HAPTIC MID-CONSOLE

Graduation Thesis Pieter Stol

Graduation Thesis

‘Aito Haptic Mid-Console: Design Of An Haptic Feedback Enabled demonstrator for Automotive HMI Applications ’
Timeframe: 12-02-2018 until 06-02-2019

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Abstract

While touch Interfaces have greatly improved the user friendliness and functional possibilities of devices, haptic feedback has been lacking in user interface design. Good Haptic feedback not only gives confirmation of a key press, but also enriches the user interaction and improves the usability of interfaces.
This absence of haptic feedback is is generally not an issue when the users field of view is oriënted at the touch interface (as is the case with Smartphones and tablets), problems arise when features in the interface have to be controlled blindly, as is the case in automotive applications, where distraction of the driver results in safety risks.

In terms of HMI design, the unique properties of Aito's HapticTouch system has shown it can potentially solve these issues and even could enrich the user experience of automotive interiors.
In reality however, when clients integrate Haptic Touch in their products, its application is generally limited to replacing traditional buttons, reducing its competitiveness when compared to other technologies. Broadly speaking, there two problems: The first one is that Aito has no demonstrators that show haptic feedback integrated with innovative UI designs. The second problem is that at this time, Aito has little experience in combining audio-visual cues with Haptic Feedback.
This graduation thesis explores the possibilities in designing an affordable demonstrator that showcases the unique selling points of AITO®HapticTouch technology for automotive applications.
To provide a sound foundation for the design process, internal- and external company analyses were done to identify the sustainable competitive advantages of Aito, trends and developments in the Automotive industry (until 2030) and companies/technologies that compete with Aito.
Based on insights from the analysis, the following Design Vision has been formulated: Future automotive HMI's should adapt themselves to the personal preferences of the user(s), taking into account the context the car is used in and the state of mind of the user(s) in relation

to their physical and digital lives. With this vision, Aito's Haptic Touch is central in making the UI contextual and personal to the user, while also being used as an additional channel of communication with the user in e.g. automated driving modes. The demonstrator presented in this thesis embodies this design vision: A light-weight structure with a wide range of personalised features, a minimalistic projection mapped GUI design, contextual to the driving situation and controls that communicate with the user through Haptic Feedback.

To validate the design, a prototype version of the gear shifter panel was built to evaluate the use of projection mapping and the quality of the stack designs. The initial validation brought to light there is room for improvement in terms of HapticTouch integration. The estimated building costs were higher than the target price, but for a demonstrator of this complexity still acceptable.

If Aito would decide to continue developing this demonstrator, would therefore be to start small with the individual panels before integrating them into a fu a demonstrator on the scale of the one discussed in this thesis.

Figure 1. The final design of the Mid-Console demonstrator which is the result of this graduation project. More details on the design can be found on pages 96 to 101.

Figure 2. Faurecia interior concept featuring AITO®HapticTouch

Introduction

In Human Machine Interface HMI design, Haptic Feedback is an often overlooked but critical product attribute. A product can have a premium appearance and sound great, but when the haptic feedback of the product does not match this experience it feels “off” or “cheap”.
While this form of haptic feedback can often been designed, other less intentional forms of Haptic Feedback also influences the way products are used. Wear, vibrations through the mechanical structure can also tell something about the state of the product, giving contributing to the character of the product.

The introduction of touch interfaces revolutionized the way User Interfaces are designed and experienced. Unfortunately however, the loss of haptic feedback resulted in the removal of a whole layer of interaction.

While this is not to much of a problem in smartphones and tablets where the product is always in the field of view of the user. Applications where this is not the case, haptic feedback is an important safety feature, this loss somehow has to mitigated with other technologies.
One application where this problem is keeping many designers busy, is in automotive HMI design.
The haptic feedback technology developed by Aito (AITO®HapticTouch) has the potential to mitigate the problems mentioned above while maybe even bringing back some of the more traditional aspects of haptic feedback.

This graduation thesis investigates the use of AITO®HapticTouch in Automotive HMI’s to be used as more than just a button replacement technology.

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Figure 3. Contents of the AIto demobox, sold to companies to demonstrate AITO®Haptic Touch.

01

Company & Assignment

What is Aito Haptic Touch and why was this project started? The first chapter will discuss the company Aito and its proprietary technology, leading up to the problem definition and assignment. Finally, the design approach for this project is discussed.

1. Aito Company Introduction

Aito was founded in 2012 when the Dutch company d-Switch merged with a team of Nokia engineers. The goal of this venture was to combine piezo-based touch buttons with piezo-based haptic feedback to create a unique and proprietary technology.

The collaboration stems from a common vision:
While the introduction of touch technology has greatly improved the user friendliness and functional possibilities of devices, the absence of haptic feedback in touch interfaces has been lacking in user interface design. Good Haptic feedback not only gives a simple confirmation of a key press, but it also should enrich the user interaction and improve the usability of interfaces. Haptic touch from Aito is able to bridge this gap in functionality.

Hence, the ambition of Aito is to make user interfaces feel more real and to combine the best of two worlds: Seamless surfaces of touch interfaces with the tactile experience of traditional buttons.
By using Aito's mechanical design guidelines together with the AITO® Chip, companies can integrate Aito Haptic Touch into their products with relative ease.

The last few years have shown a growing demand for haptics with key drivers being the richer interaction possibilities, enhanced design freedom and miniaturisation of bulky mechanical buttons.
At the time of writing, Aito employs 16 people distributed over two offices, in Amsterdam and Espoo (near Helsinki).

Buisiness Model

Selling the AITO® Chip, which is a custom designed ASIC combining Aito's proprietary firmware together with Aito's integrated touch sensing and haptic boosting circuitry.

People

Aito has a multi disciplinary team of 16 employees divided over two offices: one in Amsterdam and one in Espoo, Finland.

Markets

Aito's clients are companies in the home appliance, mobile devices and automotive markets. Of these three markets the automotive industry represents the largest share, with brands like Renault and BMW.

Figure 4. Aito Offices: Application Engineering in Amsterdam adn R&D in Espoo

2. Haptic Touch Technology

AITO®HapticTouch is the core technology of Aito. Over the last few years, Aito has finetuned and expanded a whole ecosystem of configurations and application designs. The following pages will discuss the underlying principles and unique properties of Aito's Haptic Touch technology.
An in depth description of the AITO® HapticTouch system, can be found in Appendix A.

2.1. Basic Working Principle

The touch sensing and Haptic feedback of Aito is built around single layer piezo-discs, also commonly used in buzzers and speakers (figure 1.). The unique physical properties of the piezo material allows Aito to monitor and control movement of the disc by reading or applying voltage.

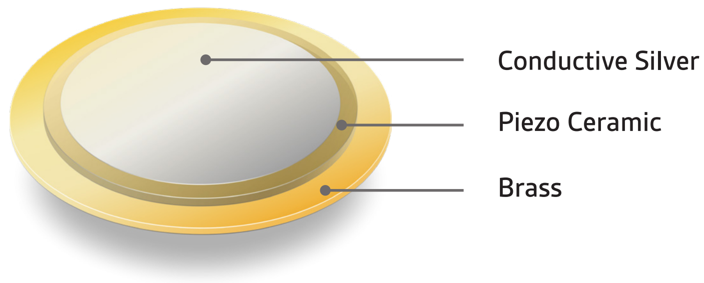


Figure 5. A typical piezo disc.

HapticTouch is the system architecture developed by AIto that is able to deliver touch sensing and feedback using the same circuit and components. The AITO®Chip is the brain of the system, which monitors the touch input, compares it to the user settings and decides when and what kind of haptic feedback should be given (see figure 2.) (Aito BV, 2018a).
The simplicity of this system combined with the programmable nature of the AITO®Chip are the key properties that make AITO®HapticTouch unique.

01. In rest

The circuit consists of the AITO® Chip and one or more piezos. When there is no activity, the chip is in low power mode. The Chip would generally be integrated remotely on the main pcb of the product, while the piezo discs are placed underneath the surface of the interface.

02. Touch sensing

A finger press causes the piezo disk to deform slightly. The deformation in the piezo ceramic causes a voltage which wakes up the AITO® Chip. If the press meets the configured threshold, a button press is detected.

03. Haptic Actuating

If a button press is registered, the AITO® Chip immediately applies a high-voltage haptic signal (100-400V) to the pressed piezo. This signal causes the piezo disk to bend within milliseconds. The deformation of the piezo is felt through the overlay material as a tactile sensation similar to a mechanical button.

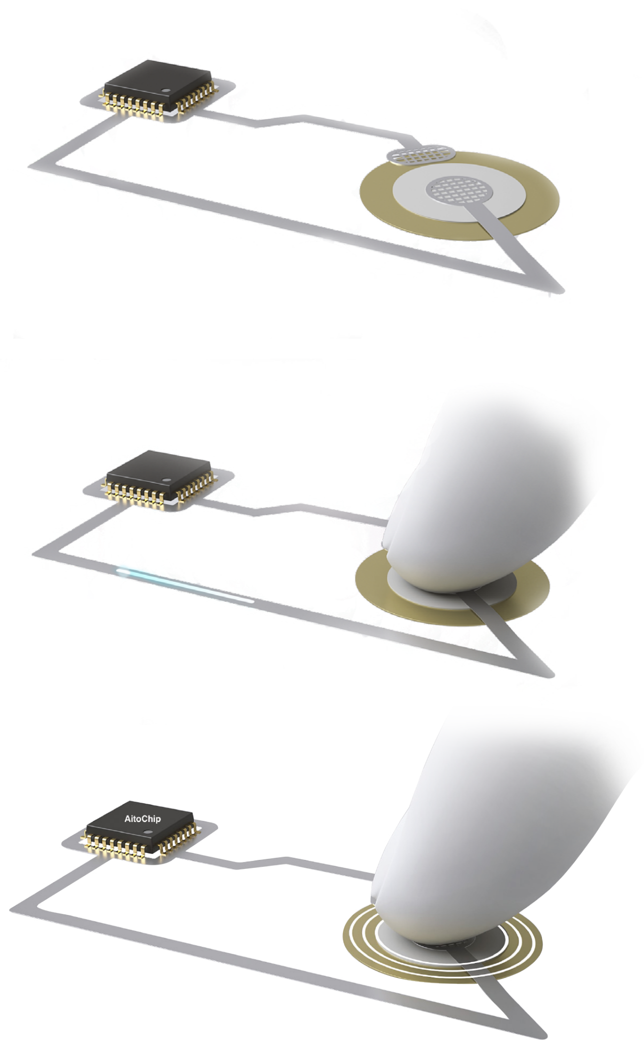


Figure 6. HapticTouch circuit during rest, sensing and feedback.

2.2. Unique Selling Points

The basic system architecture of AITO®HapticTouch provides an almost modular level of flexibility. This flexibility can be summarized into three unique selling points, which are explored on the following pages:

- **On the fly adjustment of sensing and feedback parameters**, make it possible to not only to assign multiple functions to the same key, but also make them feel differently.
- **Multiple standardized piezo configurations** (or stack designs), designed for applications like single keys, touch pads and touch screens. These configurations can also be mixed on the same chip.
- **A high degree of Geometric Design Freedom**. AITO®HapticTouch is integratable with other HMI technologies, has few geometric design limitations, is scalable and compatible with overlay materials.

USP /01

Real-time Sensing and Feedback Parameter Settings

By modifying the touch sensing and haptic feedback parameters of the AITO® Chip, a wide range of tactile sensations can be realised: from the basic click-clack feeling of traditional on-off buttons to complex analog buttons with dynamic vibrations patterns at different intervals. These “HapticTouch Parameters” are stored within the AITO® Chip, but they are adjustable by a system host - on the fly - such that the feeling of a user interface can change over time (Aito BV, 2018a). Through tools like the AITO®UX Design Studio, which connect to this system host, designers can easily experiment and adjust the following HapticTouch features (Aito BV, 2018b). A more detailed explanation of the HapticTouch parameters can be found in Appendix A.

1. **Sensing Parameters**, like touch sensitivity and detection area. Also it is possible to enable force touch, adding multiple “layers” to a key, similar to the shutter button of a photo camera.

2. **Haptic Feedback pulse parameters,** control the feeling of the click of button press. Generally the parameters of feedback strength, sharpness (determining the aggressiveness of the feedback) and timing.

3. **Vibration parameters,** consisting of a number of timing parameters which make it possible to repeat an haptic feedback pulse, creating a vibration. These vibrations in turn can also repeated at a certain intervals and can be made dynamic (e.g. with each haptic pulse the strength is of the feedback is increased).

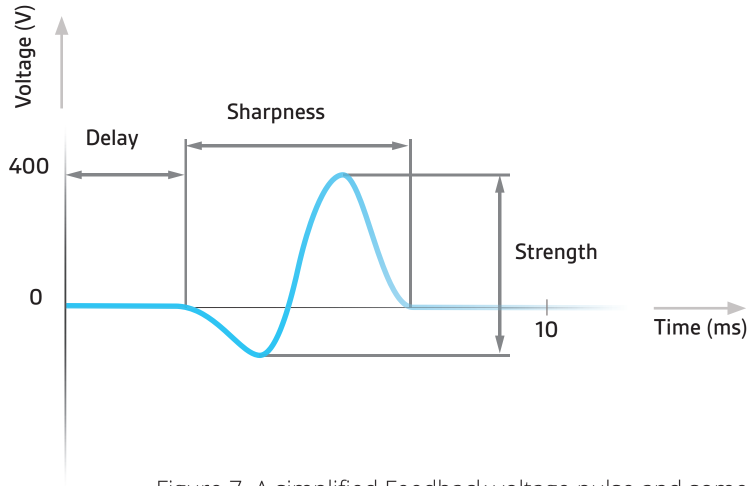


Figure 7. A simplified Feedback voltage pulse and some of the parameters that define the pulse

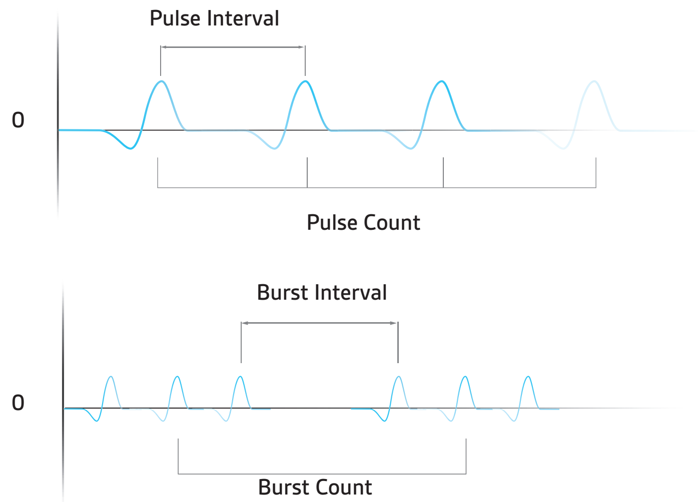


Figure 8. Some of the parameters that are used to define vibration patterns.

USP /02

Stack design configurations

There are three general design configurations or stack designs for integrating Haptic Touch in products.
Requirements such as the degree of design freedom, overlay material and display/symbol illumination technologies, generally determine which stack design is suitable (AitoBV, 2018b).

1. **Local**: Piezos are controlled and configured individually, comparable with traditional buttons. Thickness of the overlay material is limited.

2. **Global**: Multiple piezos support a "floating" surface. The entire surface is actuated during a feedback event. The shape of the surface is not limited in thickness. Touch sensing however, is restricted to force touch and the surface is not fully seamless. This design is very suitable for display integration.

3. **Hybrid:** This configuration is a mix of the local and global stack designs and is suitable for applications where a seamless finish is required. Stack thickness is limited though to allow for enough elasticity in the overlay surface.

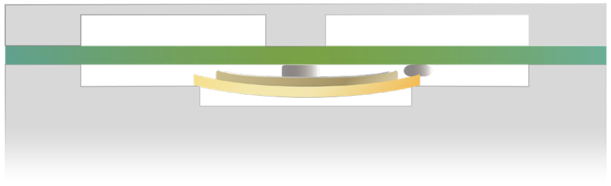


Figure 9. Local Stack

Figure 10. Global Stack

Figure 11. Hybrid Stack

USP /02
Geometric Design Freedom

Because of the use of flexible electronic foils, AITO®HapticTouch foils can be very thin and flexible (with a minimal thicknes of 0,4 mm). Therefore, HapticTouch can be applied underneath curved surfaces with a minimum radius of 500 mm. Within the stack, enough freedom of movement should be available for the piezo disc. This means some space is required in between the foil and overlay surface for movement (see figure 7. This does not apply to th global stack configuration).
Furthermore, a wide range of materials can be applied as overlay materials (e.g. textiles, leather, metals, wood vineers, glass and plastics).
Thickness is mainly the limitation and this is related to the elasticity of the material (again, a certain level of elasticity should be available). Steel for example has a maximum thickness of 0,2 mm, while plastic can have a thickness of 1,5 mm. This limitation in thickness is mostly applicable to the local and hybrid stacks.

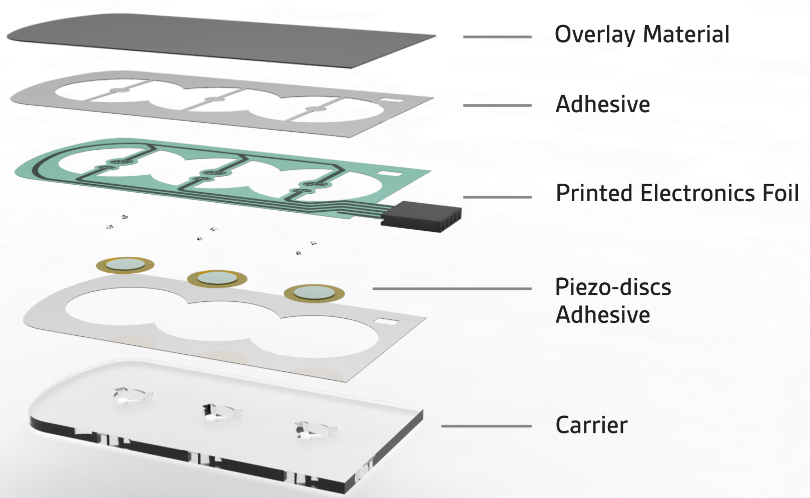


Figure 12. General Stack layering

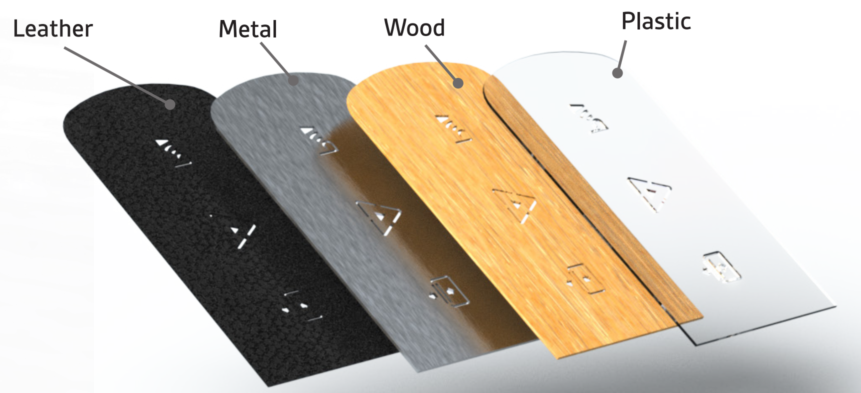


Figure 13. Some of the overlay surface options

3. Problem Definition

**While the technology of Aito has many interesting possibilities, the majority of customer projects are limited in the way Haptic Touch is applied.
Most of the customer projects at Aito have been oriented at the use of haptic touch as a replacement technology of traditional buttons and sliders. As a result, only a few of the unique selling points of Haptic Touch are capitalized on, making it harder to compete with the cheaper to manufacture mechanical buttons.**

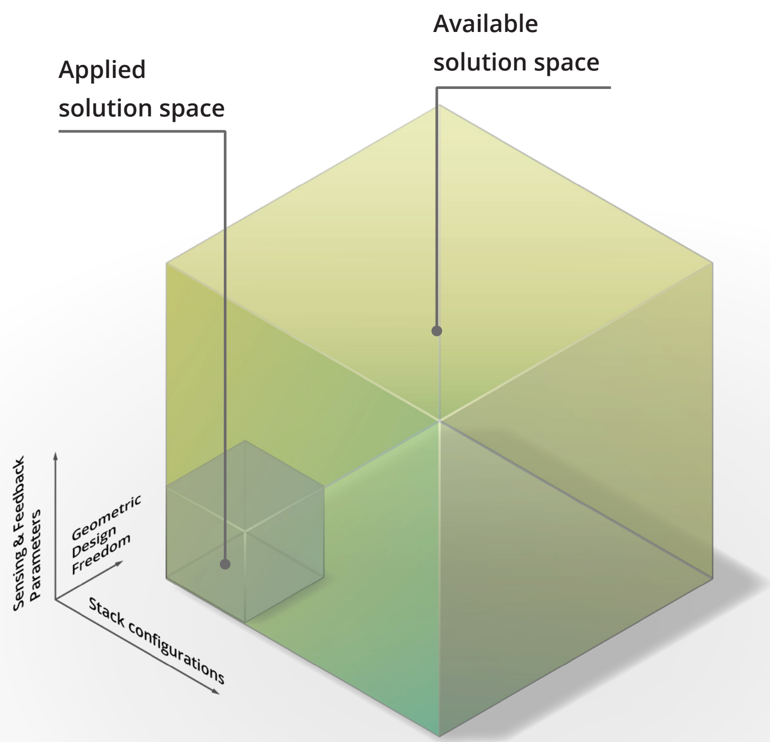


Figure 14. Applied vs Available solution space for AITO®HapticTouch

While it is tempting to blame this on the newness of the technology and development hurdles (especially development times in the automotive industry), two problems seem to limit the potential.
The first one is that the business model of Aito allocates the majority of the design work to the client to offset some of the development costs associated with maturing the technology. A typical project consists of giving a

workshop to the client to get them familiar with the technology and the Aito design tools. From there the client goes to work and for the remainder of the project, the Aito team provides technical support to make sure the client reaches its design goals with the appropriate level of quality. Lessons learned from the customer projects are used to expand and improve the feature set of Haptic Touch.

The problem is that in general, the budget and available time for most companies does not provide much room for experimentation (with a few exceptions). This often results in interface concepts which use traditional interaction principles and/or are designed with features of existing products.

The second observation is that Aito currently has limited tools available to communicate the unique selling points of Haptic Touch. Practically all of the Aito demonstrators show one or two features of Haptic touch (e.g. a trackpad demonstrator, a lighting demonstrator, a curved surface demonstrator, etc.). There is no proprietary and engaging demonstrator that shows the latest advancements of the technology, properly integrated in a user interface.

Meanwhile, the introduction of floating surface haptics is opening up new possibilities for integrating haptic touch in displays, even further expanding the feature set.

In short, Aito is lacking a compelling way to communicate its potential. There is no “concept car” that demonstrates the promise of AITO®HapticTouch when it is integrated in a user interface, as all automotive demonstrators focused on mechanical button replacement, when Aito’s HapticTouch can enrich a user interface so much more.
This thesis explores how this could be done.

4. Assignment

Combining haptic feedback with other sensory feedback (visual and audio) is currently outside the comfort zone of Aito. Also, since Haptic Touch is compatible with multiple display- and symbol illumination technologies and overlay materials, one of the challenges is to communicate this flexibility in a single demonstrator.
To allow for a certain level of flexibility and experimentation, the suggestion was made to use augmented reality or interactive projection mapping to mimic the display technologies which are compatible with Haptic Touch. This way, this device would not be limited to the formfactors of current display technology which allows for faster iterations of haptic feedback and UI design. Also, something that is not unimportant, it has the added benefit of being relatively cheap to build.
The problem definition together with the here mentioned considerations have led to the following assignment:

“To design, build and test a modular automotive demonstrator/test platform which uses local and surface haptics together with a projected/augmented reality UI to explore the possibilities in creating a more personalised user experience in automotive applications.”

4.1. Scope & Requirements

The requirements and scope described below are used as the initial guidelines for this project. The insights gained during the Analysis phase of the project will be used to further concretise and expand this list of requirements in the form of a Design Brief, allowing for a well-founded decision on the design direction.

/01

Automotive Interior Domain

A large portion of the client portfolio of Aito is related to automotive applications. During the discussions preceding this project, Aito mentioned that it is common that innovations in the Automotive market trickle down to other sectors (e.g. the Home appliance market). A demonstrator oriented at this industry is therefore an appropriate choice.

/02

Emphasize Strengths Aito

The Haptic Touch integration should illustrate the solution space and design freedom that Aito can provide. The use of virtual or augmented reality to simulate display technologies should be explored, as prototyping with real displays is generally complex, time consuming, and expensive. This requirement is also the touchpoint with the TU Delft, as the above mentioned problems also apply to non-automotive HMI's.

/03

Presentable to clients

The demonstrator should be presentable to clients. Therefore it should be demonstratable at the Aito office and conferences. Additionally, the integration of AITO®HapticTouch should be MAYA (Most Advanced, Yet Acceptable): an innovative integration in a recognizable application.

/04

Practical

The demonstrator should be produced cost effectively, with a target building cost of €3000. Ideally the demonstrator or test platform can be modified to represent the latest developments of the HapticTouch system.

5. Project Timeline

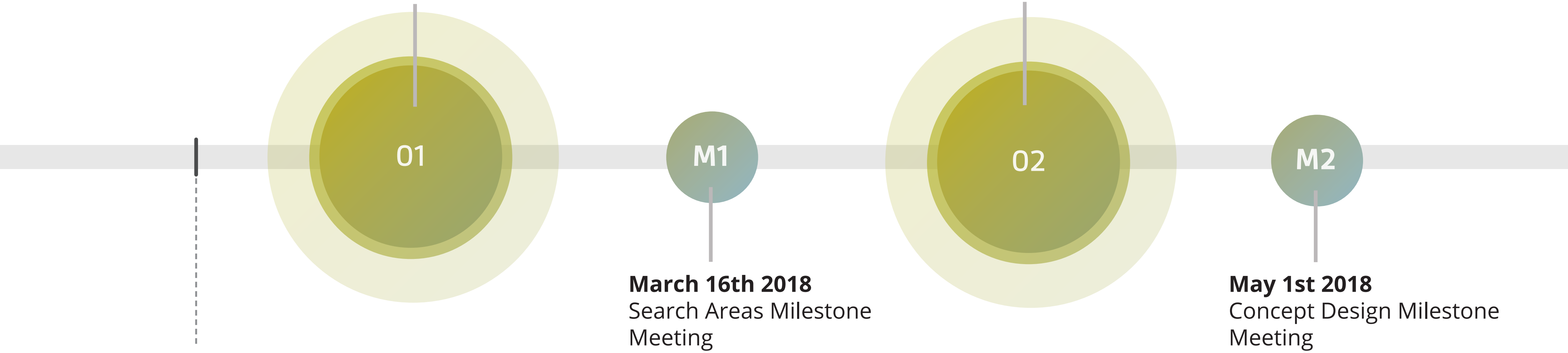
This project is divided into four phases which each have their own milestone meeting before entering the next phase. The project roughly followed the product innovation process method developed by Jan Buijs, from the strategic situation of the company up until the product design evaluation.

Internal and External Analyses are used to get a better grasp on position of Aito in the Automotive HMI domain. The results are combined in a SWOT matrix which is used to draft a Design Vision and Design Brief.

Based on the Design Brief and Analysis results a suitable search area is chosen. For this search area a number of concepts designs are developed. The most suitable is chosen for emobodiment design.

Analysis

Concept Design



March 16th 2018
Search Areas Milestone Meeting

May 1st 2018
Concept Design Milestone Meeting

Februari 12th 2018
Start Graduation Project

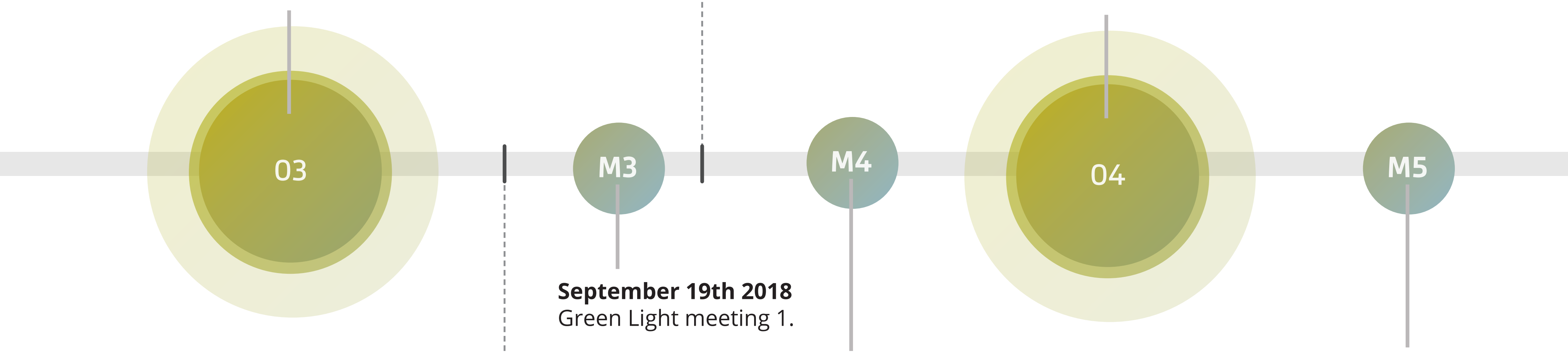
The chosen concept is further developed into detail by breaking the conept down into design challenges. Solutions to these challenges are then integrated into holistic final design.

Embodiment Design

October 8th 2018
Start part time work at Aito

The design is validated through a cost analysis and a prototype build. Together with feedback from Aito, a number of recommendations for further development will be drafted.

Validation and Finalisation



September 19th 2018
Green Light meeting 1.

August 23rd 2018
Jos Oberdorf takes over from Erik Tempelman as chair

September 19th 2018
Green Light meeting 2.

Januari 30th 2019
Final Presentation

Figure 15. "Wise city" The inclusive vision of artists Blake Robinson and Karl Schulschenk on future african cities, finalist of the Post Fossil city contest. But where are the cars?

02

Analysis

With experts stating that the during the years leading up to 2026, the Automotive industry will have seen more change than the five decades before it (Barra & Muller, 2016), it is important to get a grasp on the context Aito is operating in. This chapter will explore current automotive trends and developments, the strengths and weaknesses of Aito and potential threats from competing companies and technologies.

1. Analysis Setup

**The analysis preceding concept design consists of an external analysis of the Automotive interior domain and an internal company analysis.
The goal of these analyses is to find opportunities and threats within the aforementioned domain and to identify the strengths and weaknesses of Aito as a company. When enough insight of the context Aito operates in is gained, a position can be chosen, formulated through a Design Vision. The following paragraphs discuss the used methods in more depth.**

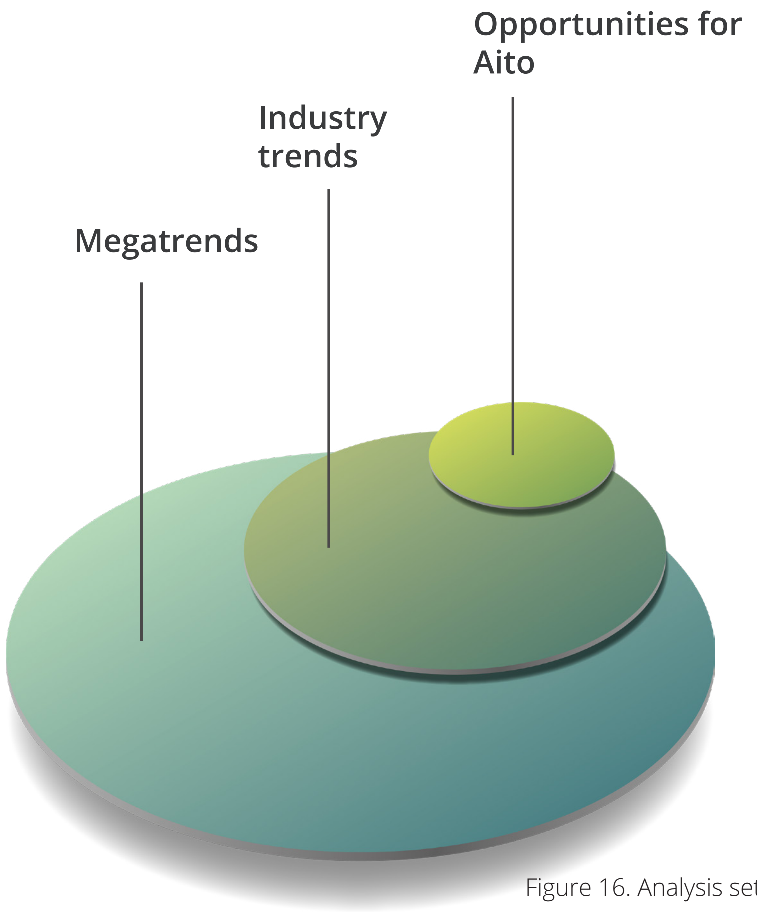


Figure 16. Analysis setup

/01

External Analysis

What direction is the automotive industry heading, which companies compete with Aito Haptic Touch and what are they trying to acheive? The external analysis starts with a trend analysis as described in the book of the automotive industry for the next 10 years (through the method described by Buijs & Valkenburg, 2005). This analysis starts broadly by identifying the global megatrends which impact the automotive industry. The megatrends are then used to categorise industry trends into a number of overarching developments. The trends are mostly based on trend reports from consultancy firms such as Mc-Kinsey and PWC, as OEM's are likely to implement insights from these firms in their strategy. Furthermore, reports on motor shows and conferences were analyzed, as well as articles professional journals. Next to the trend analysis, the competition will be subjected to analysis. The competition is divided in two parts, namely direct and in-direct competition. The direct competition consists of companies that are developing piezo-based haptic feedback solutions. The indirect competition discusses other feedback and interaction technologies that compete with piezo-based haptic feedback as a whole.

/02
Internal Analysis

What are the current strengths and weakness of Aito and AITO®Haptic Touch? A VRIO analysis is used to identify the sustainable competitive advantages of Aito and thus its strengths. Observations and insights from discussions during the internship preceding this graduation project are used to the weaknesses of Aito.

/03
SWOT summary

The Strengths, Weaknesses, Opportunities and Threats identified in the internal and external analyses are summarised in a SWOT overview.

2.1 Automotive Industry Trends

The five developments described in this section have been identified to be the key drivers for change in the automotive industry.
These developments are closely related to the following megatrends (Please Refer to appendix B for the discussion on the above mentioned mega trends):

- **Changing Demographics and Urbanisation.**
- **The Shift of economic power to the East.**
- **Climate Change and Resource scarcity.**
- **Disruptive Technologies**

The Identified industry developments are roughlydiscussed in the order of the megatrends listed above. In Addition, the relevance of each development for Aito is also discussed.The next paragraphs are a summary of the analys in Appendix B.

/01

Urban Millenials determine the direction of the Industry

While consumers between the age of 50 and 60 are responsible for the largest share of car sales, OEM's will have to appeal also to younger generations to foster brand loyalty. This means OEM's need to find new ways to seduce a generation of clients that have a significantly different attitude towards ownership and are expected to be less affluent than their parents.
Furthermore, generations Y and Z are thoroughly conditioned with the intuitivity, versatility and flexibility of their smart devices.
One characteristic of this age group that is likely to be exploited by OEM's, is the high level of individualism. This will likely happen through highly personalised cars and services.

Figure 17. “Grow-Up” the ambitious ad-campagne of Mercedes where the company tries to connect with younger generations

The necessity of winning the loyalty of younger generations, requires carmakers to offer HMI’s which are regularly updated with functionality and which are intuitive to use. This is an opportunity for Aito, as the configurability of haptic touch can make HMI’s satisfy these requirements (and ofcours make interfaces highly personalized).

/02
Changing attitude towards Mobility

Changing consumer demand forces carmakers to rethink traditional business models. While the traditional sales model is unlikely to completely disappear, new mobility services could create a new category of vehicles. Cars used by Pay-for-use- and ride hailing services have a different set of requirements compared to e.g. the traditional multi-functional family car. OEM’s are becoming suppliers of connected car packages which can be adapted to the specific wishes of mobility service providers.
This poses new challenges for Automotive interior design,

as car interiors must become more adaptable to the demands of the customers, while beïng durable and easy to clean.
There are a few benefits however. Due to heavy daily use, the expected lifespan of a car used for these services will be considerably shorter. This results in a higher conversion rate which can compensate the reduced car sales.

To set them apart from public transport, cars used for mobility services need to be generic in the way they are built, while feeling personal to the customers of these services. The configurability of Haptic Touch can be a solution in bridging this contradiction.
One less obvious advantage of the shorter lifespan, is that OLED displays are suddenly viable for use in cars. OLED displays have a lifespan which is generally too short for traditional cars. The shorter lifespan of cars designed for mobility services matches the lifespan of OLED displays much better.
For Aito this is an important opportunity, as HapticTouch can be integrated more easily with OLED than LCD.

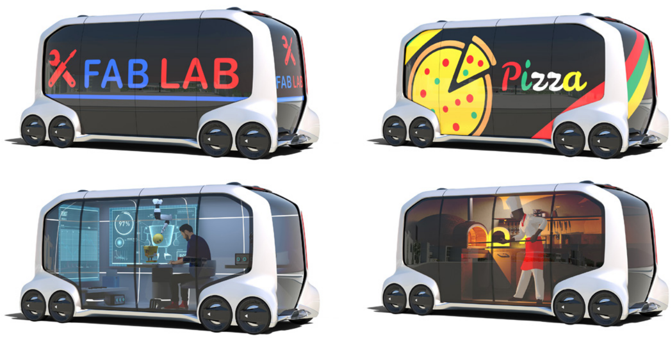


Figure 18. Toyota’s e-palette concept envisions standardised pods which can be rented by companies to perform certain commercial functions

Figure 19. Renault EZ-Go: the shared urban pod concept of Renault.

/03

Electric Drivetrains

Electrification has some profound consequences for the design and construction of cars. Heavy battery packages need to be compensated with a light car bodies that depend on relatively expensive materials, such as aluminium and carbon fibre.
For Automotive interiors this has the negative consequence that (already) high production costs for drivetrains and body have to be compensated as much as possible. One way this is done is by installing cheaper to produce interiors.
There are also a number of great advantages over traditional vehicles. Battery packs can be put in floors, resulting in a lower point of gravity and improved handling. Electric motors have the advantag that they deliver maximum torque over the whole rpm range and their small size, which allows for much more flexible driveline configurations as opposed to tradition ICE vehicles.
The above mentioned advantages can translate to smaller vehicles and/or cabins with more available space.

Figure 20. The minimalistic interior of Tesla’s model 3. For a large part the result of an attempt to build the car at lower cost.

HMI’s need to become cheaper and lose weight to compensate for the electrific drivetrains cars. With Haptic Touch, suppliers could create standardised haptic components for interiors in high volume, reducing cost and complexity.

Car manufactures would be able to integrate these components and through software make the haptic feedback brand specific.
Additionally, electric drivetrains are very suitable for drive-by-wire controls. Haptic feedback in vehicle control elements are therefore also considered an opportunity for Aito.

/04

From ADAS to Autonomous

Autonomous driving promises the most significant change in how cars are used. The expectation is that Advanced Driver Assistance systems will gradually take over responsibilities from the driver and pave the way for autonomous driving. Inherently, the driver becomes a supervisor and will eventually be able to perform other tasks. HMI's therefore need to be much more contextual to maintain an adequate level of usability.

The expected increase in features and activities is a problem for the usability of car interfaces. Because Haptic Touch is configurable through software,

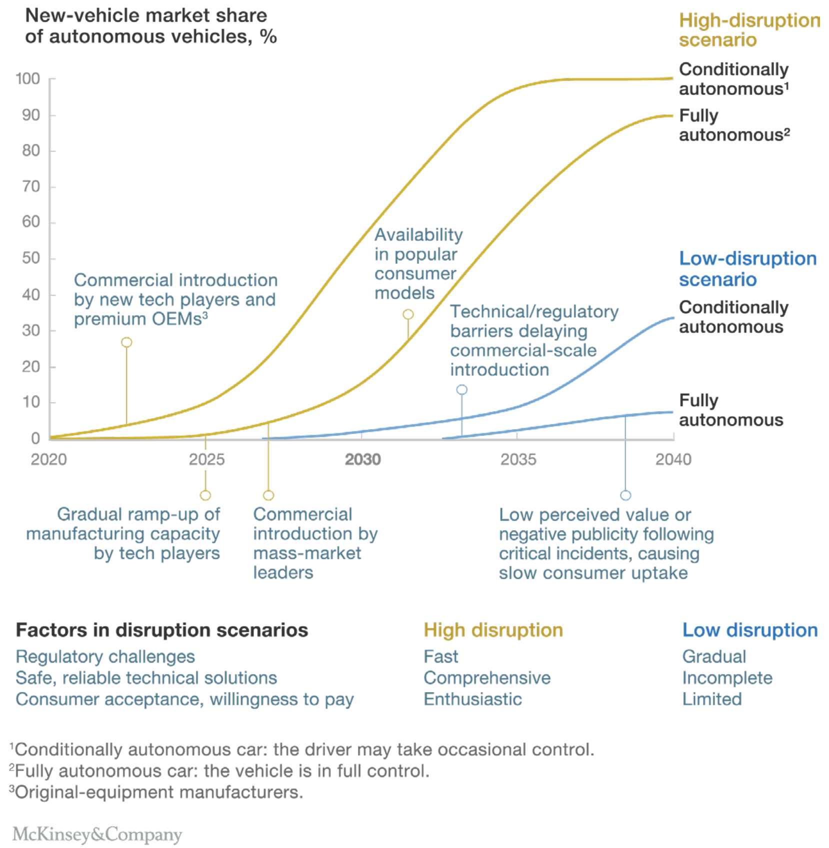


Figure 21. Disruption scenarios for the introduction of Autonomous systems. Courtesy of McKinsey&Company.

interfaces which use Aito technology can become contextual, resulting in less clutter and a more intuitive interface. Also, haptic feedback can aid in communicating to the driver what the car is doing (akin to the relatinonship between a horse rider and horse).

/05
Versatile Interiors

Autonomous driving and more cabin space available due to electric drivetrains, have sparked car makers to think of new ways of using the cabin of a car. Currently, car interior design is gravitating towards living-room like designs, of which parts can reorient themselves to match the context the car is used in.
While the rotating chairs and foldable steering wheels featured in current concept cars suggest otherwise, it is unlikely that this level of versatility will be reached in the near future due to safety concerns.
That beïng said, an interior that is less rigid can still be useful in facilitating non-driving activities in ADAS cars. A higher level of versatility can possibly use the space in the cabin more efficiently.

When interiors need to become more versatile and adaptive, interior elements need to have space to move, fold and rotate. This means these elements have to become lighter, thinner and maybe even flexible. The low hardware footprint of AITO®Haptic Touch can of value in these scenarios.

Figure 22. The 2015 Volvo Concept 26 offers a more realistic approach to versatility in interior design: The seats only move forward and backward and the steering wheel is fixed.

2.2. Direct Competition

Because piezo based haptic feedback is a relatively new technology, competition is limited. The competition can be divided in direct (companies who also use piezo-electric elements to create interfaces with haptic feedback) and indirect (competition from a number of other emerging technologies). The following companies can be seen as direct competitors for Aito.

Hap2U

Hap2U is a French startup developing haptic feedback for displays. Hap2U can mimic textures of materials on a display through ultrasonic vibrations. This is a different type of haptic feedback compared to the haptic feedback from Aito and Hap2U does not support the click-clack feeling that Aito does.

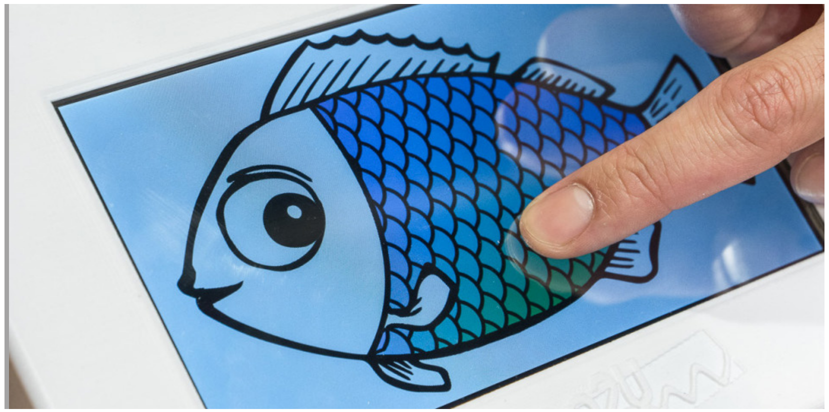


Figure 23. Hap2U demo where the user can feel the texture of the fish.

Google (Redux ST)

Redux ST is a startup which has recenly been acquired by Google. What makes the technology from Redux unique is the ability to simulate physical edges and button presses . Additionally, Redux ST's technology can use the display itself as an audio speaker altough it is not clear if this feature can be used simultaneously with haptic feedback (Cook, 2018).

Figure 24. Redux ST is able to simulate buttons and play audio with their piezo actuated displays.

Kyocera

Kyocera’s Haptivity is a technology which is similar to surface haptics from Aito, although they use rod-like stacked piezos. Their technology is finetuned to displays and uses capsense sensors to determine the xy-location of the users finger (Kyocera, sd).

Figure 25. Kyocera’s Haptivity is oriënted at displays only.

Texas Instruments

TI has developed their own piezo based haptic feedback chip next to a number of more traditional technologies. They also provide training and support (Texas Instruments, 2017). Texas Instruments is the only competitor in terms of local and global haptic feedback with piezo discs.

Three of the four competitors are focussing on integrating haptic feedback in Displays. Compared to the integration options of Aito, this is relatively limited. In addition, all companies use expensive custom made piezo elements, while Aito uses off-the-shelft components.
On the flipside however, Hap2U and Google Redux provide features Aito is not able to deliver (such as audio trough haptics and simulation of textures and edges).

Figure 26. TI sells a system which has some similarties with AITO®HapticTouch

2.3 Indirect Competition

Indirect competition comes from other technologies finding their way into the automotive sector. Technologies like voice- and gesture control have been around for a few years now. Companies like Apple and Google have recognized that their expertise and technology has value in cars. Meanwhile, established haptic feedback technologies are also still beïng used.

Voice control

For Aito, voice control is important to take into account as it will have an influence on the way HMI's in cars are designed functionally. While this technology has been available in cars for more than a decade, many often find voice control unreliable (Boudette & Winfield, 2017). Distinguishing between accents and certain phrases remains an issue that companies are trying to overcome. Because of this, people are not easily persuaded to talk to their cars.

In the coming years, Voice control will exist as an UI layer on top of existing and more traditional UI's. Eventually if the technology matures enough, there will be a risk of voice control taking over functionality from physical interfaces (Simpson, 2018). An interesting take-out for Aito could be to research how haptic feedback could add value to voice control.

Gesture control & ultrahaptics

Multiple brands offer the option to equip cars with gesture controls for infotainment systems (Dow, 2017). Research shows gestures are very suitable for specific interactions, such as volume control and picking up the phone. Interactions which are more safety-relevant are less suitable for gesture control. (Tuzar & Kirsch, 2016)

While gesture control has been around for some time now, a promising new technology is the development of haptic feedback for gesture based controls. Since 2013 the company Ultrahaptics is developing mid-air haptic feedback provided by an array of ultrasound speakers (Starr, 2014) (figure 27) .

These haptic feedback "holograms" have already been implemented in a conceptual interface of BMW at CES 2017.

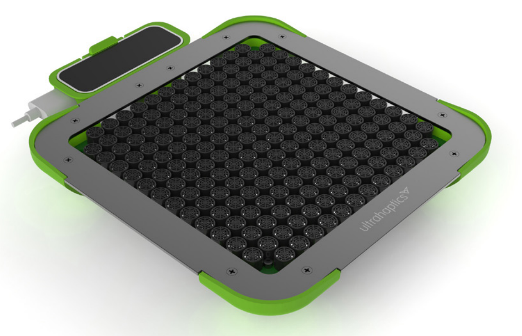


Figure 27. The Ultrahaptics system, consisting of an array of ultrasonic speakers.

Traditional LRA, LWA, ERM and solenoid feedback solutions

While these technologies could be called Low definition haptic feedback solutions, many companies still use these because of their reliability. The taptic engine of Apple for example, used for Haptic Feedback in the iPhone, is also a LRA (figure 28.).

The main downsides of these technologies are - as they are mostly based on resonance of a vibrating weight - that the whole device vibrates during a feedback event and that it takes a relatively long time to provide feedback (Aito BV, 2018a). Also these devices are relatively cumbersome when compared to piezo based haptic feedback.

Figure 28. To deliver haptic feedback, Apple uses their proprietary taptic engine for all their devices. The Taptic Engine is a Linear Resonance Actuator.

Still, OEM’s and suppliers tend to use these solutions as (until recently) they have been the only way to add feedback to the relatively heavy displays used in cars.

When looking at indirect competition for Aito, the main threat seems to come from manufacturers choosing gesture or voice controls as dominant interaction technologies. While these technologies are currently not yet reliable and practical to replace HMI’s entirely, due to the amount of resources invested in them, it may only take a few years before they have matured. For Aito it is important to set itself apart from the more traditional technologies while consolidating a place among the other HMI technologies.

3.1. Internal Analysis: Strenghts

For the internal analysis part, the outcomes of a VRIO analysis have been used to identify sustainable business advantages for Aito. The result of the analysis is shown here. Some of the strenghts have already been touched upon in Chapter 1.

A concluding remark can be found in section 3.2.

For the full analysis with the VRIO table, refer to see appendix C.

/01

High quality haptic feedback

The rich feeling of the haptic feedback, combined with the fast responsiveness provides an haptic feedback experience which is currently unique in the world.

/02

Sense and touch in one solution

The system of Aito is designed to be able to sense touch input and output haptic feedback with the same parts. While this does not work with all the stack designs right now (especially floating surface stack designs) this could be possible in the near future. This is the most important patented features of Aito haptic touch.

/03

Multiple interactions with the hardware possible

The hardware of Aito can be configured on the fly, which means that the haptic feeling can be adapted to the context. This extents also to the stack designs: local and surface haptics use mostly the same components with a different configuration.

/04

Building block approach

The Aito system design allows for a high level of modularity. The aito modules can be connected with standardised or specifically designed haptic foils. Within a short amount of time a working product can be realised. This building block approach allows for wide range of applications.

/05

Low hardware footprint

Aito haptic foils can be extremely thin (less than 0,4 mm) which compared to traditional buttons is a significant size reduction. A pcb with Aito chip and booster is still needed to drive the haptic foils, but these electronic components do not need to be placed close to the haptic foil (although there limit of course)

/06

Development partnerships with industry players

The system of Aito is designed to be able to sense touch input and output haptic feedback with the same parts. While this does not work with all the stack designs right now (floating surface stack designs) this could be possible in the near future. This is the most important patented features of Aito haptic touch.

3.2. Internal Analysis: Weaknesses

Next to the strengths, Aito also has some weaknesses. The weaknesses mentioned here have been mostly based on observations gathered during the internship preceding the project.

/01

Focus has mostly been on the technology aspect

The last few years, the focus for Aito has mostly been to further improve their technology. By working together with clients, the haptic feedback technology has come a long way. The downside however is that Aito has been mostly reactive to developments and demands from customers. This is perfectly understandable, as start-ups should always be very cautious where resources should be allocated. However, Aito's vision on what kind of interactions their haptic feedback should perform has remained relatively vague. Especially other sensory aspects such as audio and visual cues have been barely covered. The interaction in between these factors could be further explored.

/02

Clients use different design parameters

Generally with some clients there is a mismatch in the design parameters beïng used for haptic feedback buttons. This has to do with physics of traditional versus piezo based buttons. For example, for the tradional knobs and buttons, the amount of force needed to generate a press event is a typical specification. This would be unusable for piezo based haptic feedback, as the signal generated by the piezo is based on the acceleration of the deformation of a piezo element.

/03
Production costs

The production costs for Aito's haptic feedback is hard to communicate to clients, as it depends a great deal on the application (use of lighting, kind of stack, etc.). At the same time, the haptic touch solution has not been implemented in large numbers yet, so there is little reference available.

/04
Little known about long term performance

Since there has not been a product yet which is produced in large numbers, it is hard to gauge the long term performance. Some issues have been flagged, such as silver migration (detoriation of the silver layer on the piezo ceramic).

/05
End of life strategy

End of life is a subject which has not received any attention yet within Aito. This is something which will become important when haptic touch technology will be implemented on a larger scale.

Aito has a strong set of sustainable competitive advantages which can be seen as truly unique in the haptic feedback market. The flexibility of the system architecture, configurability and haptic feedback quality are the key strengths of Aito. In terms of weaknesses, the main issue in pushing Aito Haptic Touch to the market is a lack of interaction design. Haptic Touch is mostly demonstrated in a non-integrated way and interactions generally mimic existing experiences (push buttons, sliders, etc). Because of this, clients generally compare haptic touch in terms of price and specification to existing technologies, reducing relative value.

SWOT Overview

The results of both the internal and external analyses are combined in the SWOT analysis seen below. As mentioned in the conclusion of the internal analysis, Aito needs to work on the interaction aspect of Haptic Touch. Aito needs to showcase high quality haptic interactions which simply could not be done with other technologies, while using the strengths of the system architecture.

Strengths

- High Quality Haptic Feedback
- Sense and Touch in one solution possible
- Multiple interactions possible with the same hardware
- Multiple hardware configurations possible
- Building block approach
- Low hardware footprint
- Development partnerships with industry players

Weaknesses

- Focus has mostly been on haptics, not audio and video
- Clients use different design parameters
- Production costs
- Little known about long term performance
- End-of-Life strategy

The threats mentioned in the analysis are generally manageable. When looking at developments in the automotive industry, there are pressing interior design issues where Aito can have an impact. The next step in the design process is to use elements of the SWOT overview to construct a vision on Haptic Feedback in future car interiors.

Opportunities

- Brands try to differentiate more with interior design
- Younger generations expect more advanced technology interaction
- Car interiors have to become low-cost and low-weight
- Further exploration of multisensory interactions
- More versatility in automotive interiors
- Clear and Intuitive UI's through context sensitve interfaces
- on the fly personalised haptic experiences

Threats

- Risk of automotive companies committing to other technologies
- Aito lags behind on certain haptic features for displays
- Legislation on material use may have an effect on Aito Hardware

Design Vision

From the industry developments discussed in this chapter, it is clear that car interiors and the interaction model for automotive HMI's will be changing in the next few years. Shifting customer expectations forces car makers to rethink traditional business models. The feature set of cars will be expanded through the addition of connected services and autonomous driving, promising users more freedom and things to do next to driving. Electrification changes the packaging of cars, allowing for more cabin space and/or smaller cars. This increase in available space, is eagerly used to create new, more versatile interior configurations, designed to facilitate the growing feature set.

Traditional value proposition
At this point, it is good to take a step back and look at the value proposition of cars in general. This value proposition can be broken down into three main values:

1. A- to B transport
The most obvious value cars provide, is the ability to take its users from door to door, without having to transfer to another mode of transportation. This value has remained largely unchanged (albeit under pressure due the challenges related to urbanisation).

2. Comfort
The second value is the ability to travel in high comfort, a value which is unrivalled by other means of transportation.

3. Personalisation
And finally, the third value consists of personalisation. People express who they are and what they do through brand choice, the type of options they want, which color they choose, etc.

Current state
When this general value proposition is put side by side with the current industry developments in interior and HMI design, one can conclude that comfort and

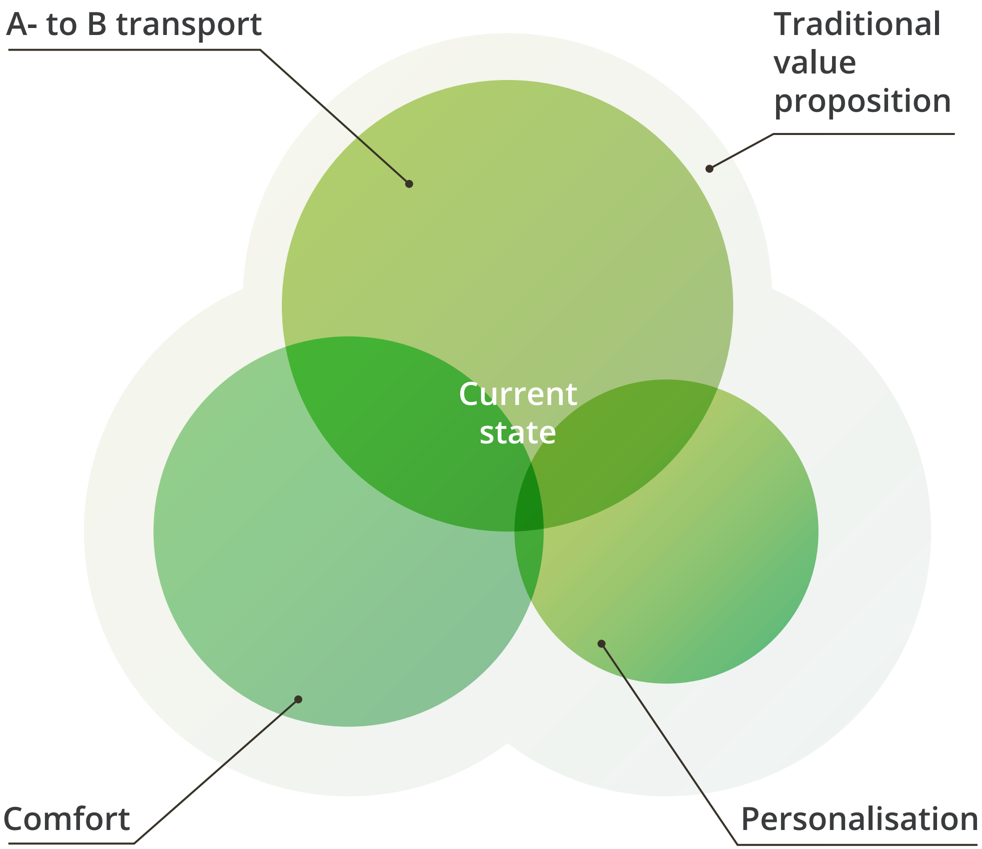


Figure 29. Value proposition of cars: traditional vs current.

personalisation in this proposition are under pressure, as manufacturers try to reïnven themselves.

Looking at the offering of cars In terms of packaging and technology, cars of today are very similar among brands, making it increasingly hard for brands to differentiate. When brands are struggling to differentiate from each other, it becomes harder to offer customers something that is unique and therefore personal. This is not only true for the exterior of cars, but also the interior. The design of the interior is determined in part by the packaging configuration of a vehicle. The integration of electric drivetrains forces OEM's to decrease the available budget for interiors to keep the price of the car competitive. This results in a minimalistic interior design with cheaper materials and a heavy reliance on touchscreens as mode of interaction, limiting the available design freedom.

Comfort is reduced in value because the underlying interaction model applied in automotive HMI's is not changing in line with current trends and developments.

In its core, the function of automotive HMI's is to present the driver contextual, relevant information, clear as day, so that the driver can make the right decisions operating the car. The relatively passive traditional interaction model is sufficient when the drivers only job is to drive the car. However, when the driver is going to perform other activities next to driving and his role becomes more passive and supervisory, car HMI's need to become more pro-active in their interaction with the driver, assuming a mediating role between the environment and the occupants.

In this light, it is remarkable that technological advancements in computing and AI make cars increasingly intelligent and aware of its surroundings, but not of its occupants. in respect to its users, the models that are currently sold, are still pretty dumb. HMI's the entire feature set of the car available to the user at all times, regardless of the context the car is in (e.g. the handbrake lever and start/stop button have absolutely no use when driving on the highway, but are present in the interface).

Additionally - although modern cars are able to connect with the users phones - they generally do not know who the people in the cabin are and what they are doing. With the expansion of the featureset of car HMI's due to autonomous driving and connected services, maintaining the passive interaction model puts a strain on the cognitive comfort of the users.
The expectation is therefore that car makers will start to make cars smarter in relation to the user.

Vision on future car HMI design
What does this mean for Aito? The vision on automotive HMI design that forms the starting point for the design phase is therefore the following:

Future automotive HMI's should adapt themselves pro-actively to the personal preferences of user(s), taking into account the context the car is used in and the state of mind of the user(s) in relation to their physical and digital lives.

Possible value proposition of a shared car:

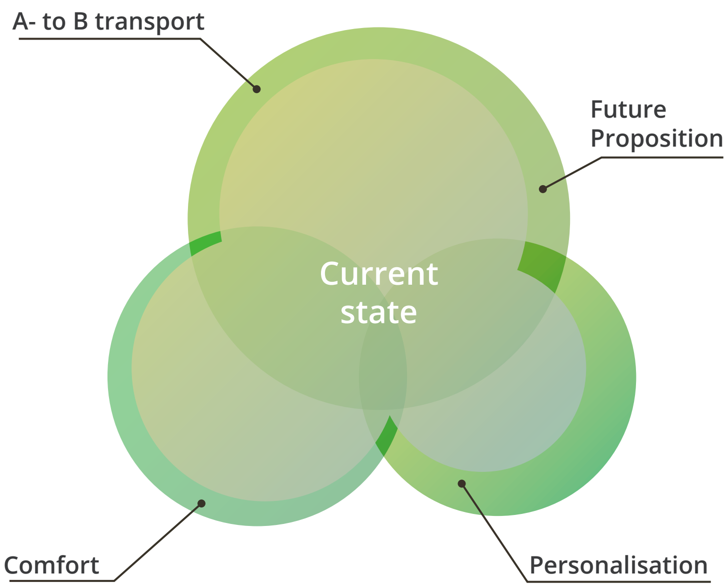


Figure 30. Proposed value proposition for a shared car. Shared vehicles may provide a better value propositions for all three values compared to he current state.

This vision implies that users can develop a more personal relationship with their cars while maintaining a high level of comfort. Interaction with the car should be multi modal, letting voice control, gestures and haptic feedback co-exist with each other, allowing users to choose which way of interacting they find appropriate in a given situation.
This Design Vision provides a playing field for both shared- and privately owned vehicles.
Shared vehicles for example can a bit boring and mostly functional, excell in daily commuting and have a level of comfort and personalisation that sets them apart from public transport (but nothing more). Meanwhile the vehicles that are bought privately offer a better design and finish, more personal space and the option to fully tailor the vehicle to the wishes of the customer.
This provides car manufactures more room for differentiation and new avenues for giving shape to their brand identity.

Possible value proposition of traditionally owned cars:

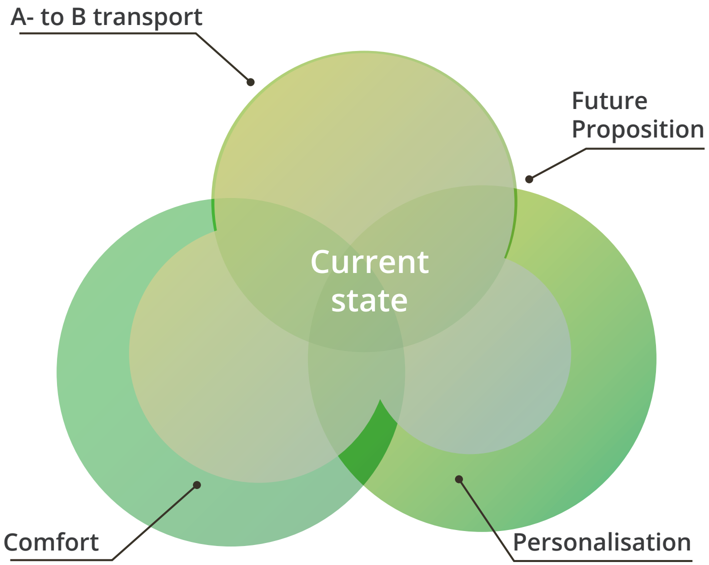


Figure 31. Proposed value proposition for a shared car. Shared vehicles may provide a better value propositions for all three values compared to he current state.

The role for Haptic Touch

Aito can contribute greatly to this vision. Because Haptic Touch is configurable through software, it can facilitate an adaptive interface outside the field of view of the users at ergonomically optimal locations (increasing comfort). The interface can be optimized for the context the car functions in, taking into account the time of day, the traffic density, urban vs long distance travelling, etc. The interface could adjust itself to person using it.

Apart from generational gaps, seniors for example, whose tactile sensing has declined due to age, may prefer a different kind of haptic feedback as compared to 18 year-olds. When taken a step further, haptic touch can become an additional mode of communication. Features that are used frequently can feel slightly different compared to features that are not used that often.

In terms of Interior Design, the use of flexible printed circuits, the configuration options in stack design (local, global and hybrid) and the ability to integrate foils with premium materials, provide a high level of design freedom. The low hardware footprint makes it possible to build interiors which are lighter and thinner than ever before, paving the way for more versatility of interior elements at an affordable price.

When integrated properly, haptic touch has the potential to be as revolutionary for car HMI design as touchscreens have been revolutionary for the way phones are designed and used.
This also leads to the following question: What is a proper integration of Haptic Touch and how can this be demonstrated.
The aim of the remainder of this thesis, is to show how this could be done.

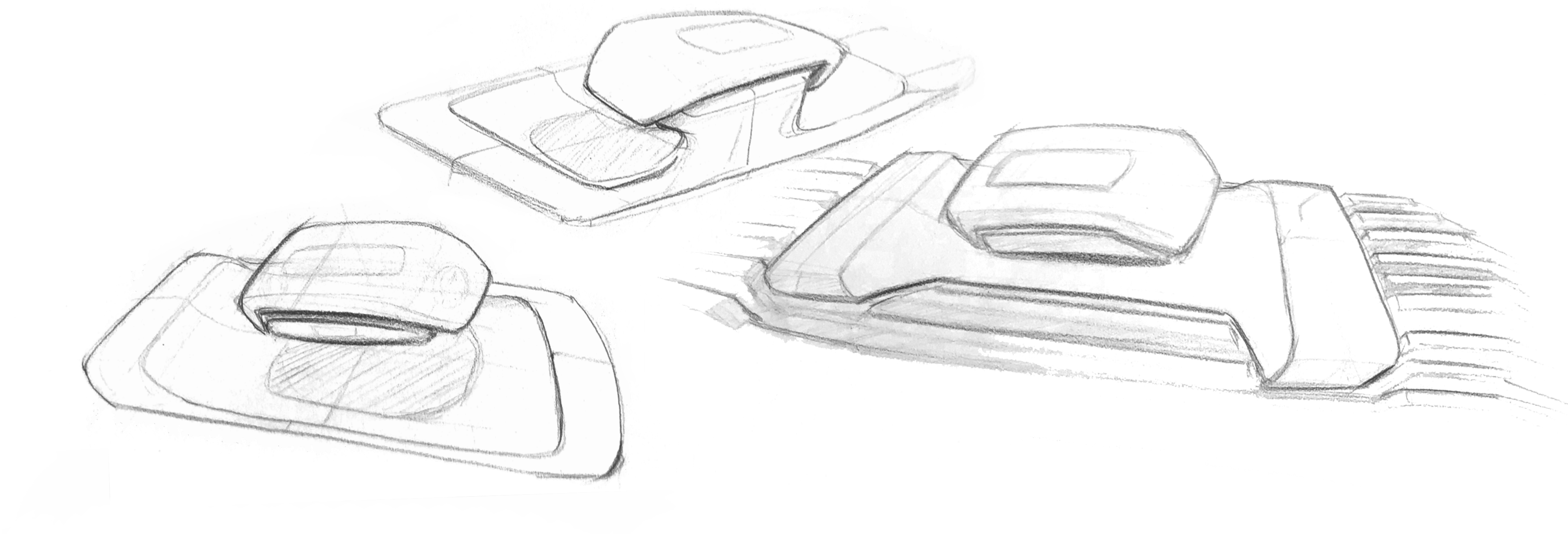


Figure 32.Sketches related to Haptic Control panel design

03

Concept Design

With the Design Vision formulated, the concept design phase of the project is started. Together with insights gained in chapter 2, a sound foundation is present to make the decisions the Design phase. This chapter discusses the Design Brief which was drafted in line with the Vision towards the chosen concept. The last part of the chapter will discuss the concept and lay out the challenges for Embodiment design.

1. Design Brief

With the vision on the application of haptic touch in future cars defined, the concept design phase is started. The Design Brief discussed in this section is an expansion on the requirements of the project assignment. The analysis and the resulting design vision have provided new handles to find a concrete design direction.

The general assignment has stayed the same: To design, build and test a modular automotive demonstrator/test platform which uses local and global haptics together with a projected/augmented reality UI to explore the possibilities in creating a more personalized user experience in automotive applications.
While this is still broad, the assignment as it is provides two general search areas: a test platform or a demonstrator. Next to this, based on the insights from the analysis, the requirements can be further detailed:

/01
Automotive

- Designed for haptic touch integration in a future automotive HMI
- Take into account the changing role of the driver
- Ideally highlight the comfort and Personalisation aspects as core values
- Showcase light and thin control panels to meet the need for lighter and more versatile interiors, ideally introducing a level of modularity.
- Convey clarity and intuitivity in interface design.
- Make Display integration believable. While no displays are integrated, users of the demonstrator have to believe display technology is integratable.

/02
Presentation

- As the demonstrator should be presentable to an audience of the automotive industry, the demonstrator has to be recognizable while being innovating, making use of the MAYA principle: Most Advanced. Yet Acceptable.

- Dimensioning should be as much as possible in line with ergonomic principles Automotive interior design.
- It is not necessary to produce the demonstrator according to current vehicle production methods (taking the “concept car”approach).

/03

Aito Strenghts

- Make use of the latest developments in Haptic Touch technology: a combination of local, global and hybrid haptic stack designs.
- Interactions showcased should only be possible with Haptic Touch technology and not with traditional control elements.
- Ideally showcase the integration of Haptic feedback with a range of low-resolution- (Symbol illumination) to high resolution Graphical Interfaces, using VR or AR as means of faking display technology.
- Ideally incorporate audio in interface design.
- Ideally use Haptic Touch as an additional way of communicating information to the driver
- Make Haptic Touch control elements as seamless as possible

/04

Aito Strenghts

- Production costs: The demonstrator should ideally cost no more than 3000 euros to produce.
- The demonstrator is Producible with widely available prototyping methods like e.g. 3D printing, laser cutting, CNC machining, etc.
- Haptic Touch elements should be interchangeable to allow for a certain level of experimentation.
- The demonstrator should be transportable as it is meant to be used at conferences.
- The demonstrator should be durable enough to withstand heavy use at conferences.
- Ideally, future Haptic Touch functionality can be added to the demonstrator.

2.1. Search Areas

The first step in concept development is to define a search area which is a logical consequence of the Design Vision. By combining Opportunities and Strenghts from the SWOT analysis, four search areas were created.

01

Search area 1: Modular HMI with low Hardware footprint

By designing control panels with standardised haptic stacks and modular overlay panels, component count and costs for suppliers could be greatly reduced while maintaining a high level of Design freedom. By emphasizing attributes such as thinness and low weight, these control panels would be suitable for electric cars and versatile interiors.

- Low cost & Low weight Interiors
- Versatile Interiors

+

- High Quality Haptic Feedback
- Versatile Interiors

02

Search area 2: Haptic Feedback enabled infotainment system

A demonstrator that explores the inclusion of haptic feedback in a specific use case: an Infotainment system. Because infotainment systems are becoming more complex and elaborate, this specific case would explore how haptic feedback in displays could be used to make this systems easier and more intuitive to use.

- Target younger generations
- Intuitive & Contextual HMI

+

- High Quality Haptic Feedback
- Different interactions, same hardware

03

Search area 3: Test platform for multi-sensory HMI's

Haptic feedback is experienced differently when combined with visual- and audio feedback. A test platform where these three types of feedback are combined could be used to optimize usability for e.g. elderly users or contextual scenarios such as competitive driving. Also, new interactions that combine animations on displays with multi-level and dynamic haptic feedback patterns could be explored to appeal to younger generations of users.

- Target younger generations
- Multisensory HMI interactions
- Personalised Interfaces

+

- High Quality Haptic Feedback
- Different Interactions, same hardware

04

Search are 4: Haptic feedback in basic vehicle control elements

Drive-by wire systems are finding their way into modern cars. This demonstrator would explore the integration of haptic feedback into vehicle controls such as pedals and shifters. This way controls could become monolithic elements of the interior, reducing complexity and space required for integrating these controls.

- Integratable with other technologies
- Low cost & light weight interiors
- Versatile Interiors

+

- High Quality Haptic Feedback
- Different interactions, same hardware

2.2. Search Area Choice

**The Search Areas were judged for their fit with the Design Vision,
The ability to mitigate weaknesses and threats and provide the most value for Aito. Discussion with the supervisory team for the project also had influence on the choice for the design direction.**

Search Area 2: test platform for multi-sensory HMI's, was chosen as the most suitable design direction. The following considerations have let to this decision:

A logical next step for development
As mentioned in the company part of this thesis, the focus of Aito during the last few years has mostly been on maturing Haptic Touch technology. The interaction part of Haptic Feedback has been touched on very superficially to provide a minimum viable product. Currently, the technology has reached a level of maturity which allows for a larger focus on interaction design for Haptic Feedback.
A test platform with a focus on combining visual and audio feedback in one system would allow for gaining more insights on the relation between these different kinds of feedback. As mentioned in the SWOT analysis, this is a weakness of Aito. It is hard to sell the technology if the potential cannot be shown. When a better understanding has been

developed, search areas 3 or 4 could be logical steps after development of a test platform.

Input from Aito and the supervisory team
During discussions with the supervisory team the outcome was that search area 1 and 4 were considered as suitable design directions as well. Search area 1 however was dismissed because promoting lightness and thinness were already important goals in the development roadmap of Aito. Search area 4 was a close runner-up to search area 2, because this kind of application has not yet been considered for piezo-based feedback. However, because of current legislation, drive-by wire applications are only interesting as an application further down the road (5+ years).

Search area 2 would provide more benefit in the shorter term, as it could be used as insights and lessons learned could function as a stepping stone for vehicle control elements.

3.1. Design directions

To initiate the concept design, the search area was broken down into four design problems that had to be solved. These problems are related to each other and span a solution space that can be used as a framework for concept design (figure 33.). Based on these problems, a morphological chart was constructed where solutions to each problem were explored. By combining these partial solution, four concepts were created.
The following design problems relating to the search area were identified:

Supported Interactions & Technologies

What technology is implemented and how? This design problem covers the system architecture and the chosen general haptic stack construction with overlay surfaces

Application

Chosing a very specific application such as a dashboard, determines the scope of interactions that are tested.
An in-car module for haptic feedback provides different possibilities for testing interactions as compared to a full-fledged car interior mock-up.

Modularity

The level of modularity can range from no modularity to a high level of modularity, by adjusting the level of integration and the noticeability of the “building blocks”. Modularity together with Technology greatly influences the possible applications and supported interactions.

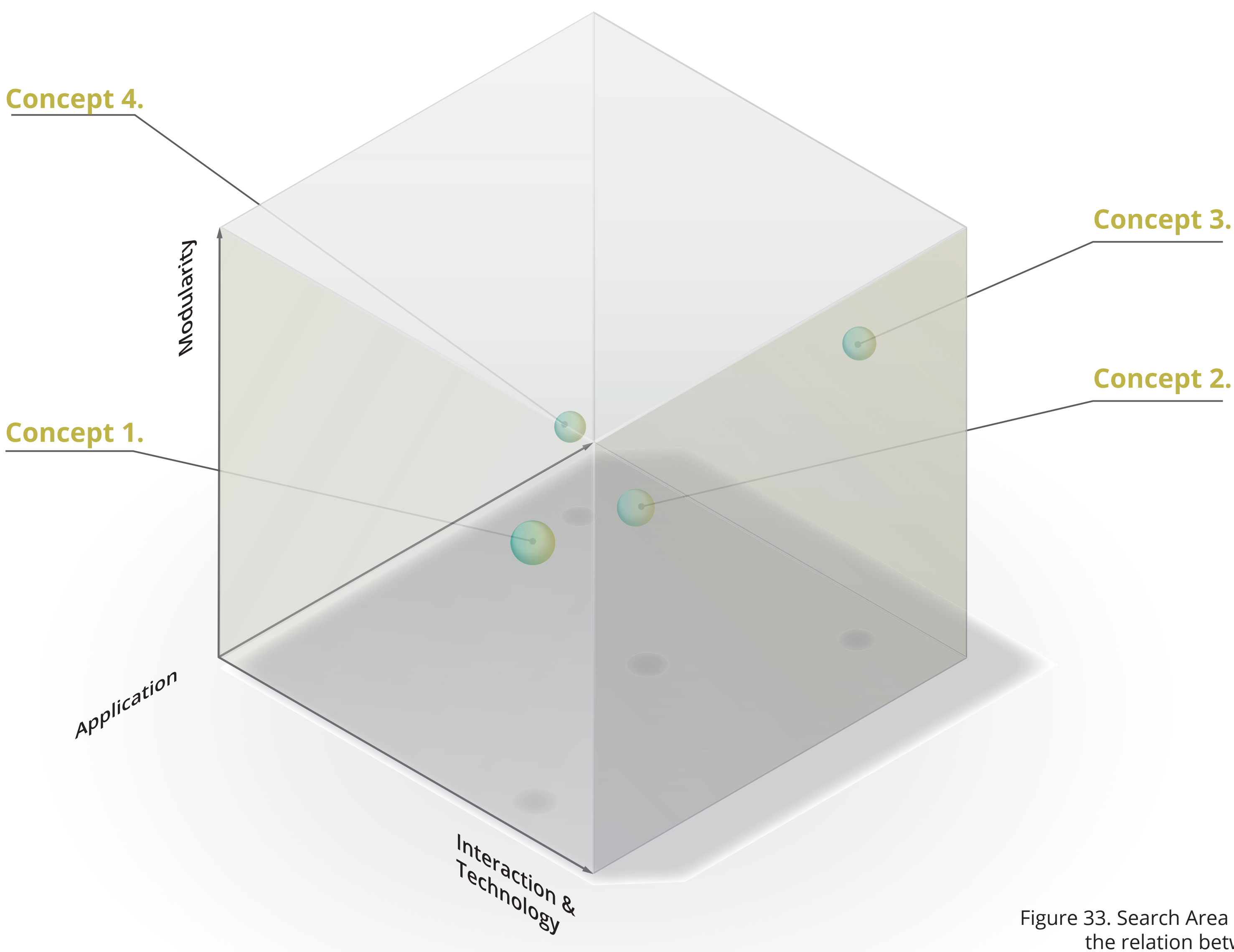


Figure 33. Search Area solution space and the relation between the concepts.

3.2. Concepts

Four concepts were designed in a way where the application and level of complexity were varied, making them realistic for the scope of a graduation project. Common with all concepts is the use of Interactive projection mapping, as this would be a more accessible method for prototyping.

Concept /01
Table-top Modular Demonstrator

This table top demonstrator consists of a floating haptic stack with an overlay tile which can be swapped out. When multiple demonstrators are coupled, a more intricate interface can be created. Capsense applied through carbon paint is used to track the position of a finger. Each control panel is slightly suspended in the air to emphasize lightness and thinness.

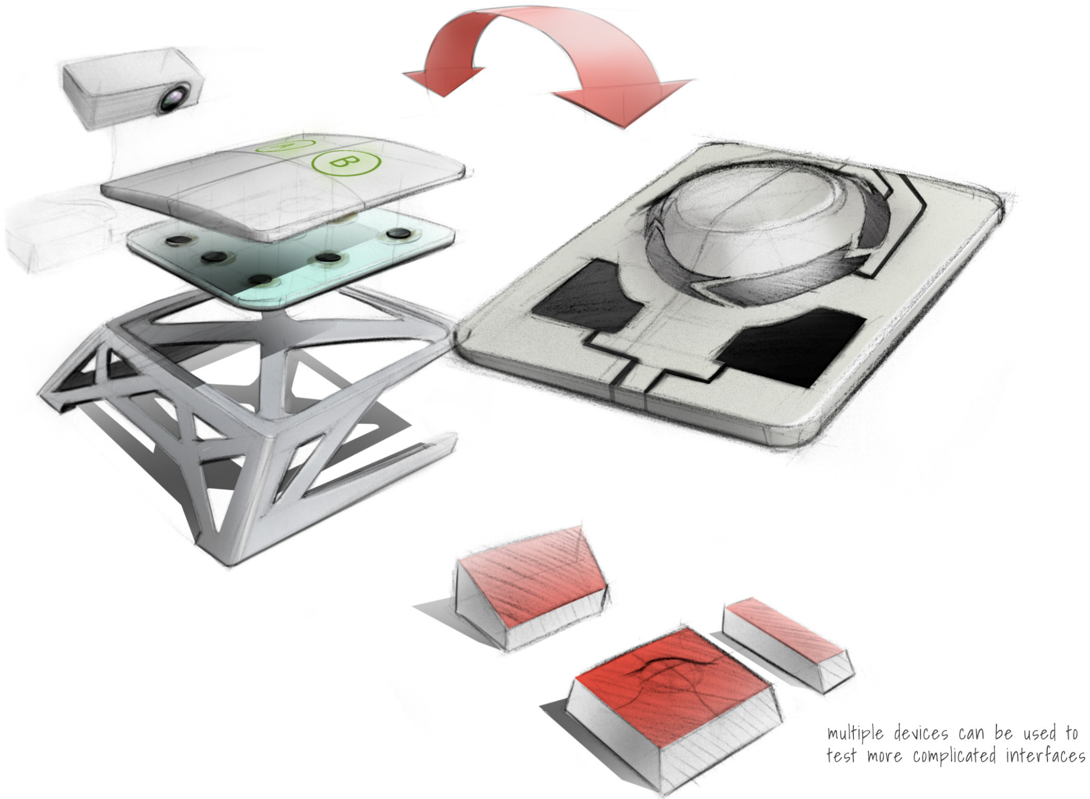


Figure 34. Concept drawings Concept 1.

Concept 02
In car Haptic demonstrator

This concept takes over infotainment navigation functions of an existing car. This demonstrator has a similar size as the table-top demonstrator, but the overlay surface is more complex. The overlay surface also additional piezos which can be used for sensing and search haptics, which enhances the number of interactions possible.

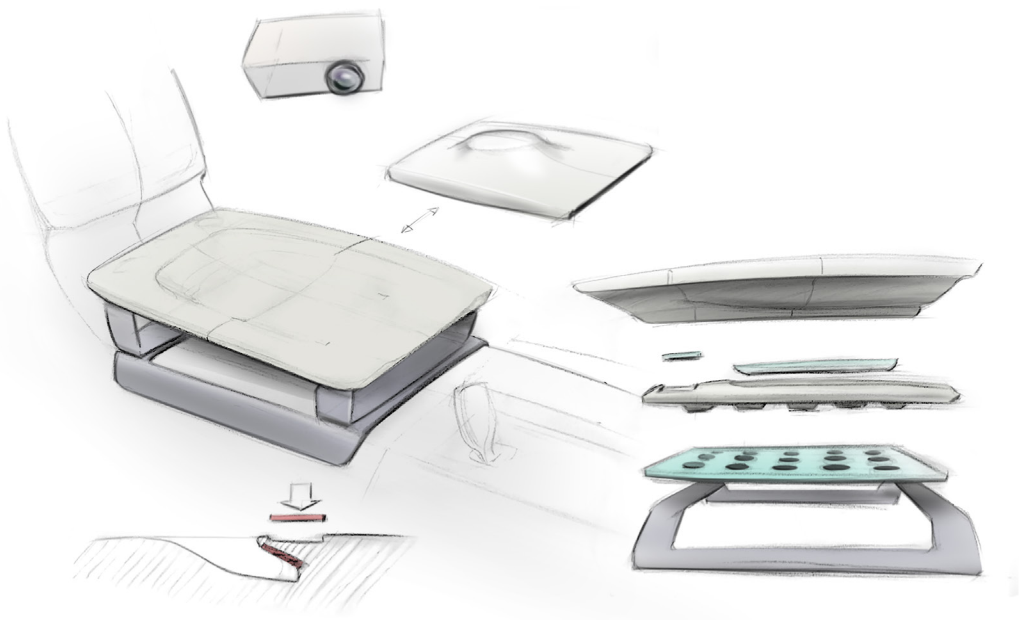


Figure 35. Concept drawings Concept 2.

Concept 03
Modular Mid Console

More oriënted at designing for functional areas in car interiors, this concept consists of a carrier which resembles a mid-console. This way Aito technology can be showcased in an integrated way. The carrier uses powerhaptic elements to actuate 3D panels which can be swapped to integrate different interactions. The proposed concept uses no sensing technology. Users will have to follow directions from animations project on the console.

Figure 36. Concept drawings Concept 3.

Concept 04
Armrest Interface

More oriented at demonstration purposes, this concept consists of an existing chair where one of the armrests is rebuild with integrated haptic feedback. The interface is oriented towards I-drive like interactions. This limits the possibilities and modularity of the concept, but makes the console more presentable.

Figure 37. Concept drawings Concept 4.

3.4. Combined Concept

During the concept design meeting with the supervisory team, it became clear that no concept particularly stood out, but all had features that were interesting to use. Therefore, the decision was made to combine aspects from concept 2, 3 and 4 into a combined concept.

During this meeting, Concepts 3 and 4 were considered to be the most suitable in terms of application, while concept 2 integrated the most interesting stack design. It also became clear that powerhaptics were preferably not used by Aito, as the Aito considers haptic feedback quality to be worse compared to the piezo-disc haptic feedback.
At this stage, Aito expressed a preference towards a demonstrator as opposed to a test platform. The idea of combining furniture design with a car interface in particular (as proposed in concept 4) was considered a promising approach, since many OEM's try to create a livingroom-like atmosphere in car interiors. With this approach, the test platform could function as a presentable demonstrator for conferences. During the discussion however, it became clear that concept 4 would to be too limiting in showcasing Haptic Touch for automotive applications. Therefore, the choice was made to merge the furniture aspect of concept 4, the proposed stack design of concept 2 and the mid-console application of concept 3.

Initial Design Challenges

The choice to design a mid-console demonstrator/ test-platform for advanced Haptic Touch interactions introduces a number of new challenges that would have to be solved.
As mentioned in the design brief, the dimensioning and layout, the mid-console should be relatable, realistic and ergonomically as sound as possible, to appeal to

designers and engineers from OEMs.
Meanwhile, the mid-console should be designed to be build with accessible and relatively low-cost production methods such as laser cutting and 3D printing, to reduce building costs. Finally, a certain level of modularity would be appropriate, to allow the mid-console to 'grow' with the development of Haptic Touch. With the new concept, a start was made in solving these challenges.

The following aspects were therefore explored during the concept design phase:

- Layout .
- General dimensions.
- Demonstrator construction.

Mid-Console Ergonomic zones

The layout of a mid-console has a lot to do with the ergonomic limitations of certain areas. A generic mid-console can be divided into three zones (Bhise, 2016):

Zone 1.
This is a much contested area, mostly used for functions related to driving such as gear shifters and the handbrake. The introduction of infotainment systems also placed remote control-like panels such as BMW's idrive system.
This zone is the most comfortable area for the driver to manipulate blindly, as the drivers arm can often rest on an armrest.

Zone 2.
Control elements for features that are used less often than the control elements in zone 1. In most cars, settings related to comfort can be found in this area (climate control, blower controls, seat heating, etc.). The driver should in most cases be able to find these controls blindly.

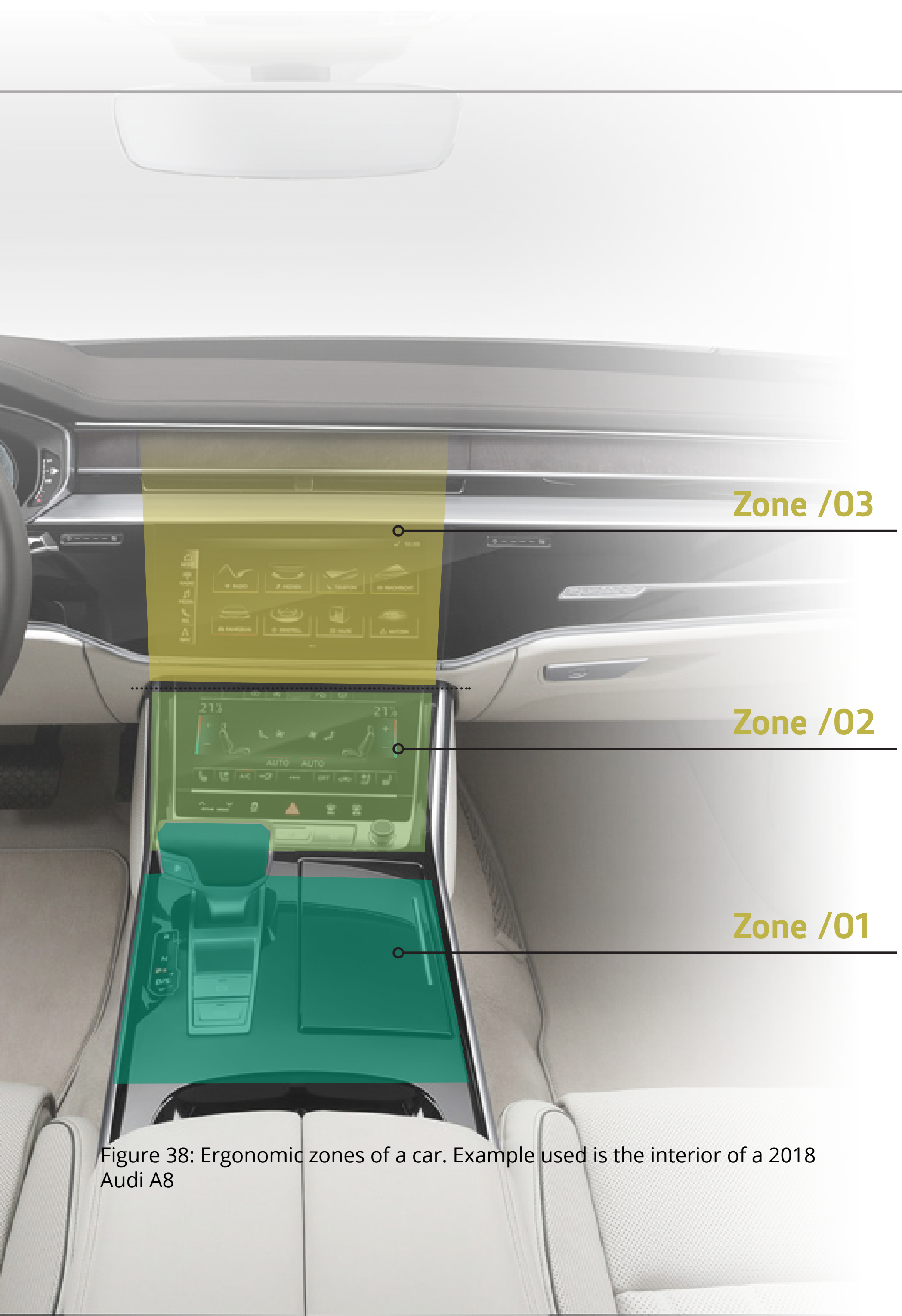


Figure 38: Ergonomic zones of a car. Example used is the interior of a 2018 Audi A8

Zone 3.

The traditional location for the car radio and currently one of the areas where OEMs place their infotainment system . The lower boundary of this zone is determined by the lower sight line of the drivers vision when he/she is looking at the road. Functionality placed in this zone often requires the driver to look at this area.

Functionality grouping

The layout chosen for the mid-console demonstrator is fairly generic. This is a deliberate choice, since the layout itself should not draw attention, but the implementation of Haptic Touch. The functionality has been divided according to the aforementioned zones:

In zone 1 the car controls are placed on the side closest to the driver. The infotainment control panel is placed directly besides the car control panels, comfortably operatable while the driver rests his/her arm on the armrest.

Zone 2 is reserved for the secondary display including a button row used to control comfort settings.

Zone 3 only features the primary display placed which is placed on the dashboard. This display is solely used for the infotainment system.

Also noticeable is the mobile phone stow-away, which makes sure the phone is out of reach of the driver. As mentioned before, functionality of the phone is taken over by the mid-console.

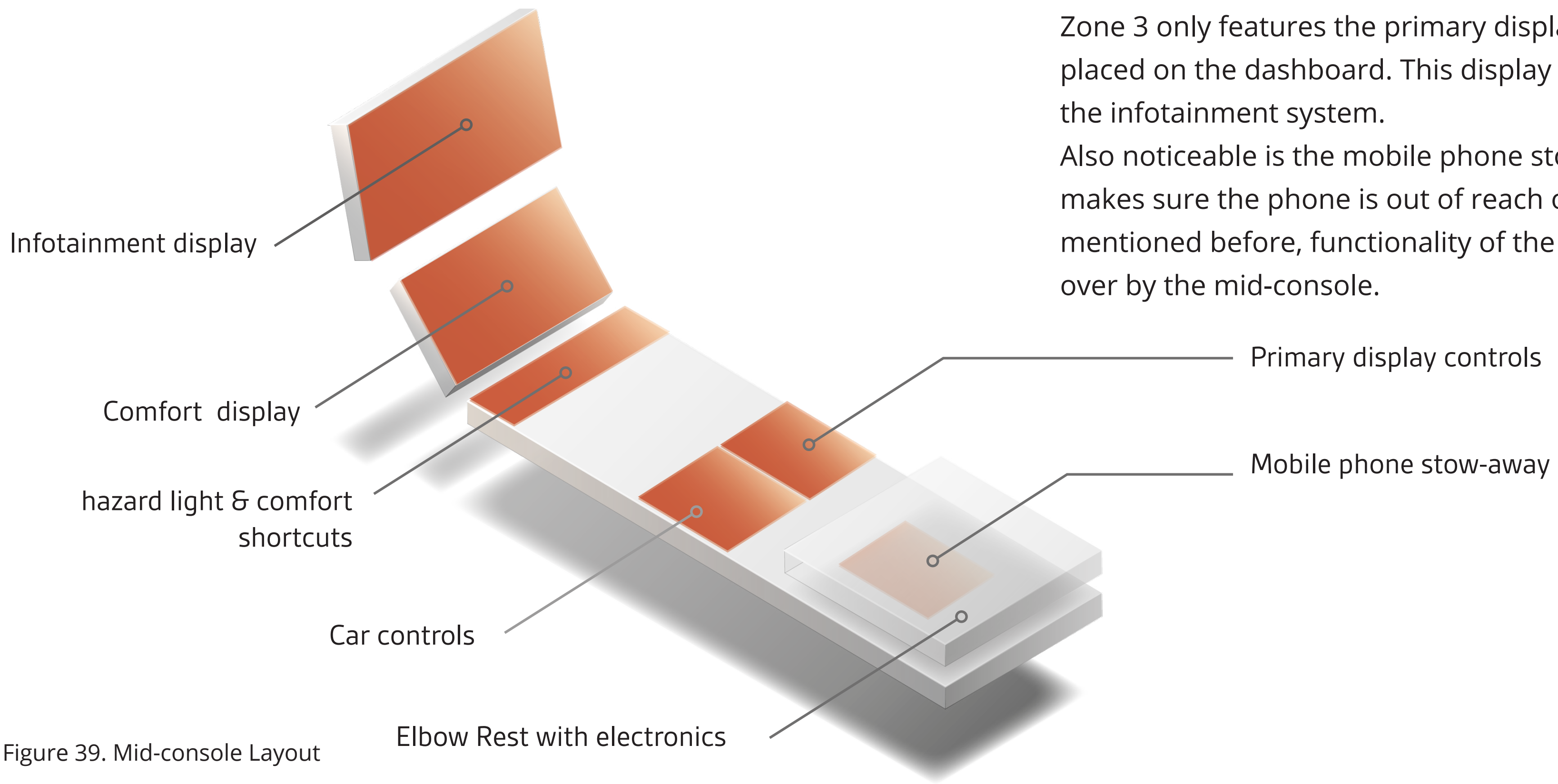


Figure 39. Mid-console Layout

Measurement Existing Mid-consoles

The measurements taken included general dimensions such as length, width and height, as well as the relative location of control panels and their dimensions. Mid-consoles of multiple car models were measured:

- Mercedes S-class
- Mercedes E-class
- Mercedes B-Class
- Mercedes A-Class
- BMW 3 series
- BMW 5 series
- BMW 2 series

The measurements for each car can be found in the appendix.
The chosen general dimensions for the demonstrator mid-console is displayed on this page.

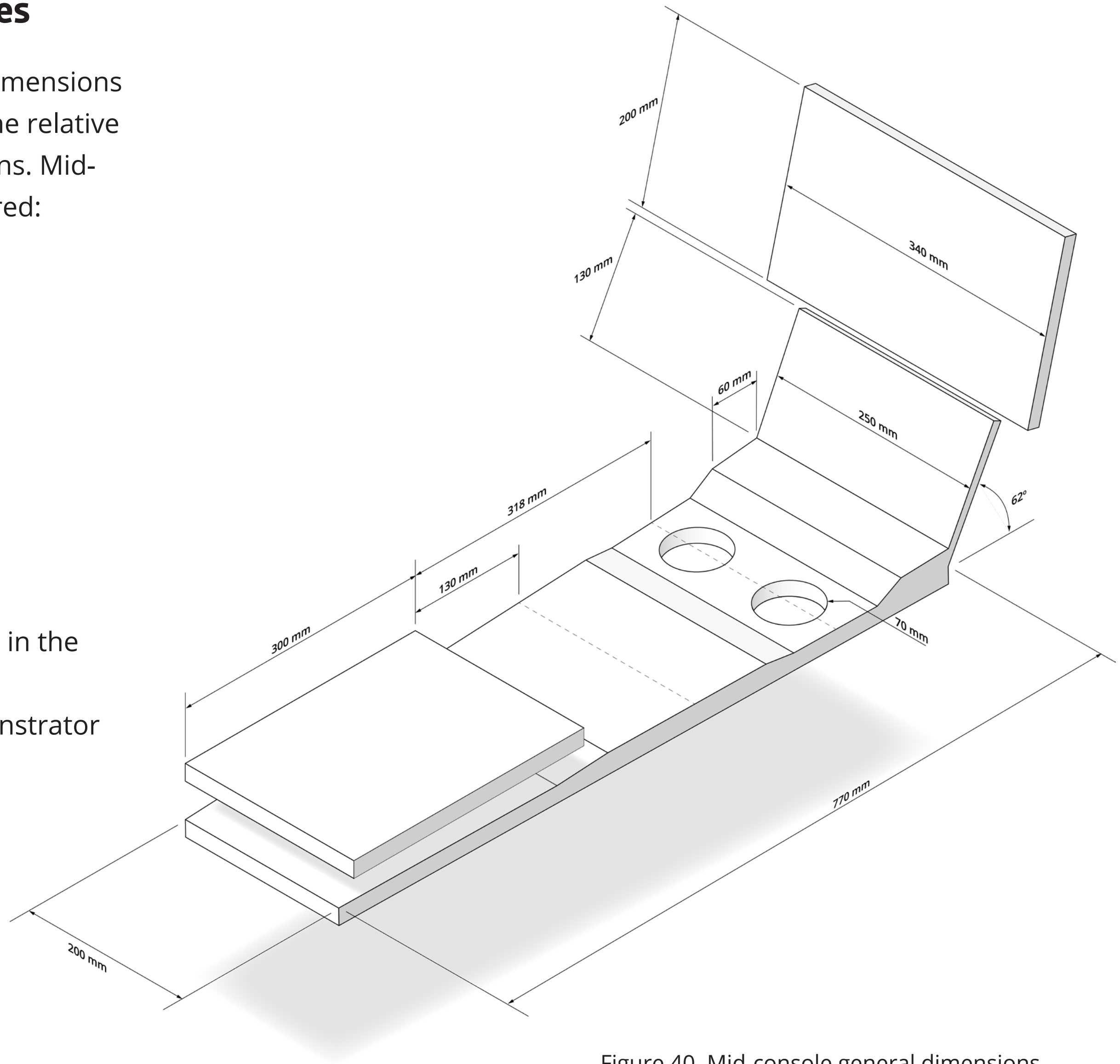
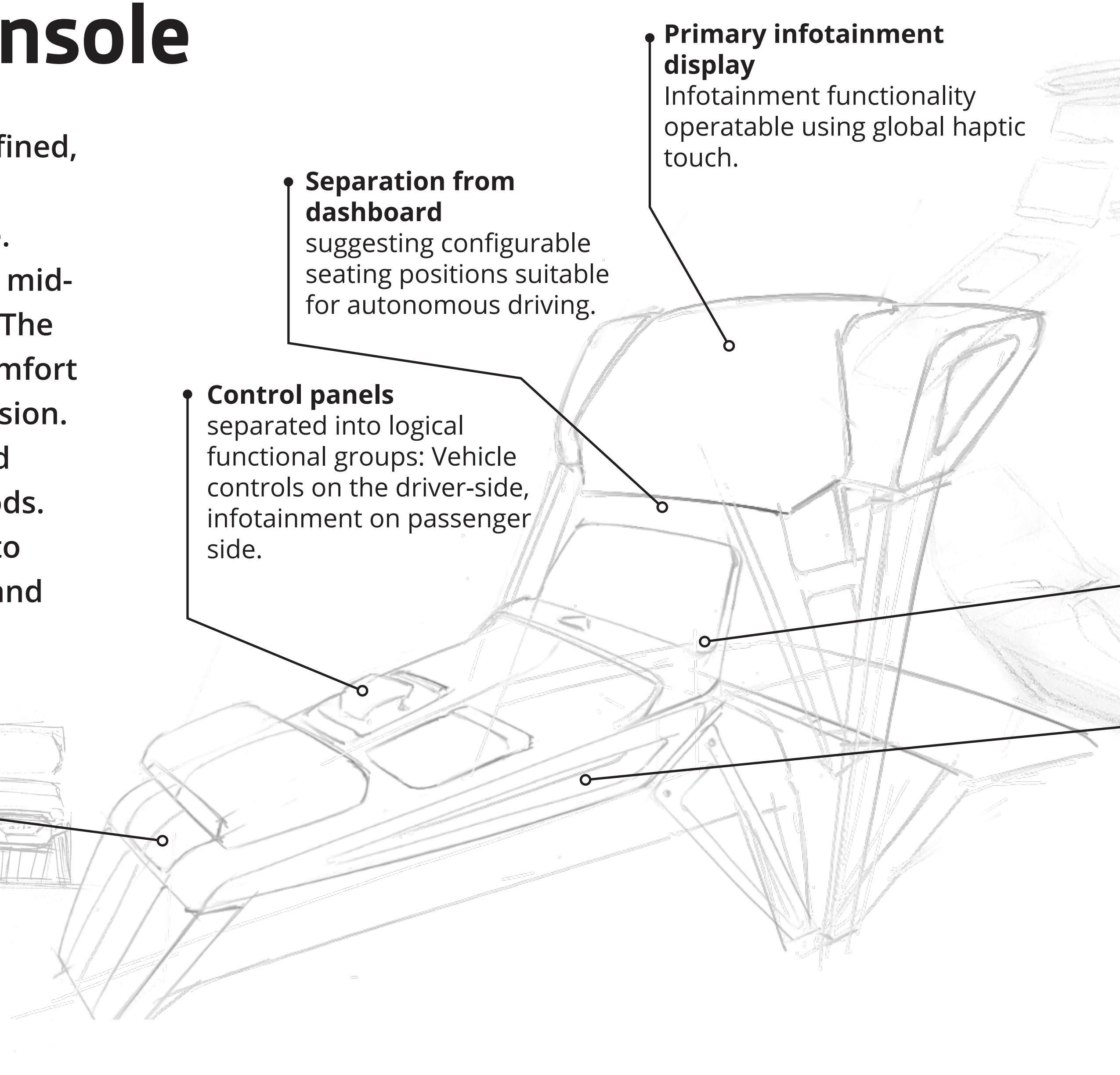
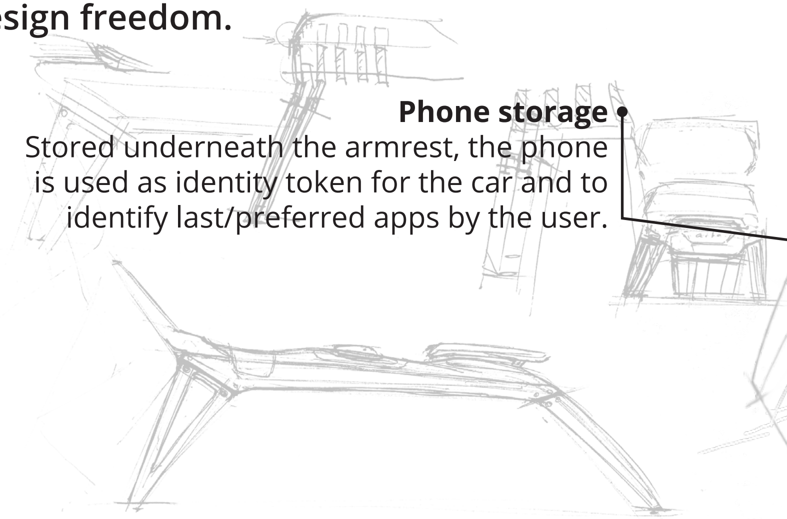


Figure 40. Mid-console general dimensions

4. Aito Haptic-console

With the layout and general dimensions defined, the concept design of the mid-console was started, resulting in the AIto Haptic-console. The Aito Haptic-demonstrator is a full-scale mid-console, designed as a stand-alone device. The furniture-like appearance illustrates the comfort and personalizable aspects of the Design Vision. Furthermore, the demonstrator is produced using accessible low-cost fabrication methods. Characteristics of these methods are used to emphasize lightness, a level of modularity and design freedom.





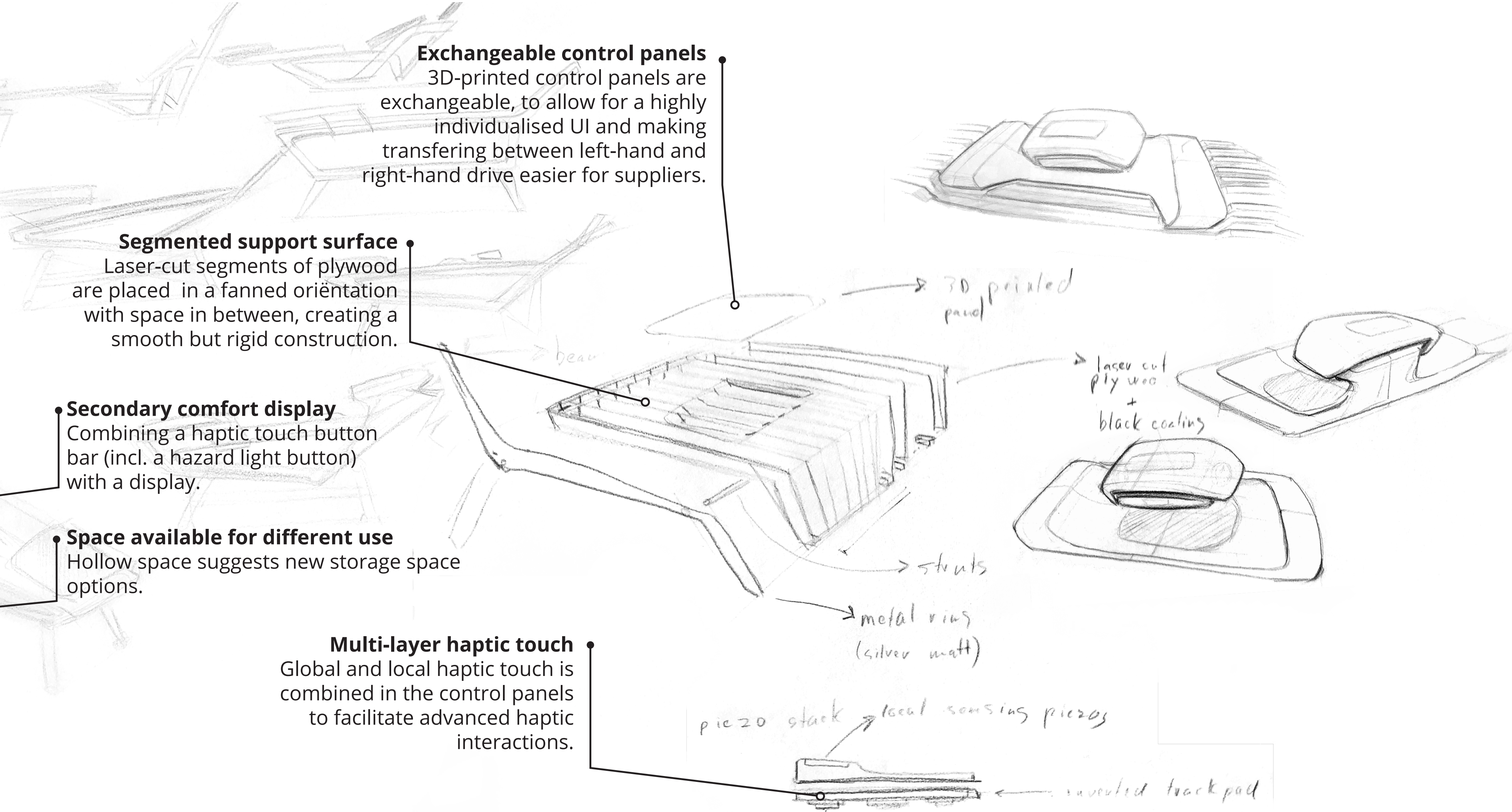
Exchangeable control panels
3D-printed control panels are exchangeable, to allow for a highly individualised UI and making transfering between left-hand and right-hand drive easier for suppliers.

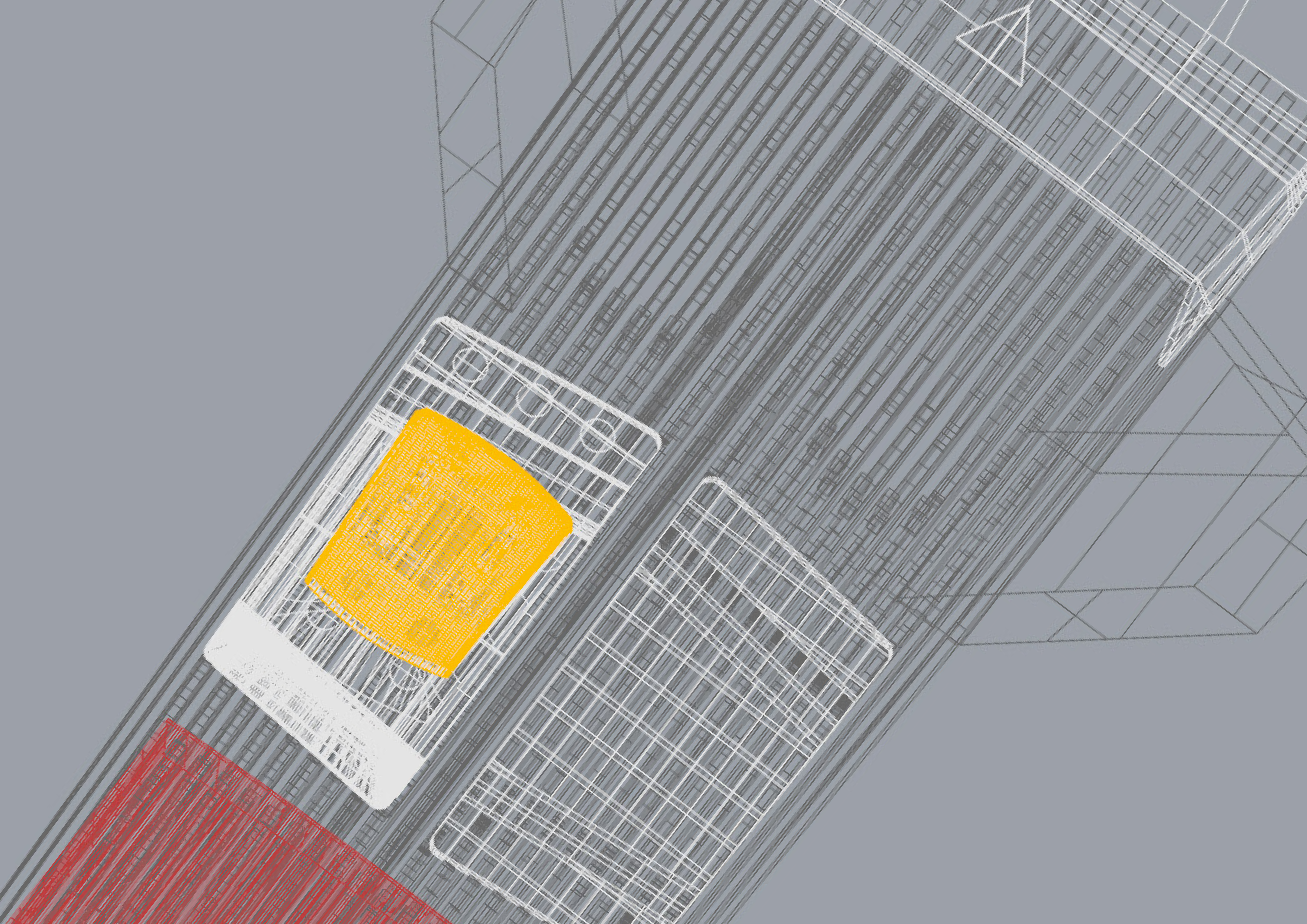
Segmented support surface
Laser-cut segments of plywood are placed in a fanned oriëntation with space in between, creating a smooth but rigid construction.

Secondary comfort display
Combining a haptic touch button bar (incl. a hazard light button) with a display.

Space available for different use
Hollow space suggests new storage space options.

Multi-layer haptic touch
Global and local haptic touch is combined in the control panels to facilitate advanced haptic interactions.





04

Embodiment Design

With the concept design phase finished, the design is further detailed. Before the concept is further developed, initial design challenges are formulated to structure the process. From there, solutions of for these challenges are combined into a final design which is then further optimalised.

1.1. Embodiment Challenges

The concept design has features that raise questions. To name a few: How would someone use the demonstrator? What would an innovative integration of HapticTouch look like? How is projection mapping going to work in practice and how is it going to be made interactive?
The design brief also still applies, as well as the main design goal with this demonstrator: To showcase the unique selling points of Haptic Touch in an integrated and relatable way for automotive designers and other experts from the industry.
The design challenges formulated on this page form the framework for the embodiment design. Each challenge is chosen to cover the practical requirements set in the assignment and design brief, while embodying the vision formulated in chapter 2.

/01

Use Case scenario

The use case scenario provides the framework for the other challenges in this Design Brief. Design decisions made during the embodiment design phase have to fit a scenario in which the mid-console is fictionally used, relating to the trends and developments happening in the industry.

/02

Haptic Feedback Integration

When the general layout and dimensions are decided upon, the integration of Haptic Feedback can be addressed. The goals with this integration are: To support HMI interactions that are not possible with other technologies and to increase the amount of functionality of control elements, while maintaining a high level of intuitivity.

/03
Projection Mapping

The use of projection mapping provides a number of practical challenges that have to be solved. First, Haptic Touch output has to trigger animations which are project on the demonstrator. These projections have to be corrected to take into account curvature of surfaces and the projection angles of the beamer(s). One or more beamers also need to be placed in way that they won’t be a hindrance when the demonstrator is used.

/04
Construction

The entire mid-console carrier construction has to provide a stiff support for the haptic feedback panels and should be heavy enough to not be moved during interaction. Also, the construction of the mid-console is designed around accessible manufacturing techniques which are suitable for prototyping. Meanwhile, the mid-console should have a futuristic appearance to capture attention. As mentioned in the concept chapter, a certain level of modularity to allow the demonstrator to grow with Aito would be preferable.

1.2. Use Case Scenario

The use case scenario proposed in this chapter is designed to match the expected functionality of cars between 2020 and 2030. The car in this scenario is able to support manual and highly automated driving, is connected to a number of internet services and it has a more personalised and pro-active relationship with the driver.

The smartphone as integral part of the design
To emphasize the latter in this concept, the smartphone of the driver is used for identification and storage of user preferences, making it plausible that this fictional car would possibly be used for ride hailing- or car sharing services.
To increase safety, this smartphone concept is taken a step further. The phone itself is made inaccessible during driving and the HMI of the car is an extension of the smartphone, seamlessly taking over communication, navigation and other connected services. The cars HMI optimizes apps and services for the driving context by merging car related functionality. The car decides which services are appropriate in which context.

To provide a functional framework for further design, the use case scenario is divided into 4 levels, ranging from standby mode to automated driving. Functionality is divided in three groups: infotainment, comfort (climate control and seat functions) and vehicle controls, corresponding with the layout discussed in Chapter 3.

Level 0. /Standby

The user gets in the car but has not been identified yet. only the hazard light is available, control panels are off or limited in functionality. Displays show minimal information related to the cars state.

Level 1. /Pre-Driving

The user is identified by placing the phone in the phone holder and personalised settings are uploaded to the car. Control panels are activated and full infotainment applications and services are available. Seat comfort settings are prioritized. Car controls are oriented towards car settings and maintenance status. A start button is prominently visible.

Level 2. /Manual driving

The car transitions to manual driving by pushing the start button. Infotainment options are reduced, allowing only for non-distracting applications. Climate control is prioritized. Car controls relevant for driving such as gear- and suspension settings are shown. When the gears are put in Drive mode the start button disappears.

Level 3. /Automated Driving

Automated driving is activated through the car control panel. The full range of infotainment options are available. Comfort controls are similar to manual driving and car controls are minimized.

1.3. AITO®HapticTouch Integration

With the use case scenario, general dimensions and layout defined, a more in depth look can be taken as to how Haptic Touch could be integrated. To solve this problem, the following questions were asked: How are the control panels constructed and which advanced Haptic Touch interactions would be suitable for the mid-console?
Generally, the approach has been to take designs from the more experimental client projects and combining them into a single general design. Taken into account during this proces is expandability of functionality in the future. The displays for example could possibly function as audio speakers and instead of using capsense for tracking finger movements on displays, sensing from the piezo elements could be used. These are features that would have to be further developed by Aito in the near future.
The following pages discuss the design process of the control panels, beginning with the proposed Haptic Touch interactions, followed by the design of the control panels and the integration of haptic stacks to support the chosen interactions.

General Stack Design

The basic stack design of the HapticTouch panels is shown in figure 41. By combining the different stack configurations in one panel, the best properties of each configuration can be used: The design freedom of the global/hybrid stack configuration with the sensing capabilities of the local stack.
An important fundamental design feature is proximity sensing. When the user approaches the panel with his/her hand, the panel will be activated (letting the panel become less visible when not beïng used). This also has the benefit of beïng able to filter vibrations during driving, preventing accidental activation of features.
In some cases, cap-sense is also used for touch sensing, as HapticTouch is sensing is not (yet) capable of high resolution touch sensing.

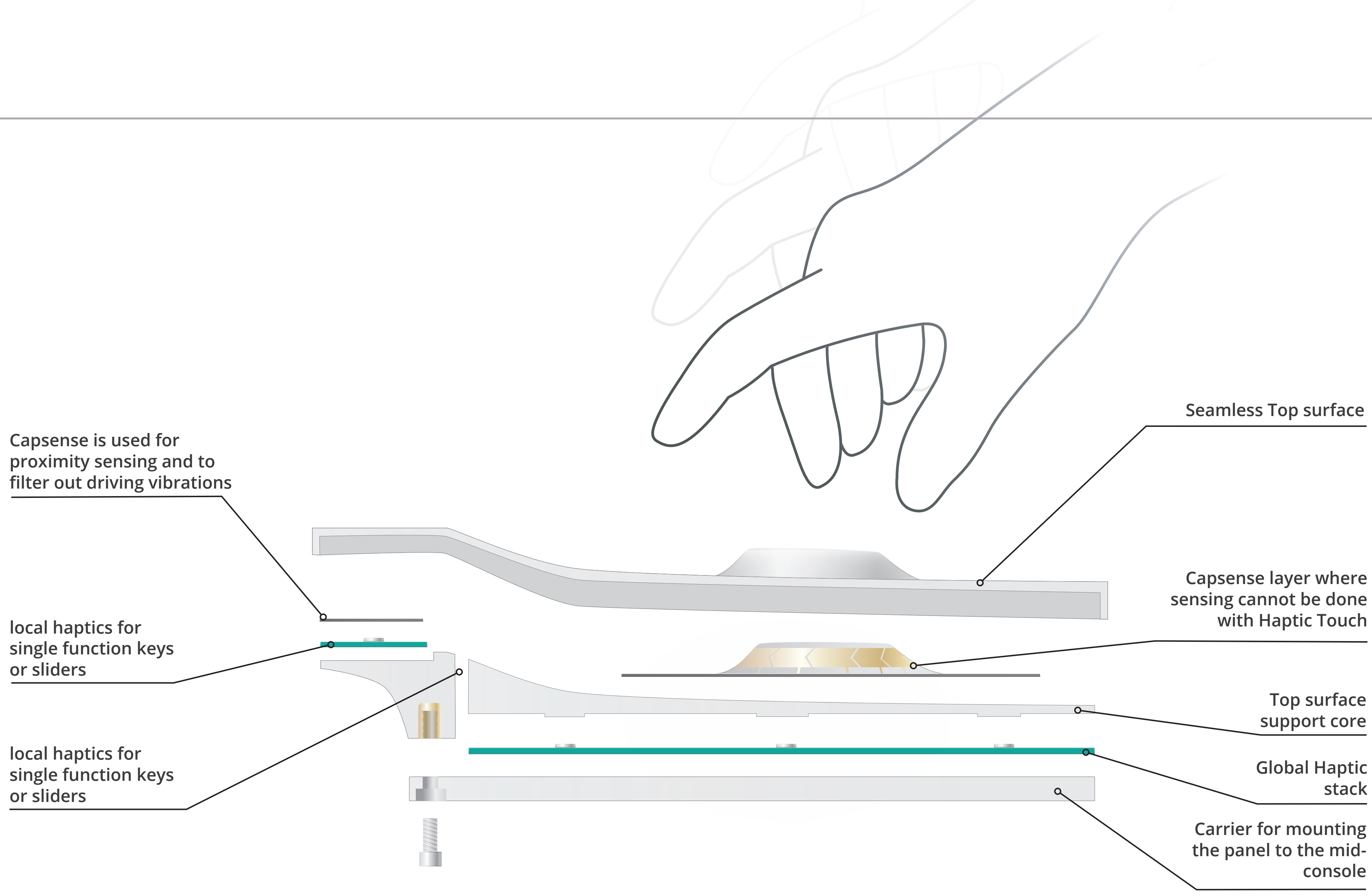


Figure 41. General stack design for all control panels. The cap-sense layers are mostly used for proximity sensing.

Advanced Haptic Touch Interactions

The interactions which were created are meant as a stepping stone for further development and discussion. The main goal was to come up with a number of combined GUI and Haptic Feedback interactions that would not be possible with other technologies than Haptic Touch.

The following starting points were used to design these interactions:

- Minimize the information displayed in the GUI.
- Use distance sensing for activation of GUI elements
- Combine contextuality with multi-level force touch.
- Minimize percepted boundaries between displays and local buttons.

The interaction concepts discussed on the next page do not describe the use of search haptics. Dynamic feedback patterns however could be very suitable in communicating the function and location of an UI element.

Multi-Level quick settings

A local key or GUI which uses multi-level force feedback. A light press turns a feature on or off. By pressing harder, each setting has its own light haptic feeling. Holding will confirm the setting with a distinguished feedback pattern and audio cue.

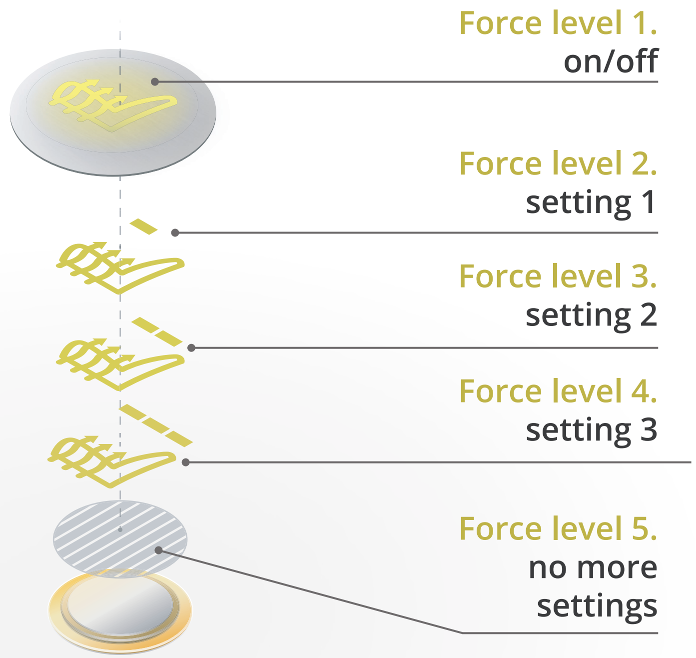


Figure 42. Multi-level quick settings

Multi-Level quick settings with GUI element

This interaction concept is similar to the first multilevel concept, but then placed next to a display. Pressing the local key for a setting will show a bar on the display which represents the visual feedback of the setting.

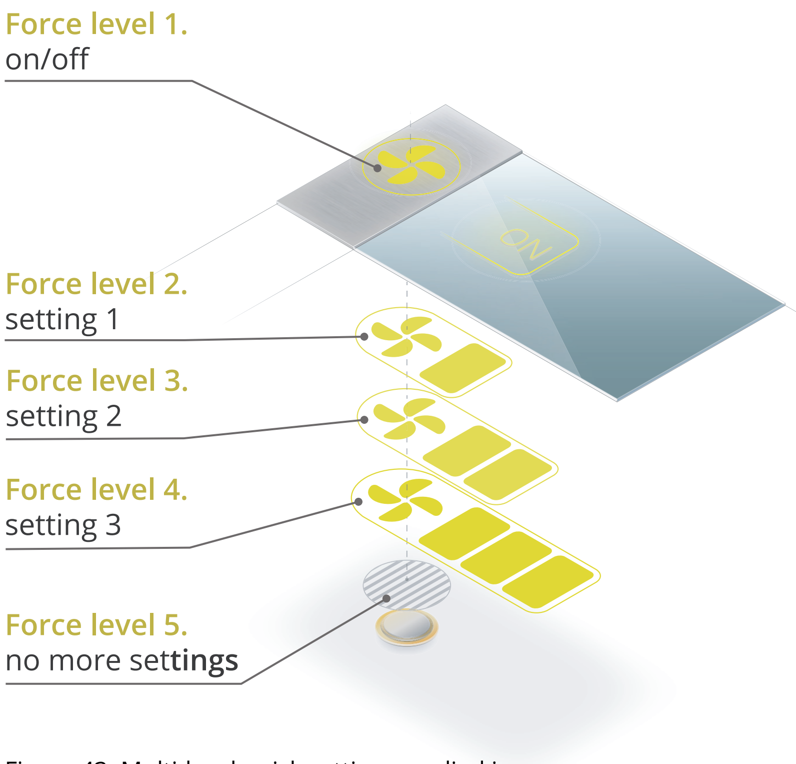


Figure 43. Multi-level quick settings applied in combination with a display.

Slidable press button

Sliding and pressing a button is an interaction concept for functions that need to be operated consciously by the user. A button can be dragged to a highlighted location and when pressed, the feature is activated.

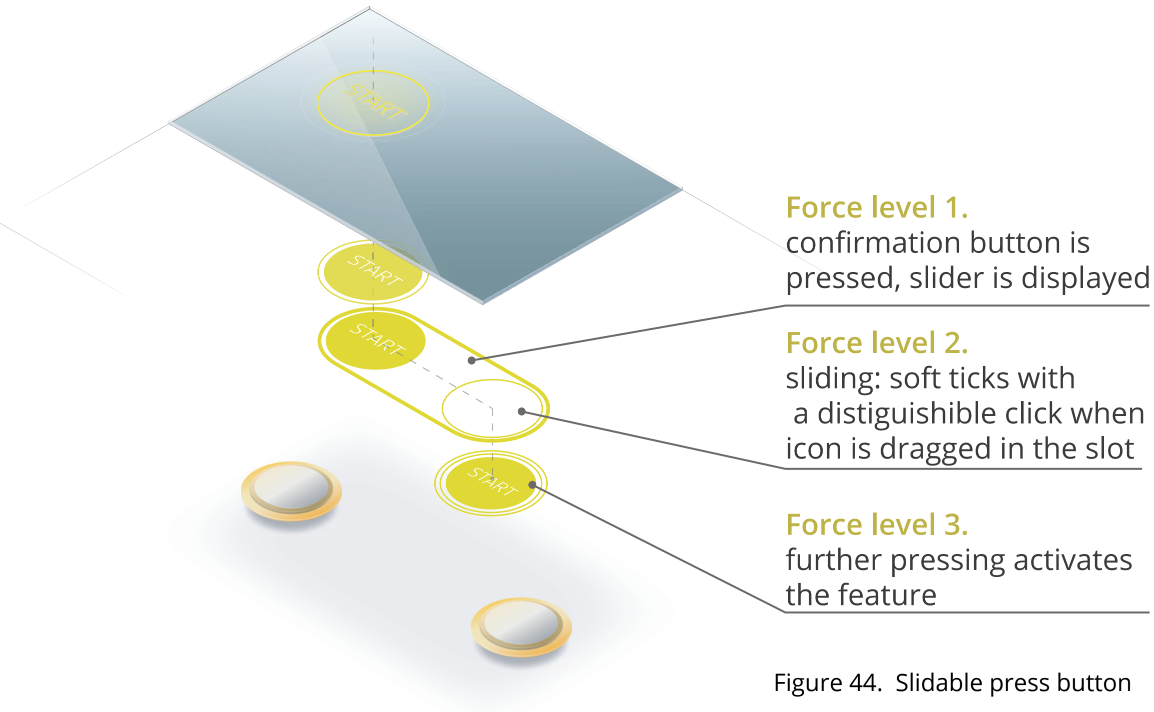


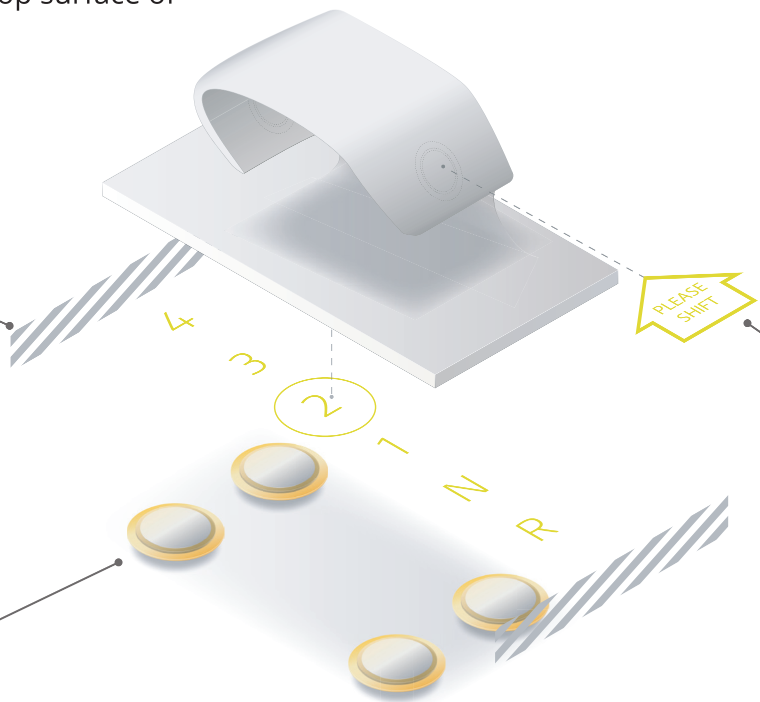
Figure 44. Slidable press button

Solid Vehicle Control Elements

Piezos or capsense underneath the top surface are used for sensing, while a global stack underneath the core geometry would be used for feedback. This construction would be suitable for e.g. a gear shifter or rotary control knob.
With the right feedback setting, illusion of movement can be given to the solid feature of the panel
The use of piezos underneath the top surface of the solidfeature, allows them to be used to haptically communicate with the to the driver. A sports car for example could indicate the optimal shifting point through haptic feedback, allowing the driver to respond almost by reflex. The functionality and feeling of the control element can be completely different, based on user preference (e.g. a standard automatic vs sequential gearbox.

End of setting range
An "error" haptic indicates the when the highest/lowest setting has been reached.

Global haptics to mimic shifting
Pushing/pulling the shifter actuates the global haptic stack, optionally with distinguishable haptics.

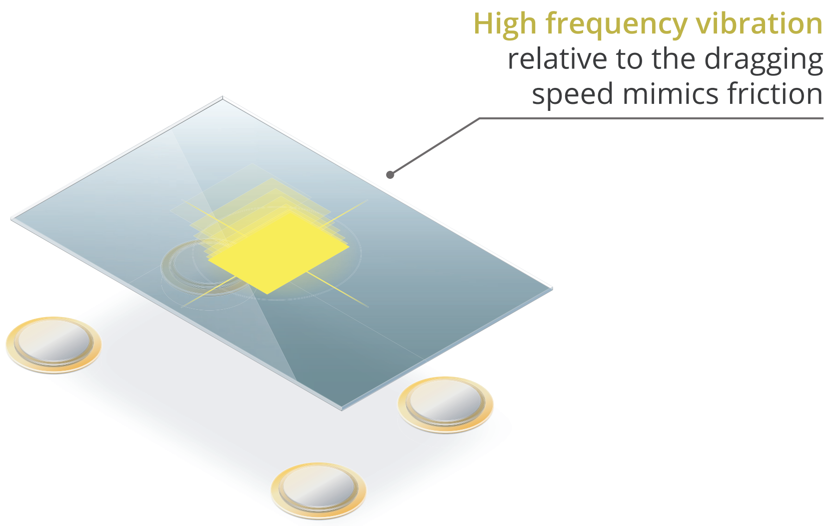


Sensing piezos
in the gear shifter communicate optimal shifting points and are used to sense if user shifts.

Figure 45. Solid control elements

Gesture Feedback

Giving feedback to commonly known gestures is a must for feedback integration in display applications, but also the most complicated to get right.
Scrolling through a list of menu items for example could a click feedback corresponding to the speed at which is scrolled and the feedback strength could indicate the end of a list has been reached.
Another exmaple would be to add a high-frequency, low strength vibration when an item is dragged, giving the illusion of friction when an GUI item is dragged. Objects that collide can also have more friction in relation to standard dragging.



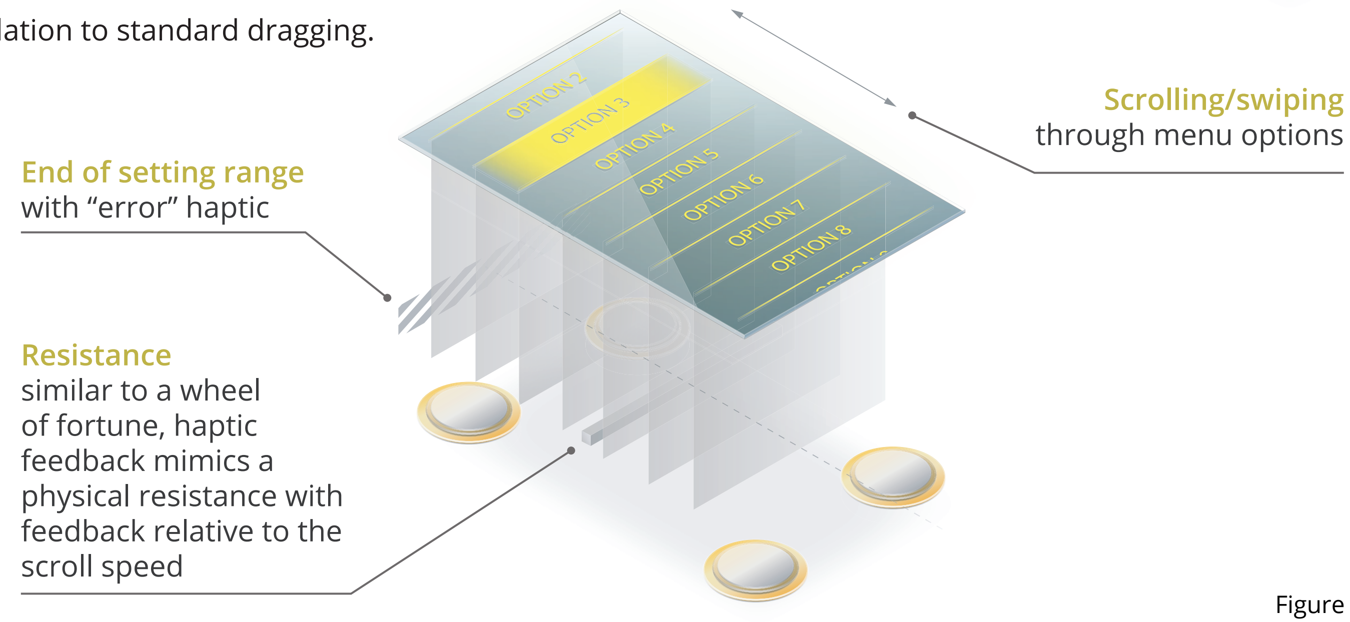


Figure 46. Examples of gesture interactions

1.4. Projection Mapping

As mentioned in the concept phase, interactive projection mapping is used to display the Graphical User Interface on the demonstrator. The use of projection mapping enables Aito to demonstrate the types of displays Haptic Touch can be designed with and allows for flexibility in showcasing interaction concepts. This section discusses projector placement and how input from AITO®HapticTouch is coupled to the projected image.

Projector Requirements

The projectors used for projection mapping have a number of requirements. Considerations taken into account with the beamer choice are the dimensions (portability), resolution, projected image light intensity and the relationship between distance and width of the image. A beamer which has speakers is also preferred, as it makes it unnecessary to place separate speakers for audio cues.

The projector shown in figure 47. is an example of a projector with a favorable mix of specifications and price point.

A short-throw projector is recommended for an application like this (HeavyM, 2018). The fact that these projectors can be placed very close to the object makes them suitable for this demonstrator: The sharp projection angle means that the projected image is distorted much later by the user's hand, compared to a standard projector.

1. LG P450UG

Type: Ultra Short throw

Dimensions (B x H x D): 132 x 200 x 80,5 mm)

Image diagonal: 102 to 204 cm

Resolution: 1280 x 720 pixels

Brightness: up to 450 lumens

Other Features: WIFI, Bluetooth, Li-ion battery

Speakers: yes

Price: € 384,80

Figure 47. LG P450UG projector

Projector Positioning

For the positioning of the projecters, the context in which the demonstrator has to function, is the most important consideration.
When a conference stand provides the possibility to mount the projectors to the stand itself, this would be the preferred position. Otherwise, one or more UST projecters (like the one of figure 48.) mounted on a stand would be recommended.

The setup shown in figure 34. shows the oriëntation of two UST projectors in relation to the demonstrator. Using two projectors in stead of one is expected to improve the brightness and quality of the image. In terms of distance and angle, each beamer is ideally placed as perpendicular above the interface as possible, albeit under a slight angle (to delay image distortion by the user). If the angle with the projected surface becomes too extreme, the pixels will be deformed and sharpness in the image gets lost. The software used for projection mapping can be used to compensates the slight angle of the projector.

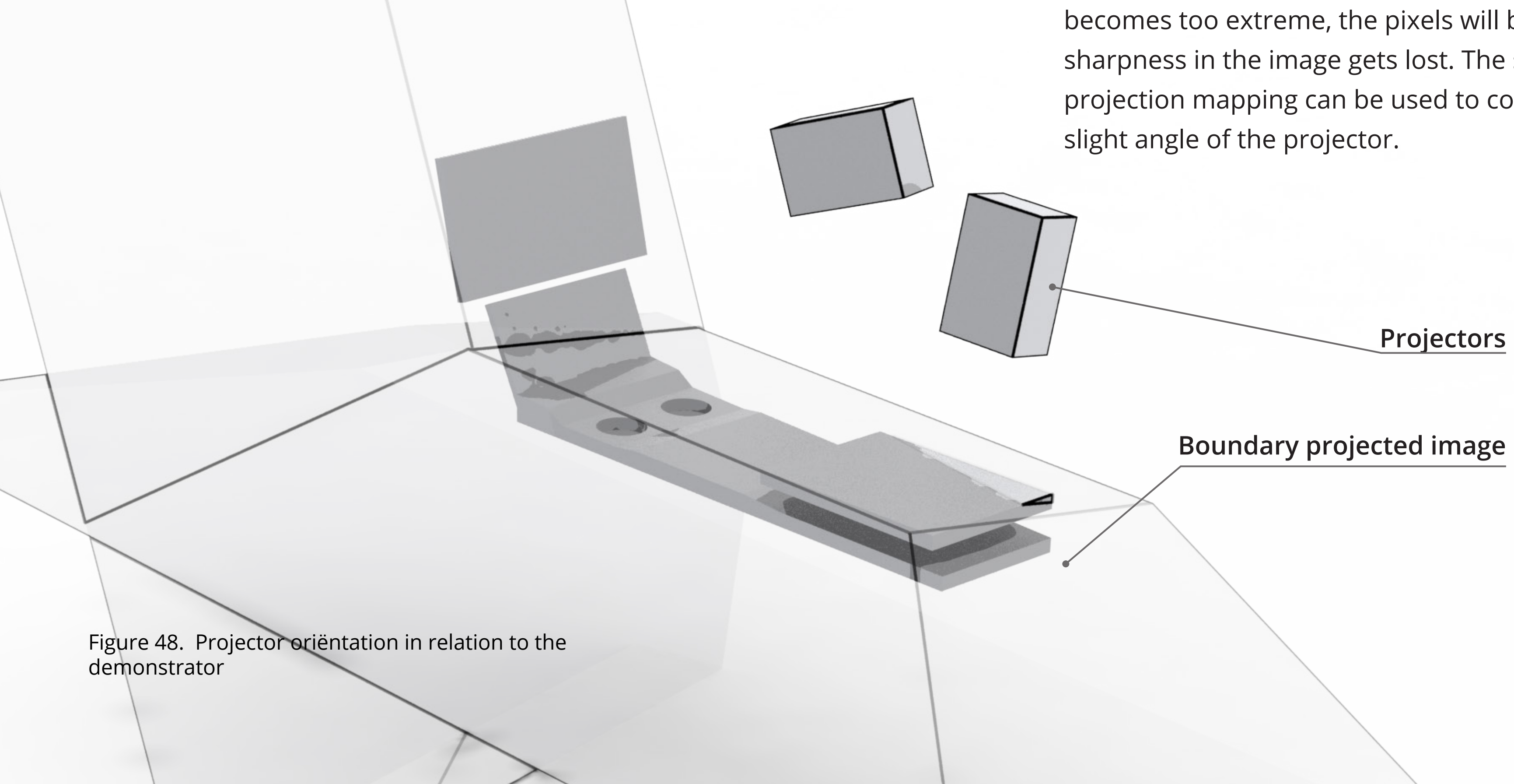


Figure 48. Projector oriëntation in relation to the demonstrator

Software Pipeline

The software used in the back-end of the system is crucial to the functioning of the demonstrator. A laptop running in the background is used to manage the haptic configurations of the Haptic Touch hosts and to trigger animations in the projection mapping software based on host output.

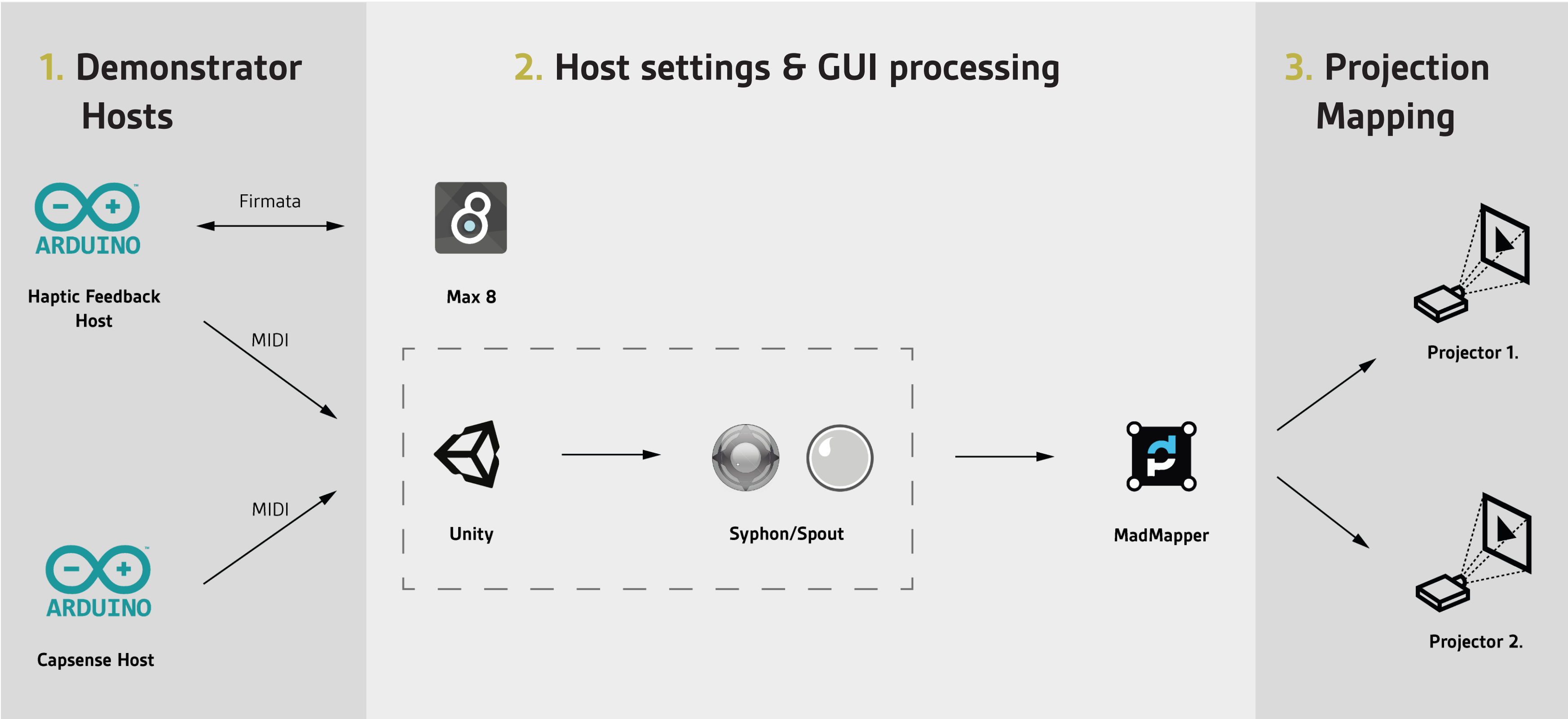


Figure 49. Proposed software pipeline. The part inside the dashed framework would be the optional more advanced software pipeline. In the simplified version in for this project, MIDI signals from the host electronics is send directly to Madmapper.

Two designs for the system topology were considered. The first design would use a game engine like unity to convert Arduino serial communication into visual output. The benefit of unity is that it is possible to create interfaces with three dimensional assets that can be manipulated with custom build controllers. The downside however is that out of the box, unity is not meant to be used for projection mapping, requiring some extensive programming knowledge to make it work.
The second option, which was eventually chosen, is to use of an approach which is based on MIDI signals and a projection mapping software package called Madmapper. The software for this system does not require extensive programming knowledge, is mostly free (except for madmapper), and allows for a high level of flexibility.

Why MIDI

MIDI signals are very suitable as a communication protocol for this demonstrator. Because it is widely used in the music industry, multiple Arduino code libraries have been developed in recent years to program Arduino controllers for MIDI over Serial communication.
MIDI is suitable, as it can be used to communicate a wide range of inputs, varying from on/off switches to analog sliders and rotary knobs. This analog flexibility makes it possible to assign HapticTouch parameters to MIDI parameters.
To illustrate: A generic MIDI signal consists of four parts:

(Note on/off) (channel) (note) (velocity)

When a piano key is pressed, a keyboard sends a MIDI “note on” signal which communicates the identity of the key (the note). When the key is released, the keyboard sends a separate not off signal. Additionally the MIDI signal will contain the velocity of a press or release to interpret the loudness the musician intends for the note. The press of a Haptic Touch local button is very similar, as the press and release of a key is registered separately by the Aito Chip. The channel can be used to separate signals from multiple modules and the velocity signal can be used to communicate haptic force touch.

Madmapper

To translate MIDI signals to animations projected on 3D printed objects, Madmapper is the perfect choice. Madmapper is a software package specifically designed for lightshows and has an easy to learn User Interface. It is compatible with multiple communication protocols, including MIDI, supports multiple projectors for a single object and can handle complex objects. 3D models can be loaded into the program and can be used to calibrate the projected image to the object. The texture map of the model can then be used to position the GUI elements. GUI elements can be imported into madmapper as animations, custom materials (script based GUI elements with predetermined parameters) or generated by other software packages such as Syphon (a tool used by VJ professionals to send real-time animations from one software package to the other).
Finally, switching between the different levels of the use case scenario can be done by creating scenes, which can also be activated with a MIDI button press (e.g. the start button to transition to driving mode).

Configuring Haptic Touch settings

For a simple interface, switching between haptic touch configurations can be done with the code on the Arduino host itself. Interfaces that require more processing power (e.g. because of a high number of panels or intricate GUI designs), make it necessary to use a laptop instead of the Arduino host to manage configurations.

An object based visual programming toolkit such as Max 7 or VVVV (free scripting software which is similar to grasshopper in Rhino) would in this case be suitable. Such tool could be used to build the framework of the interface, linking HapticTouch input with the visual output. To control in real time what is happening on the demonstrator, the Arduino code on the host has to be programmed with a Firmata sketch. This a sketch readily available in the Arduino IDE that lets a computer adjust the code of the Arduino without having to recompile and reset the board (see figure 34.).
Why would such an architecture be valuable? Using a systme like this, enables a single key press to set in motion a whole cascade of changes in the interface.

If, for example, someone would activate a different suspension mode, the HapticTouch key press would tell the Max7 script on the laptop to upload the performance mode HapticTouch configuration to all of the panels on the demonstrator, While also adding performance related elements to the projected interface. This makes it possible to design complex interfaces with relative ease.

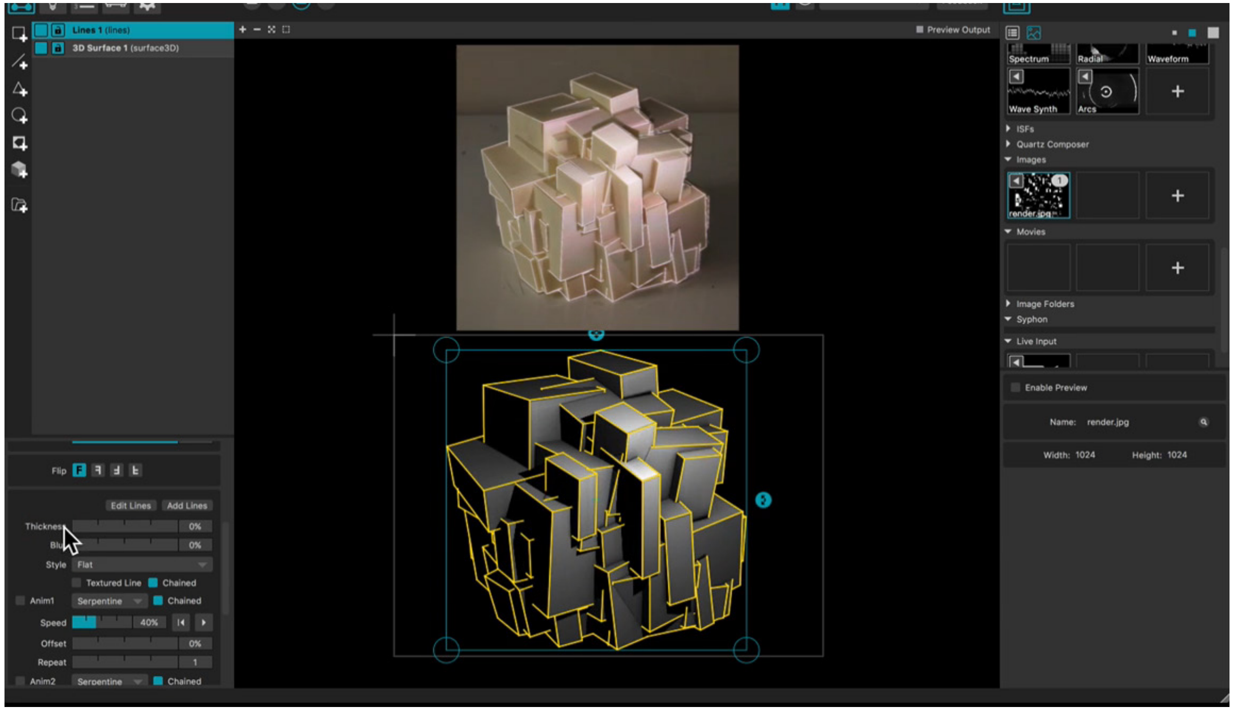


Figure 50. Screenshot of the Madmapper UI, imported CAD files can be used to calibrate the projected image on a 3D printed model. MIDI input can be assigned to the texture parameters.

1.5. Construction

The construction of the mid-console surface must provide enough stiffness to the demonstrator, to ensure strong Haptic Feedback and make it feel durable to the people that use it.
Also it should be relatively easy to change out control panels and to take the demonstrator apart for travelling.
The guiding principle in the construction design is to use form-locked connections as much as possible and to either 3D-print or laser-cut the parts, so they can manufactured in one order.
Furthermore, the aesthetics and material choice have to give a high quality impression. The laser-cut parts are therefore sanded, primed with sprayable filler, sanded again and finished with satin-black paint.

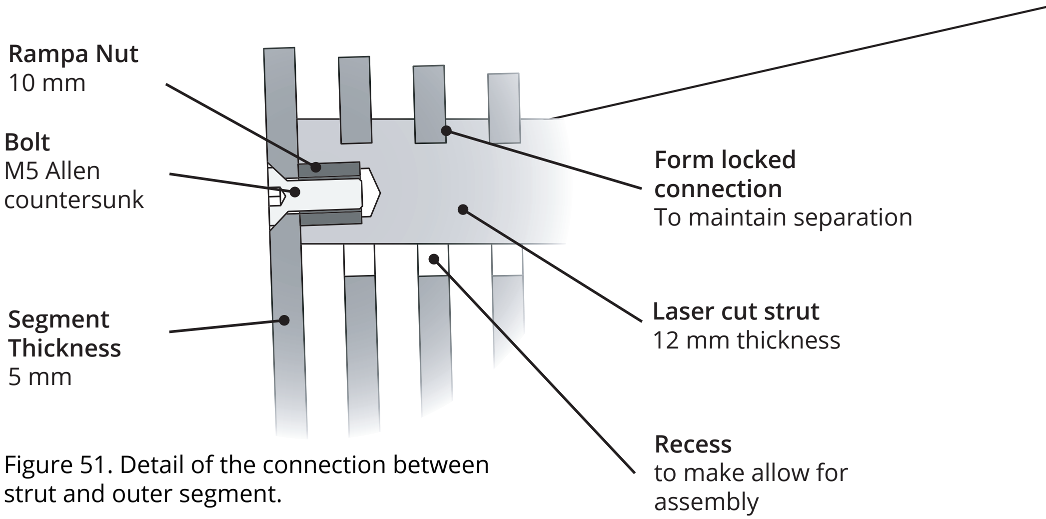


Figure 51. Detail of the connection between strut and outer segment.

Mid-console general construction

As discussed in the concept design chapter, the support structure is constructed from laser cut multiplex segments which are feathered outward towards the secondary display. To connect these segments, laser cut struts are screwd in to ther outer segments. The 3D printed panels are screwd to these struts. The construction of the main surfaces displayed on this page also applies to the other support structures.

Legs

The legs will be separable from the mid-console surface to make transportation easier. The connection points are 3D printed parts which are attached to the edges of the support structure. These 3D prints fill the space in between the segments to form a durable connection. They are locked in place by the struts that run through thes parts or secured with screws that screw in threaded inserts.

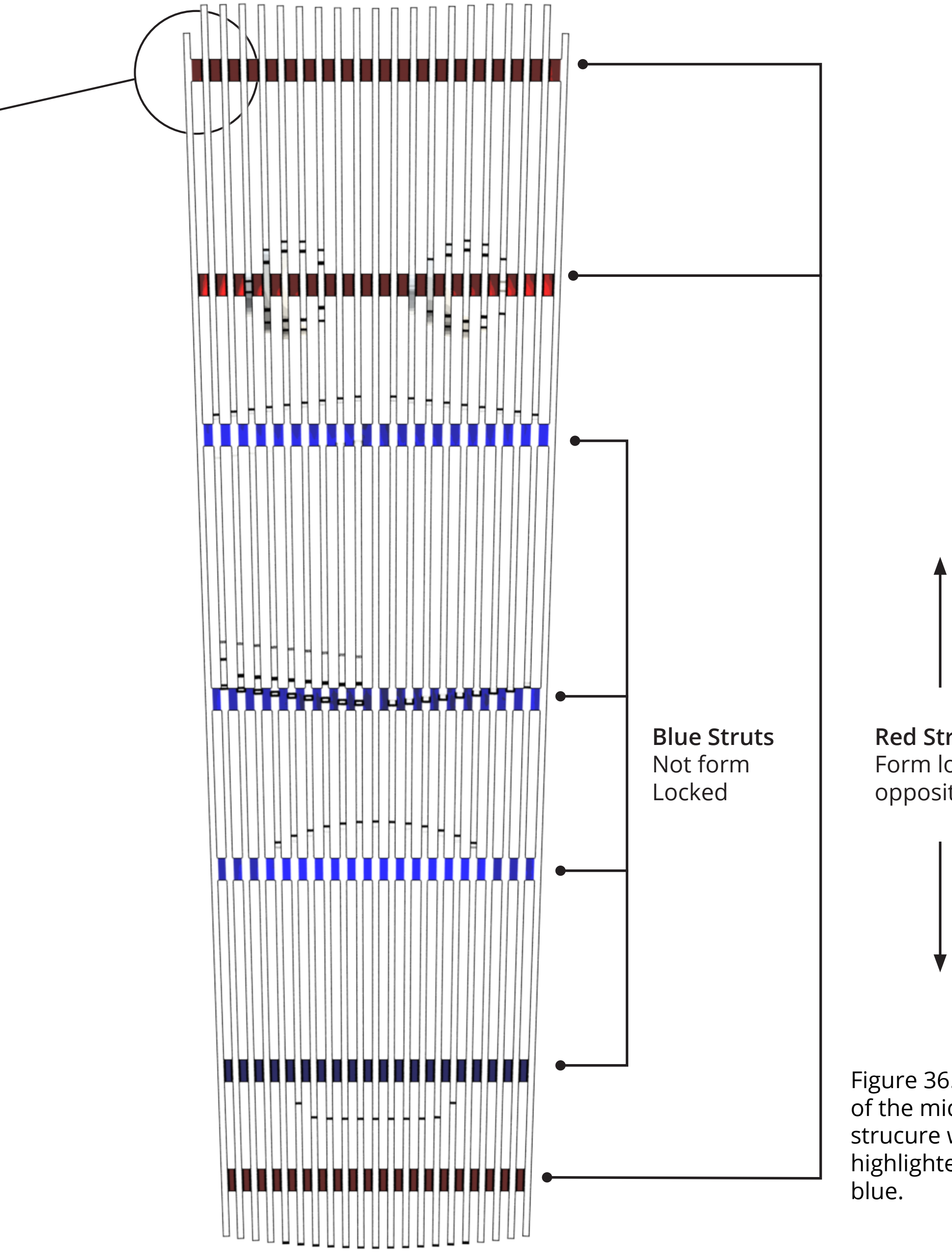


Figure 36. Left: top view of the mid-console strucure with struts highlighted in red and blue.

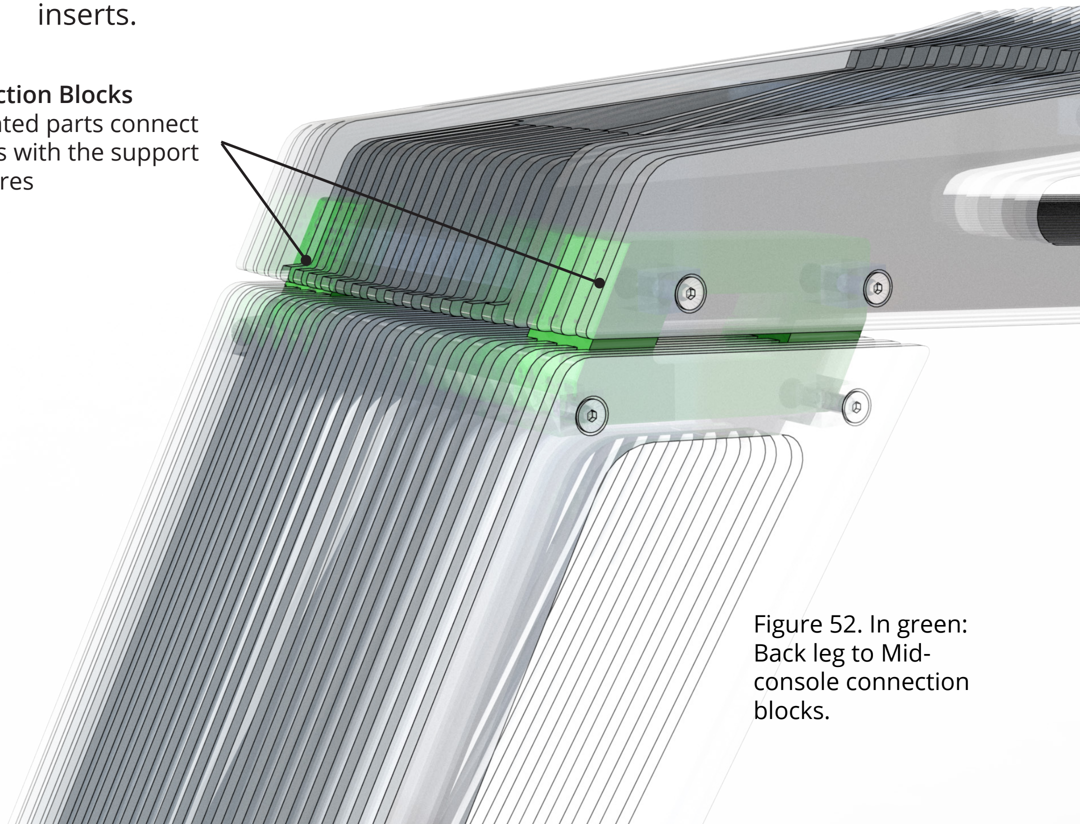


Figure 52. In green: Back leg to Mid-console connection blocks.

AITO®HapticTouch foil integration

The goal with HapticTouch foils integration, is to use leftover foils and/or foil design of finished project. By using these foils, production costs can further be reduced.

The following pages discuss the integration of the piezo-foils in the control panels, as well as the routing of the wiring.

Primary Display

Using the construction principles from the general stack design discussed in the haptic touch integration section, the primary display consists of a 3D-printed carrier and core (no overlay top surface).
The carrier and overlay surface are held together with a series of screws at the curved back- top part of the panel (figure 53). This is done to prevent shear forces on the piezos, which could damage electrical connections over time.
Cap-sense is used for finger tracking and distance sensing. In a later stage, the decision can be made to use capsense only for proximity sensing and/or global stack of the display to play audio cues. This panel is designed to support gesture feedback and multi-level quick settings.

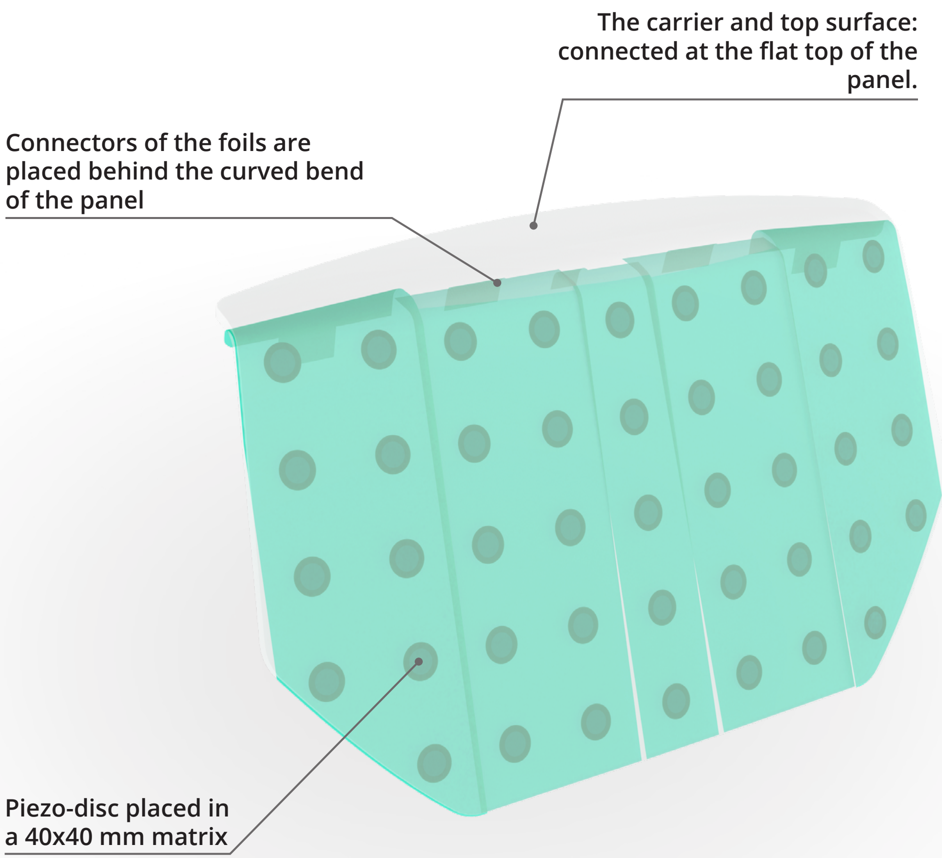


Figure 53. Foil integration in the Primary display.

Secondary Display

The secondary display is similar to the primary display in terms of stack design, except that the stack is turned upside down (partly to illustrate this is also an integration option. The lower horizontal part of the panel features a button row of local keys. These keys are used for enabling multi-level quick settings with a GUI elements. The Hazard light is placed in the middle and is slightly raised to provide a good reference point

Touchpad panel

The front part of the touchpad panel has a button row of local keys which can also function as a slider. The trackpad area in the middle is a flexible global stack design with a cap sense foil for position tracking. On the lower row, local keys have been placed for home, settings and return keys that are only visible when needed.

With this panel, the front button row is used to provide shortcuts for infotainment applications. The Trackpad is used to control these applications with gestures and can also be used as keypad for text- and numerical input.

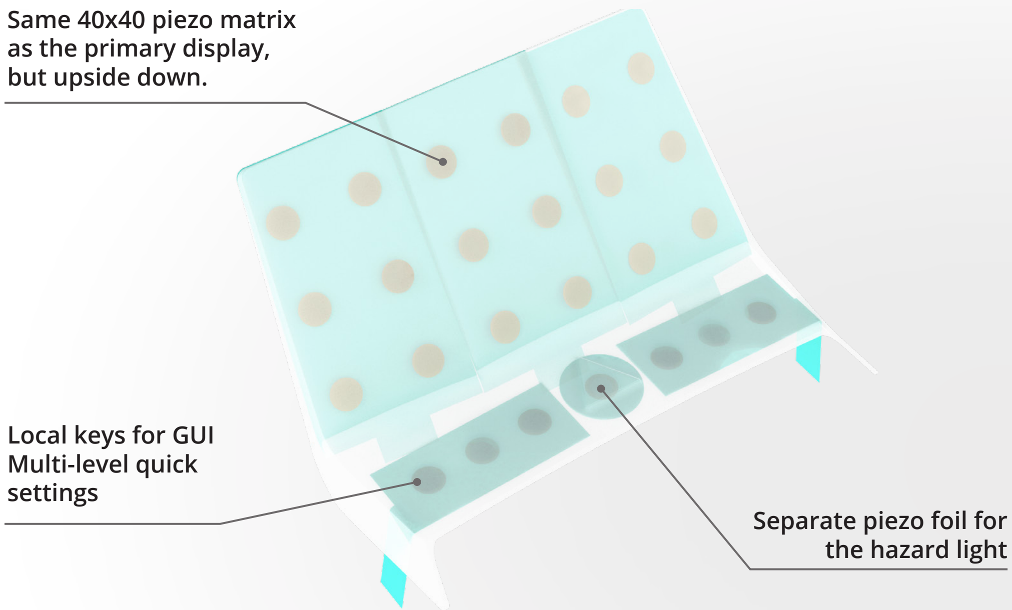


Figure 54. Foil integration in the secondary display.

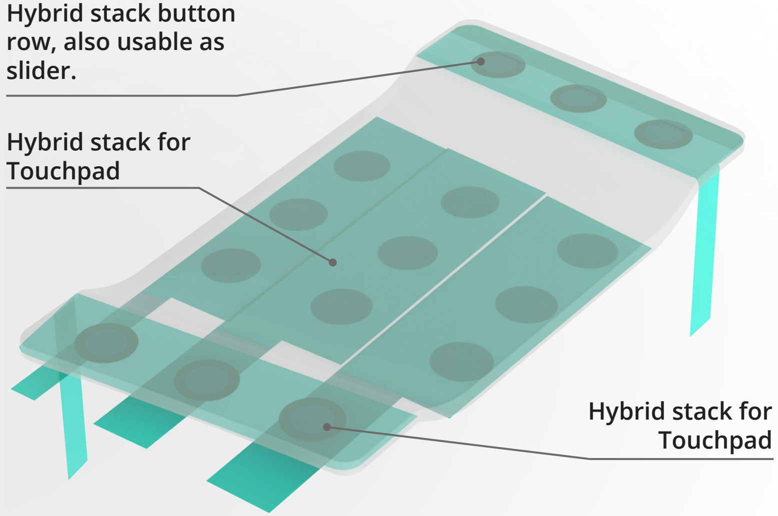


Figure 55. Foil integration in the touchpad panel.

Vehicle control panel

This control panel has the most advanced implementation of all panels in terms of design. While, the choice for a traditional gear shifter may seem obsolete for future cars, it is the implementation of AITO®HapticTouch that makes it innovative

There were two motivations for choosing a gear shifter for this panel. Initially the idea was to implement a rotary knob for gear selection. Early in the design process however, the cap sense implementation became a problem, as the partner company of Aito specialized in this technology was unfortunately unavailable for this project. To solve this, the decision was made to move away from a rotary knob and to design a panel that could use piezo sensing input.

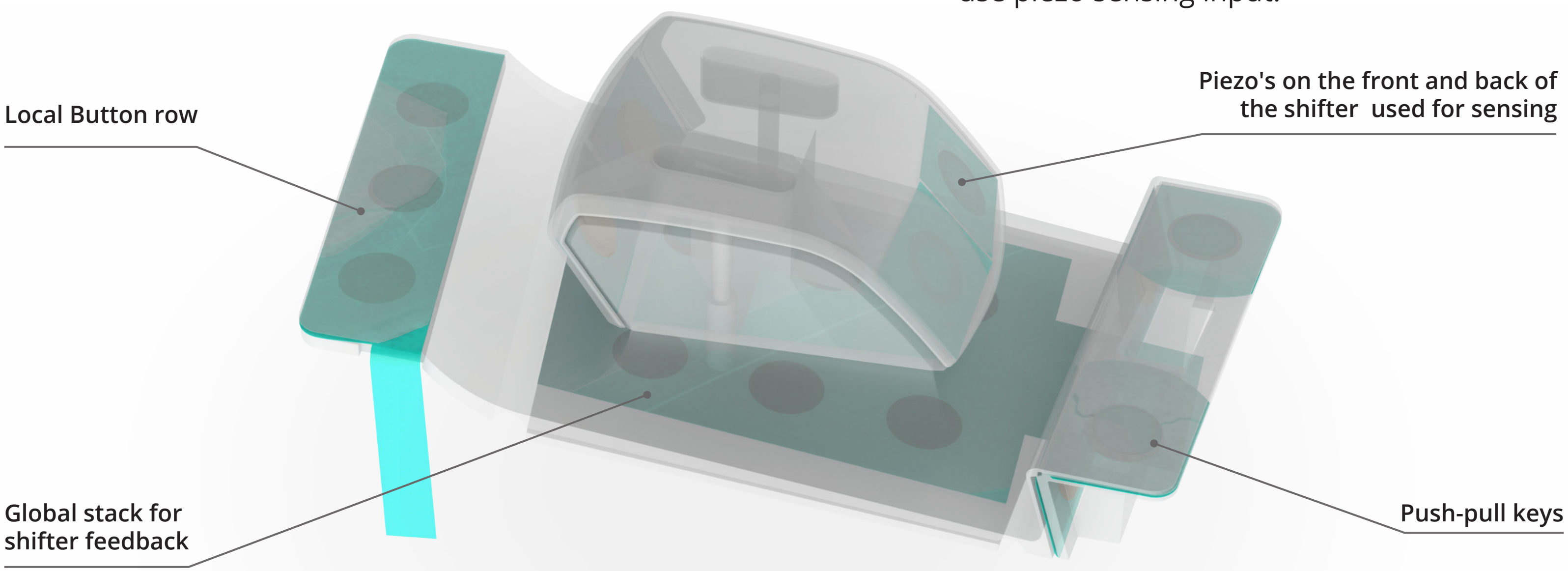


Figure 56. Foil integration in the vehicle control panel

The second motivation was the expressed interest from the supervisory team in exploring haptic feedback for vehicle controls. A gear shifter is a very recognizable vehicle control element and therefore suitable for demonstration purposes. The chosen gear shifter design for this control panel is mostly solid and haptic feedback for each gear shift is generated with a global stack, similar to the Touchpad. Added benefit of this design is that because the shifter is solid, this control element will take up less space compared to traditional shifters.
Apart from the shifter, the vehicle control panel can be divided into three parts: a button row, the gear shifter and a row of local push/pull buttons. Throughout the control panel, cap sense distance sensing is used to for feature activation, so illumination can be dimmed when the panel is not beïng operated.

Wiring

The Haptic modules are connected to an external module box with flat cables that run along the support structure segments. This reduces the need for additional electronics to be integrated in the demonstrator. This would also be realistic in an automotive application, as the Haptic Touch chip would be integrated on the pcb of a dedicated HMI computer.

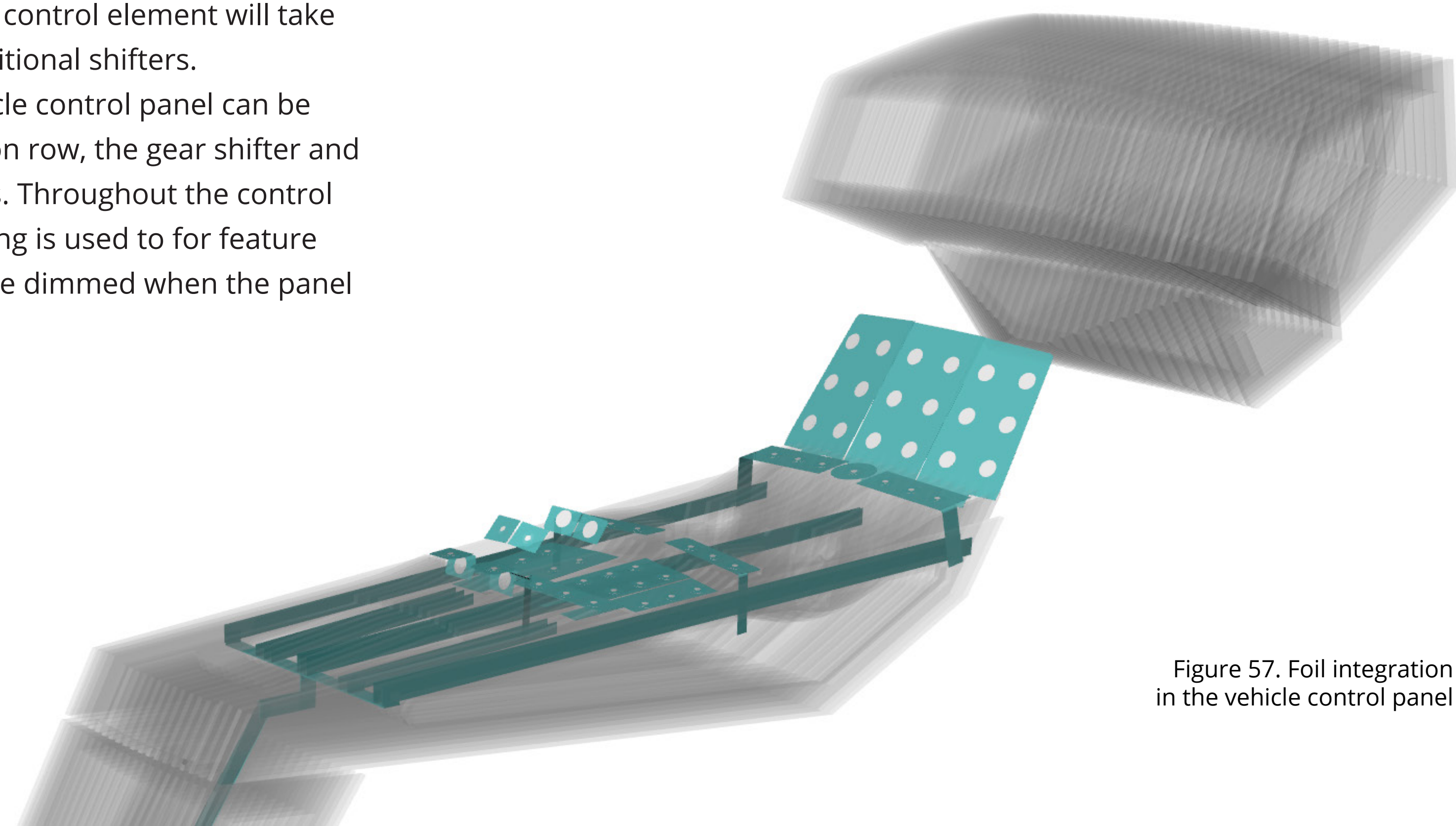
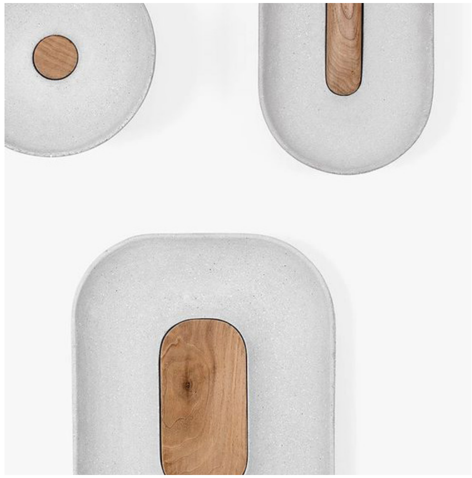


Figure 57. Foil integration in the vehicle control panel

Figure 58. Top view of the
Mid-Console

2.1. Integrated Design

With all the challenges relating to embodiment design solved, the final stage of embodiment design consists of integrating the earlier found solutions into a single holistic design. To guide this process, a moodboard was created.
The starting point was to emphasize the available design freedom while retaining a high level of minimalism. Also, the strengths of the chosen fabrication methods were taken into account.

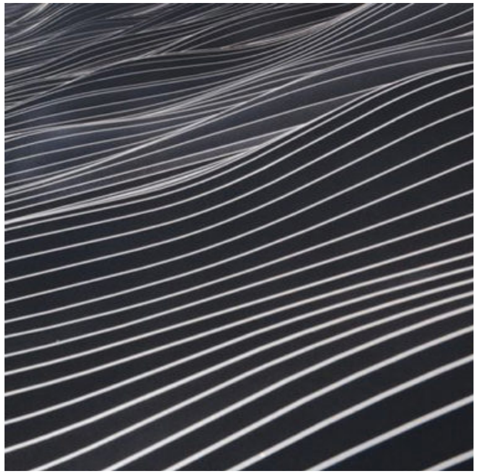


High Material contrast

Clear distinction between functional and non-functional areas of the mid-console with high quality materials. Application of warmer materials such as wood and leather where ther is contact with the user

Floating Functional panels

The edges of the flowing surface around the panels has a slight offset. Together with the absence of material underneath the panel edges, the impression is given these panels are floating. This is meant to emphasize lightness.



Rythmic Flowing surface

Creating continually flowing surfaces with consistently spaced elements to create a sense of lightness. This continuïty is taken over by the 3D-printed panels

Minimalist support structure

Functional straight lines and rounded edges of the support structure make sure the attention is drawn to mid-console surface, while maintaining a furniture- like appearance.

AITO®Haptic Mid-Console

Demonstrator Feature Overview

Figure 59. full size

General Dimensions

Demonstrator Feature Overview

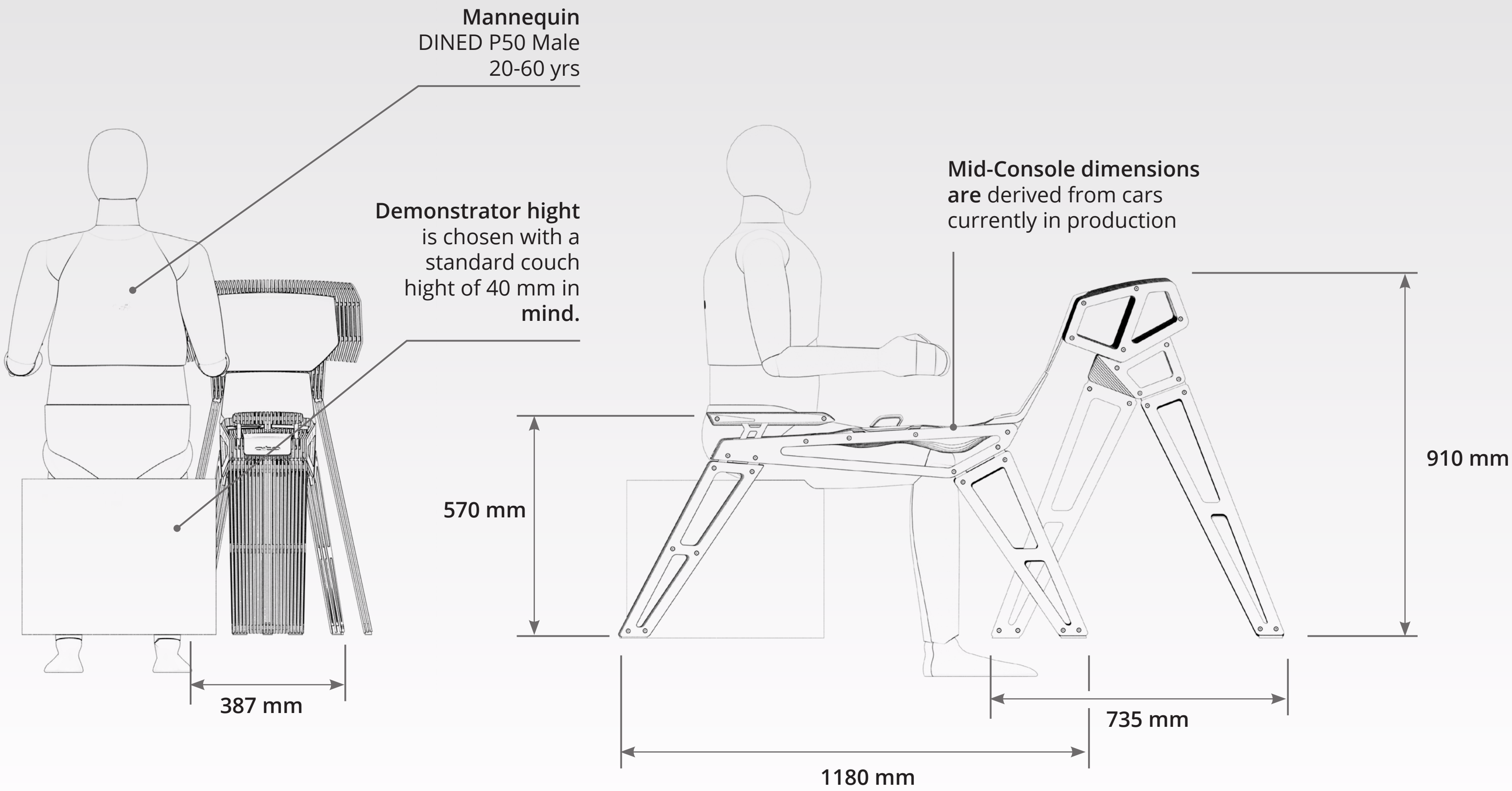


Figure 60. General dimensions

Mid-Console Details

The light-weight appearance
of the panels is caused by the contrast in material and the slightly camfered edge of the segments, almost pushingthe panels upward.

Haptic Panels are exchangeable
to showcase other the different kinds of Haptic Panels that Aito has developed or when a right-hand drive demonstraion is appropriate.

The satin black coated structure
Gives the demonstrator a high quality minimal apearance, while reducing distracting light refelections.

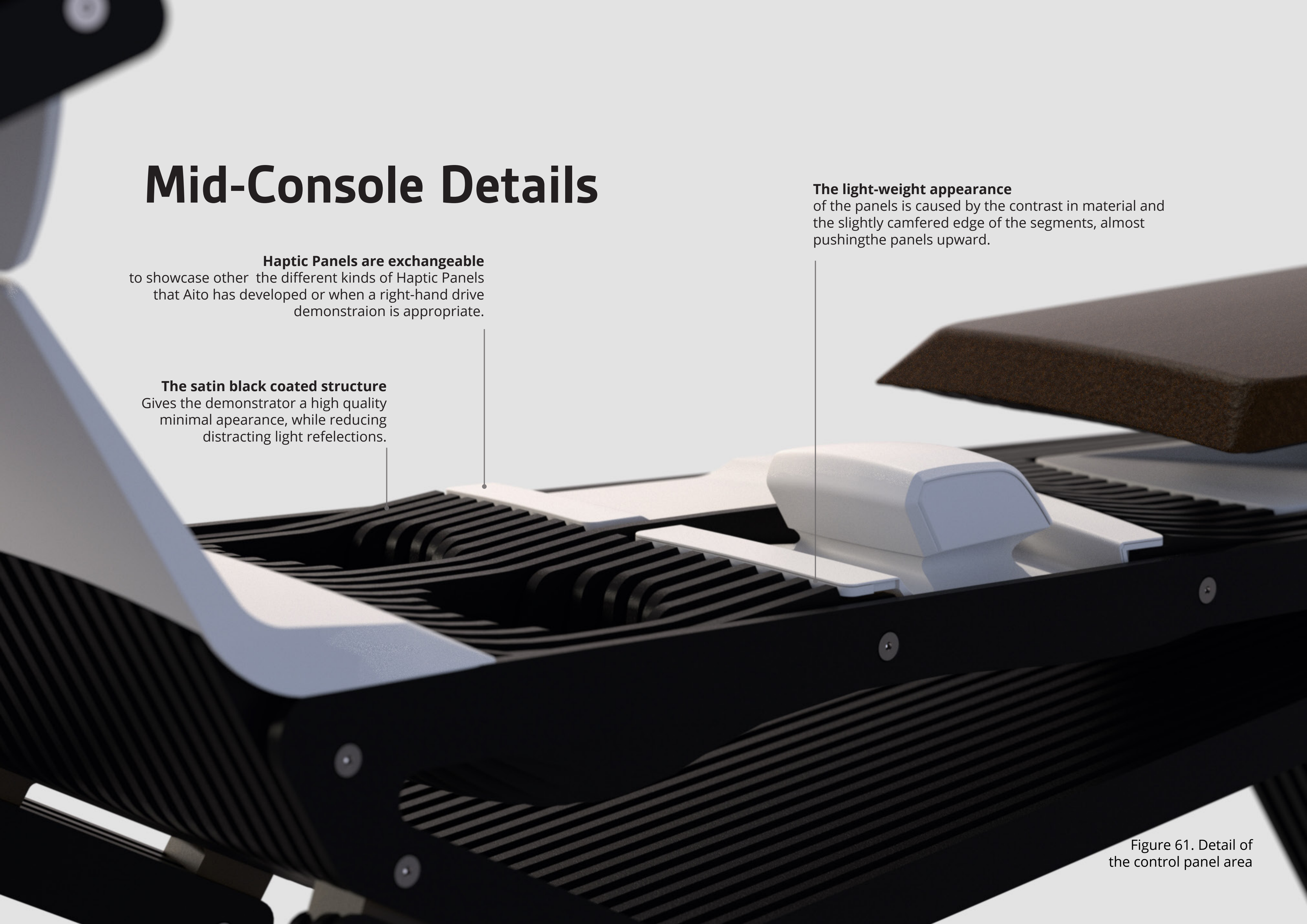


Figure 61. Detail of the control panel area

As the Armrest
is closed during driving and used to support the drivers arm, the user is dissuaded to use the phone while driving.

The Phone Tray
loads personal data of the user to the interface through NFC communication. The users phone gets also charged through NFC during driving.

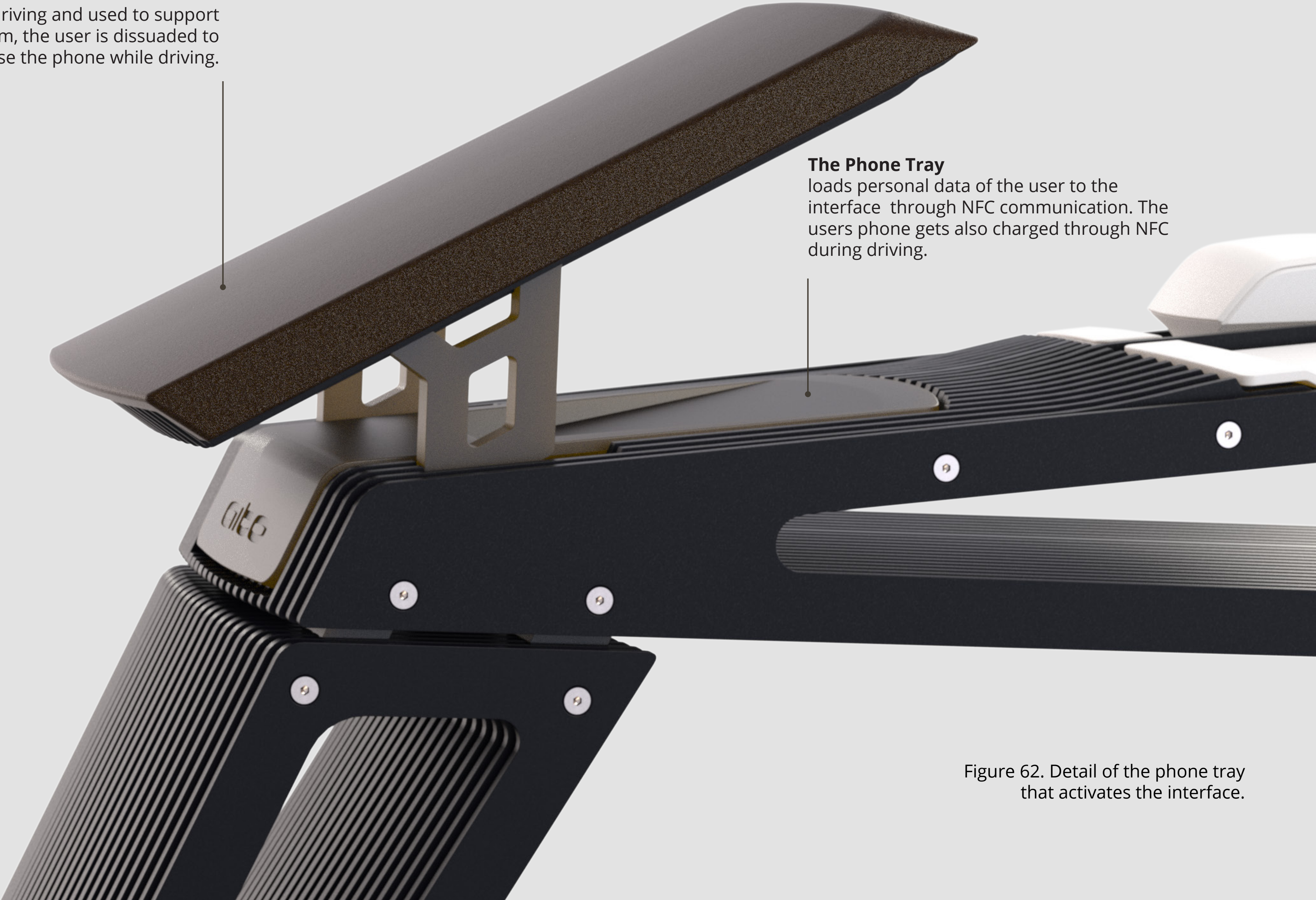
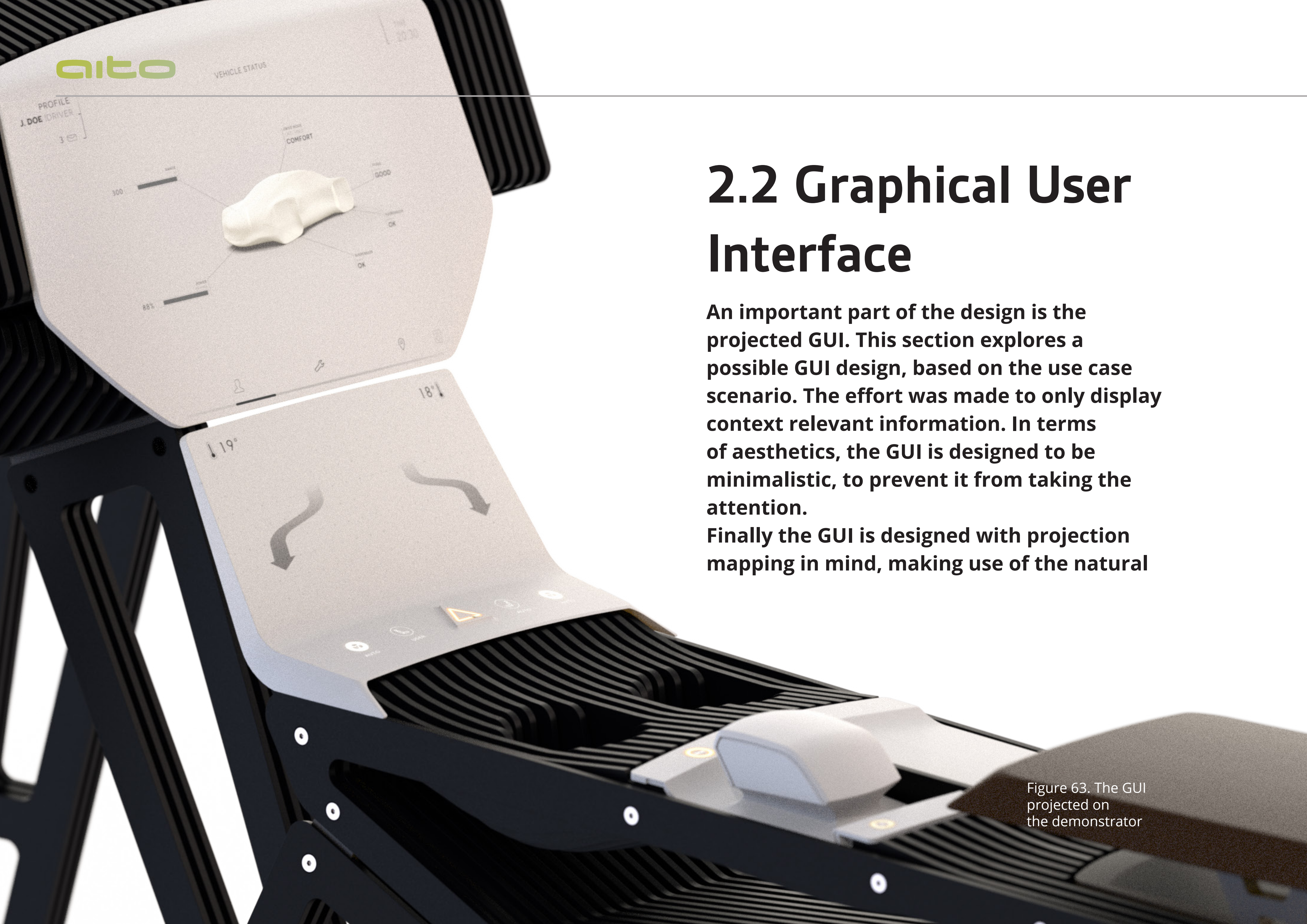


Figure 62. Detail of the phone tray that activates the interface.



2.2 Graphical User Interface

An important part of the design is the projected GUI. This section explores a possible GUI design, based on the use case scenario. The effort was made to only display context relevant information. In terms of aesthetics, the GUI is designed to be minimalistic, to prevent it from taking the attention.
Finally the GUI is designed with projection mapping in mind, making use of the natural

Figure 63. The GUI projected on the demonstrator

color of the printed material for darker colours. Because the GUI is secondary to the haptic feedback in and because of the “concept car” nature of this demo.

Level 0. /Standby

The user takes place next to the demonstrator. Placing his/her phone (or another NFC token) in the phone holder will activate the next UI level.

Primary Display

- Branding displayed on primary display

Secondary Display

- Secondary display shows “insert phone animation

Button Row

- Hazard light (always available)

Vehicle controls

- Parking brake Setting visible

Infotainment controls

- inactive

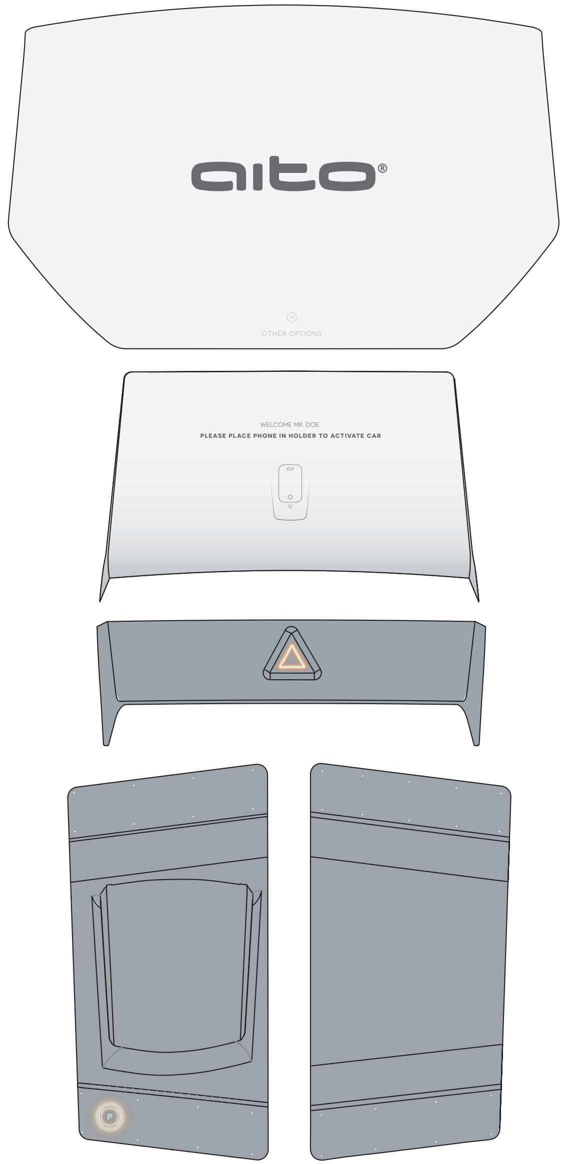


Figure 64. GUI level 0

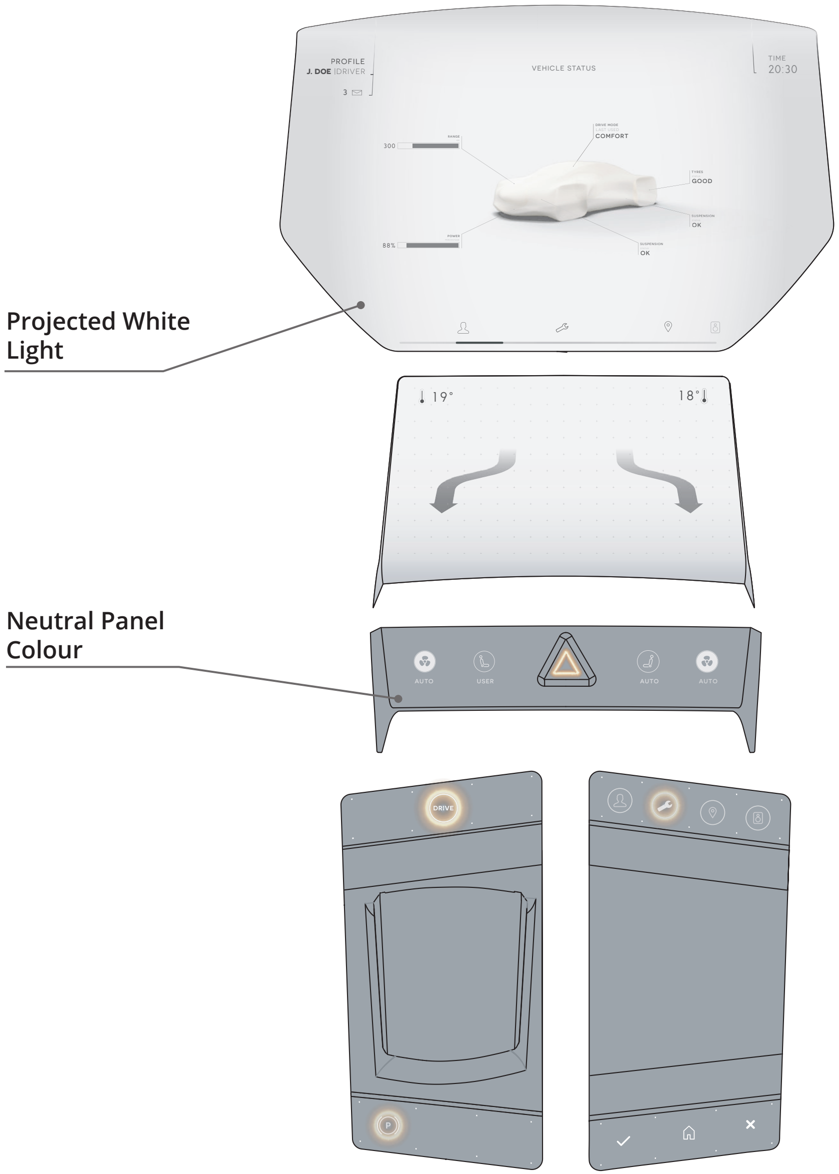


Figure 65. GUIlevel 1

Level 1. /Pré-driving

The pre-driving level has a GUI focused on settling the driver and preparation before departure. The start button on the vehicle control panel puts the demonstrator in manual driving mode.

Primary Display

- short maintenance update if relevant
- navigation screen is displayed, other infotainment options available (here limited to music, news, messaging and youtube). These will be just screenshots without functionality

Secondary Display

- Driver position settings are prioritized if driver is not known to the car. If the driver is known to the car, climate control settings are prioritized.
- Climate control is always set to auto. Initiating controls on the secondary display puts Climate control in manual mode
- Climate:
  dragging controls airflow direction
  force pressing increases airflow, holding confirms it.

Button Row

The button row shows shortcuts for comfort settings.
Tapping lightly will show settings on the secondary display.
Force pressing the buttons brings up often used functions:

- Seat: heating on/off
- Fan: fan speed multi-level settings
- Window: window heating front/rear on/off

Vehicle controls

- Button row:
  Active driving mode highlighted
  Start button: drag right to start
- Gear lever:
  Inactive
- Push/pull: Hold on/off

Infotainment controls

- Infotainment control
  Buton row: Shortcuts to infotainment apps
- Trackpad area:
  Gestures are used to quickly change e.g. volume
  Keypad functionality
  Touch Navigation on primary display
- Lower button row
  Back key, Home key, Settings key

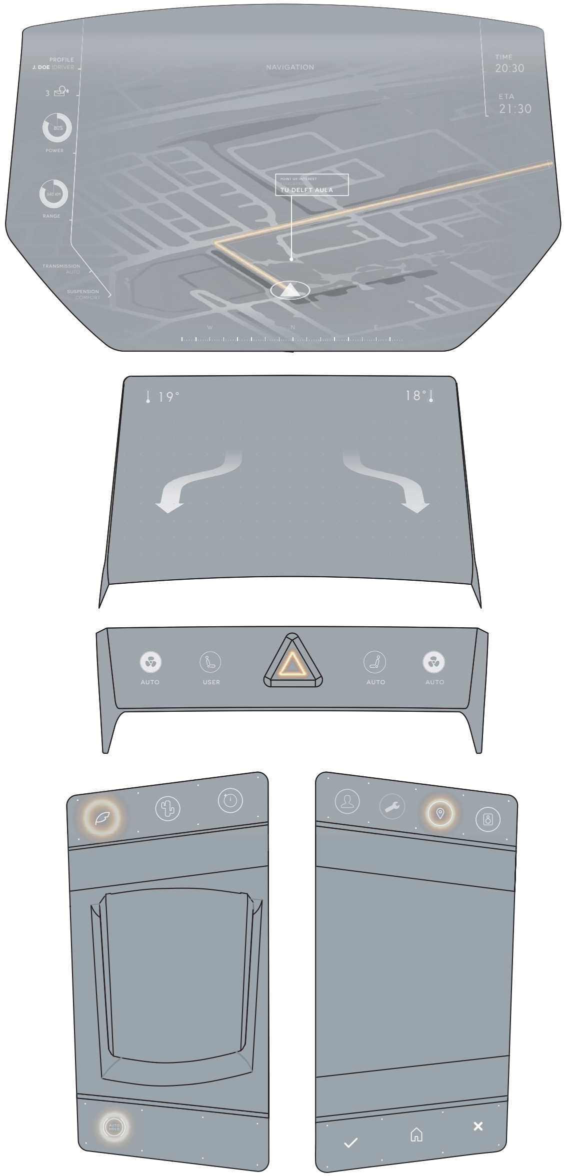


Figure 66. GUI level 2

Level 2. /Manual driving

After pressing start, the car is in manual driving mode. Certain infotainment functionality is restricted or limited.

Primary Display

- Navigation map is shown
- Manual input for messaging is restricted, only voice recognition is available
- Video and apps that require reading are disabled
- Car power status is displayed as well as manual suspension mode

Secondary Display

- Same functionality as with standby, climate control is prioritized

Button Row

- Same functionality as with standby, climate control is prioritized
-

Vehicle controls

- Stop button visible when car is standing still and gear is in Park
- Suspension settings visible, changing the setting

changes the mood of the GUI:
Comfort: cosy lighting, apps are oriented at comfort, normal automatic gearbox, soft suspension, etc.

- Performance: driving related information is prioritized main display also shows performance related information e.g. temps, g-forces, apex on map, etc. Gear lever becomes sequential instead of automatic
- Gear lever:
  Sequential or automatic, depending on driving mode
- Push/pull 1:
  Auto Hold
- Push/pull 2:
  activate autonomous mode

Infotainment controls

- Same functionality as with level 1.

Level 3. Assisted or Automated driving

Autonomous mode changes the mood of the interface and minimizes car information.

Primary Display

- Full functionality available, similar to pre-driving.
  Navigation shows what the cars sensors pick up from the environment. A blueish haze shows the car is in Autonomous mode

Secondary Display

- Same functionality as with level 1, climate control is prioritized

Button Row

- Same functionality as with level 1, climate control is prioritized

Vehicle controls

- Gear shifter inactive
- Comfort or performance mode change the way autonomous driving is experienced:
  Comfort: provide the most comfortable ride to the driver

Get to destination ASAP, fastest route is selected. Speed and lane change prioritized to shorten travel time. Suspension set-up for fast driving

Infotainment controls

- Same functionality as with level 1.

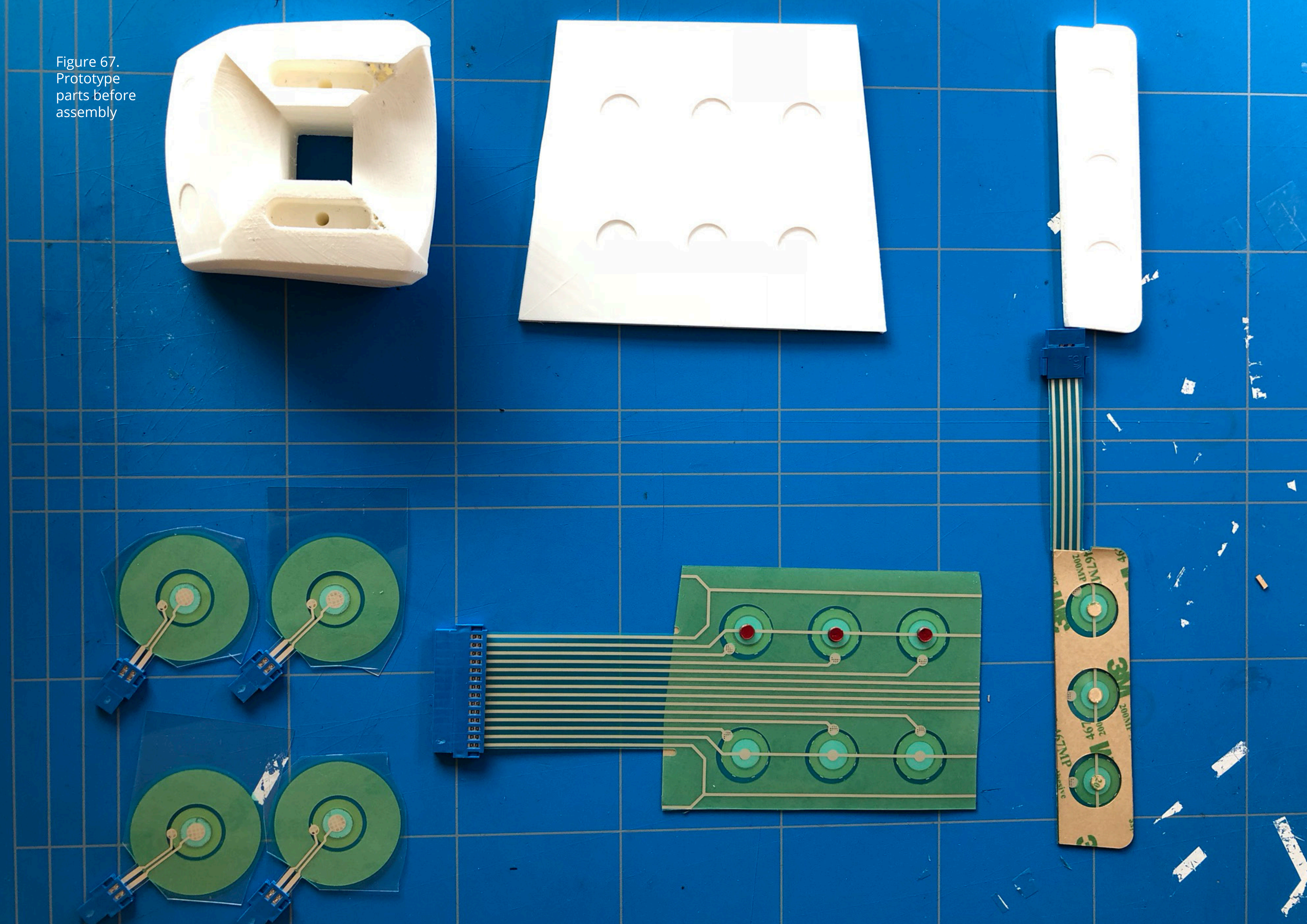


Figure 67. Prototype parts before assembly

05

Prototyping & Validation

Before the design can be handed over to Aito, certain design decisions needed further testing and validation. This chapter will discuss the validation of Technology integration, interface usability and cost analysis for the full demonstrator. The chapter will conclude with recommendations for further improvement of the design and a discussion on the following steps .

1. Prototype Evaluation

To validate the demonstrator, a protype of the vehicle control panel was build. Building the entire mid-console fell outside of the scope of this project and therefore a single control panel was chosen to validate the design.
The Vehicle control panel was suitable because of its variety of haptic interactions concentrated in one surface: local-, global- and floating surface haptic feedback. Also, the application of piezo-based feedback for a complex three dimensional shape such as a gear shifter would be interesting to test, as objects as thick as the shifter had not been tested before by Aito.

Technical Prototype

As the name suggests, the goal of the Technical prototype was to evaluate the technical aspects of the design: The quality of the haptic feedback, the practical application of projection mapping and the implications of the chosen beamer position in relation to the panel. Finally, this first iteration was used to see if the software pipeline described in chapter 4 for linking HapticTouch to Madmapper would be feasible.

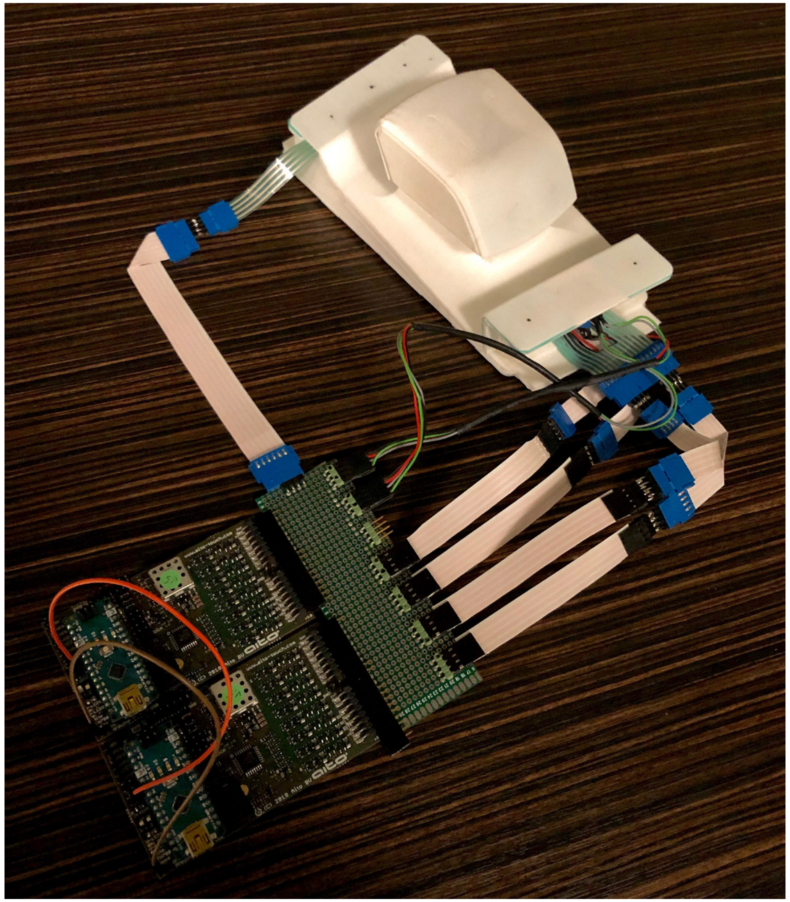


Figure 68. Technical Prototype

Evaluation of Haptic Touch integration

The installation of haptic touch foils was quite effortless. The accuracy of the 3D printed parts were adequate for this prototype, with most of the parts fitting at the first attempt. There were a few issues in terms of design. It took three iterations to get the gear shifter top surface to be mountable without breaking, as it was quite thin. Also the haptic support at the push/pull buttons was relatively fragile, because of the non filleted edges. Overall, the dimensioning of the panel was adequate. The space allocated for wiring proved to be sufficient, but the next iteration should – in terms of electronics – mainly improve the wiring and connector layout.

The most important point of critique applies to the quality of the haptic feedback. The local stack construction on the button row was problematic. Available space for adhesives was limited, resulting in de-lamination of the foil. This had a negative effect on the

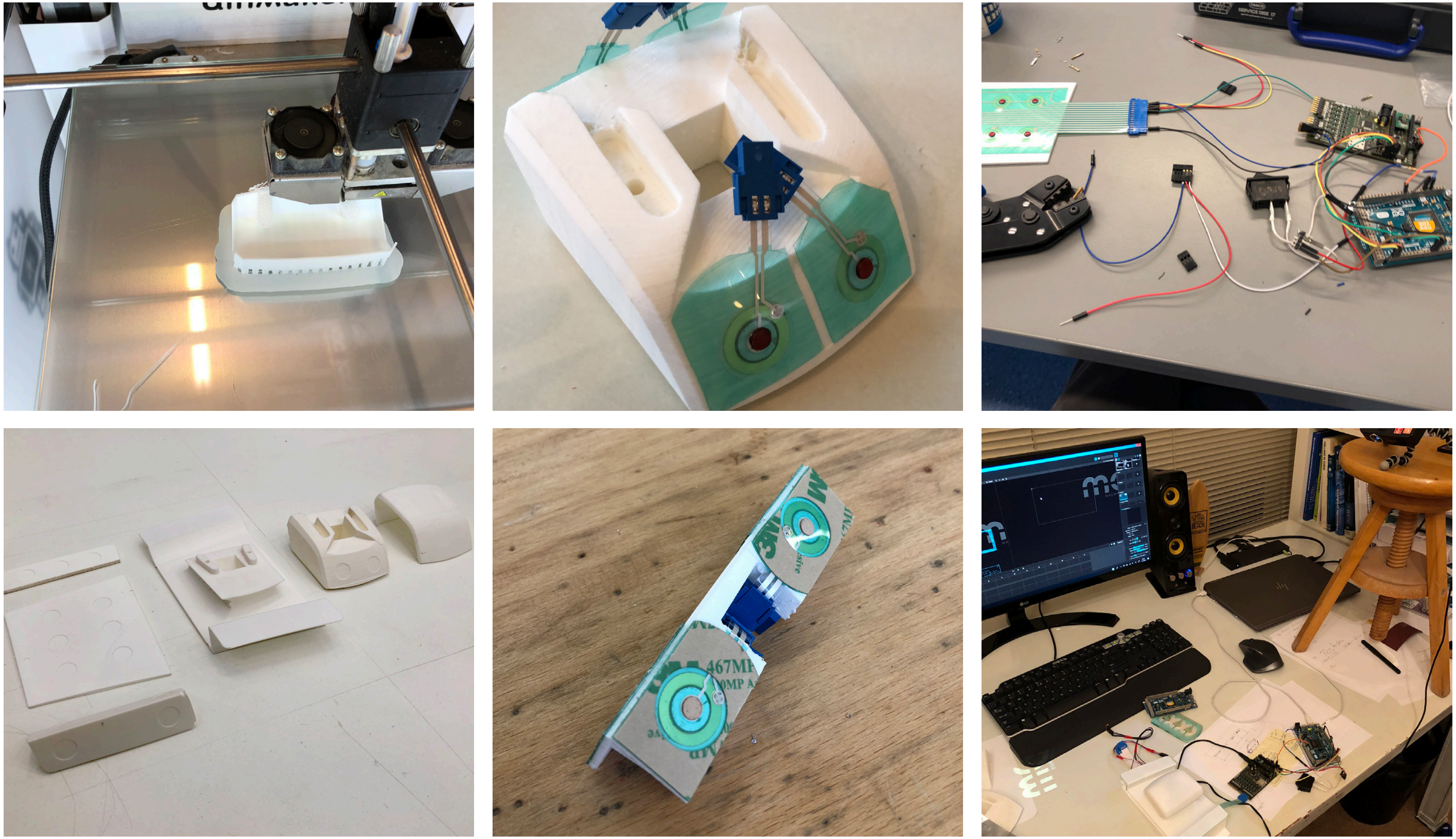


Figure 69. The prototype building process and testing.

feedback quality and was somewhat expected, since the surfaces were not sanded and degreased. Furthermore, the positioning of the pull piezos was not optimal, with the dot of the piezo-discs positioned close to the relatively stiff lower edge of the surface. This also had a negative effect on the strength of the feedback. 12mm Piezos would be more suitable for this location, as they would have more space to move. Overall, the feedback for the other keys was good acceptable.
Piezo feedback from the global stack could be felt through the shifter. The strength however was lower than expected. An interesting observation was that a higher sharpness reduced the actual feedback strength, probably because the elasticity filtered out the acceleration of the piezos.
Suggestions for improvement of feedback for the shifter would be: larger hinges in the top surface, using more piezos in the global stack (only four were used in the test) and maybe also apply bigger 20 mm piezos. These piezos respond a little slower, but this could be compensated with a higher sharpness setting. Because these piezos have more ceramic, they are slightly stronger than the 15 mm piezo's.

Software pipeline test

The initial software tests have been promising. A standard three-button Arduino code, exported from the UX design Studio was adapted to include MIDI functionality. With some help from one of the software engineers in Finland, the code was written in a way that press and release events were communicated as note on/ note off MIDI messages. After the Arduino and MIDI events were visible in MIDI-OX (MIDI connection test software), the Arduino successfully showed up in MadMapper. From there a test was done with a standard MadMapper animation that was triggered through the MIDI input. The test was limited in functionality as no distinction could be made between buttons, but sufficient since the communication between MadMapper and the Arduino host were of primary concern.
Lessons learned from this test were that the chosen library did not work with the Arduino micro boards that Aito generally uses as host, due to processing and memory limitations. The Arduino Due which was eventually used for this test, has a lot more processing power available and is therefore the primary choice when multiple modules have to be connected through I2C.
An Arduino Uno could potentially work as well, as it is mentioned to be supported by the library (tttapa, 2018)

2. Building costs analysis

A key requirement from the design brief is affordability. This section discusses the expected building costs for the mid-console demonstrator. The analysis shown here has been detailed as much as possible to give an indication to the production costs, though this indication remains a rough estimate. The complete cost analysis can be found in the appendix.

Cost breakdown

The building costs have been broken down into the following categories:

Material costs
In this category, materials of larger components that have to be manufactured have been listed.

Production
Costs for machining the listed materials and 3D printing components. This also includes finishing

Parts to order
Catalogue parts that can be ordered directly, like screws, electronics, etc.

Software licensing
Licenses for software packages.

Aito parts
Consisting of the ATH756 demonstration modules and printed electronic foils. The demonstrator is designed with the current stock of foils in mind to reduce costs.

Assumptions

The following assumptions have been made in making this analysis.

- SLS 3D printing costs are mostly affected by volume and density, not the level of detail. Therefor only the volume of the complete control panels have been taken into account.
- Administrative costs of suppliers have not been included
- Taxes have not been included
- The demonstrator is assembled at the Aito office in Amsterdam.

Laser Cutting	amount	Costs in euros
Multiplex 5 mm	6,8 m2	40,14
Multiplex 12 mm	0,1 m2	8,85
startup costs		10,00
laser cutting	91 segments	235
shipping		9,50
Sub-total		299,45

Catalogue Materials	amount	Costs in euros
M5 15 mm Hex socket Countersunk Screws	50	8,16
Rampa nut M5	10	12,57
Sub-total		20,73

3D printing	amount	Costs in euros
All parts SLS Nylon	1	2660,99
Shipping		15,00
Sub-total		2653,77

Projectors	amount	Costs in euros
LG P450UG	2	769,92
Sub-total		769,92

Finishing Materials	amount	Costs in euros
Filling Primer 500 ml	10	74,06
Satin Black spraypaint 500 ml	9	38,7
Shipping	1	6,50
Sub-total		119,80

Software	amount	Costs in euros
Madmapper License (2 computers)	1	359,00
Madmapper Monthly	1	35

Figure 70. summary of building costs for the Mid-console demonstrator. Software is not taken into account for the final price, as there are multiple options available.

Aito parts	amount	Costs in euros
Aito Modules ATH 756	14	385
Sub-total		385,00

Grand Total	4263,08

Cost evaluation

At first sight, building a demonstrator like this does not seem to meet the initial project requirements. However, there are multiple ways to alleviate some of the costs:

3D printing

A significant portion of the budget goes into 3D printing the haptic panels and other functional parts. There is a lot of optimization that can be done in the way these parts are printed, since the total volume and especially the height of the printed volume determines the cost. Choosing a supplier that has a machine with a larger surface print bed in relation to the height may reduce printing cost significantly, as most objects are relatively flat.

In this analysis, next to the haptic panels, other parts such as connectors for the support structure and feet for the legs were included in the SLS printing job. Other 3D printing- or production methods than Selective Laser Sintering may be more suitable for these parts, as surface finish is less important.

Additionally there is also the option of printing the haptic panels with Fused Deposition Modelling and finishing the parts with spray putty and a paint finish. FDM printing is generally a simpler and more effective way of printing and parts produced with this method can be made relatively durable by finishing the parts with e.g. ABS vapor smoothing (source). While being more labour intensive, production costs could be significantly reduced. this could possibly improve the surface quality of the haptic panels as well.

Laser Cutting

Next to Plywood, MDF might be a suitable alternative material. Generally MDF is a cheaper material and has a smoother finish than Plywood, reducing the amount of spray filler needed in preparation for spray painting. Initially plywood was chosen for its higher strength and lower weight (source). Considering the number of segments used in the demonstrator design, a slightly reduced strength might not be an issue. It would be advisable though, due to the above mentioned material properties, to produce the cross member struts from plywood.

Printed Electronic Foils

Haptic and cap sense foils require a significant share of the budget. There are a few side notes however. As mentioned earlier, the haptic foils used in this design are foil designs from previous Aito projects. This means that a large portion of the haptic foils can be sourced from leftovers of application engineering projects, possibly fully eliminating this post from the list.

Capsense is a different story though, as these are more complicated to produce in terms of layering (due to Electromagnetic shielding and the presence of curvature in the panels). In this analysis, the capsense foils are produced at one of the partners of Aito in Belgium (QUAD industries). However, there are methods available for prototyping these foils more cost effectively. One example which was also mentioned in the first concept in chapter 3 was the use of Carbon based electronic inks. These could be easily spray painted on PE foils masked with a circuit design. The downside of this method however is that the quality in touch sensing is sub-par compared to professionally produced foils.

Projectors

As mentioned in the projection mapping section in chapter 4, there are multiple ways for setting up the projectors. The setup in this cost analysis uses two Ultra Short throw projectors to project the interface. In reality, a single projector may also be suitable. Such a projector could also be used for other purposes aside from this demonstrator. Additionally, when presenting the demonstrator at conferences it may be easier to rent the projector(s) locally.

Software licensing

Next to a perpetual license, a subscription based license for Madmapper may be more suitable for Aito. Madmapper offers a monthly subscription license for 35 euros per month. This subscription could then be started only when Aito has to present a demonstrator. For testing and design of the GUI, the trial version would be adequate (although slightly more complex as the trial does not allow to save projects).

3. Recommendations and Further Development

This project was an extensive exploration of aspects associated with building a high-end Automotive demonstrator which covers (most if not all) USP's of Aito HapticTouch technology. The Mid-console design for this project is not set in stone, as this system is designed with flexibility in mind. If Aito would decide to further develop this demonstrator, the main recommendation would be to start small with single control panels (akin to concept 1 from Chapter 3) and when successful, integrate these panels it into a larger scale demonstrator as the one presented in this thesis.

During the design process , a number of other directions for further development came to mind. These directions can also be seen as starting points for future TU Delft projects.

GUI Design

The GUI design has only touched upon in this project, and should be developed more in depth to make optimal use of the potential of HapticTouch. The contextuality aspect of the GUI in this project barely scratched the surface. An interface could be adjusted for certain age groups or feel completely different when driving more competitively. Furthermore, the infotainment system can be considered a graduation project in itself. One direction could be to find out how HapticTouch could make these systems more intuitive for the user (e.g. gesture feedback, machine learning algorithms, etc.). Letting an interaction designer loose on the Mid-console demonstrator can provide valuable insights and new interaction concepts.

Smart- and/or exotic materials

In respect to the visual aspect, exploring new types of smart materials with lighting effects can be very interesting. Applying OLED or Electroluminescent lighting foils underneath partly translucent leather or perforated metal can also function as low resolution displays in areas outside the field of view of the user. Combined with e.g. search haptics, these smart materials can result in intriguing and intuitive interaction concepts, which would be testable with a prototyping platform like the Mid-console demonstrator.

Additionally, the control panels do not have to be produced with 3D printing. What if a panel would be made with LG Himacs/Dupont Corian? The 2012 Peugeot Exalt for example, used a material made from stacked old newspapers for the interior panels.

More HapticTouch instead of cap-sense tracking

Most of the control panels where finger position tracking is needed have to use capacitive sense. The goal ultimately should be to track the finger position by comparing signal values of the individual piezos and that way triangulate the position. This would reduce the amount of components and therfore complexity. For proximity sensing capsense would still be useful to act as a filter for applications where vibrations are likely to be present.

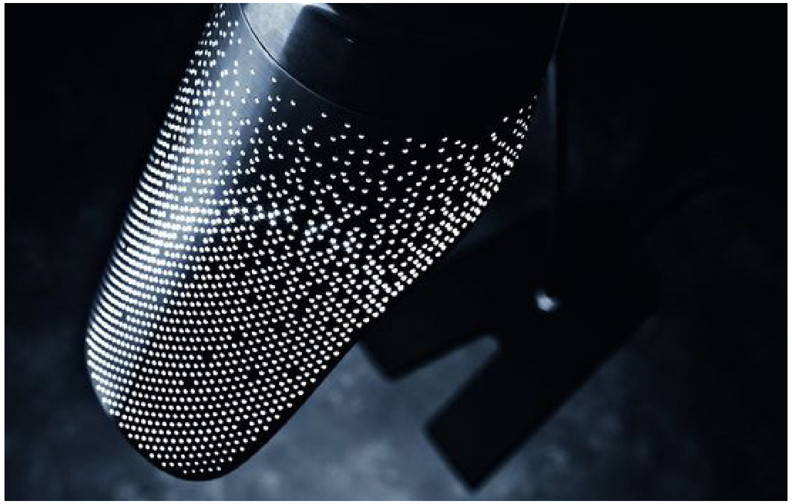


Figure 71. Similar to this desk lamp, using light patterns together with haptic feedback can result in surprising interaction designs.

Figure 72. The 2012 Peugeot onyx concept used a material made of glued newspapers in large surfaces of the interior, giving it a wood-like texture.

Optimize Projection Mapping
Testing of projection mapping in this project has been limited to getting some first insights and experience with the software. Key aspects that were identified during this test were that the resolution, projection angle and brightness are important parameters for the quality of the projected image. Multi-projector setups would have to be explored to maintain the right image quality and increase the brightness in lighter spaces (e.g. conference halls).

Software pipeline optimization
In addition to the projection mapping, the software pipeline discussed in this thesis offers many opportunities for improvement. The use of a game engine like unity could make it relatively easy to create three dimensional interface designs which are relatively easy to build (certainly considering that Aito has multiple programmers in Finland who have already some experience with Unity). Currently, new players in the automotive industry such as Nvidia are proving game-engines can work in automotive GUI's. Experience with these game engines also provides an opportunity for providing more value in consumer electronics markets. Creating a toolset for prototyping

Figure 73. Instrument cluster developed by Nvidia.

GUI's in a game engine can also be of great value for the Interaction Design department at the TU Delft.

Explore relationship active vs passive feedback.
In terms of Haptic Feedback research, the relation between active and passive haptics could be further developed.
It would be very interesting to see how subtle surface features which are amplified with active haptic feedback could provide additional value.

Audio through Global feedback

One aspect which is mentioned in chapter 3 but unfortunately not covered during this project, is the use of the global stacks underneath the display panels as loudspeakers. After all, the piezo discs used for HapticTouch were originally designed as such. Considering that Redux (acquired by Google) is able to this with their proprietary piezo based system proves there is potential here. Aito HapticTouch would even have an edge over Redux, as Aito's system is scalable and not limited to displays. Surfaces in door panels in the interior for example could potentially be turned into loudspeakers, making it possible to integrate speakers with HMI elements. This could potentially reduce construction costs.

Concluding Remarks

With this paragraph, the design process of the demonstrator comes to a close.
During the design process, the effort was made to touch as many aspects as possible. The demonstrator designed during this project is however, a first iteration. There are many things that can be further improved and it is up to Aito to decide if they would like to continue developing this demonstrator.

Apart from the Mid-Console demonstrator design, this progject has shown that a design exercise like the design of the Mid-Console demonstrator, can result in surprising new insights and ideas. Developing for specific apllications without too many restrictions brings associations to the foreground which would never have been considered on a more general level.

If Aito would like to become a disruptive force in the HMI sector, it is important to continue working on demonstrators like the one described in this thesis, as the results of such a process give more concrete directions for technical development.

In relation to the TU Delft, the conclusion can be drawn that there are a lot of avenues for further research relating to Haptic Feedback. As is made clear in this thesis, the rules of interface design change with technologies like AiTO®HapticTouch and this results in new opportunities in creating better HMI's. Research in this field is important, especially with complex environments like car interiors, where safety is always of primary concern. In respect to this, the prototyping methods outlined in this thesis could prove valuable in research applications outside Automotive interior design.

4. Personal Reflection

With the design process finished, now is the right time to look back and reflect on the project. This Graduation project has been incredibly instructive and challenging, but also inspiring and exciting. Looking back, I can definitely say I have grown on both a personal- and professional level.

First of all, this project has teached me a lot about the developments in the Automotive industry. While following the automotive design courses, I always found myself a bit lost because of changing dynamic in this sector. It is fair to say that Automotive design is not as concrete as it used to be and this project has helped me to form a more informed opinion on Automotive (HMI) design.
Also, I found it refreshing to work on a technology driven innovation project. The majority of projects I worked on at the TU Delft were oriented at human centered design problems. Trying to discover how a new technology can create value and truly be meaningful for both the people that use products and the companies that produce them, is an exercise that makes you think differently about how things are designed. I like for example that the end result is quite different as compared to what I thought it would become when I started this project (which in my opinion is always positive).

In terms of the skills I applied during this project, it is safe to say I learned a lot as well. I have become better in programming, designing with electronics and learned a lot about interaction design (something I think is quite valuable in current day product design). In terms of CAD design, combining rhino surface modelling with Solidworks feature based design was something I had not done before. Also, visualizing something abstract as Haptic Feedback interactions, has proven to be a challenging but useful exercise that thoroughly improved my visualization skills in Adobe Illustrator.

Of course there were also a few things that did not go well, with project management beïng primarily the point of criticisim. In hindsight, the assignment may have been too broad for a graduation project. Automotive interior design is quite complex in itself, let alone with a new technology like HapticTouch. On the other hand, this also made the project intriguing.
One could say there were numerous occasions where my own ambition got the better of me and I had to lower my own expectations a number of times. In a group project, my tendency of losing myself in design problems would have probably been contained much sooner. In a way this therefore has been a humbling experience.
Structuring the project has turned out to be a steep learning curve, and I really need to keep working on this.

Project planning and stakeholder management particular will be important focus point for me in the coming years. In the end though, I am proud of the end result. I think both the demonstrator design and the thesis can be valuable for Aito in many ways. Also for the TU Delft, aspects related to prototyping can be useful.

In conclusion, it is nice to see how the courses I followed at IPD and the bachelor came together in sometimes unexpected ways. In that sense, this graduation project has been a true keystone for my time as a student at TU Delft and I am looking forward to kick-off my professional life at Aito

Abbreviations

ADAS - Advanced Driver Assistance Systems
EV - Electric Vehicle
GUI - Graphical User Interface
HMI - Human Machin Interface
ICEV - Internal Combustion Engine Vehicle
OEM - Original Equipment Manufacturer
UI - User Interface
UX - User Experience

06
Appendices

Graduation Thesis Appendix

'Aito Haptic Mid-Console: Design Of An Haptic Feedback Enabled demonstrator for Automotive HMI Applications'
Timeframe: 12-02-2018 until 06-02-2019

Thesis supervisory team:

Chair TU Delft 1st half of the project: Dr. Ir. E. Tempelman

Chair TU Delft 2nd half of the project: Prof. Ir. J.E. Oberdorf

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Student: Pieter Stol
Master Integrated Product Design

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APPENDIX A.

AITO®HapticTouch Technology in Depth

Haptic Touch Technology

AITO®HapticTouch is the core technology of Aito. Over the last few years, Aito has finetuned and expanded a whole ecosystem of configurations and application designs. The following pages will discuss the core elements of the Haptic Touch technology, focusing on the piezo discs, the AITO®Chip and Aito's user experience HatpicTouch parameters.

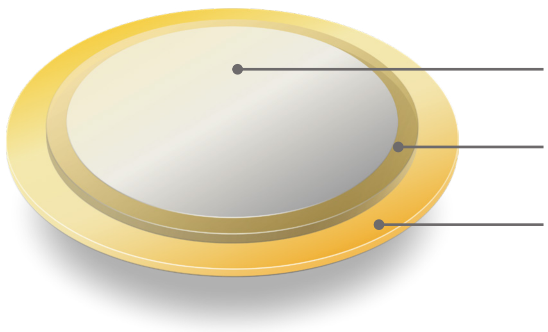


Figure A1. A typical piezo disc

1.1. The Piezo Disc

The touch sensing and Haptic feedback is built around single layer piezo discs, also commonly used in buzzers and speakers (figure A1.).
The unique molecular structure of piezo-electric ceramics causes the material to develop an electrical charge when mechanical stress is applied. In reverse, applying a voltage to the piezo causes it to deform . Piezo-electric materials therefore can be simultaneously used as a very sensitive sensor (able to detect a person's breath) or a precisely controllable actuator (albeit at μm level). This property of being a precise sensor and actuator at the same time is exploited by Aito Haptic Touch and results in the fastest- and, according to Aito, the most natural haptic feedback response currently on the market (Aito BV, 2018a).

/01
In Rest

The piezo disc is mounted onto a carrier, which allows the disc to bend downwards. Because piezo discs, are passive components, no power is consumed.

/02
Touch Sensing

The piezo bends slightly, distorting the molecular structure of the ceramic. This generates a small electric charge, such that the pressure can be determined.

/03
Haptic Actuation

An instant voltage signal of up to 400V causes the piezo ceramic to bend further downward. The tactile and audible sensation is designed to match various physical button presses.

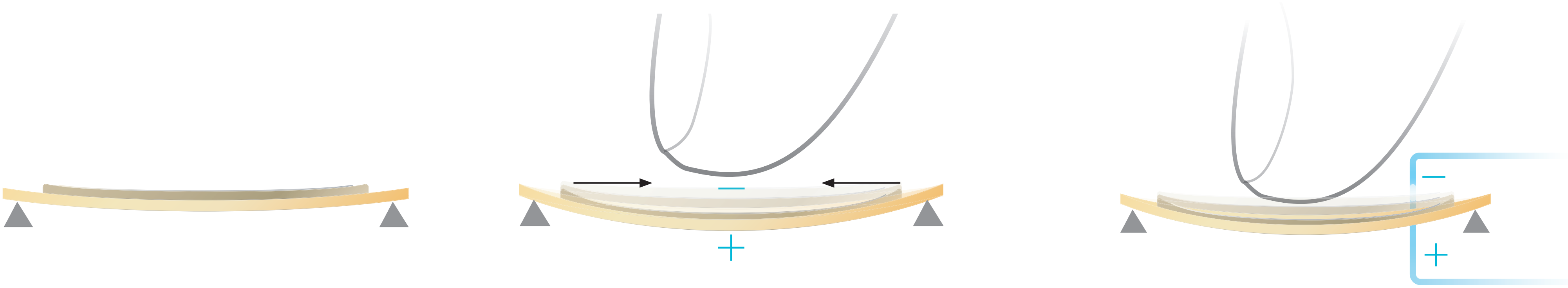


Figure A2. Touch sensing and feedback

1.2 The AITO® Chip

Aito's HapticTouch is designed to monitor (i.e. sense) and Control (i.e. actuate) the piezo disc. The AITO® Chip is the brain within the system. It controls the input and output from/to the piezos and uses an incorporated booster to amplify haptic signals to the appropriate voltage level. By adjusting the characteristics of the boosted signal, a plethora of haptic experiences can be created: From simple click-clack buttons to complexvibration patterns. One AITO® Chip is able to support up to 8 Haptic Touch keys. The chip uses I2C to communicate with other controllers in the User Interface system (e.g. capsense-, display- and symbol illumination controllers (Aito BV, 2018b).

The figures below and on the right illustrate in a simplified way what occurs when a haptic touch button is pressed.

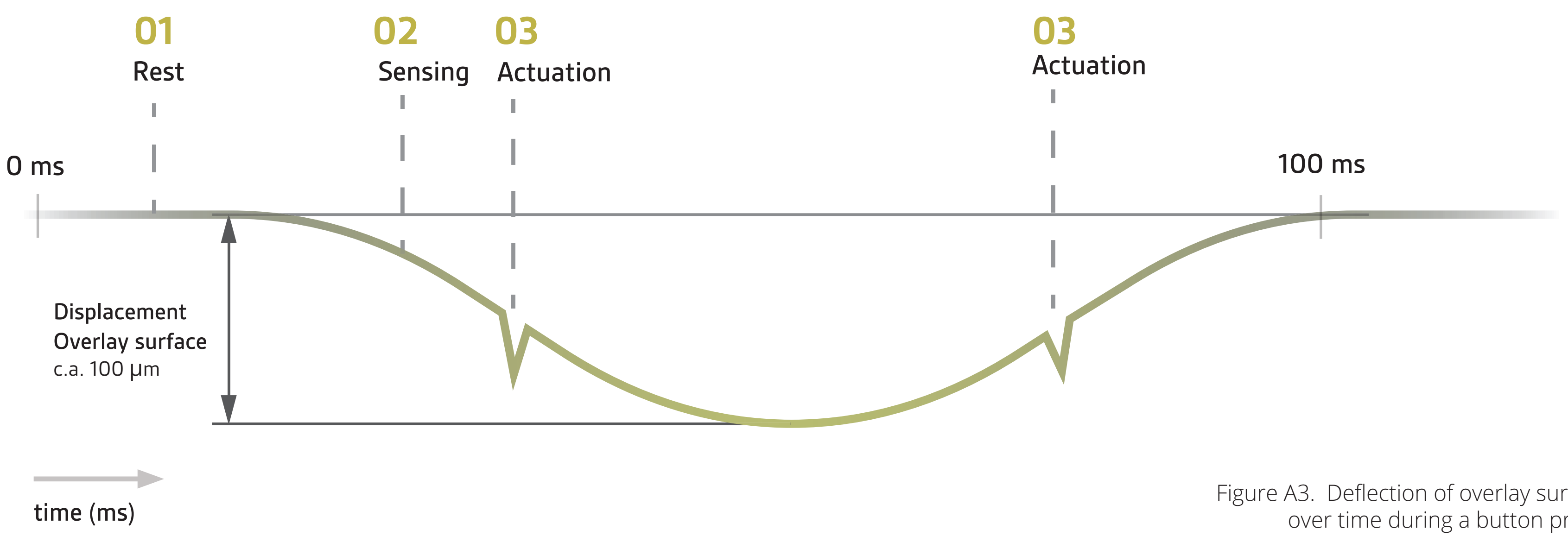


Figure A3. Deflection of overlay surface over time during a button press.

/01
In rest

The circuit consists of the AITO® Chip and one or more piezos. When there is no activity, the chip is in low power mode.

/02
Touch sensing

A finger press causes the piezo disk to deform slightly. The deformation in the piezo ceramic causes a voltage which wakes up the AITO® Chip and if the press meets the configured threshold, a button press is detected.

/03
Haptic Actuating

If a button press is registered, the AITO® Chip immediately applies a high-voltage haptic signal (100-400V) to the pressed piezo. This signal causes the piezo disk to bend within milliseconds. The deformation of the piezo is felt through the overlay material as a tactile sensation similar to a mechanical button.

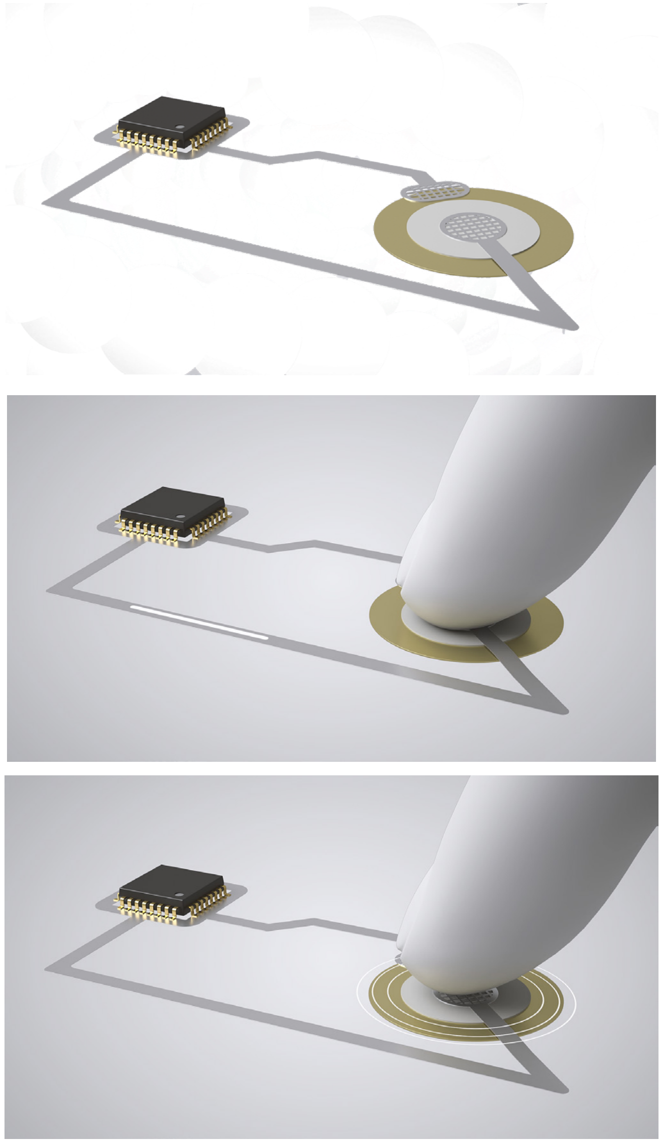


Figure A4. HapticTouch circuit during a button press.

HapticTouch Parameters

By modifying the touch sensing and haptic feedback parameters of the AITO® Chip, a wide range of tactile sensations can be realised: from the basic click-clack feeling of traditional on-off buttons to complex analog buttons with dynamic vibrations patterns at different intervals. These "HapticTouch Parameters" are stored within the AITO® Chip, but they are adjustable by a system host - on the fly - such that the feeling of a user interface can change over time (Aito BV, 2018a). Haptic Feedback is controlled through a number of parameters which can be adjusted within their corresponding ranges. Generally a button press is divided into a press event and a release event (emulating the deformation of dome plates in switches). When Haptic Force Touch is enabled, additional events can be added to the key (Aito BV, 2018c). The figures on the right show the deformation of the overlay surface over time of a Haptic Touch button press.

/01

Sensing Parameters

Specifies the required force and active area to trigger a key press.

Sensitivity

Sets the sensitivity range for triggering a press/release event. This parameter determines whether a key feels "hard" or "soft".

Detection area

Sets the size of the active area where a press can be detected. This is done by comparing input from surrounding piezos to the pressed piezo.

Force Touch

Adds 3D functionality using various force levels to trigger different actions, similar to for example the shutter button of a photo camera. Each level can be assigned with a unique feedback event, with up to 7 levels per key.

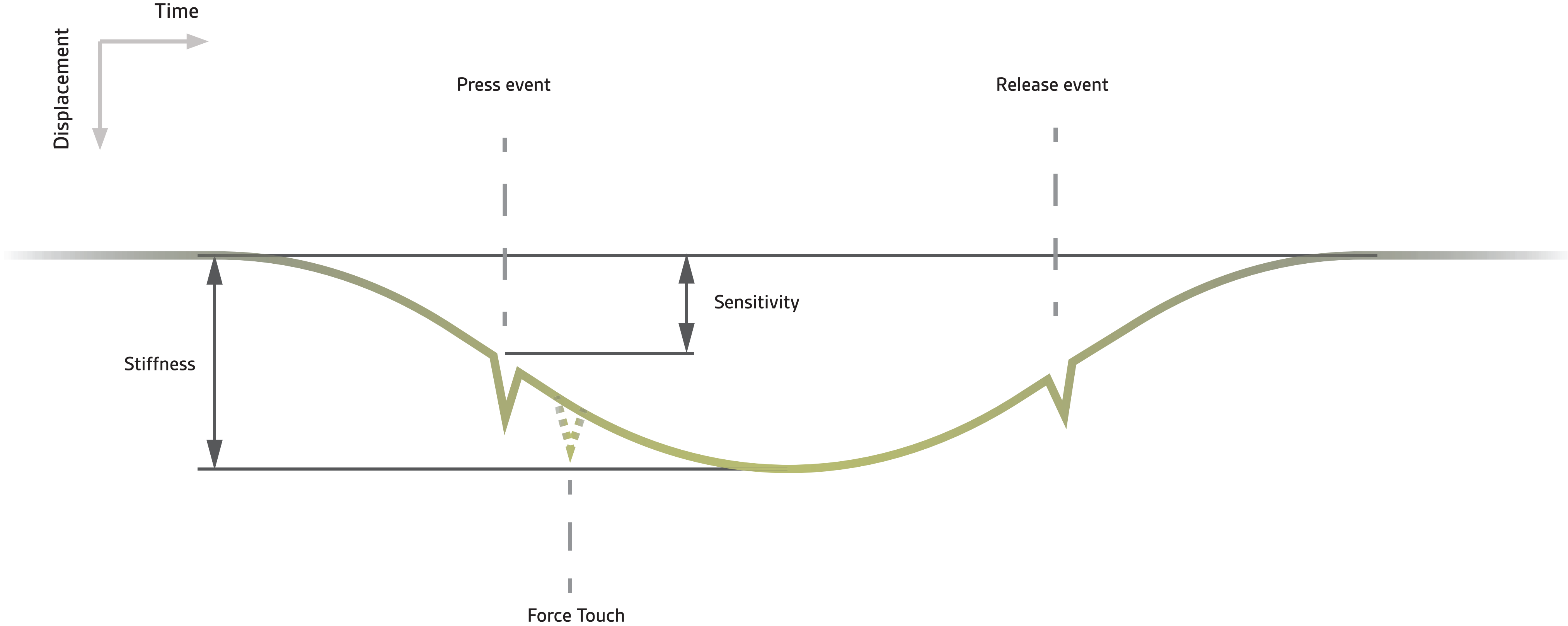


Figure A5. Breakdown of sensing parameters

/02

Haptic Parameters

Each press or release event is driven by an electric signal. By varying the following haptic signal parameters, a plethora of haptic user experiences can be realized. These can also be applied dynamically.

Strength

Controls the amplitude of the signal (i.e. the voltage). Increasing this setting gives a stronger "kick" to the feedback. The analogue scale can vary between 100 and 400V.

Bipolar Drive

Adds a negative voltage of -150V prior to the Haptic Pulse. This increases the delta travel of the piezo, thus giving a stronger tactile feeling.

Sharpness

The sharpness setting controls how "aggressive" the haptic feedback is. A higher sharpness results in a shorter haptic pulse, which causes more overlay surface acceleration and therefor feels "harder". The softest pulse is half a sinus wave lasting for 10 ms and the sharpest possible pulse is a cut sinus wave (in haptic jargon referred to as sharkfin) lasting 3 ms.

Response Delay

Haptic signals can be delayed. when a press/release event occured. The timing sets a delay before the haptic pulse is given.

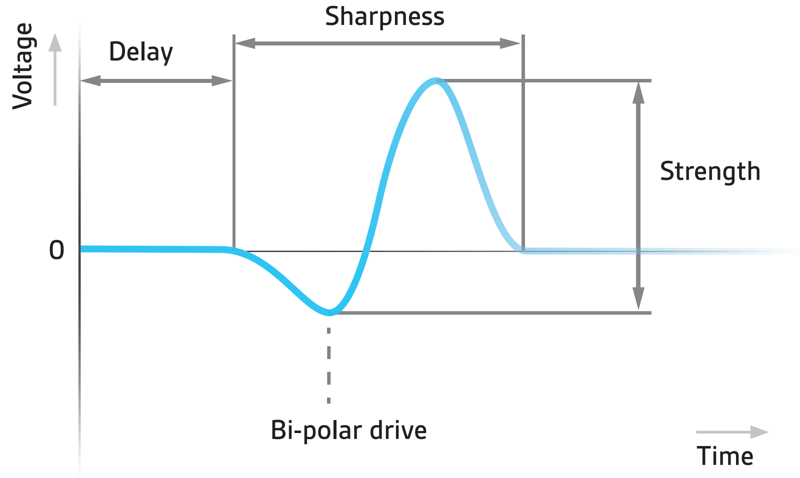


Figure A6. Piezo driving signal parameters consisting of a voltage over time.

/03
Multi-pulse Patterns

The haptic signal can consist of more than one pulse, which makes it possible to create vibration patterns. The following types of patterns can be created:

Vibration patterns
A single haptic pulse can be repeated infinitely. The designer can determine the number of pulses that are repeated (**pulse count**) and the amount of time between each pulse (**pulse interval**). T By controlling these parameters, frequency of vibrations can be controlled and with that the audible pitch of the vibration pattern. his is comparable to traditional vibration motors in e.g. phones.

Burst Patterns
Finally, the vibration patterns can be grouped in bursts, where each burst consists of a specified number of pulses. Again, the number of bursts (**burst count**) and time between each burst (**burst interval**) can be specified. Burst patterns can be used to communicate e.g. error messages.

Dynamic Vibration Patterns
Vibration- and Burst- patterns can be made to behave dynamically. For example, one can choose to add 5 ms to the pulse interval parameter after each pulse, or to increase the strength of a burst group after the previous burst has finished playing.
Basically any of the aforementioned haptic parameters can be made dependend on another parameter.

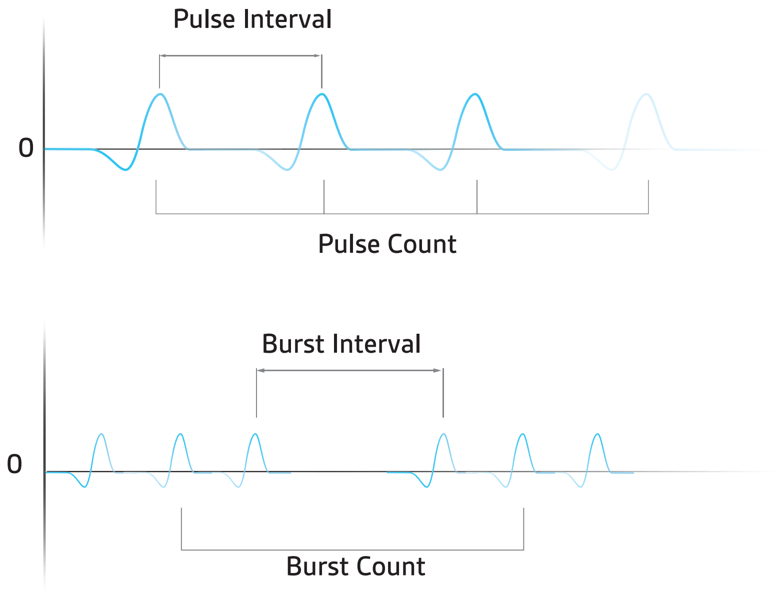


Figure A7.Multi pulse pattern variations

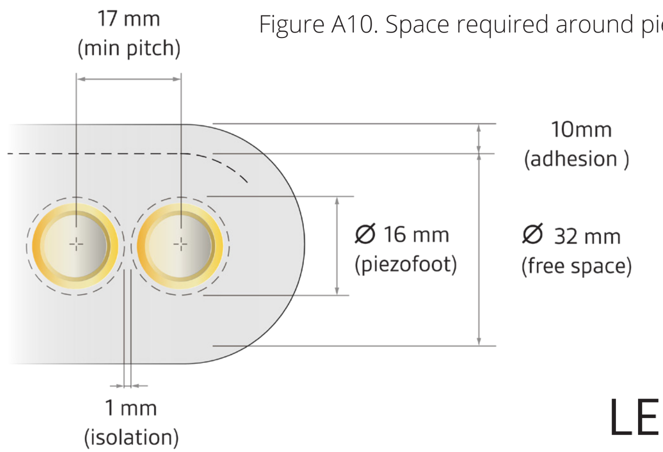
1.3. Haptic Touch Design Freedom

Due to the modular nature of AITO® Haptic Touch, a high degree of design freedom is available when integrating Haptic Feedback in user interfaces. The following pages discuss the basic geometric freedom of a single piezo system, the multi-piezo configurations (stack designs) and supported material finishing options.

Geometric Freedom

To allow for proper functioning of AITO® Haptic Touch there are number of minimal dimensions. Because of the use of flexible electronic foils, Aito® HapticTouch foils can be very thin and flexible. Figures A11 and A9 show the minimum thickness and bending radius of the Haptic Touch stacks. Figure A10. on the right shows the minimum distances relating to piezo positioning.

Figure A10. Space required around piezos



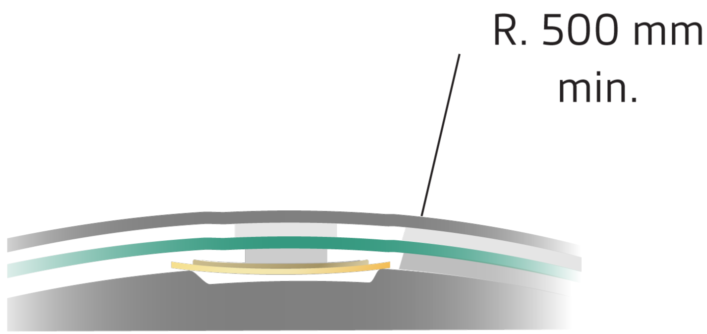
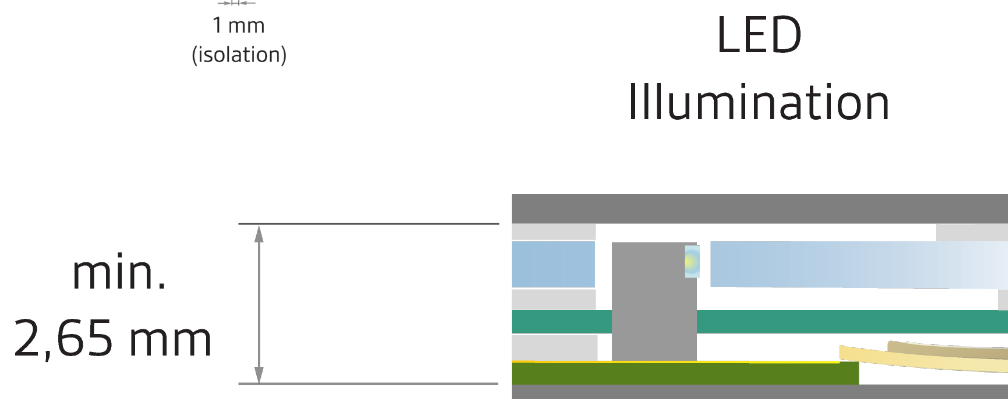


Figure A9. Max curvature radius



Stack Designs

There are three general design configurations or stack designs for integrating Haptic Touch in products: Local, Global and Hybrid. Each method has its advantages and disadvantages.
Product requirements such as the degree of design freedom, overlay material (or the other technologies used in the interface, eg. capsense, LCD, OLED, etc.) will determine which stack is suitable to choose.
These designs are not rigid and it is possible to combine these designs if the application demands it.

Local

This type closely resembles traditional buttons. Every piezo acts as a single key. With this stack design, thin, seamless and durable interfaces can be realised. This stack design also allows for LED symbol illumination. The main downside is that - depending on the material stiffness - only thin overlay materials can be used (0,2 - 1,5 mm)

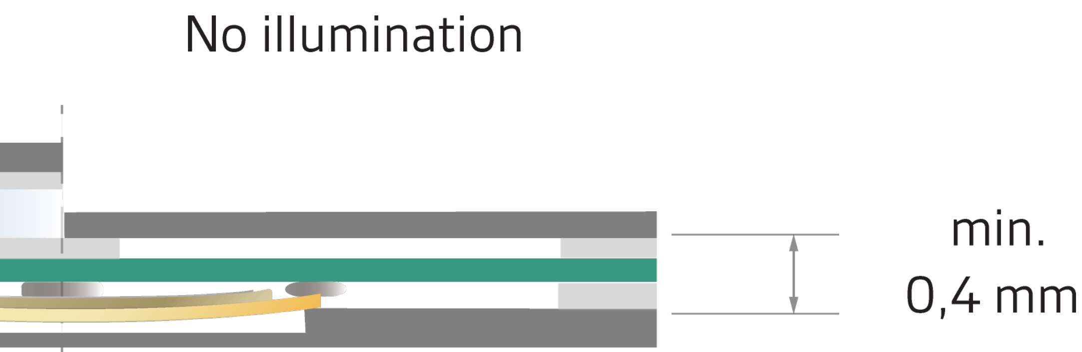


Figure A11. Stack thickness with- and without LED lighting.

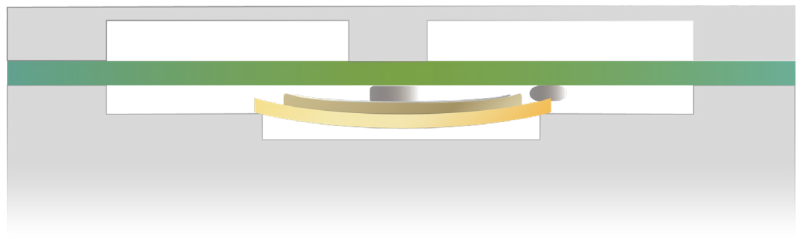


Figure A12. Local stack design

Global

By suspending the overlay surface above multiple piezos, a trackpad-like interaction can be accomplished. The AITO® Chip is configured to actuate all of the piezos at the same time, resulting in movement of the entire surface. Because there is no connection between the overlay surface and the haptic stack, more complex and thicker surfaces can be actuated. This stack design is particularly suitable for LCD displays. The main disadvantage is that capacitive sensing is needed for finger position tracking and an apparent gap in between the piezo foil and overlay.

Hybrid

The stack design is similar to the floating surface stack, except there is no visible gap in between the overlay surface and the carrier.
To ensure enough elasticity for piezo movement, the thickness of the overlay surface is limited to 2 mm. This thickness is enough for the integration of OLED in the overlay surface. This stack supports local key sensing. For global sensing, capsense is needed.
The Hybrid stack design is mostly suitable for applications where space is limited and a seamless finish of the overlay surface is needed (such as tablets or smartphones).

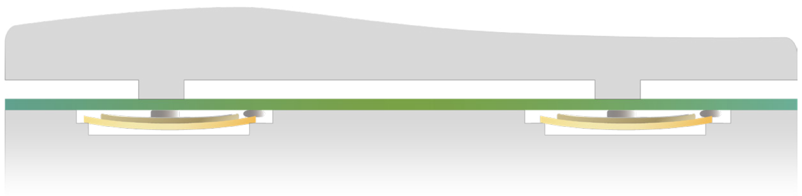


Figure A13. Global Stack design

Figure A14. Hybrid Stack design

Overlay Surfaces

AITO® HapticTouch allows a wide range of overlay materials, as long as the limitations of the choosen stack design are taken into account.
Because thickness of the overlay surface is generally the limiting factor in choosing an overlay material (mainly with the local stack design), a wide range of material types can be used (e.g. textiles, leather, metals, wood vineers, glass and plastics)
When combined with LED/OLED symbol illumination, dissipating interfaces can be realised which are only visible when needed.

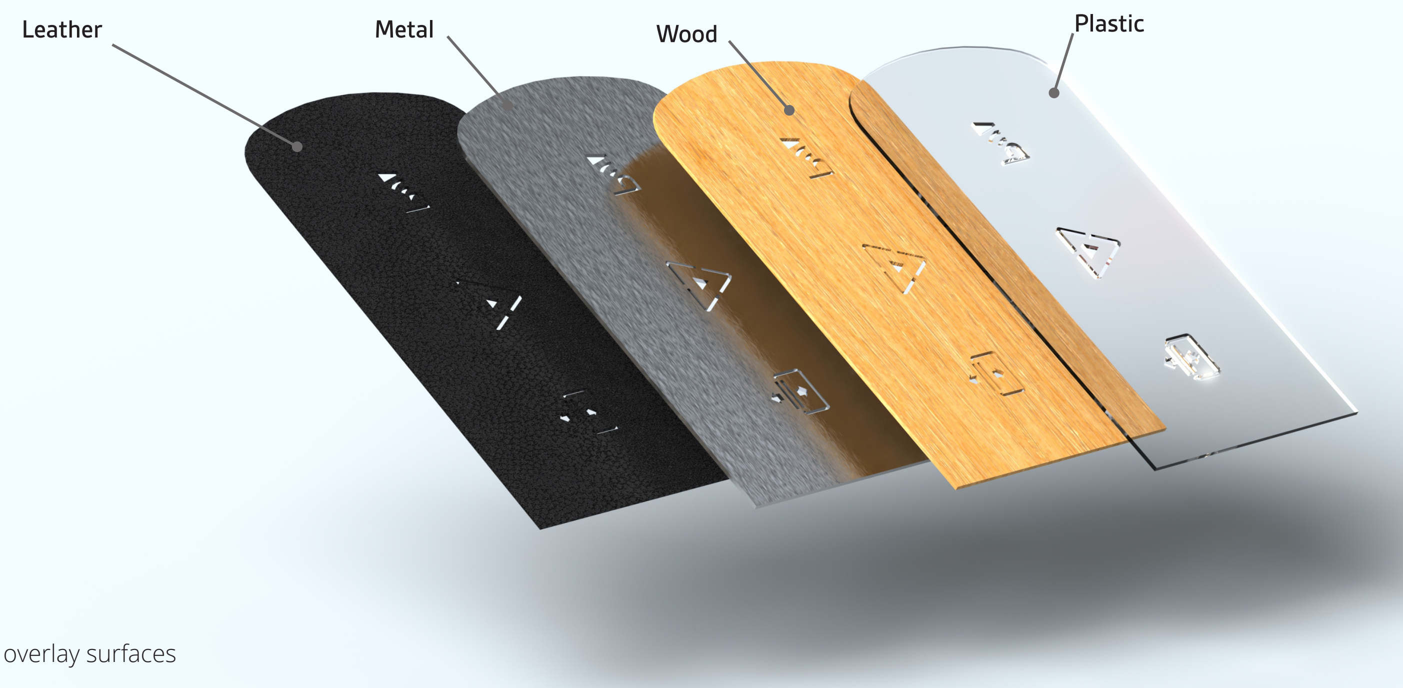


Figure A15. Examples of overlay surfaces

APPENDIX B.

Automotive Industry Trend Analysis

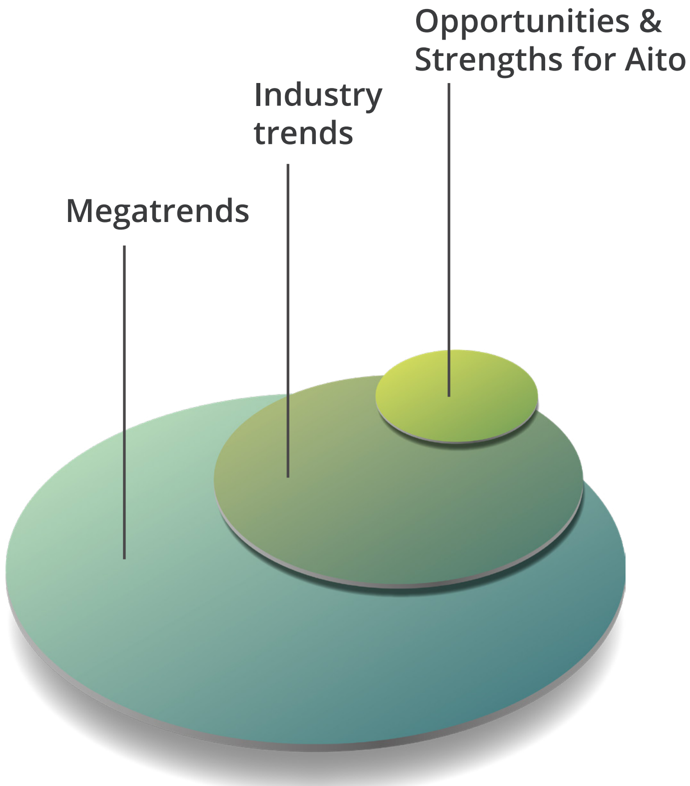


Figure B1. Structure of industry analysis

Megatrends

Four megatrends are at the root of current developments in the Automotive industry. These megatrends will be shortly discussed on the follwoing pages. These global trends provide the necessary context for the key industry developments in the Automotive Industry.

Demographic trends

One of the most important developments is the increase in world population. By 2030, the world population will have grown with 1 billion. Across the regions, the change in demographics are very different. Populations in western countries are getting increasingly older because of improvements in healthcare and a declining birth rate.

This aging of the population has some profound effects on the spending patterns in western countries (pwc megatrend source), as patterns of older age groups are different from those of younger age groups. In contrast, in Africa, India and East-Asia, the populations are growing, which results in a much younger population, with their own set of expectations. For example, 30% of the Chinese total population is from the 1980-1990 cohort and this cohort is growing more affluent and turning their attention to the countries car market. These highly connected consumers will have different demands compared to their European counterparts. Next to the population growth, the prediction is that 60 percent of the world population will be living in urban areas. This urbanisation is currently accelerating (each week additional 1.5 million people are moving to the cities) and will result in an increase in the number of megacities in the world. The increase in urbanisation will also apply to Europe and North America. This Worldwide, inhabitants of the cities consume 75 percent of the natural resources. This raises the question if existing infrastructure will be able to support this.

Economic power shift to the East

Economically, power is shifting from the west to the East. The US economy is losing its influence over the global economy, while in Europe growth is also sluggish and fragile. Meanwhile, China and India are enjoying sustained economic growth. These emerging market economies are increasingly important in international finance and this already has had clear effects on the automotive industry, with cash affluent Chinese companies buying themselves into western automotive groups and acquiring/merging with western brands. Also most of the current growth in the automotive industry is generated by the upcoming markets, while growth in Europe and the US - which experienced a boost during the last few years due to more jobs, rising wages, low interest rates and low gas prices - is flattening. (source needed).

Climate Change and Resource scarcity

Climate change is a problem which is increasingly growing in urgency. The effects of climate change are starting to manifest itself while the solutions are implemented at a pace which seems to be too slow to meet the goals set in the Paris Climate agreement. This is further complicated by the worlds expected population growth and the electrification of developing countries. Since 14% of the current global CO2 emissions are produced as result of the worlds transportation needs, automakers are forced by policy and consumer demand to create more sustainable ways of transportation. This means OEM's have to make a radical shift from internal combustion engine based platforms towards electric with non-fossil fuel power storage solutions.

At the same time, the increasing world population and emerging markets put a higher pressure on the living environment because of an increasing demand on natural resources. Humanity currently uses resources at a rate 50% faster than they can be regenerated by nature (source). The metal price declines of the 20th century, for example, have been negated by a price jump of 176% from 2000 to 2014. Also 80% of the countries consume more biocapacity (e.g. cropland, fisheries, forests) than is available within their borders. Rare earth metals (like copper, zinc, tin and nickel) have seen an exponential rise in production and based on the levels used in western lifestyles, there is no longer enough copper to meet the demands of the future global population.
For a resource intensive industry like the automotive industry, resource scarcity is a significant issue. The increasing use of electronics and the electrification of powertrains in cars are for a large part dependent on rare earth materials such as, for example, cobalt and nickel for batteries (source). This raises affordability issues and with that will influence the adoption rate of electric vehicles (source).

Upcoming disruptive technologies

A number of new technological breakthroughs will have a substantial impact on organisations, consumers and markets where interaction between organizations and consumers take place. According to PWC the technologies which will have a large impact are:

- big data, cloud computing
- dna-sequencing
- energy storage
- advanced robotics
- Artificial intelligence
- internet of things
- mobile payments
- nano-technology
- 3D-printing

These technologies promise increased efficiency, better alignment of supply and demand, enhanced influence of consumers on company processes and products (source). On top of this these technologies enable new types of services, products and product/service combinations. New technologies also allow consumers to take responsibilities away from organizations.

Of the above mentioned megatrends, new technologies will have the most visible impact on the automotive market, as these are increasingly beïng used to develop new mobility concepts which are supposed to mitigate economic and environmental issues and leverage the opportunities they provide.

Industry Development 1.

Urban millennials are determining the direction of the industry

The prediction on which target group will be most influential differs per age group and sales region. In general the expectation for Europe and the US is that 50 to 60 year olds will still be the biggest sales group, especially for premium cars. These customers are generally oriented towards traditional mobility concepts and will look at the development of new mobility solutions with a degree of scepticsim. Inevitably though, the percentage of traditional customers will decline and automakers will have to appeal to younger generations to create customer loyalty (Kuhnert, Stürmer, & Koster, 2018).

The expectations of these younger generations are quite different compared to their predecessors and this seems to be a constant among regions. Generation Y and Z are more pragmatic compared to their predecessors and will start buying cars at a later age. This can also be seen in the share of young people who hold a driver's license, which is declining (Mohr, Kaas, Gao, Wee, & Möller, 2016).

The big difference is that these generations buy out of need, not necessarily out of want. In urban areas in particular, the hassle of owning a car seems unattractive and expensive. This means multi-modal transportation is more appealing. Also, these generations starting to lease more as they can enjoy the benefits of owning a new vehicle at a low price point with the latest features. This is seen as an opportunity for OEM's, as a positive first impression can result in a long lasting relationship. This is strengthened by the desire of Generation Y and Z to express themselves through branding (Loyalty Facts, 2016).

Especially in Asia, where in terms of demographics younger generations have a larger share (China and India), there will be an increasing demand for new mobility concepts such as ride sharing and ride hailing services. In urban areas, services like Didi Chuxing are actively beïng embraced, also because of a push from the government to reduce congestion and pollution ((Kuhnert, Stürmer, & Koster, 2018).

Important to note is that traditional car ownership will not go away, as above mentioned developments mainly cover urban areas. In rural areas traditional ownership is expected to remain the norm (Kuhnert, Stürmer, & Koster, 2018).

Figure B2. “Grow-Up” the ambitious ad-campagne of Mercedes where the company tries to connect with younger generations

Industry Development 2.

New Mobility concepts

To meet the changing demands of the customers, manufacturers are expected to experiment more with new mobility services, mostly focused on urban areas. Today, consumers use their cars as “all-purpose” vehicles, no matter if commuting alone or taking the whole family with them. In the future it is expected that consumers want more flexibility to choose the best solution for a specific purpose on demand (Mohr, Kaas, Gao, Wee, & Möller, 2016).The earlier mentioned affordability issues play an important role with this. According to PWC, carmakers will become suppliers of connected car packages, which comprise of advanced vehicle management and consumer/commercial features. These packages are then used through external companies and specialist service firms. These firms will market these with additional consumer services, such as internet and cloud services, which add to the driving experience. Suppliers are expected to get more revenue from ADAS systems, Connectivity, infotainment and HMI systems (Viereckl, et al., 2016). New mobility services will require more specialised vehicles, such as vehicles for long distance travel and vehicles for daily commuting. OEM’s have been teasing mobility concepts of more specialised vehicles at autoshows and conferences the last few years, with

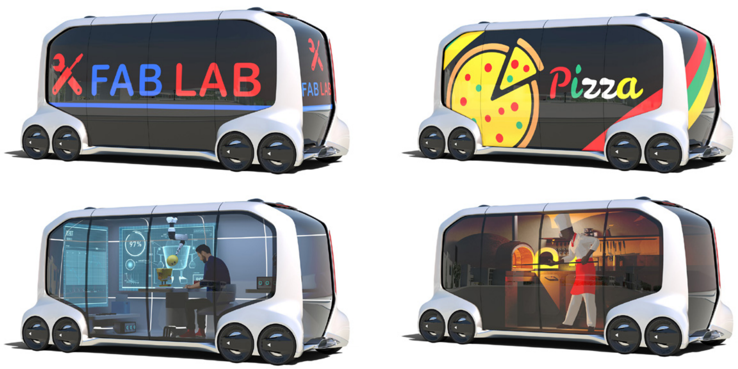


Figure B3. Toyota’s e-palette concept envisions standardised pods which can be rented to perform certain commercial functions

pod-like urban services such as the Renault EZ-go and Toyota e-palette (Reichert, 2018). Cars which are used for sharing and ride-hailing services will likely be replaced more often due to high usage, which is expected to correct the decline in unit sales for privately owned cars (Viereckl, et al., 2016).
Privately owned cars are unlikely to disappear in the coming decade, but won't be immune to change either. Some brands hint to the car as an extension of the home. Currently, battery powered cars like Tesla can be used as a storage solutions for renewable energy.
Other relationships might also emerge. With the Renault Symbioz concept, Renault presented a car which would be part of the living room.

HMI's for mobility services need to be generic in the way they are built while feeling personal to the customers of these services. The configurability of Haptic Touch can be a solution in bridging this contradiction.

Figure B5. The Renault Symbioz is designed to have a symbiotic relatiionship with the owners house and functions as an addiional living room.

Industry Development 3.

Electric Drivetrains

Where a few years ago a handful of brands would only look at developing electric cars to appease legislators, currently most brands have an (upcoming) electric car in their model range. This electrification has a significant impact on the way cars are beïng designed. Heavy battery packs need be compensated in the construction of the body and as a consequence interior are simplified and stripped (by Tesla marketed as minimalistic). While battery powered cars are currently the norm in terms of electric cars, other power storage solutions such as for example hydrogen fuel cells may be an alternative worth developing, although proponents are struggling with the chicken or the egg problem concerning infrastructure and available car fleet .

The trend of electrification is expected to continue and depending on the regional to local level of consumer pull and regulatory push the share of electric cars could range from 10 to 50 percent of new vehicle sales. Rural areas are expected to adopt electric cars at a slower rate due to a lack of infrastructure.

An interesting development accompanying electric cars is drive-by-wire implementation. Drive-wire systems replace hydraulic and mechanical technology by electric actuators for basic vehicle operations. While already widely beïng used in the aircraft industry, the automotive industry has been slow due to safety concerns of customers and weary regulators (Parsania & Saradava, 2012).

The possibilities are attractive though. Less maintenance, low-weight, better accuracy and more flexibility in vehicle configurations are good reasons to keep developing these systems and drive by wire has the potential to radically change the way cars look today. These systems are slowly finding their way into cars. The 2018 Audi a7 features optional all wheel steering, where the electronically actuated rear wheels help in steering the car.

Autonomous driving systems are expected to be an important stimulant to further pursue drive-by-wire as well as the need for more efficient fuel consumption.

Figure B6. The Jaguar E-pace, one of the many electric cross-overs beïng released in 2018.

HMI’s need to become cheaper and lose weight to compensate for the electrification of cars. With Haptic Touch, suppliers could create standardised haptic components for interiors in high volume, reducing cost and complexity. Car manufactures would be able to integrate these components and through software make the haptic feedback brand specific.

Industry Development 4.

ADAS to Autonomous

Something that until a few years ago seemed utopian is autonomous driving. The advantages are clear, just to name a few: the ability to work while commuting, the convenenience of using social media, resting while travelling, etc. (Viereckl, et al., 2016). Currently the primary challenges are pricing, consumer understanding and safety/security issues. These are the hurdles which have to be overcome before autonomous driving is widely accepted.

Advanced driving assistance systems (ADAS) are paving the way towards fully autonomous driving. The most advanced level of autonomy currently on the road is level 3 and numerous incidents have shown the technology has not matured enough to move to the next level. While car manufacturers have to make autonomous systems more reliable, regulators have to figure out who is liable in an accident where the car would be driving autonomously. Is it the driver or the car manufacturer who is responsible?

Meanwhile consumers need to learn to trust autonomous cars. Autonomy will add a new interaction layer to user interfaces in cars. Especially in the coming years, cars will have to communicate their situational awareness and manoeuvres to win the trust of the driver.

Interesting side effect is that the advent of autonomous systems has already led car manufacturers to fantasize what more they can do with the interior of cars. This in a way is remarkable, as only the driver is beïng relieved from his/her task, while other passengers have always been free to do what they want. This development seems to be also driven to the reduced amount of space taken up by electric drivetrains.

Nevertheless, the last few years a large number of car companies have presented their vision on the functionality of future interiors, ranging from living room like to more restraint concepts.

The expected increase in features and activities is a problem for the usability of car interfaces. Because Haptic Touch is configurable through software, interfaces which use Aito technology can become contextual, resulting in less clutter and a more intuitive interface. Also, haptic feedback can aid in communicating to the driver what the car is doing.

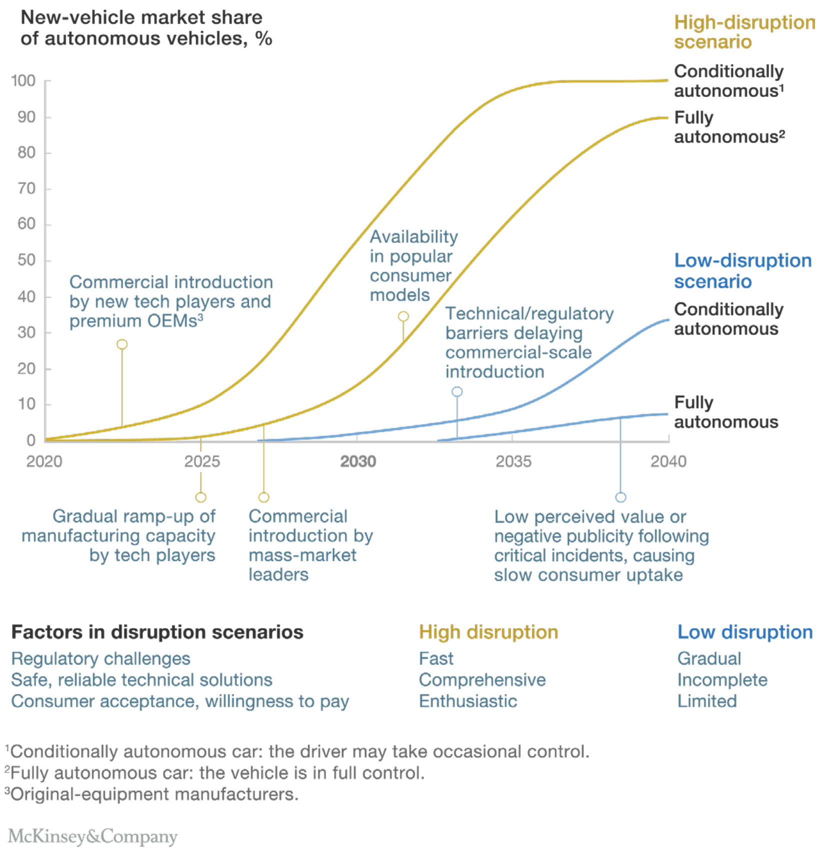


Figure B7. Disruptive scenarios for ADAS to Autono

Industry Development 5.

More Versatile Interiors

As said before the electrification of cars and the development of autonomous driving systems is changing the meaning of car interiors. Infotainment systems are growing in importance and car manufactures are putting more displays into their interiors. It seems the bigger the display, the more luxurious the car (e.g. Mercedes s-class and more recently the at CES presented Byton). These displays are evolving rapidly, making cars which hit the market just a few years ago look outdated with their smaller screens.
The introduction of more displays has an important side effect, which is that it is becoming harder for OEM's to differentiate from each-other in terms of interior design. Design of Graphical User Interfaces are getting more important and need to be updated yearly - similarly to smartphone GUI's - to prevent beïng perceived as outdated (Walsh, 2017)
The autonomous concepts of the last few years often feature a living-room like feel, with couches and rotatable seats. How fantastical these concept may seem, the main hurdle in the way of extravagant living room like interiors with rotating chairs is safety. Experiencing a head-on collision while sitting sideways in a car can result in serious injury and even death. Placement of airbags in an interior like this is a design nightmare, so it is unlikely in the coming decade that - until autonomous systems can prevent accidents - this type of interior will be implemented in cars.
A common thread of this living room like versatility however is that interiors have to adjust themselves to the context the car is used in. This is a logical outcome of a more connected car. Where ten years ago most cars would only feature an audio system as entertainment feature, a car connected to the internet would support a lot more activities consumers could perform. In terms of physical interaction this poses new challenges and OEM's are experimenting with touch interfaces, voice recognition, gesture controls, etc., anything to try to make the interior more intuitive. Prioritization of functions which are relevant to the context the car is used in, is inevitable. For example when commuting,

the driver may switch to an autonomous driving mode to finish some work. The interior would adjust itself to create suitable work environment while presenting only autonomous related driving controls. When driving the car more sportively, a car could display functions that would enhance the driving experience.
As an added complication, the introduction of audio-visual entertainment in cars for each individual makes it necessary to take measures in preventing annoyances. Each individual should be able to carry out their activities without disturbing each other. This is something car manufactures are acknowledging and interior concepts like the BMW i Inside Future Sculpture use noise cancellation in the headrests to let each individual experience their own entertainment without annoying each other.
Personalisation is also a driver for more versatile interiors. Especially in cars which may be used in shared mobility services this is expected to be important to differentiate from public transport. Cars should recognize the person entering the car and automatically adjust the car to his/her preferences.

The expectation in the next few years is that with the introduction of more ADAS features, cars will get more connected services as well. Seating arrangements are unlikely to change much, apart from front seats moving forward or backward depending on the involvement of the driver (Volvo interior concept).

When interiors need to become more versatile and adaptive, interior elements need to have space to move, fold and rotate. This means these elements have to become lighter, thinner and maybe even flexible. The low hardware footprint of Aito Haptic Touch can be a solution to this problem.

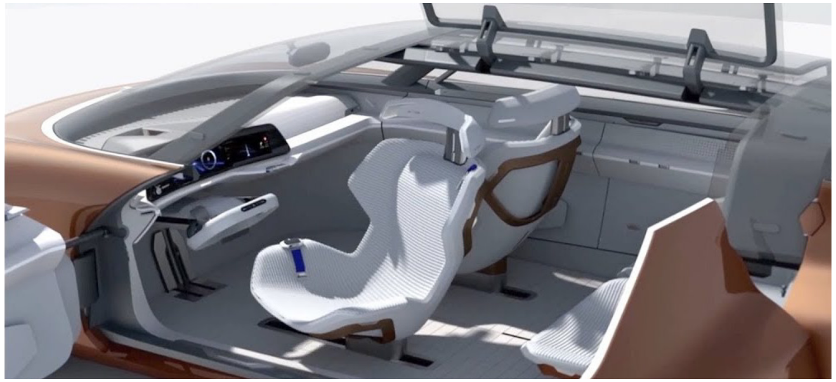


Figure B8. Renault symbioz, a concept car with a highly versatile interior.

APPENDIX C.

VRIO analysis

The VRIO table

A useful starting point for assessing Aito's company strengths, is a Vrio analysis. This analysis is used to find the company's sustainable competitive advantages based on the parameters Value, Rarity, Inimitability and the level of organisation of an asset within the company.
Tangible and intangible assets of Aito have been identified for the VRIO analysis. Tangible assets could be products or patents. Intangible assets are for example certain expertises and company relationships. The tables on the following pages listzzz all the assets that were considered with their respective scores.

1/ Technology

In terms of the Technology, Aito has a generally favorable position. The HapticTouch technology is flexible in application and provides a high degree in design freedom, both in Hardware and Software. All the capabilities that are related to the features of the AITO® Chip can be consideredas a sustained competitive advantage. Local Touch and Sensing is a key capability. Due to the reliance on capsense for global designs, global feedback is considered currently a temporary advantage.

Asset and Capabilities	Competitive implication	1. Valuable	2. Rarity	3. Inimitable	4. Organised
AITO® Chip can handle all stack configurations and settings	Sustained Advantage	Yes	Ye	Yes	Yes
Multiple stack designs available	Sustained Advantage	Yes	Yes	Yes	Yes
Local Touch Sensing and Haptic Feedback in one solution	Sustained Advantage	Yes	Yes	Yes	Yes
Global Haptic Feedback	Temporary Advantage	Yes	Yes	No	n.a.
High Degree of Design Freedom in for product integration	Sustained Advantage	Yes	Yes	Yes	Yes
Use of off-the shelf components for stack design	Temporary Advantage	Yes	Yes	No	n.a.
Integratable with a wide range of symbol illumination and display technologies.	Sustained Advantage	Yes	Yes	No	n.a.
Feedback is adjustable in real-time with a wide range of settings	Sustained Advantage	Yes	Yes	Yes	Yes
Automotive Certified (AEC-Q200)	Temporary Advantage	Yes	Yes	No	n.a.

2/ Expertise & Patents

One of the most valuable assets for Aito is the amount of experience and knowledge on integrating and designing products with piezo-based Haptic Feedback. Next to the development roadmap, feedback from client projects is used to develop features that further improve the position on the market. Key in this is the available specialist knowledge in software development and electronics engineering. In the VRIO they are considered a Parity, but having these capabilities in house is still very valuable.

Finally, Aito's patents are crucial assets as they provide the foundation for all other activities.z

Asset and Capabilities	Competitive implication	1. Valuable	2. Rarity	3. Inimitable	4. Organised
High level of expertise on Piezo based mechanical stack designs.	Sustained Advantage	Yes	Ye	Yes	Yes
High level of expertise on Piezo feedback driving signals	Sustained Advantage	Yes	Yes	Yes	Yes
Expertise in software development	Parity	Yes	No	n.a.	n.a.
Expertise in electronics engineering	Parity	Yes	No	n.a.	n.a.
Patents on mechanical stack design and system architecture	Sustained Advantage	Yes	Yes	Yes	Yes
Patents on Tactile and Acoustic signals	Sustained Advantage	Yes	Yes	Yes	Yes

3/ Products

As the Aito Chip is the emodiment of the proprietary technology of Aito, this is an asset which provides a clear sustained competitive advantage. The modules are more or less prototyping tools, which are relatively expensive to develop and of which the electronics circuits are patent protected. The UX design Studio is a tool which is extremely useful as a prototyping tool. It is however interface software to make programming the Arduino Hosts easier. Software with similar functionality could in theory be build by other parties. Finally, the design guidelines offer clients instructions for integrating AITO Haptic Touch in their products.
Finally, the guidelines translate aspects found in Aito's patents for integration in products. Some of the less protected aspects however could be imitated by examining products that use Aito HapticTouch.

Asset and Capabilities	Competitive implication	1. Valuable	2. Rarity	3. Inimitable	4. Organised
AITO Chip	Sustained Advantage	Yes	Yes	Yes	Yes
Aito modules	Temporary Advantage	Yes	Yes	Yes	Yes
Aito UX design studio	Temporary Advantage	Yes	Yes	No	n.a.
Aito Design Guidelines	Temporary Advantage	Yes	Yes	n.a.	n.a.

/4. Company Relations

A number of relationships Aito has with other companies has helped/helps the technology of Aito moving forward. The development relationships with piezo element manufacturers is valuable, because they help to simplify stack design and improve the haptic performance through hardware changes in the piezo elements. These changes are not exclusive to Aito though and while it does not happen currently, other companies could also partner with these piezo suppliers to improve haptic performance.
Next to the piezo element suppliers, Aito also has a large number of projects at automotive companies, ranging from OEM's to tier 1 suppliers. These clients are extremely valuable, as the feedback these companies.
Finally, companies that are suppliers of Aito (e.g. Printed Electronics) have proven themselves in the past, but are of course not exclusive to Aito.

Assets and Capabilities	Competitive implication	1. Valuable	2. Rarity	3. Inimitable	4. Organised
Development Relationship with Piezo manufacturers	Sustained Advantage	Yes	Yes	Yes	Yes
Partnerships Automotive OEMs	Sustained Advantage	Yes	Yes	Yes	Yes
Partnerships Automotive Tier 1 suppliers	Sustained Advantage	Yes	Yes	Yes	Yes
Partnerships non-automotive clients	Sustained Advantage	Yes	Yes	Yes	Yes
Network of Suppliers of Aito	Parity	Yes	no	n.a.	n.a.

APPENDIX D.

Demonstrator cost analysis table

Cost Analysis

As mentioned in the main part of the thesis, the cost analysis is a rough first estimate on the production cost of the demonstrator.

The following assumptions have been made in making this analysis.

- **SLS 3D printing costs are mostly affected by volume and density, not the level of detail. Therefor only the volume of the complete control panels have been taken into account.**
- **Administrative costs of suppliers have not been included**
- **Taxes have not been included**
- **The demonstrator is assembled at the Aito office in Amsterdam.**

1/ Parts manufacturing

Laser Cutting	Units	Price per unit	Amount	Price	Supplier
Mid-console segments (5 mm multiplex)	m2	€ 5,91	1,47 m2	€ 8,69	Houthandelonline (1)
Armrest segments (5 mm multiplex)	m2	€ 5,91	0,152 m2	€ 0,90	Houthandelonline (1)
Back leg segments (5 mm multiplex)	m2	€ 5,91	1,26 m2	€ 7,45	Houthandelonline (1)
Front legs segments (5 mm multiplex)	m2	€ 5,91	0,3 m2	€ 1,77	Houthandelonline (1)
Dashboard segments (5 mm multiplex)	m2	€ 5,91	2,25 m2	€ 13,30	Houthandelonline (1)
Dashboard support segments (5mm multiplex)	m2	€ 5,91	0,64 m2	€ 3,78	Houthandelonline (1)
Dashboard legs (5mm multiplex)	m2	€ 5,91	0,72 m2	€ 4,26	Houthandelonline (1)
Connection struts Dashboard (12 mm multiplex)	m2	€ 10,58	0,064 m2	€ 0,68	Houthandelonline (1)
Connection struts short (12 mm multiplex)	m2	€ 10,58	0,036 m2	€ 0,38	Houthandelonline (1)
Laser cutting startup costs	n.a.	€ 9,50	1	€ 10,00	Snijlab (2)
Laser cutting	segment	€ 2,50	91	€ 235,00	Snijlab (2)
Shipping	30 kg	€ 9,50	1	€ 13,25	Snijlab (2)
Sub-total				**€ 299,45**	

3D printing	Units	Price per unit	Amount	Price	Supplier
SLS Nylon (PA-12) batch 1	n.a.	n.a.	2.865,91 cm3	€ 2531,05	JB Ventures (3)
SLS Nylon (PA-12) batch 2	n.a.	n.a.	148,44 cm3	€ 129,94	JB Ventures (3)
Shipping	package	€ 15,00	1	€ 15,0	JB Ventures (3)
Sub-total				**€ 2653,77**	

Finishing Materials	Units	Price per unit	Amount	Price	Source
Motip Filling Primer	1,5 m2	€ 7,46	16	€ 74,60	INDI (4)
Motip Satin Black RAL 9005	1,9 m2	€ 4,30	16	€ 38,70	INDI (4)
Shipping	package	€ 6,50	1	€ 6,95	INDI (4)
Sub-total				**€ 119,80**	

Total				**€ 2730,30**	

2/ Catalogue parts

Fastening articles	Units	Price per unit	Amount	Price	Source
Hex Socket M5 15 mm CS	50 pcs	€ 4,08	2	€ 8,16	Farnell (5)
Rampa Nut	10 pcs	€ 4,19	3	€ 12,57	Gamma (6)
Sub-total				**€ 20,73**	

Electronic components	Units	Price per unit	Amount	Price	Source
Arduino Due	1 pcs	€ 28,99	2	€ 57,98	Farnell (7)
LG P 450 UG Projector	1 pcs	€ 384,81	2	€ 769,62	Visunext (8)
Aito ATH756 Module	1 pcs	€ 27.50	14	€ 38500	
Sub-total				**€ 1212,60**	

Grand-Total				**€ 4263,08**	

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3. https://calculator.rapidprototyping.nl/calculator/index
4. for creating a smooth paintable surface ont the laser cut parts
5. https://nl.farnell.com/tr-fastenings/m5-10-kh10mc-z50/screw-socket-csk-bzp-m5x10/dp/1420657?st=M5%20KH10MC%20Z50%20-%20%20Socket%20Screw,%20BZP,%20Flat%20/%20Countersunk
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