		SC	(S) accelerator is disabled when instructor activates the (DI) brake pedal	3	W	Customer requirement	Software					
43		SC	Accelerator pedal shall have heel support, not fitted onto the pedal		W	Customer requirement	CAD					
44		OC	Coordinates of Accelerator Heel Point (X/Y/Z)		D	ISO 16121-1	CAD	mm	0/<300/0	0/<250/0		
45		OC	Operating force		D	ISO 16121-1	Enginering eval./	N	25-40	30-35		6
46		C	Longitudinal clearence between accelerator pedal and body work (in X direction)		D	ISO 16121-1	CAD	mm		>50		
47		C	Lateral clearance between accelerator pedal and bodywork (in Y direction)		D	ISO 16121-1	CAD	mm		>30		
48		C	Clearance between accelerator pedal and brake pedal		D	ISO 16121-1	CAD	mm		50-75		
49		C	Width of accelerator pedal and brake pedal		D	ISO 16121-1	CAD	mm		>40		
50	**1.3.1.2 Brake pedal**	**** FR	**Transfer movement to main brake pedal**		D	BRD	CAD					2,16
51		SC	Brake pedal shall preferably be linked pneumatically	2	W	Customer requirement						
52		C	Force for maximum braking effect		D	ISO 16121-1	CAD	N	<250		1	
53		C	Clearance between brake pedal and any component to the left of the pedal		D	ISO 16121-1	CAD	mm		>30		
54	**1.3.1.3 Sound signal**	**** FR	**Inform (S) with sound, when (I) is controlling brake pedal**		D	BRD						26,(15)
55		SC	A-weighted sound pressure level	3,5	W			dB	<80		8	
56		Non-FR	Brake sound is optional	3	W	User requirement						28
57	**1.3.2 Control panel**	*** FR	**Control vehicle traffic functions**		D	BRD						38
58		OC	Control button layout offers a simple workflow	3	W	User requirement (ergonomic)	Link analysis, cluster				10	24
59		OC	Adjustable controlpanel placement	4	W	Ergonomic requirement	CAD	mm	400-800		14	36
60		SC	Design mimics driving compartment design in terms of control button placement (Horn, mirror heater, mirror adjustment, familiar)	4	W	Ergonomic requirement						18
61	**1.3.2.1 Housing**	**** FR	**Carry and enclose components**		D	Customer requirement	CAD					
62		SC	Controls are placed at adequate position		D	ISO 16121-*, User requirement						
63	**1.3.2.2 Switch/push button**	**** FR	**Control high and low beams**		D	BRD						
64	**1.3.2.3 Switch/push button**	**** FR	**Control opening and closing of front door, D1**		D	BRD						
65	**1.3.2.4 Push button**	**** FR	**Control horn**		D	BRD						
66	**1.3.2.5 Switch/push button**	**** FR	**Control parking brake**	3	W	Customer requirement						19
67	**1.3.2.6 Push button**	**** FR	**Control direction indicator lights**		D	BRD						21
68	**1.3.2.7 Switch**	**** FR	**Control hazard light**		D	BRD						
69	**1.3.2.8**	**** FR	**Control steering**	1	W	User requirement						20
70	**1.3.2.9 Push button**	**** FR	**Perform Security Check**	3	W	User requirement						29
71	**1.3.2.10 Control light**	**** FR	**System active indicator**		D	BRD						27
72	**1.3.2.11**	**** FR	**Space for radio control panel (see R19.976) with extra swan-neck microphone and loudspeaker**		D	BRD	CAD					
73	**1.3.2.12 USB**	**** FR	**Charging station**	3	W	User requirement, delighter						

74	**1.4 Inform**	** FR	**Inform about state of Vehicle**		D		CAD					22
75	**1.4.1 Speed indicator**	*** FR	**Display current speed**		D	Customer requirement						22
76	10" display		Preferably digital type indicator	4	W	Customer requirement						22
77	**1.4.2**	*** FR	**Display current gear**	3	W	User requirement						22
78	**1.4.3**	*** FR	**Display direction indicator signal state**	4	W	User requirement						22
79	**1.4.4**	*** FR	**Display current RPM**	3	W	User requirement						22
80	**1.4.5**	*** FR	**Display inside temperature**	2	W	User requirement						22
81	**1.4.6**	*** FR	**Display current date and time**	3	W	User requirement, convenience						22
82	**1.4.7**	*** FR	**Display state of high, low beam**	4	W	User requirement						22
83	**1.4.8**	*** FR	**Display state of hazard light**	4	W	User requirement						22
84	**1.5 Driver gate**	** FR	**Keep driver gate out of the way of (WP)**	4	W	Customer, User requirement	CAD		lock/remove			
85	**1.6 Rear view system**	** FR	**Support Monitoring surrounding enviroment**			EU, Regulation 46			90-100%	100%		30,31
86	**1.6.1 Mirrors**	C	Driver and instructor must have the legally imposed sight in the exterior mirrors		D	BRD, EU, Regulation 46	CAVA					
87		SC	Time water obstructs the view of DI.	1	W	User requirement						32
88	**1.6.1.1 Class II mirror**	C	Mandatory mirrors M3, 1 on driver's side 1 on passenger's side		D	EU, Regulation 46	CAD					31,33
89		C	Mirrors placeed so (DI) has clear view of road to the rear, side(s) or front of vehicle from seating position		D	EU, Regulation 46	CAVA					31,33
90		C	Exterior mirrors visible through sidewindows		D	EU, Regulation 46	CAD					32
91		SC	Field of vision on driver's side mirror such that • (15.2.4.2.1) Driver can see at least 5m wide, flat horizontal portion of road, bounded by plane parallel to median longiutudinal vertical plane and passing through outermost point of vehicle on driver's side of vehi....		D	EU, Regulation 46	CAD/CAVA					33,34
92		SC	• Extends 30m behind driver's ocular points to horizon. Field of vision on passenger's side mirror such that Same as driver's side		D	EU, Regulation 46	CAD/CAVA					
93					D							
94	**1.6.2 Cameras**	SC	Adjustment of device for indirect vision, other than mirrors (camera) requires no tools		D	EU, Regulation 46		s	2			31,32
95		SC	Screen framerate <2s		D	EU, Regulation 46						
96		C	Critical objects are observable over entire required field of vision		D	EU, Regulation 46	CAD/CAVA					
97		OC	Device for indirect vision obstructs drivers direct view minimally		D	EU, Regulation 46	CAD (Catia Human)					
98		C	Viewing direction of monitor equivalent to that of main mirror		D	EU, Regulation 46	CAD(Catia Human)					
99		C	In vehicle designed for special purpose, obstruction of required vision of Class VI mirror may be greater than 10%		D	EU, Regulation 46	CAD					
100		SC	Exterior cameras are either • mounted 2m above ground when vehicle is under max loado Or, if lower edge i less than 2m from ground, • do not project more than 50 mm beyond overall width of vehicle • have radii of curvature no less than 2.5mm		D	EU, Regulation 46	CAD					

Appendix B

Mission statement

Mission statement:	Instructor’s workplace for driver’s education buses
Product Description:	• Module consisting of multiple parts necessary for a driver's education bus • Main module parts are: Platform, seat, pedals, control panel, rear view mirror/camera, driver’s door locking mechanism
Benefit Proposition:	• Certain number of buses are needed for driver's education and are by local law required to be equipped with dual control for the instructor • By developing a detachable driving instructor's module, which complies with the legal requirements, driving school buses are at disposal for regular public transportation
Key Business Goals:	• Support development of bus for Belgian and EU market • Comply with regulations and capture a new market
Primary Market:	Belgian public transportation organization De Lijn
Secondary Markets:	Other driving schools and public transportation organizations Rest of Europe

Assumptions and Constraints:	**Assumptions**
	Instructors workplace consists of the following components:
	• **Platform** - developed along with attachment to bus, strength analysis
	    o (horizontal surface, or a structure with a horizontal surface, usu. raised above the level of the surrounding area)
	• **Instructor’s seat** - same as driver's seat provided by Volvo buses (ensures certification fulfillment)
	• **Dual command pedals** (throttle and brake) - Existing pedal systems from suppliers evaluated for provision of suitable system
	• **Control panel** - only button layout of user interface, little to no industrial design study
	• **Rear view vision** - provided by either mirrors or cameras (exclude other solutions due to feasability/time constraints of development)
	• **Driver’s compartment door** - can either be locked in open position or removed completely
	Constraints
	Module must
	• fit in the designated area of the bus
	• allow for assembly or disassembly in bus within 1 working day (8 hrs.)
	• comply with regulations for regular buses
	• attachments will support interface between bus and module
	    o Critical mechanical analysis (FEM) of these will suffice

Stakeholders:	Volvo AB, Benteler Engineering Services AB, De Lijn, Driving instructors, Driving students, (Governments)

Stakeholder analysis

Stakeholder	Requirements	Measures
Public transportation organization (Customer)	Buses fulfill legal requirements to transport people	Fulfill requirements specification
Driving instructors (User)	Useful functions that don't interfere with teaching	Map instructor needs
Driving students	-	-
Governing authorities and certifying bodies (EU, Belgium)	Safe public transportation on roads	Fulfill legal requirements

Appendix C

Interview guide

1. Hur går en körlektion till idag?
   Var tycker du är en bra område att stå?
   Har du något behov av att flytta dig?
   Vilka är de viktigaste momenten att lära sig när det gäller bussar?

2. Fordonet som används till körlektioner, används det för alla körkortskategorier?
   Lågentré, Coach(Långfärds)
   Vilken är den vanligaste typen tror du?

3. Vad tycker du är viktigt att lära sig när man kör buss?
   Vad är den största skillnaden mellan buss och bil?

4. Vilket är det svåraste momentet att lära ut?

5. Är det enkelt att kommunicera med eleven under körlektionen?
   Hur är ljudnivån under körning?

6. Hur känns säkerheten idag, ni kör utan dubbelkommando?
   Om vi jämför med lektion i bil?
   Vad skulle du vilja överföra om det är möjligt?
   Vad tycker du om dubbelkommando i bil?

7. Om man inför dubbelkommando, vilka av förarens funktioner skulle du vilja ha?

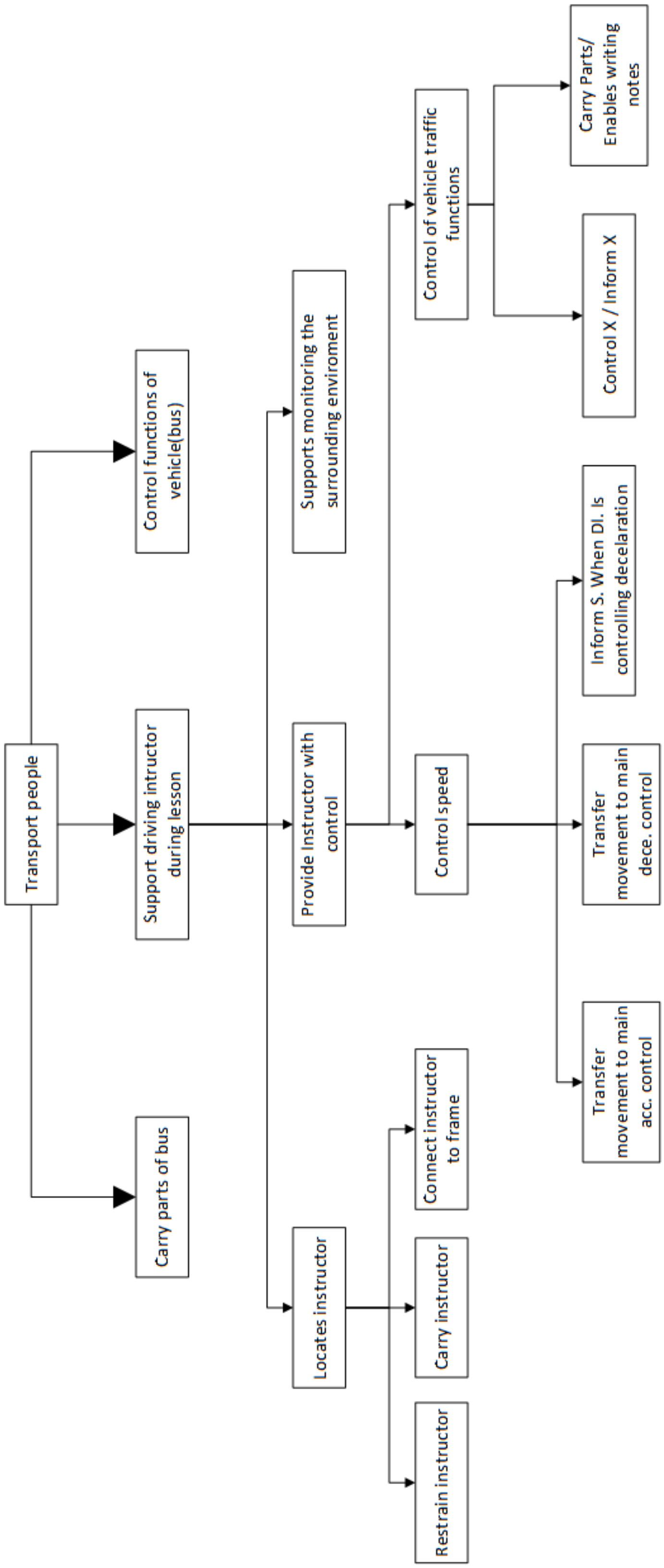
8. Vad tycker du om kamera system som finns ute idag?
   Finns det något du tycker de saknar?

9. Har du sett några trender inom dubbelkommando för buss?
   (vet du någon som tillverkar såna?)
   Varför har man inte haft det tidigare?
   Kan du tänka dig att någon skulle vara intresserad av detta, och varför??

Har ni egna bussar på körskolan eller hyr ni?
Kan era bussar användas för kollektivtrafik?

Appendix D

Functional decomposition tree



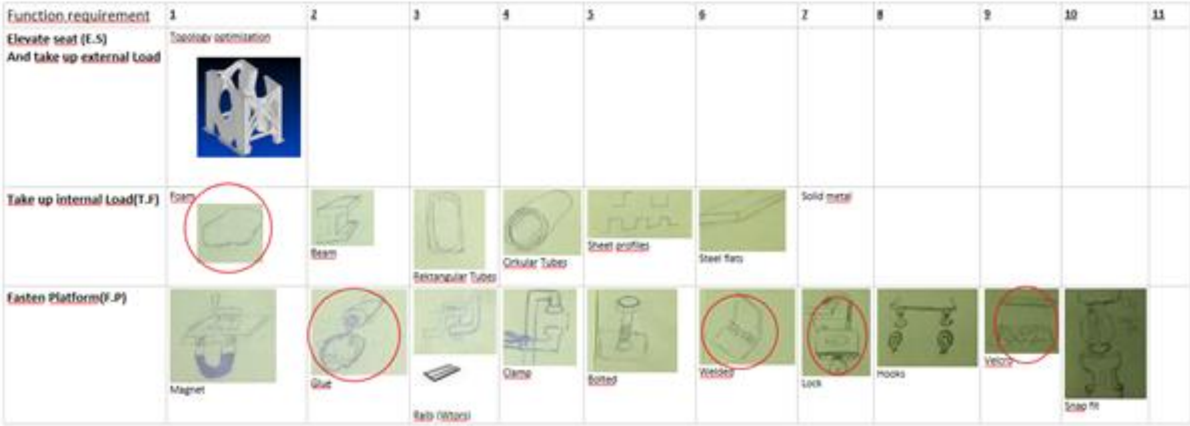
Means tree


Bus
Chassi
1: Module
Function ECU
Tacograph
Instructor support system
3 Point Belt
Seat
Platform
Writing area
Width
Length
Spotlight
Control system
Dual control unit
Wire conected to DCU gas pedal
Wire connected to brake
Sound signal
Control panel
Low/High Beam
Parking brake
Horn
Direction indicators
Door opening
Speed indicator
Radio
Hazard lights
Spot light
Enclosure Arm
Door locking mechanism
Information system
Left/right indicators
Gear indicator
Speed indicator
Light indicator
RPM indicator
Temp indicator
Mirror/camera system

Appendix E

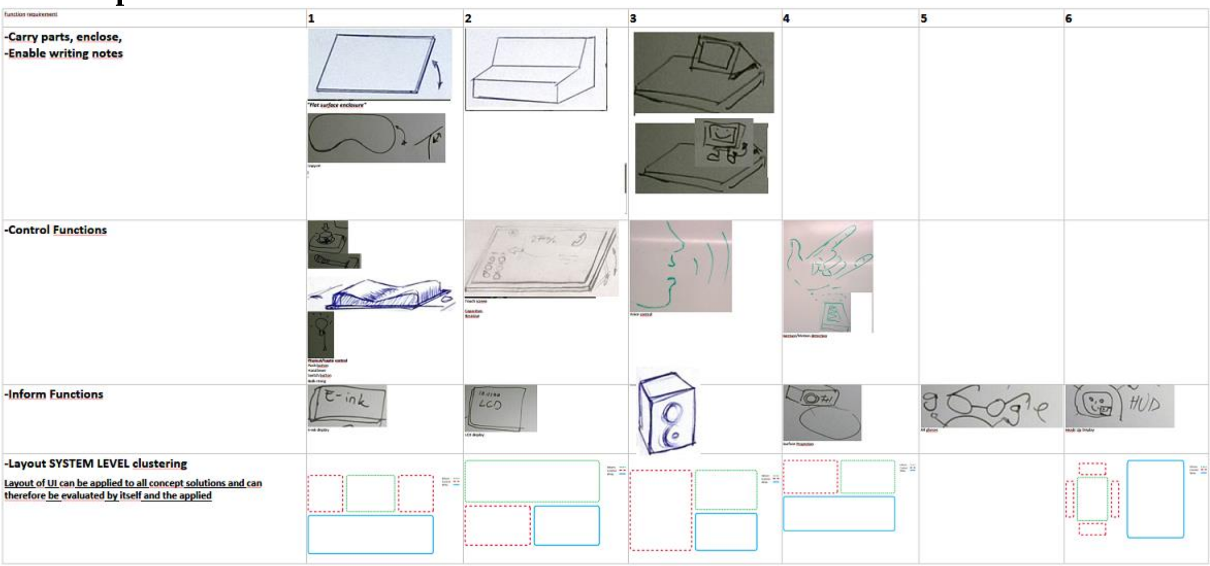
Morphological matrices

Platform



Function requirement	1	2	3	4	5	6	7	8	9	10	11
Elevate seat (E.S) And take up external Load	Topology optimization										
Take up internal Load(T.F)	Foam	Beam	Rektangular Tubes	Cirkular Tubes	Sheet profiles	Steel flats	Solid metal				
Fasten Platform(F.P)	Magnet	Glue	Rails (Wtors)	Clamp	Bolted	Welded	Lock	Hooks	Velcro	Snap fit	

Control panel



Function requirement	1	2	3	4	5	6
-Carry parts, enclose, -Enable writing notes	"Flat surface enclosure"					
-Control Functions						
-Inform Functions						
-Layout SYSTEM LEVEL clustering Layout of UI can be applied to all concept solutions and can therefore be evaluated by itself and the applied						

Appendix E

Platform screening

Concept Platform for Module

Document Number:	Doc001														
Project:	Drivers intractor Module														
Solution area:	Platform					Reference		Solution area concept 1		Solution area concept 2		Solution area concept 3		Solution area concept 4		Solution area concept 5	
Date:	20150410														
Created by:	Miguel & Armin														
Req. No	Criteria	Req.	Req. value	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
1	Platform Height is equivalent or higher than drivers platform	430 mm or higher	430	>430	0	>430	+	>430	0	>430	0	>430	0	>430	+
2	Platform is removable		yes	yes	0	yes	0	yes	0	yes	0	yes	0	yes	0
3	Anchorage must withstand longitudinal horizontal deceleration/acceleration no less than: 20 g applied for 30 ms	Must withstand the pulling force of around 34139 N		yes, bolts are used in current solution	0	According to TÜV test the rails can withstand 19306 N pulling force(Two rails),8 rails are incremented ok	1	No the Clams cant withstand those forces	-1	low adhesive force in shear direction.	-1	same solution used to strap wheelchairs	0	The snap-fit has to be flexible and stiff at the same time.	-1
4	Structure must withstand a pulling force of 20*g*M M=mseat+moccoupant+mplatform	34139	47794	yes	0	yes	0	yes	0	yes	0	yes	0	yes	0
5	Manufacturability	"Standard manufactoring methods"		yes, but can be bulky	0	yes, much easier to manufacture.Plate-Tube	1	The solid parts might be bulky	0	Using tubes in manufacturing will be easier	1	Difficult to weld in contact zones.	-1	'yes, much easier to manufacture.Plate-Tube	1
6	Cost			Nothing out of the ordinary	0	StandardTubes and plate	1	Standard tubes	1	Standard tubes	1	standard beams	1	standard tube and plates	1
7	Ergonomic Handling (Weight)			high weight, around 89 kg	0	18,2 kg from CAD+ around 1 m Vtors. (2,93 kg/m)	1	37 Kg+Clams	1	20,5 Kg + weight of magnets	1	30 kg +straps	1	18,2 kg + snap-fits	1
8	ease of assembly(Weight+assembly)			difficult to lift+but easy mounting	0	ok weigh+easy mounting Vtors(First time installation takes long time)	1	ok weight+ clamps are easy to look	1	ok weight+ magnets might be little difficult to get right	1	ok weight+ look to position as with cargo straps	1	good weight+snap fit works well when it works	1
			SUM		0		5		2		3		2		3

Criteria agreed to be used for concept solution

Concept Platform for Module

Document Number:	Doc001													
Project:	Drivers intractor Module													
Solution area:	Platform				Solution area concept 1			Solution area concept 2			Solution area concept 3			
Date:	[illegible]													
Created by:	Miguel & Armin													
Req. No	Criteria	Req.	Req. value	Criteria weight	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	
1	Anchorage must withstand longitudinal horizontal deceleration/acceleration			[illegible]	According to TÜV test the rails can withstand 19306 N pulling force(Two rails),8 rails are incremented ok	4	0.59	Solution used today Same	5	0.73	Solution used today Same	5	0.73
2	Structure Highest Von Mises Stress	Between 230 Mpa to 700 Mpa		[illegible]	Front Dir. 670Mpa Side Dir.755 Mpa, 45deg.979 Mpa,	3	0.44	Front Dir. 670Mpa Side Dir.755 Mpa, 45deg.979 Mpa,	3	0.44	Front Dir. 632 Mpa Side Dir.366 Mpa 45deg.679 Mpa	5	0.73
3	Structure Buckling Factor	>1		[illegible]	Bfactor_Front 25 Bfactor_Side 22 Bfactor_45 deg 20	5	0.73	Bfactor_Front 25 Bfactor_Side 22 Bfactor_45 deg 20	5	0.73	Bfactor_Front 16 Bfactor_Side 12 Bfactor_45deg 13	3	0.44
[illegible]	Manufacturability			[illegible]	Cut tubes & Bolts weld	4	0.25	Cutting Tubes, Weld	5	0.32	Cut tubes, Laser cut parts	4	0.25
[illegible]	Cost of Anchorage			[illegible]	Price of 748 per rail of 1.5 m	5	0.05	Price of bolt. Around 3 SEK/bolt	5	0.06	Price of bolt. Around 3 SEK/bolt	5	0.06
7	Ergonomic Handling	As low weight as possible		[illegible]	18.2 kg	5	0.45	[illegible]	4	0.36	37 Kg	2	0.18
8	Implementation of concept	Least amount of redesign on bus		[illegible]	Can be implemented, normally on minibuses, requires gluing rail to floor	2	0.24	Solution today	5	0.59	Solution today	5	0.59
9	Space needed to implement	Minimum area needed for the concept		[illegible]	Minimum area needed	4	0.62	Solution today is much easier to implement, as much area needed	4	0.62	Solution today is much easier to implement, as much area needed	4	0.62
10	Assembly symmetry	Does it matter how the concept is mounted		[illegible]	Symmetric assembly is possible	5	0.32	Concept can be implemented in a symmetry assembly	5	0.32	Concept can be implemented in a symmetry assembly	5	0.32
11	No Of Parts Needed for assembly	Minimum parts needed for assembly		[illegible]	1-The platform	5	0.27	1-platform, bolts, Nuts and washers	3	0.16	1-platform, bolts, Nuts and washers	3	0.16
			Total SUM	[illegible]			[illegible]			[illegible]			[illegible]

Control panel screening

Concept dashboard for Solution area concepts

Document Number:	Doc002
Project:	Driver's Module
Solution area:	Control panel
Date:	maj-15
Created by:	Armin Fatic
	Miguel Hoezo Martinez

Criteria No	Criteria	Req.	Criteria weight	Solution area concept 1			Solution area concept 2			Solution area concept 2		
												
				Competitor Solution 1 (Control Panel)			Competitor Solution 2 (App)			Replicator		
1	Cost	Estimation	4.167%	Software dev. :- N/a Casing :-2000 (rough estimation) Joystick:- 1000(estimate)	4.0	0.17	App development :- N/a Generic Tablet:- 2000-4000	4	0.21	LCD Display 10" :- 800-1500 SEK Raspberry Pi :-399 SEK Development of software :- N/a Casing :- 2000 SEK (rough estimation) Mechanical controls :- N/a	4	0.17
2	Quality impression	Modern impression	2.778%	No touch screen Solutions look	2.0	0.06	Looks modern	5	0.14	No touchscreen, Solution can be viewed as outdated	2.0	0.06
3	Function	Can all required functions be implemented	11.111%	Inform function is implemented, write area. brake function, horn, and seat heat is included in controls	2.0	0.22	Generic tablet, App only copies dashboard. No controls and no writing area	2	0.22	All functions can be implemented	5.0	0.56
4	Reliability	Can there be any relibility problems? Safety	15.278%	Solution using wires to minimize interference	4.0	0.61	Battery has to be charged at all times	3	0.46	Solution using wires to minimize interference	4.0	0.61
5	Durability	Risk of damaging	4.167%	Good solid stucture.	5.0	0.21	Tablets are sensitive to rough handling. Lifespan is short	3	0.13	Same durability as controls in bus toda	4.0	0.17
6	Control Feedback	Feedback from control	11.111%	The solution uses joysticks and buttons. The brake is only (all or nothing)	3.0	0.33	No controls, no feedback.	2	0.22	Control feedback is recieved. Writing	4.0	0.44
7	Obtrusiveness	Supports I. in focusing on Student driving (unobtrusive)	13.889%	Does not take away focus from student. Minimalistic design. The student doesnt get distracted	5.0	0.69	Other apps can be used, can be distracting	3	0.42	Looks like a small copy of the dashboard. Less distraction for student . Screen area is small 7 ".	5.0	0.69
8	Ease of learning	Is it easy to learn?	19.444%	Does not mimic dashboard, new UI must be taught	3.0	0.58	Easy to find information, copies the dashboard. No controls	4	0.78	Concept can be used without glances, by using tactile senses. Easy to learn, Copy od current dashboard.	4.0	0.78
9	Technology adoption	How willing are the users to adop this technology	18.056%		3.0	0.54	Generic tablet is common use	4	0.72		4.0	0.72
			TOTAL			3.42			2.57			4.19

Criteria agreed to be used for concept solution

Additional knowledge gaps to close

Appendix F

Assembly time estimation of final concept

		Number of parts	Number of connectors	Weight (kg)	Solid parts manual handling time (s)	Separate operation times (s)	Weight penalty	Total time (s/part)
Platform								
	Filler section	1	14	15	20,7	113,4	1,5	144,45
	Main platform section	1	14	22	23,28	113,4	1,5	148,32
	Pedal section	1	8	15	22,8	64,8	1,5	99
	Middle profiles	4	0	4	56,24	18	1	74,24
	Sheet metal step	1	4	1	16,23	32,4	1	48,63
	Plywood cover	3	4	9	56,7	32,4	1,5	117,45
Pedals		1	2	1	31,1	16,2	1	47,3
Seat		1	6	60	38,34	48,6	1,5	106,11
Control panel		1	1	5	25,9	4,5	1,5	43,35
	Steel pipe attachment	1	1	0,5	12,9	4,5	1	17,4
Mirrors		2	1	2	20,2	25	1,5	55,3
SUM		17	54	134,5	324,39		seconds	901,55
							minutes	15,02583

Cost estimation of final concept

		Number of parts	Area (m^2)	Weight (kg)	Cost	Cost (SEK Total)
Platform						
	Filler section	1		15	25 SEK/kg	375
	Main platform section	1		22	25 SEK/kg	550
	Pedal section	1		15	25 SEK/kg	375
	Entrance framework	1		50	25 SEK/kg	1250
	Middle profiles	4		4	25 SEK/kg	100
	Sheet metal step	1		1	25 SEK/kg	25
	Plywood cover	3	1,6		200 SEK/m^2	334
Pedals		1				3000
Seat		1				33000
Control panel		1		5		6000
	Steel pipe attachment	1		0,5	25 SEK/kg	12,5
Mirrors		2		2	1000 SEK/piece	2000
					SUM	47021,5