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DESIGNING A HAPTIC INTERFACE FROM A
**VISION-CENTRED
APPROACH**

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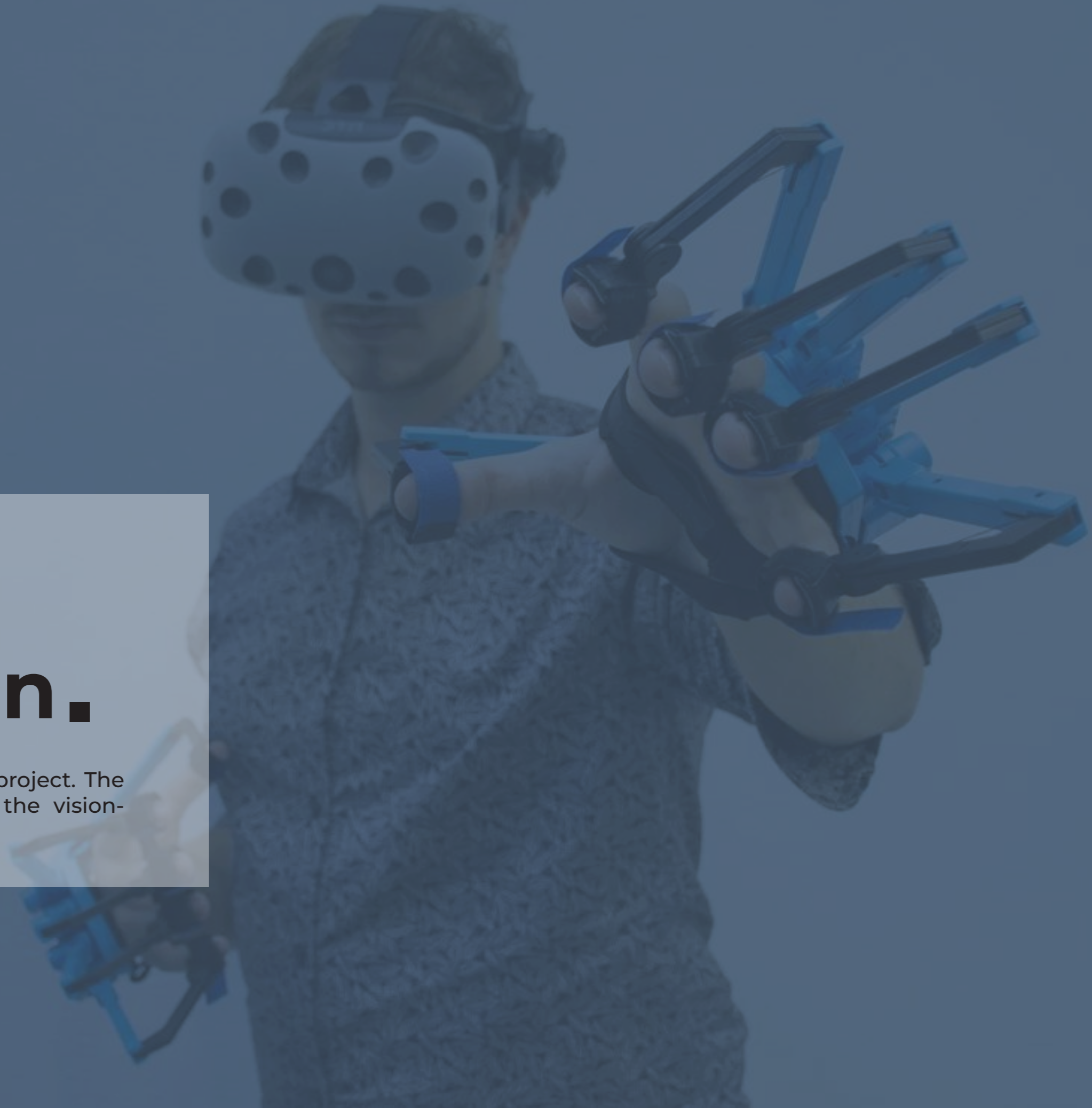
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Acknowledgements**References****Appendix 1: Kick-off document****Appendix 2: User Mapping****Appendix 3: Vision session****Appendix 4: Participatory design****Appendix 5: Concept evaluation****Appendix 6: list of requirements****Appendix 7: Personas****Appendix 8: Feature list****Appendix 8: Raw interview notes**

01

Project Description.

This chapter describes the goal of the project. The problem definition is presented, and the vision-centred approach is introduced.



DESIGN BRIEF

Introduction

We live in a world that is rapidly transforming towards the digital domain. Instead of reading newspapers or books, smart devices have become the new standard medium for accessing information. New technologies and ways of interacting with those new media are continually in development.

Interactions involving the sense of touch, better known as haptics, already became a standard in consumer electronic devices. As technology's role in communication, training and entertainment increases, so does the number of potential applications of haptics (Culbertson, Schorr, & Okamura, 2018, p. 408). Whether it is the notification of a smartwatch or the vibration of a game controller, haptic feedback can be a powerful way of interacting with a user.

The market of haptic technology has grown for the last years and is expected to do so in the future (Inkwood Research, n.d.). According to Inkwood Research (see "Figure 1" on page 9), the global haptic technology market is expected to grow with 14.4% over the next eight years. The segments of the software, actuators, drivers and controllers are expected to double over the next eight years (Inkwood Research, n.d.). New haptic technologies are continuously developed, with each their benefits and use-cases. Before those new technologies can be used for industry use-cases or consumer electronics, research is conducted to test the capabilities of the new technology and whether it is suitable and useful for a specific use-case.

SenseGlove is a three-year-old company that developed a haptic glove with hand tracking, force feedback and tactile feedback capabilities. In the three years that SenseGlove exists, they have noticed an increasing demand from the academic industry. Their product has been used to evaluate interactions, workplaces and more.

Problem definition

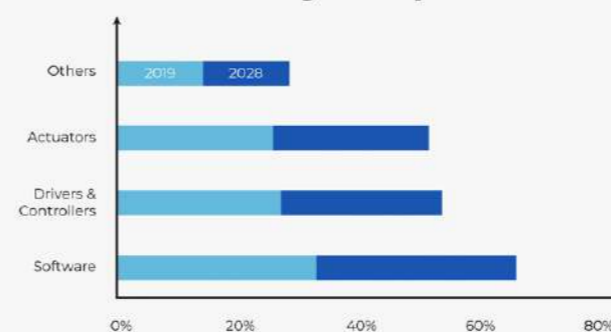
In the growing market of haptic technologies, SenseGlove has identified the academic industry as an important target group for their future generation products. Before SenseGlove can successfully target this group of users, they need to understand how their technology can be used effectively to match the user's expectations. Given that this target group consists of users that are pushing the boundaries of knowledge, they are likely to have a clear scenario in mind of what the future of their research field should and could be. The goal of this project is to collect individual visions, synthesize them towards vision drivers, and use those to design a future-proof product concept.

The final concept direction will be presented with a physical model and a product video which presents the product concept and its features. These deliverables will be used to direct the development team at SenseGlove towards feasible and future-proof product.

The original problem definition can be found in the project kick-off document in "Appendix 1: Kick-off document" on page 120.

“ **The goal is to synthesize future visions, and use them to design a future-proof concept** ”

Market by components



Market growth by applications

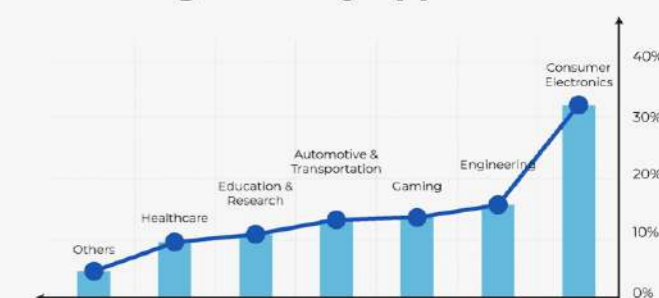


Figure 1 Trend analysis (Inkwood Research, 2020)

Approach

As mentioned in the problem definition, the project follows a vision-centred approach. This project's approach shows similarities to future vision innovation, described in Images of Design Thinking (Valkenburg, Sluijs, & Kleinsmann, 2016). Valkenburg describes that future-driven innovators see a world in which the far future is uncertain and unknown. The challenge in vision-driven innovation is to engage in developments that are future proof. They state the following: "As innovations are about introducing new concepts and new ways of thinking, they must resonate with the users – who have to recognize these innovations as something they need or want."

Marcel de Graaf, a R&D manager at Maars Holding BV, who applies the future vision innovation approach states the following: "You continuously have to take risks where you choose a certain direction of development, based in part on intuition with the belief that it will end up with some kind of product with which you can make money." Relying on intuition is a natural step within the design scene, but would not be the most promising for this specific use-case. Given that the target group consists of highly specialized and educated users relying purely on intuition might not be appropriate since sufficiently emphasizing the target group is far from reach.

For that reason, the first part of the project will not be focused on the definition of a future vision by the designer, but by capturing the future vision, researchers have themselves. Since researchers are highly educated and future-oriented, it is expected that individual users each have their unique interpretation of what the future research platform should be. In the first stage of the project, those individual future visions will be captured and compared. From this collection, similarities and discrepancies will be identified, which will form the vision drivers for idea generation.

Instead of only using the designer's generative capabilities, users from the target group will participate in a creative session and use their expertise to suggest the product challenges with solutions that fit their future vision. By actively engaging in problem-solving and discussing the results, possibly represented with visualizations, the chance of a misinterpretation by the designer is minimized. The result of this step will be a selection of concept directions derived from challenges and solutions that match the user's

future-vision. Unfortunately, during this specific project, the COVID-19 crisis withheld the possibility to meet with the participants in person. This forced me to use alternative methods to retrieve similar results as the creative session would provide. See section "Session 3: Participatory design" on page 54 for the full documentation. This session concludes the exploration phase, after which one concept direction is selected for further development using weighted objectives. This decisionmaking process can be found in the

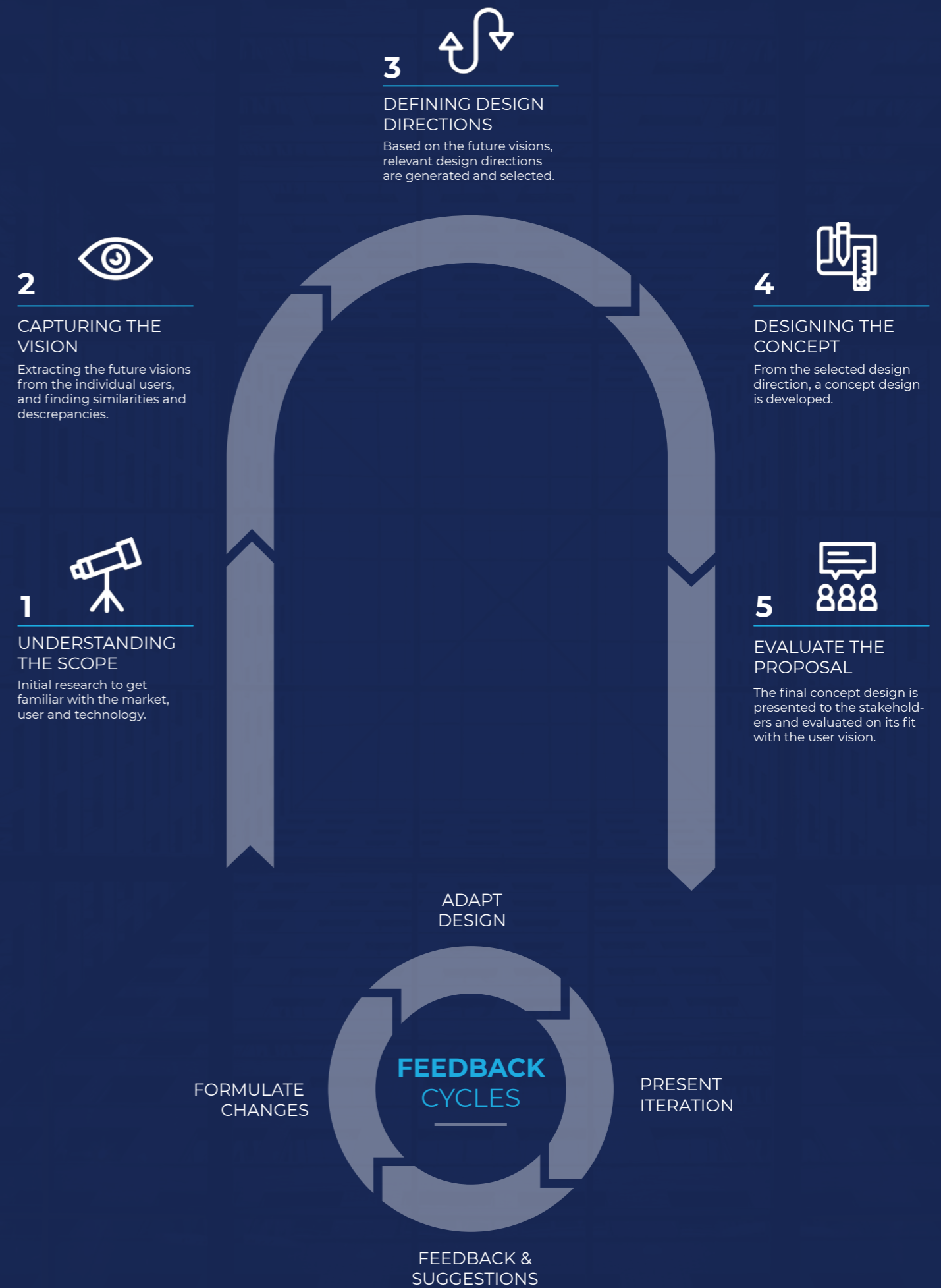
“This project dares the users to dream and to imagine their future”

chapter "Weighted Objectives" on page 68.

The final product concept is evaluated by the target user. The last series of user sessions are organized to reflect upon the project result and approach. Recommendations are collected and formulated for further implementation. A list of features and planning are included to kick-off the further development of the product concept by the client company.

Each step in this approach, mainly when users are involved, follows a standard feedback cycle. First, a new concept or idea is presented to the user. The user will provide the designer with feedback and suggestions to improve the concept towards his personal future vision. The feedback of users is collected, compared, and new changes are formulated. The design is then adapted based on the formulated changes and ready for the next presentation to the users. By continually presenting and collecting feedback, the quality of the product's aesthetics and features will improve with each cycle.

VISION CENTERED DESIGN PROCESS



The future vision

The definition of vision is as follows: the act or power of anticipating that which will or may come to be. In other words, a vision describes a future condition based on knowledge and imagination. Vision statements should not be mistaken for mission statements. The purpose of a mission statement is to tell the world what you do and why you do it, where a vision describes more of an idealistic future. Visions can be both fuzzy or distinct but are powerful instruments when used appropriately. By successfully communicating a vision, you can inspire people and characterize objectives, both functional or non-functional. A vision statement can be the anchor point of any strategic plan. It lines out what an organization would like to ultimately achieve and gives a reason for the existence of the product or service.

Although visions do not provide detailed insights on requirements or solutions, they give a direction in which solutions should be found. Some say that the use of visions could be defined as problem-definition rather than problem-solving. Either way, a strong vision-statement is an excellent tool for describing a desirable and somewhat realistic future scenario. This way, it provides a design direction that is worth exploring.

This project's approach is partly inspired by Chyun-Chau Lin's vision-oriented approach for innovative product design (Lin & Luh, 2009, p. 199). According to Lin, it is increasingly important to emphasize innovative concerns rather than pure performance, such as speed or strength. He states that providing unique, innovative, and value-added products become a crucial strategy for success. This approach perfectly fits the project brief, which provides the designer with a technical framework and a target-group, but does not yet describe what the unique value is for the end-user.

In this project, the user-vision will be captured during various user sessions. Together with other user-interviews, in which surface-level functionalities and concerns are discovered, the information will be synthesized towards a coherent future product vision. This future vision will represent the most ambitious research platform in the far future and will be the inspiring design direction for the development of the concept. The end-users in this project are researchers in the academic industry. Although a lot about these users is yet unknown, one thing is obvious; researchers are highly educated and experts in their own field. Most researchers gained years of experience before they could look into the unknown principles they are trying to prove with their current research.

This is precisely why the future vision method can be a powerful tool in this project. The goal of a researcher is to find or prove new principles. They are not only familiar with the latest developments within their field; they are responsible for those developments themselves. This means that compared to outsiders, researchers have a clear vision of what the future holds for them in the coming years. As mentioned before, researchers are not only the target users but also the experts when it comes to their field. There are simply not enough resources to fully understand the reasoning behind each researcher's concerns. The user group is too diverse and too specific to pin down every single user concern.

This combination of future-orientation and knowledge seems like a promising set of properties to create a future vision. In this project, those future visions of individual users are collected, compared and synthesized. This synthesis concludes in vision drivers, which are the main drivers for ideation and concept development.

“**The method seems seems an unique combination of envisioning and user-input in an iterative process.**”

Other methodologies

The vision-centred approach shows similarities to some other design methodologies. For example, Vision in Product design (VIP) also uses a future vision as the main design driver (Hekkert, 2016). However, this method is strongly driven by the overall context. By analyzing this context and finding trends in technology or behaviour, a future context allows the designer to create his own vision of a better future. This is not the case for the approach in this thesis. This thesis allows the target user to think about personal future context and formulate a vision. In this project, multiple visions are collected and synthesized. Therefore, this method is strongly driven by the user and their personal beliefs, instead of just context factors.

Another future-oriented methodology that uses future vision is Roadmapping (Simonse, Iwanicka, & Whelton, 2018). Roadmapping works in three stages: vision, roadmap, program roadmap. It is a method used to drive innovation within businesses. In this method, the vision is formulated based on value mapping through analysis of trends, technologies and strategic position, which means that just like in VIP, the user concerns are merely included until later in the process. In step two of the road mapping process, the phase of idea mapping starts. In this phase, technology scouting linked to user value mapping helps in constructing the roadmap. Instead of feeding the user concerns in the future vision, potential combinations of technologies and user concerns are formulated. The design roadmapping concludes with the phase of program roadmapping, which formulates the intermediate steps towards the future vision.

The project approach is definitely is a version of the Iterative design process (Sharp & Macklin, 2019). Continually evaluating the findings and developments with end-users allowed the concept to develop in a fruitful direction. This iterative process was not just applied to optimize

the development of the concept itself, but also in the process of synthesizing the user visions. Co-creation (Sanders and Stappers, 2012) is a design process in which the end-user is involved in the development process of the concept. Users can be involved on different levels, from surface-level interviews to highly engaging creative sessions. The method describes a mental process where the user in the presents relates to his own experience to formulate his dreams and desires for the future. This is precisely the purpose of the vision-centred approach. The vision-centred approach differentiates itself from co-creation in how the user input is integrated into the project. The insights from the user sessions in the vision-centred approach lead to the creation of vision drivers which drive the design features. Co-creation has a more direct influence on the final concept itself.

The vision-centred approach shares workflow and structure with some other methodologies but seems a unique combination of envisioning and user-input in an iterative process.

LIST OF REQUIREMENTS

Introduction

The list of requirements (LoR) states the characteristics that the final product concept must meet to be successful. The list is formulated by using Pugh's checklist for generating design requirements (Pugh, 1991). The LoR gives the designer an overview of all expectations provided by all stakeholders involved. Also, it creates an understanding of the stakeholders in the decision-making process by informing them of requirements outside of their expertise.

Since this project aims to design a product concept and does not include full embodiment or user tests, most quantitative requirements can not be tested at the end of the project. In this case, those requirements are used in discussions with engineers in which the viability of concept features are considered. This way, the requirements protect the product's performance based on the engineer's expertise, without the actual testing of the product.

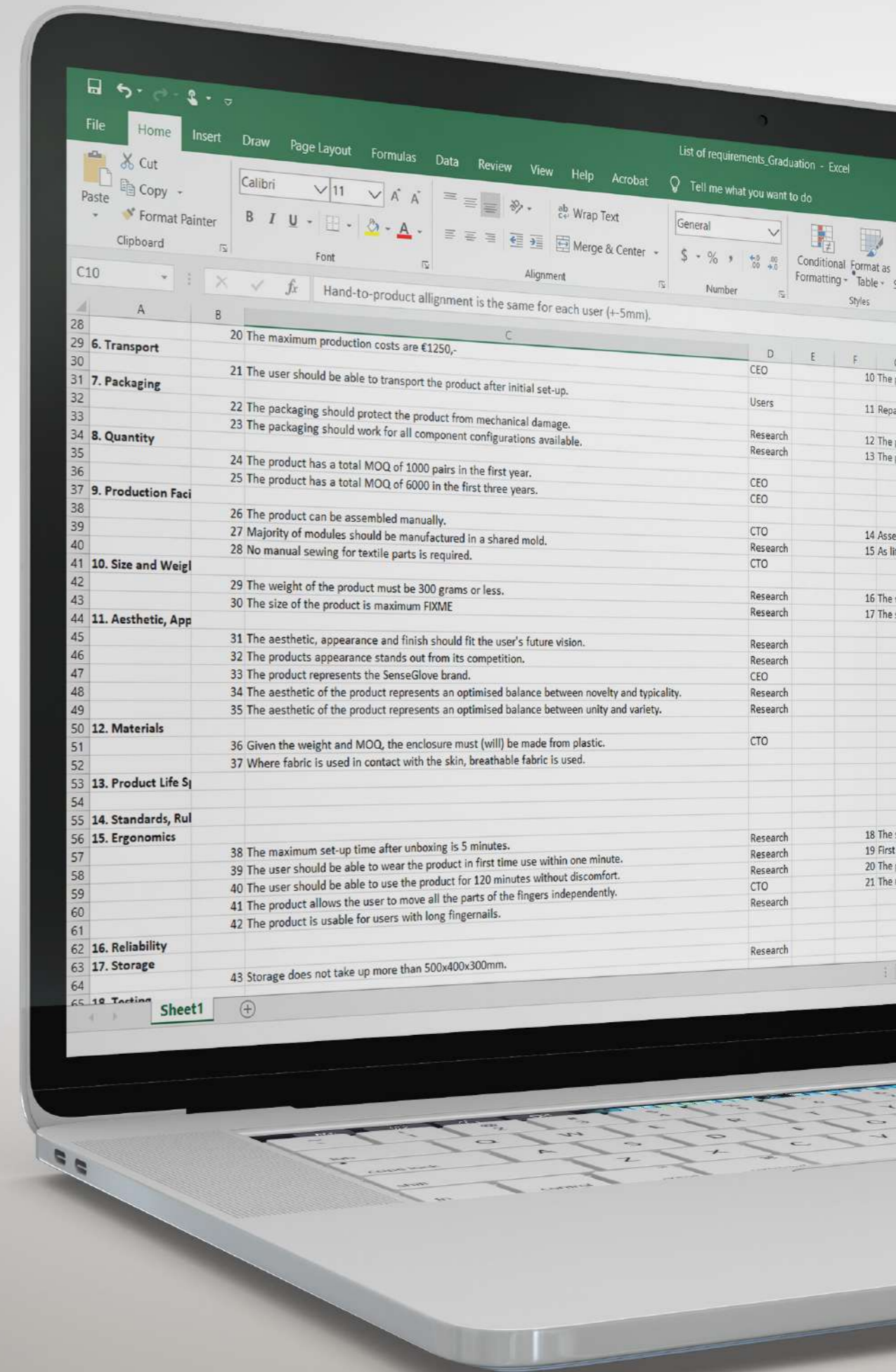
Requirements are formulated in such a way that their variables are observable or quantifiable characteristics. This means that eventually, the final product will or will not meet the requirements. In addition to the requirements, a list of wishes is included. The wishes describe the desired direction in which the requirements can be optimized. For example, the requirement describes a maximum production cost of € 1250,-, where the wish describes a production cost to be as low as possible. The most important wishes play an important role in the selection of a concept direction later in the "Weighted Objectives" on page 66.

Requirements and wishes

In "Appendix 6: list of requirements" on page 132, the full list of requirements can be found. The list of requirements has been used as a "living document", which means that new findings in the project constantly influenced the requirements themselves. In "Figure 2" on page 14, you can find a short overview of the most important requirements.

Area	Nr.	Demand	Source
Aesthetic	35	The aesthetic of the product represents a balance between unity and variety.	Research
Life in service	13	The product can be used in sessions of maximum 120 minutes each.	Users
Quantity	25	The product has a total MOQ of 6000 in the first three years.	CEO
Aesthetic	31	The aesthetic, appearance and finish should fit the user's future vision.	Research
Production Facilities	27	Majority of modules should be manufactured in a shared mold.	CTO
Reuse	49	The product's lifetime can be increased by replacing/upgrading modules.	Research
Maintenance	17	Parts that are in frequent contact with the users skin, are directly replaceable.	Research

Figure 2 Highlights of the LoR



Literature study.

This chapter describes the insights gained that are required to design a sufficient concept features. The literature study covers subjects such as haptics, vibrotactile feedback, force feedback, anthropometrics, and design principles for aesthetics.

HAPTICS

What is haptics?

The word haptics originates from the Greek word hapto - to touch- and refers to the ability to touch and manipulate objects (Mihelj & Podobnik, 2012, p. 38). However, nowadays, the term haptics is more frequently used to refer to sensing and manipulating virtual objects. As humans, being able to feel our environment is an excellent source of information. By implementing haptics during virtual interactions (such as VR), the user's experience becomes more simple, immersive and efficient (Mihelj & Podobnik, 2012, p. 38). Haptic displays are (mechanical) devices designed to provide the user with haptic stimuli, signals that can be felt by the user.

In daily life, we regularly get in contact with products that use haptics to enhance interaction and its experience. The most relatable example can be found in our smartphone (see "Figure 3" on page 18). Phones use haptics in all kinds of ways, of which the most obvious is a vibration as a notification to grab our attention. Haptics also play an essential role in the active use of a smartphone. For example, the little vibrations when typing on a touchscreen enhance the clarity of the interaction. Research shows that this feedback enables users to type faster while making fewer mistakes than typing without feedback (Kim & Tan, 2014, p. 230).

The latest generations of iPhones replaced the mechanical "home button" on the bottom of the screen with a pressure sensor. Although this sensor does not physically have any physical motion when pressed, the sensation of a button click is simulated by a vibration motor. The user can even adjust the exact signal in the settings of the phone. This application is an excellent example of how haptics can boost the usability and experience of a product feature, in products where physical features are replaced by electronic components.

Since the potential positive effect of haptics has been demonstrated, it has continually been implemented in new interaction systems. Virtual reality, a platform that enables the user to see a virtual environment all around him, is one platform in which haptics shows excellent potential. Since virtual reality is often used to immerse users in a realistic environment, researchers are continually looking for ways to enable the user to interact naturally with objects around him. The sense of touch is an essential component of those interactions, especially when enabling the user to use his hands instead of traditional controllers.

Vibrotactile feedback

This kind of feedback actuates vibrations or deformations directly on the skin. Vibrotactile feedback is sensed by various kinds of mechanoreceptors in the skin. Each kind of mechanoreceptor is responsible for processing a certain kind of stimulus, which depends on the receptor's size, density and fibre branching. By combining all receptors' properties, the human skin can detect vibration frequencies from 0.4 to 1000 Hz. Vibrotactile feedback can be used to communicate textures, object edges and vibrational cues (such as the click of a button) (Hale & Stanney, 2004, p. 37).

Vibrotactile actuators, can be quite compact and easily integrated in wearable electronics. Each actuator has its own range of specifications, and serves well a single purpose (such as simulating textures). There are various types of actuators. One of the most popular ones is the eccentric rotating mass vibration motor (ERM). The actuator is practically a small electromotor, which rotates an unequal distributed mass. By increasing the voltage, the rotation speed of the mass can be controlled. When rotating, the moving mass creates a force, which can be perceived by the user as a vibration. The application of this actuator depends on the rotating mass, the voltage and the frequency range. ERM's are available in different form factors, as can be seen in "Figure 5" on page 19.

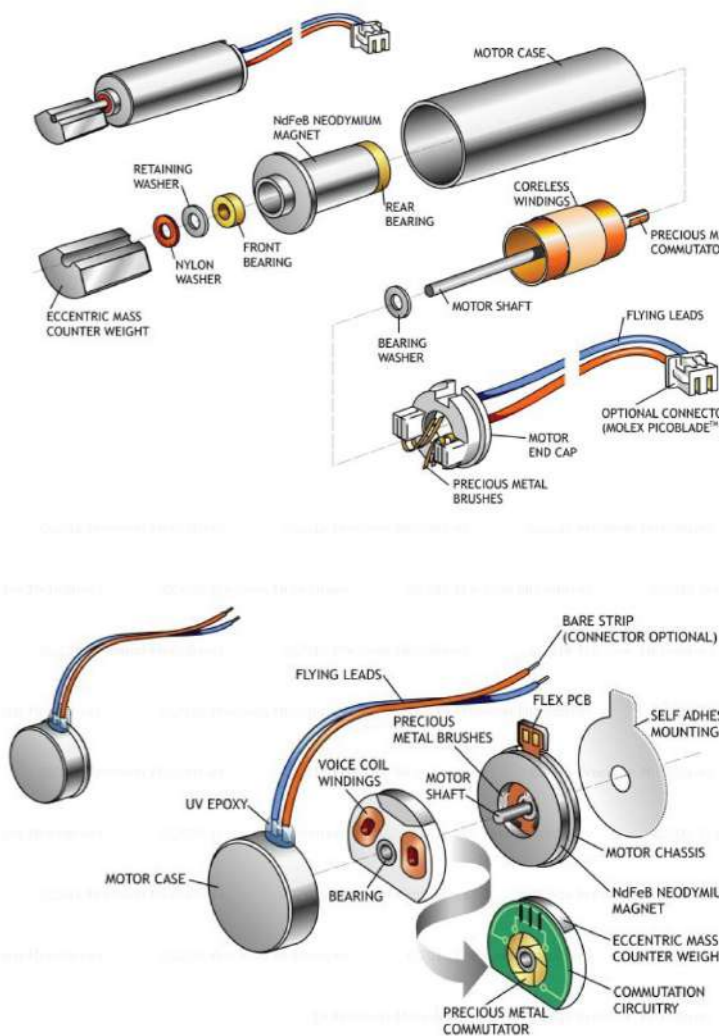


Figure 5 The two most common formfactors for ERM actuators

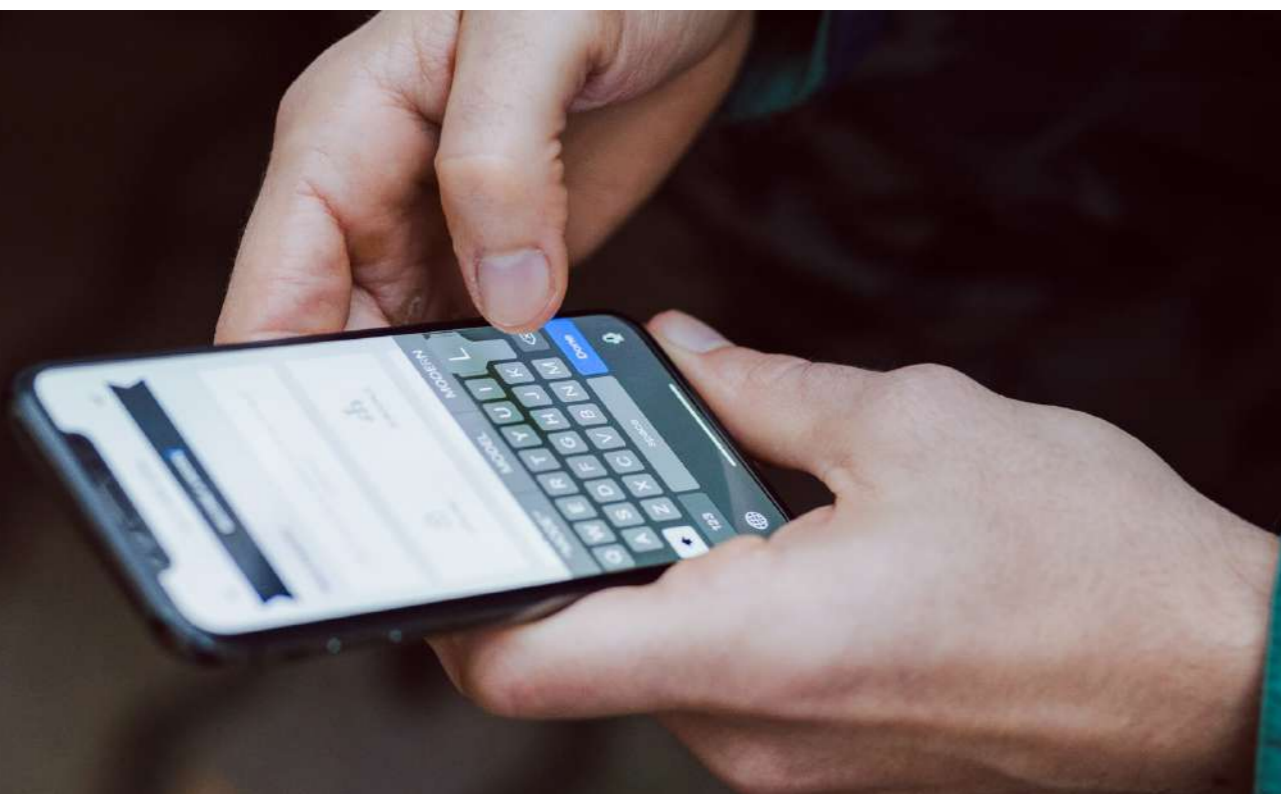


Figure 3 Haptic feedback while typing on a touchscreen

Figure 4 Haptic feedback in the trigger of gaming controllers (Xbox, 2013)

Another popular type of vibrotactile actuator is the Linear Resonant Actuator (LRA). LRA motors are different from ERM motors in the way they work, they are used and how long they last (Precision Microdrives, 2018).

However, LRA motors can look a lot like ERM motors; they work entirely differently. An ERM uses a rotating mass, and an LRA uses a mass attached to a spring, which is moved by a voice coil. This design is comparable to the design of a speaker. The two most common form factors for LRA motors can be seen in "Figure 7" on page 20.

An AC signal can drive LRA actuators. The moving mass is attached to a spring, which causes a resonance effect. This means that this kind of actuator has a small frequency range in which the vibration will be way stronger, as can be seen in "Figure 6" on page 20. Since LRA motors use a voice coil (which means they are brushless), their lifetime is significantly longer than ERM motors, making them more durable.

Like the LRA, bigger voice coil actuators with a higher moving mass are often used as thumpers. Thumpers are vibration motors that are used to provide a powerful vibration to simulate impact. The SenseGlove has one thumper module integrated into the hub of the glove.

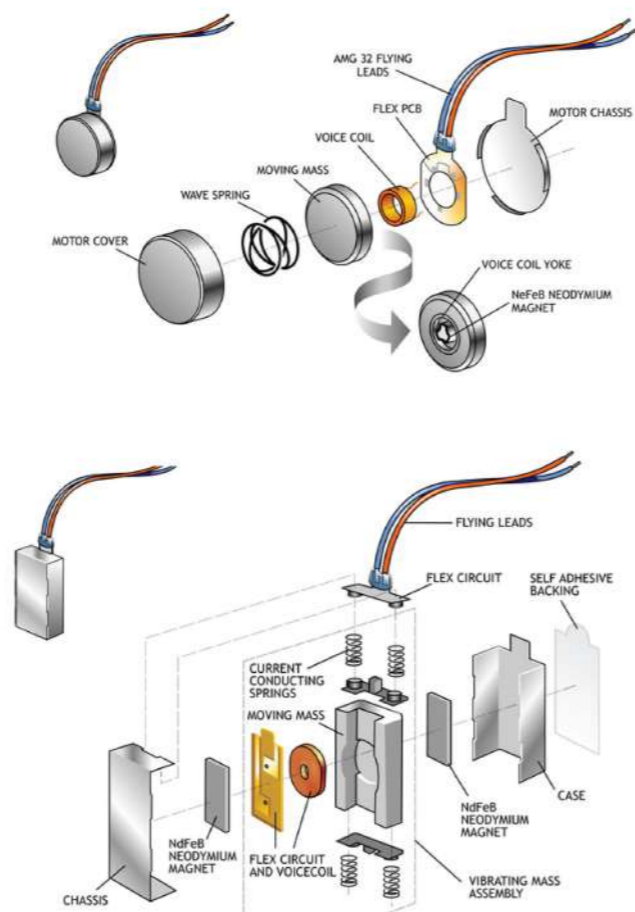


Figure 7 The two most common formfactors for LRAs

C10-100

Typical Resonator Frequency Response

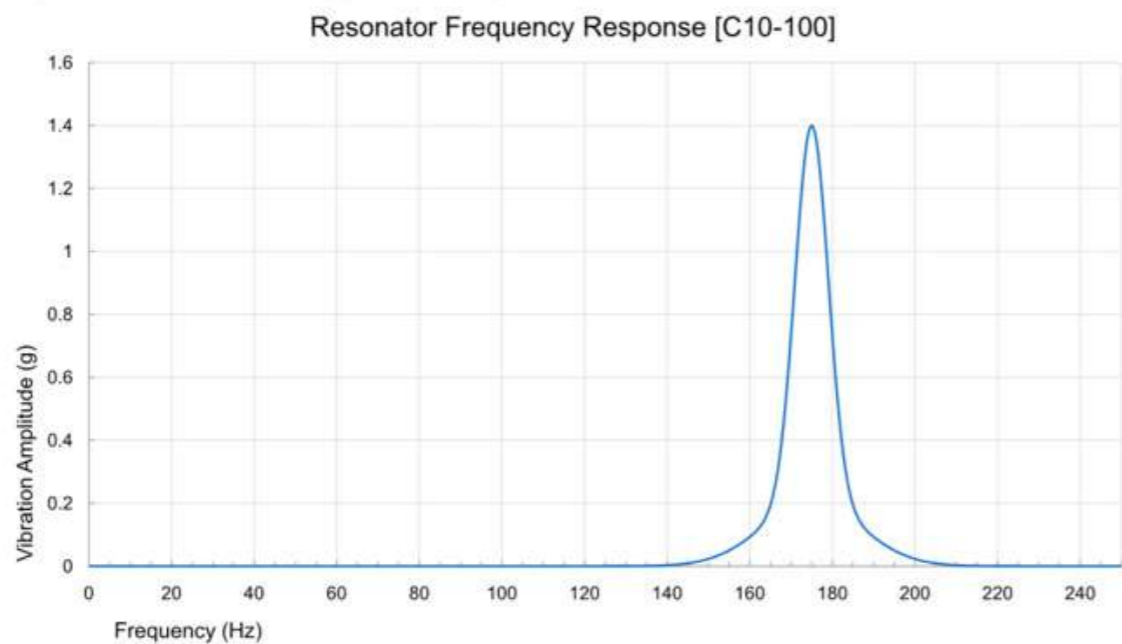


Figure 6 Example of a LRA frequency range (Precision Microdrives, 2020)

Drivers

To get the most out of an electronic component like a vibration motor, LRAs and ERMs are often connected to drivers. A driver is an electronic component that controls the behaviour of the motor. A driver provides the user to get more advanced control over the hardware. Examples of a driver's features could be custom waveforms, internal memory, and issue detection. Just like vibration motors, there are plenty of drivers on the market. Each driver has its unique specifications and compatibilities, making it compatible with a selection of actuators and use-cases. An example of a haptic driver can be seen in "Figure 8" on page 21.



Figure 8 An example of a haptic driver (Seed wiki, n.d.)

Kinesthetic feedback

Kinesthetic feedback, also known as Force feedback, relies for a big part on receptors in muscles, tendons and joints. This kind of haptic feedback relies on applying forces that influence the position of bodyparts or invoke muscle stimulation. Providing force feedback to an interaction with a virtual object improves discrimination of weight shape and size (Hale & Stanney, 2004, p. 37). Force feedback can be either active, where motors actively push the bodypart, or passive, where the movement of the user is obstructed. This passive feedback breaks the movement of the user, initiating a reaction force which can be perceived as an object.

Force feedback is more complex and is less common than vibrotactile feedback in our daily lives. A common example is the racing simulator steering wheel, as can be seen in "Figure 9" on page 21. This controller provides rotational feedback to the user by forcing the steeringwheel in a direction that matches the running simulation. That means that the steering wheel uses an active force feedback system. Since force feedback stimulates the user by applying larger forces to the user, devices are more volumous. A common form factor for kniesthetic feedback devices is the exoskeleton.



Figure 9 Steeringwheel with force feedback

Motion-tracking

Motion tracking, also known as motion capture, is a process where the movement of an object or person is recorded. Motion tracking is applied in many industries such as filmmaking, robotics and video game development.

Modern virtual reality becomes more and more realistic. Technologies are constantly being developed to make interactions within those virtual environments as intuitive as possible. In daily life, we don't use computer mice or controllers to interact with objects; we use our hands. Ultimately, this would be the most natural way of interacting in virtual environments, since there is no difference between real-life interactions and the virtual equivalent. According to Wang (2017), the biological range of motion varies between individuals. In general the fingers flexion is around 90 degrees. This is slightly less for the index finger. Abduction and adduction generally have a greater range when the fingers are fully extended, being as much as 30 degrees in each direction. The active hyperextension of the finger is approximately up to 30 percent. These ranges set the requirements for tracking capabilities for the final product concept, and can be found in the list of requirements as requirement 3.

In order to use our own body as an "input device", it is important to communicate accurately what the position and orientation of our body parts are. Motion tracking allows to translate the motion of a body part rapidly into usable data, which means that the body can be tracking in real-time. This is not only an advantage during VR or telerobotics interactions, but also in processes such as animation and VFX, where traditionally each body part is moved manually frame by frame. In practice, to track the position of an object in a room-based setup, standard controllers or trackers that are compatible with the VR setup are

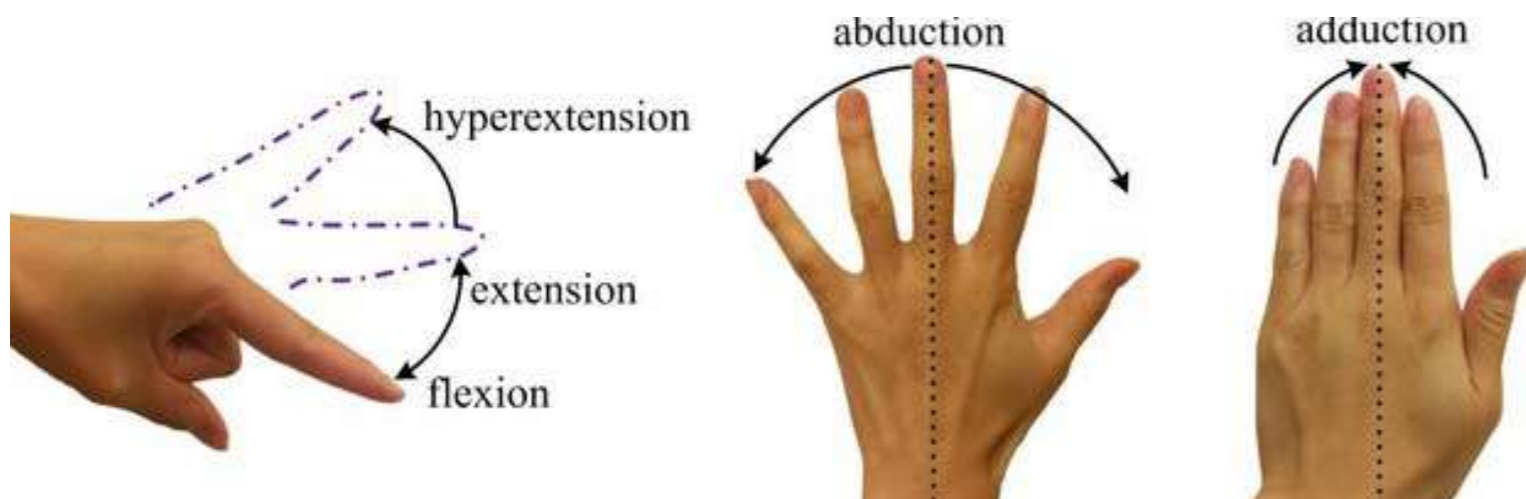


Figure 10 Freedom of movement for hands and fingers

used. This means that these kind of product should be mountable on the final product concept. This requirement is formulated in the list of requirements as requirement nr. 4.

Through the application of (reflective) markers on the moving subject, an optical system can track the displacement of each marker and the attached object. Using multiple camera angles, object can be tracked in three-dimensional environments. However this method does not require any physical coupling and allows the user to move completely freely, it does require a full room setup. Since more and more tracking systems for VR are included in the HMD itself, fully tracking hands in 3D can be tricky. Since the optical system records the hands from one direction, occlusion of fingers or phalanges occurs, causing the system to lose tracking information.

Tracking through mechanical motion relies on tracking through a physical coupling with the object. By physically measuring the displacement and/or rotation of objects, the relative position of points can be tracked. The advantage of this method is that the tracking does not suffer from occlusion and is for that reason reliable.

Anthropometrics

To gain insights into the required dimensions for the SenseGlove, the Dined Anthropometric database (TU Delft, 2020) has been used. In this database, hand width, hand length, forefinger breadth and thumb breadth have been found. Three pools of users have been used since none of the user pools covered all required dimensions. The overview of used dimensions can be found in "Figure 11" on page 23.

Measures	Dutch Adults 18-30, mixed				Dutch students 17-27, mixed				Dutch Adults 31-65, mixed			
	P5	P50	P95	SD	P5	P50	P95	SD	P5	P50	P95	SD
Hand width	72	85	98	8	71	81	91	6	-	-	-	-
Hand length	174	195	216	13	166	184	202	11	170	193	216	14
Hand thickness	-	-	-	-	23	26	29	2	-	-	-	-
Forefinger breadth	14	17	20	2	13	15	17	1	-	-	5	-
Thumb breadth	16	21	26	3	-	-	-	-	-	-	-	-

Figure 11 Anthropometric data (Dined, 2020)

Design principles

The original SenseGlove has been designed to demonstrate the functionality of the technology. This resulted in a first proof-of-concept for an industry-ready product but lacked the aesthetic quality the academic industry would expect. In order to design a new concept with an improved aesthetic experience, the principles of pleasure in design by Paul Hekkert can be used (Hekkert, 2006, p. 158).

Hekkert describes the first principle as “maximum effect for minimum means.” This principle relies on the fact that human perception tends to function as economically as possible. Designing products that can communicate information in a glimpse of an eye can be perceived as more pleasant. This can be achieved by design features like repetition, pattern or metaphor. In “Figure 12” on page 25, this principle can be seen in practice as the pattern in the cooling holes of the beamer.

The second principle that Hekkert describes is “Unity in variety”. The principle relies on the perceptual tendency of grouping and discovering relations. Because we as humans enjoy seeing connections, we find it pleasing to invest effort in finding them. For this reason, unifying mechanisms such as symmetry, good continuation and closure are effective tools to bring aesthetic pleasure in product design. In “Figure 12” on page 25, this principle can be seen in practice by the continuation of various shapes and lines in the taillight.

The third principle, “most advanced, yet acceptable” (MAYA), is all about finding the balance between typicality and novelty of a product. Humans tend to prefer products with an optimal combination of both aspects. It’s a designer’s role to design something for the

future, but it is essential not to lose touch with past archetypes that already proved sufficient. An example where this principle is well applied is the design of the Apple watch (see “Figure 12” on page 25). The electronic wearable is worn and (for some parts) used as a traditional watch. Using the archetype while introducing innovations, the product manages to find a nice balance and evoke a pleasurable experience.

Principle four, “optimal match”, describes the importance of matching messages from different senses. When we see a smooth object, it is perceived as satisfying when we can confirm the smoothness with our sense of touch. The same applies for matching each sense’s perception with the intended overall experience. For example, drawing tablets (see “Figure 12” on page 25) try to give the user the experience of drawing on paper. However due to the slippery feeling of the glass surface, this sketching method is disliked by many artists.

The desire for an aesthetically pleasant experience, by optimising the design according to these principles is added to the LoR as requirement nr. 34.



Figure 12 Examples of applied design principles



YES YES... OHH YES!

Client Company.

This chapter describes the company for which the new product was designed for. The company drivers that are used in the development and the general concerns that lead to the product concept.

SENSEGLOVE

Company

SenseGlove is a three-year-old hardware start-up company. With its headquarters in YES!Delft, an incubator closely connected to the university, SenseGlove is a good example of how technology driven start-ups can emerge from this innovative environment. In a world that's constantly transitioning towards the digital domain, SenseGlove envisions a virtual world that feels like real. They do this by adding the components of touch to interactions with virtual objects, providing natural interactions in human computer interactions (HCI). SenseGlove is founded by Johannes Luijten and Gijs den Butter, both former students from the faculty at Industrial Design Engineering at the TU Delft see "Figure 13" on page 28. SenseGlove consists of a talented multidisciplinary team of young engineers.

Product

This sense of touch is provided by the self-titled product, the SenseGlove. This version of the SenseGlove is the baseline for the concept created in this project. That's why it's of importance to understand the technical complexity of the current generation SenseGlove.

Just like the current version, the SenseGlove Pro will be an exo-skeleton based interface. Each "finger" of the exo-skeleton contains a hall effect sensor in each of its joints which measures the rotation of a magnetic pin. Because of the physical connection of the user's outer phalange with the skeleton, the readings of this sensor can accurately be

translated to monitor the position of the user's finger. Unlike sensors that are in physical contact with the moving parts, vision-based tracking solutions have to contend with occlusion, and therefore inconsistent readings of the finger's position.

In addition to the accurate motion-tracking, the exo-skeleton also enhances the haptic experience of SenseGlove's force feedback (FF). Most VR interactions that can be performed by a hand, consist of grasping and moving objects. When grasping an object, the finger applies a force perpendicular to the surface of the fingerbed. The angle in which the force is applied to the finger, is of importance for the perceived realism of the haptic cue. The closer the cable runs over the finger, the more the force tends to apply to the second phalange, while bending.

The analog sensor readings from the sensors are transformed into digital signals by the electronics in the hub of the glove. This data is transferred to the computer that runs the application by a micro-USB connection. The software within the application translates the digital output of the glove to a virtual equivalent of the hand in the virtual environment. Based on this model and the interactions within the applications, signals driving the actuators within the glove can be sent.

The force feedback of the SenseGlove can be activated in different behaviors. By defining the strength from 100 (full force) to 0 (no force) the difference between hard and soft objects can be carefully defined.

The force feedback of the SenseGlove is actuated by activating electromagnetic brakes. By running a current through the coil, a pulley around which a cable is spun is prevented from rotating. This cable runs through the fingers of the exoskeleton to the thimble. When the brakes are activated, this cable prevents the finger from flexing. Just like everyday interactions in real life, grasping



an object creates a counterforce on the finger bed, which is in this case simulated by the thimble connected to the cable.

The glove is mounted on the user's hand through two loops of Velcro around the palm and one loop around each fingers' distal phalange. The Velcro loops allow the user to tighten or widen the straps, enabling the SenseGlove to be worn by both big and small hands. For the last year, a new concept for a strap has been in development. The SenseGlove Pro should allow this new concept to be integrated within the product.

The same applies to the new actuator in the hub of the glove. The actuator that simulates impact on the hand, better known as the thumper, has found to be most effective when mounted at outer side of the hand palm. In the DK1.2 the thumper was a simple LRA. For coming generations, SenseGlove wants to be able to use higher fidelity actuators such as the LoFelt or Taptic engine. These actuators allow the use of more complex haptic signals that provide the user with a more realistic sensation.

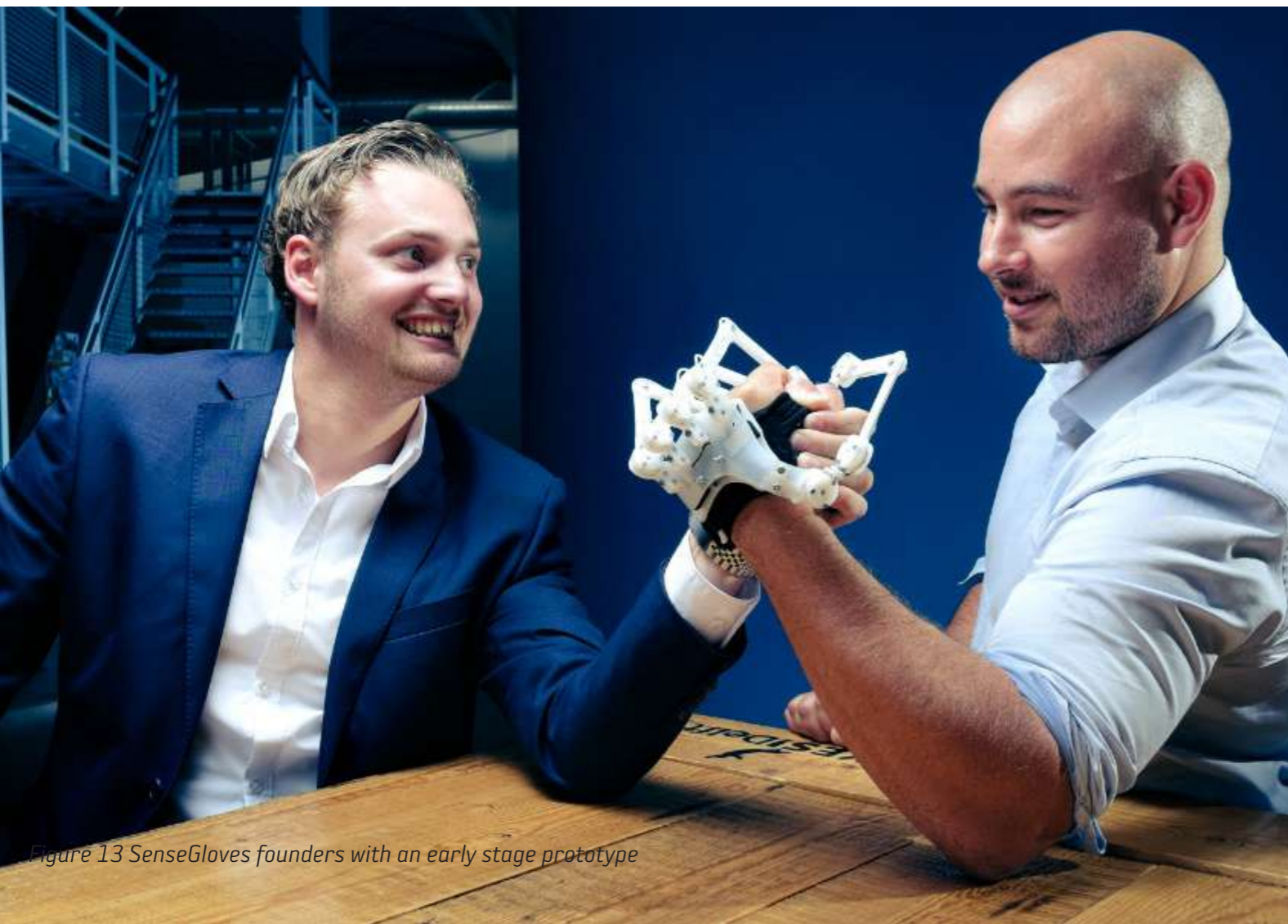


Figure 13 SenseGloves founders with an early stage prototype

Company roadmap

Now, two years since the initial launch of the DK 1, SenseGlove is using their insights from last years to develop two new products (see “Figure 14” on page 30). The first product is the Fino, a product that targets the industry for virtual trainings. Its main goal is to provide the user with immersive and clear haptic interactions, embodied in an easy-to-use and maintainable product. The product does not use an exo-skeleton to track the motion of the user, but relies on tracking capabilities of head mounted devices.

Simultaneously to the development of the Fino, the SenseGlove Pro (also called Rembrandt) is in development. This is the product for which the product concept is developed in this project. This product is targeting researchers within the academic industry and R&D departments within development departments. The development of the SenseGlove Pro started in early 2020 and is planned for a design freeze at the end of 2020.

Parallel to SenseGlove’s product development, tons of research projects are run. Some of those projects resulted in product features that are planned for implementation in the SenseGlove Pro. These features are described in the LoR which can be found in “Appendix 6: list of requirements” on page 132. The most important acceseoire is the wireless kit, which allows the user to use the SenseGlove with a bluetooth connection. The wireless kit will remain in the product portfolio for the foreseen future.

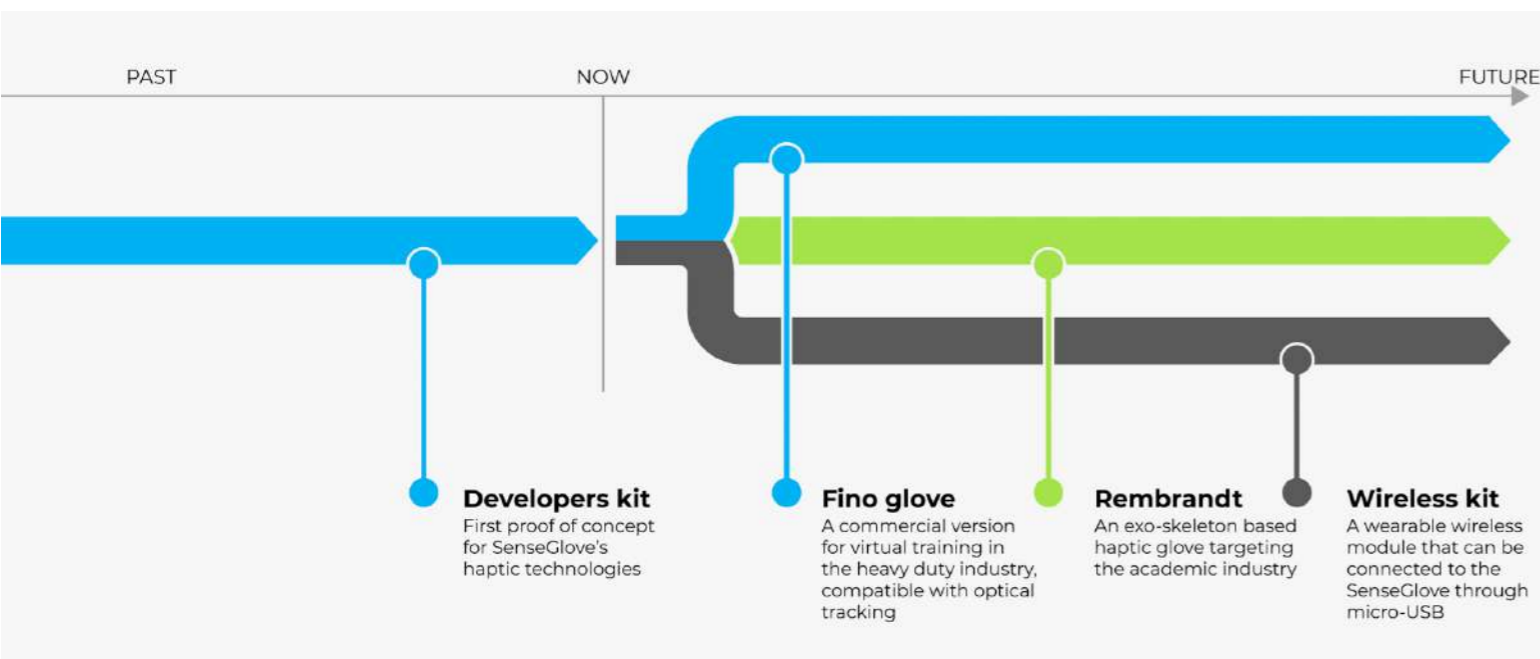


Figure 14 The roadmap for past and future SenseGlove products

SenseGlove's Strengths

SenseGlove is a technology driven company. For that reason it is no suprise that the technology within the haptic glove is a big asset in SenseGlove’s value proposition. Compared to other haptic actuators, SenseGlove’s force feedback is easy to produce in higher quantities without compromising in quality. This allows SenseGlove to design products that can be scaled up in MOQ. SenseGlove’s technology is protected by high quality patents, which gives them a headstart from their competitors.

SenseGlove consists of a talented multidisciplinary team focused on the development and improvement of the product. With years of experience, SenseGlove is capable of quickly pivoting design features to try out new principles. These strong development capabilities allow SenseGlove to quickly response to new developments in the industry.

SenseGlove's Weaknesses

The performance and specifications of the SenseGlove have not been officially benchmarked. This means that the general performance of the glove is unquantified, which does not support the perceived quality of the glove. Especially for the academic industry, transparancy in the products specifications can be a dealbreaker.

This lack of benchmarking can also be noticed in the applications of the SenseGlove. While in principal, the glove is a universal product with practically unlimited use cases, the actual value per use case is not clearly demonstrated or proven.

SenseGlove's Opportunities

The market for force feedback systems is growing since the popularity and amount of HMD’s (Head Mounted Displays).

The industry for research and development has been identified as an area of growing potential. The amount of research projects has been growing over the last years, and is expected to continue so for coming period.

Competition is behind on quality, force feedback is a rare feature among market ready products. SenseGlove can use this weakness by targeting markets competitors can not reach yet.

SenseGlove's Threats

Haptic actuators (especially vibrotactile) keeps developing rapidly. The haptic actuators in a launched SenseGlove can be outdated fairly quick after the introduction of revisioned actuators. This is specifically a problem for the academic industry, where using state-of-the-art equipment is of high importance to the quality of the research.

Some engineers develop hardware themselves, and might not be interested in pre-defined off -the-shelf products.

Specialized products might be more suitable for practical implementation within the industry.



Figure 15 The SenseGlove being used for virtual training

Company drivers

The introduction of the first developer kits has brought a variety of learnings to the company. Besides strategic insights into market positioning, there are also takeaways from a technical point of view. In this chapter, the most important technical driven requirements are described, and a strategy to meet those requirements is introduced.

Exo-skeleton based haptic gloves have always been extremely complex products. The integration of actuators and sensors, spread over various moving parts within the product, has been a problem SenseGlove faced ever since the release of the prototypes. For this reason, given that the production quantity in the coming years increases dramatically, design for manufacturing is a significant company concern. The manufacturing on a part level should be prepared for these numbers, and the assemblage of the product should be reconsidered.

This does not only apply to the product concept that will be developed in this project, but also for future products yet to come. Ideally, the way this product can be manufactured should lay the fundamentals for future generation gloves or different configurations of the same product.

A popular example is the so-called MQB platform, the driver behind Volkswagen's great success (Buiga, 2012). The MQB platform is a strategy for a shared modular design of many front-wheel driven cars within the Volkswagen group. Many of Volkswagen's cars share the same front axle, pedal box, and engine positioning. By defining

this "standard configuration" within the portfolio, Volkswagen managed to save tons of manufacturing resources, without limiting themselves in their product portfolio in terms of style and performance.

This principle could be implemented for SenseGlove's haptic gloves as well. By designing a standard base for the hardware to be mounted in, the actuators, sensors, and housing can be changed for each model. The major question that should be asked is to what extent the model should be flexible to satisfy the consumers' need for different models. This need is integrated in the LoR as requirement nr. 29.

Ever since the first SenseGlove has been developed, functionality has always been the main concern. The next generation SenseGlove is meant to be more of a mainstream product, and its appearance should be designed as such. The product should not only look functional, but should also have a fit with the company identity and user concerns.



Figure 16 MQB platform by Volkswagen

The SenseGlove Identity

Since SenseGlove is a relatively small and technology-oriented company, there's not a clearly formulated brand identity for products and visuals that are released. In order to capture and define the desired brand identity that can be applied to the new concept, a creative session has been organized (see "Figure 18" on page 33). Within this session, various stakeholders from within the company with different backgrounds were stimulated to discuss the look and feel of various concepts and designs.

The discussions were based on a number of common contradictions within design language. For each contradiction, the stakeholders were asked where the ideal SenseGlove product would be positioned, and why they thought this would fit the company.

Not only the brand itself should be represented by the look and feel of the product, but also the representation of the product within the portfolio should be considered. Compared to the FINO glove, which is in parallel development with this product, the SG Pro should present itself as a more sophisticated, high-performance and high-end product. An overview of the brand identity can be found in "Figure 17" on page 33.

The current version of the SenseGlove DK1.2 is easily recognized by its bright blue color. The same color is used in the logo within all communication from the company. SenseGlove does not require the implementation of this color as the main color of the product. However, the color should be implemented at detail level, to keep a connection with the existing portfolio to remain recognizable as a SenseGlove product. See "Color selection" on page 88, for the full process.



Figure 17 SenseGlove's identity



Figure 18 Creative session at SenseGlove

Key takeaways ■

- **SenseGlove Identity**

Through a creative session involving company stakeholders, a brand identity for SenseGlove has been described. This brand identity will be used for further decisionmaking in the design of the appearance of the new product concept

- **SenseGlove Product**

The functionality of the traditional SenseGlove has been analysed, which clarifies the overall technical framework for the new concept product. It provides insights in SenseGlove's current expertise on a functional level.

- **SenseGlove Roadmap**

The position of the new concept within the product roadmap has been defined. This information can help in the creation of a unique value proposition that complements the portfolio, but does not overlap with other products within

- **SenseGlove SWOT**

The strengths, weaknesses and following opportunities and threats are layed out and can be used for ideation and decisionmaking later in the process.

- **SenseGlove drivers**

SenseGlove's learnings from launching their developer kits have been summarized and can be taken into consideration for the development of the product concept.



04

Vision Synthesis .

This chapter describes the collection and synthesis of the individual future visions for research platforms like the SenseGlove. In various user-sessions, design drivers, ideas and design directions were discovered and iterated upon by feedback from the target user.



SESSION 1: USER MAPPING

Goal

Every group of users is unique and has their own concerns when it comes to their research activities. In order to provide the target group with a product that adds value to their use-case in the future, it is important to get to know the users and understand their current concerns. Especially in the academic industry, in which many different research directions and roles can be identified, user needs can vary. The first user session's goal is to obtain contextual information about the target users and their individual concerns, identify differences and similarities between individual users, and get an initial impression of what they consider a positive or negative product

experience. This information should provide the designer with an initial understanding of the target group's preferences based on their current experience.

Research questions

- What are the main concerns for the target users and their research activities?
- Which product qualities are important for academic workers?
- What differences and similarities can be identified within the target group?

Method

Four researchers with varying backgrounds and positions from the TU Delft were interviewed for this user session. During the introduction, the interviewer tells about his background and shortly elaborates on the background of the project. In the case of multiple interviewees, the participants will be able to introduce themselves and talk about their fields of research. The participants are encouraged to answer questions as honest and complete as possible in order to get the most in-depth insights possible. The participants should feel free to speak their minds without any expectations.

The participants will be presented with certain statements and fill in or answer the statements based on their background and past experiences. The first statements describe topics around the participants and their personal drivers, and will slowly transition towards topics around research activities, equipment and experiences. In appendix 1, the full research setup can be found. This way, the users can "warm-up" by providing information

close to them, and provide more in-depth and complex insights later during the interview.

The participants will be asked about experiences and expectations on the use of products within their lab. First, they are asked to provide insights on common frustrations and benefits they encounter in product use. Then the participants are asked to elaborate further and highlight moments of product experience in the customer journey. Lastly, after discussing many elements of product use, the participants are asked to name the three characteristics that the ideal research tool should embody. To stimulate the participants, a list of random characteristics will be presented. The participants can, but are not limited and to, choose characteristics from this list.

On the right, some of the statements from this user session can be found.



Results

To summarise and communicate the findings of the first user session, three user persona's and a storyboard are made.

These archetypal representations of the intended users describe the most important values and needs that are identified. It is important to note that the persona's show both similarities and discrepancies when it comes to certain concerns and value's. For example, researchers with an engineering background prefer to customize their tools as they work through the project. In contrary, non-engineering researchers prefer an off-the-shelf solution that requires no effort to set up.

In "Appendix 7: Personas" on page 136, the complete user persona's can be found. On the current page, the most important goals, frustrations and concerns are presented.

David

INDUSTRY R&D

Goals

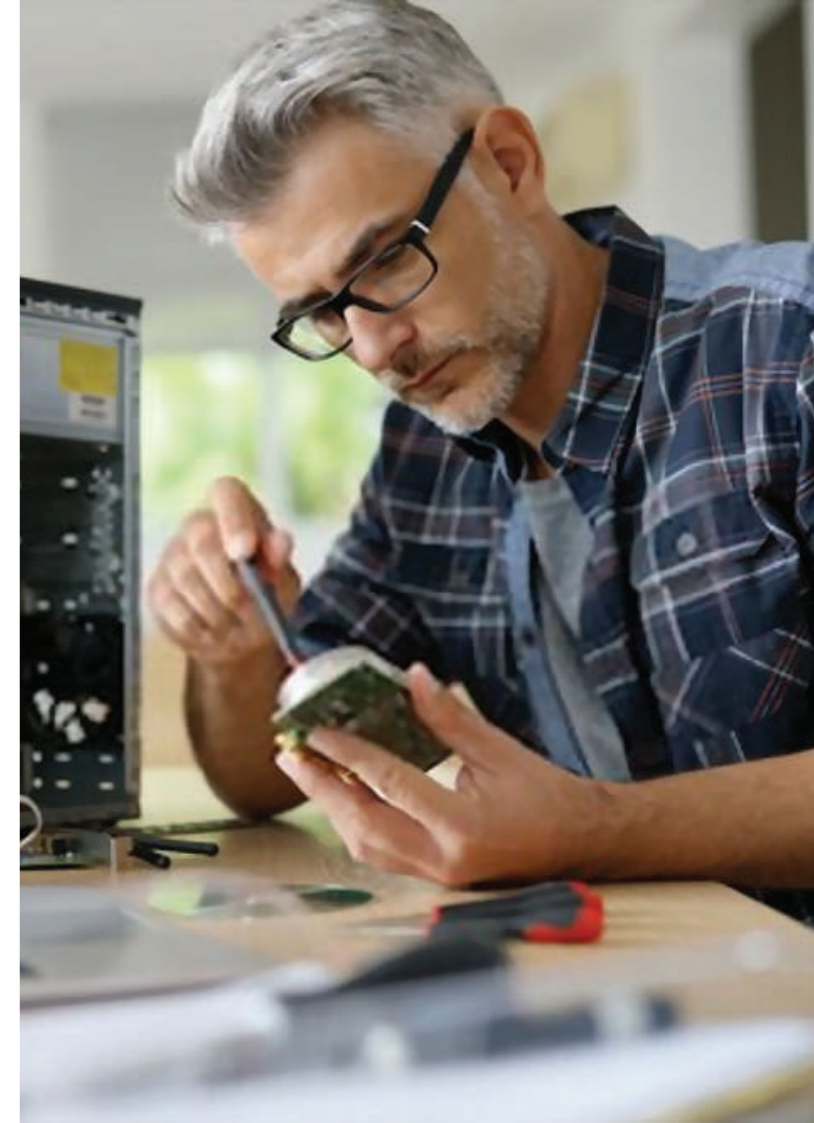
- I want to test and implement new functionalities
- I want solutions to be industry-proof in the long-term
- In want to innovate the system within my company
- I want to get recognized for my achievements

Frustrations

- Prodcuts release constantly, and outdates my setup
- Products do not represent my professional use-case
- Many products do not meet my specific requirements

Concerns

- I want freedom to explore and experiment
- I want to have my own side managers
- "I want to explore that next big thing that will bring my company to the next level."**
- My tools is comfortable, I wear it every day



Michael

PHD CANDIDATE

Goals

- I want to develop myself as an expert
- I want to be able to work in different places

Frustrations

- Constantly building and tweaking distracts me
- I'm uncomfortable doing tasks out of my expertise
- Lack of transparency disables to to draw conclusions

Concerns

- The tool allows the participants to act natural
- The tool is safe and comfortable to work with
- The tool is easy to work with

"I do not want to worry about my equipment and the safety of my participants. They should behave as natural as possible."



Karen

PROFESSOR - LAB OWNER

Goals

- I want to motivate my labmembers
- I want to contribute and guide the community
- I want to get recognized for achievements

Frustrations

- I always need to re-invest in equipment to keep my equipment state-of-the-art.
- Moving my equipment can be a hassle
- Lack of transparency disables me to draw conclusions

Concerns

- I want to understand unknown principles
- My tools do not require adaptations.
- My tools get recognized as state-of-the-art

"Benchmarking with the golden standard? No, want to work with the golden standard!"



The storyboard is a visual way of documenting and communicating (positive and negative) experiences that researchers experience during their research projects.



Figure 19 Defining specific requirements

The first area of the storyboard, as can be seen in “Figure 19” on page 42, highlights a phase where the researcher is defining the requirements for his research setup. Since the quality of the equipment has to be high, but often suitable for a very specific use-case, it can be a burden to find the right piece of equipment that meets the requirements.



Figure 20 Collectively unboxing

A little later, as can be seen in “Figure 20” on page 42, the unpacking of the new piece of equipment is a highlight for most researchers. Playing around with the new “toys” is an activity that brings the whole lab together, since everyone gets excited. According to lab owners costs for equipment are rarely too high. For this reason, lab owners like to invest in more premium products that stimulates the researchers in the lab to work with the tools.

After finishing the standard demo's of the new equipment, the researcher tries to integrate the tool in his existing system for the first time (see “Figure 21” on page 42). This part of the customer journey evokes the most negative product experience, since this process is frustrating and time-consuming. In many cases, integration requires software- or hardware modifications, which for many (non-engineering) researchers is experienced as a huge burden. It often forces the researcher to perform task they are not experienced with or feel like should not be their responsibility.

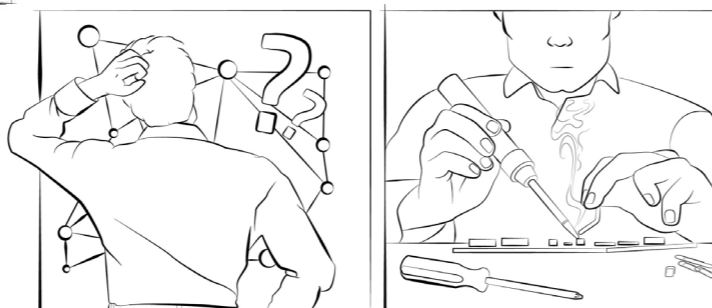


Figure 21 Integrating a tool in the labs setup

After successfully finishing the research project, the project results can often be used by an industry partner for implementation or further development. In many cases, an industry partner is (partly) responsible for funding, and can be considered a client for the researcher. Satisfying the industry partners (see “Figure 22” on page 42).

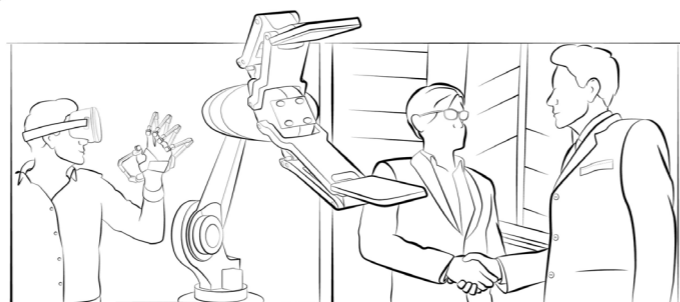


Figure 22 Industry partners involved

At the end of the research project, most hardware is stored. The lab owner hopes that the tool can be used for a second use-case, but in most cases this will never happen.



Key takeaways

- **Variety of sub-target groups**

The target group of researchers consists of a variety of users with different positions, backgrounds and use-cases. Although the workflow among the researchers is similar, the requirements for their research platforms are specific for each use-case.

- **Trustworthy, reliable and robust**

When asking the participants about three important characteristics of their research platform, the most occurring keywords were trustworthy, reliable and robust. These characteristics are in direct relation with the functionality and performance of the product.

- **Providing transparency**

Each interviewed researcher stated that transparency has always been a crucial factor for their research tools. Without transparency and a good understanding of the flow of information of a piece of equipment, the researcher can not justify the relevance of the collected data. This directly correlates to the quality of the researcher's publication.

- **Integration in the set-up**

The sub-target groups show differences and similarities in their frustrations. Researchers without a background in engineering often find themselves struggling while integrating a tool in their already existing set-up. In their experience, making custom changes in both hardware and software is an inevitable part of preparing their set-up. On the other hand, Engineering researchers think that customizing a product is an important part of the development and pushing the boundaries of their field. Many engineering researchers build their own research platforms from scratch. For them, integration is something they like to experiment with in order to test various configurations or methods.

- **Industry stakeholders**

Many research projects are supported and funded by industry stakeholders. Involved companies are often looking for new innovations in their company that come from these research projects. This means that a the industry stakeholders agenda is of high importance to the researcher, which means that the research platform should suggest its relevance to industry applications as well.



SESSION 2: VISION MAPPING

Goal

The goal of this interview is to obtain insights on the future vision from the target group's perspective, on the developments within HCI- & haptics research platforms and their direct context. The interview is performed with individual participants, enabling the interviewee to steer and discuss as a response to specific thoughts and statements they consider a positive or negative product experience.

The results from this session should give insights in the individual visions of the researchers. The results will be compared, similarities and discrepancies are identified. Then the visions will be synthesized towards vision drivers; the main design drivers for the new product concept.

Research questions

- What is the future vision on HCI- & haptics research platforms in the foreseeable future according to researchers in those fields?
- What do those research platforms look like, according to researchers?
- How will those research platforms be used, according to researchers?
- What should be, according to researchers, the most important developments to make research platforms relevant for their use-case?

Method

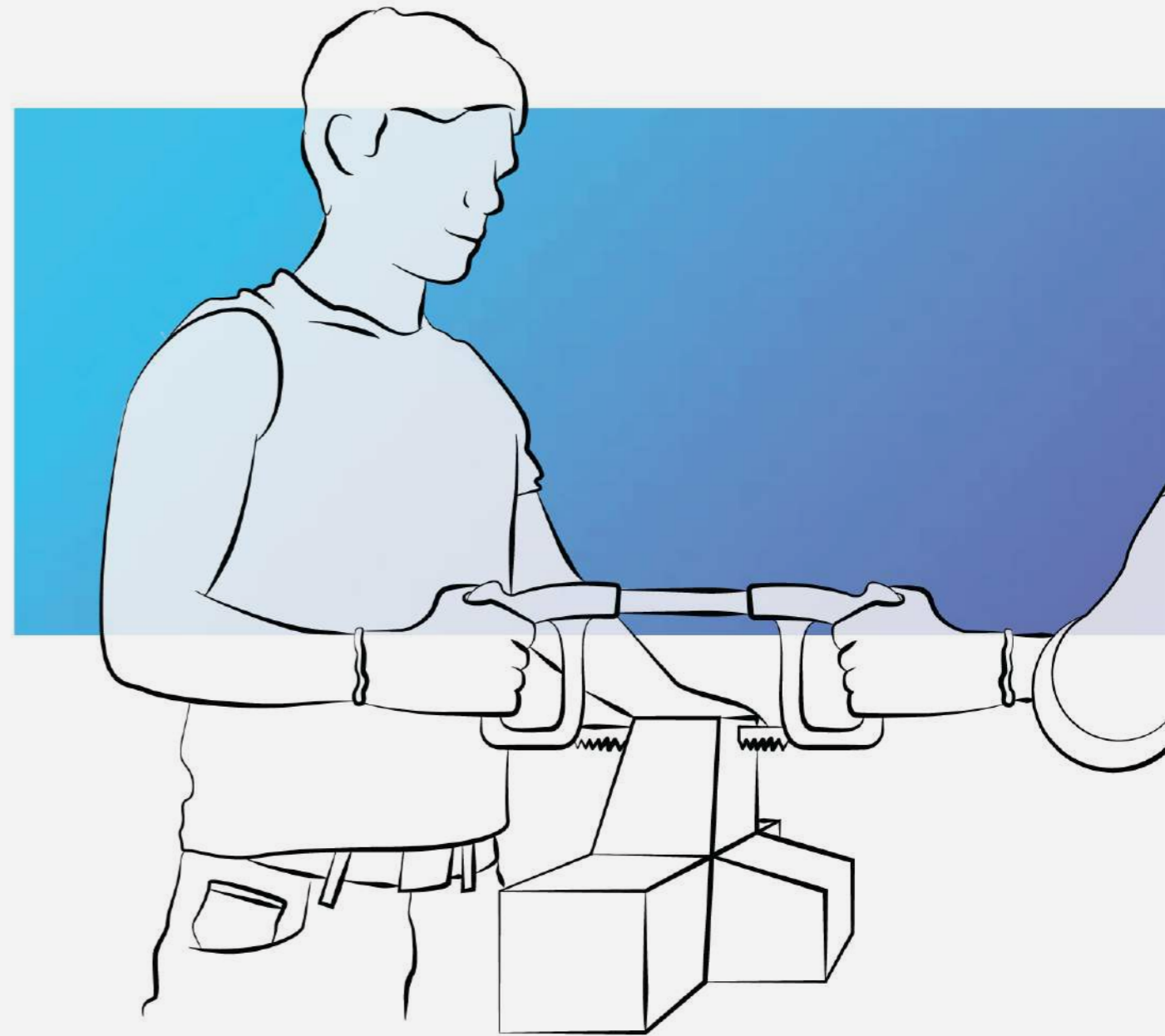
The participants during this session are academia and/or R&D workers. A minimum of three sessions, and thus participants, are required for this research. The interview is performed in a relaxed atmosphere without distractions. The participants are offered refreshments to remain comfortable and satisfied during the interview. During the interview audio will be recorded to review the research outcomes. The participant will be informed and will provide permission for making and using the recordings. This will be done through signing a consent form. After wrapping up the formalities, the interviewer tells about his background and shortly elaborates the background of the graduation project. Then

the participants answer a series of open questions. The participants are encouraged to answer questions as honest and complete as possible in order to get the most valuable insights as possible. The participants should feel free to speak their mind without any expectations. The participants will be allowed to introduce themselves and tell about the current situation within their field of research and projects. To get a better understanding or steer the interview in interesting directions, the interviewee is free to ask the participant to elaborate the answers even more.

A full overview of this session's research plan can be found in "Appendix 3: Vision session" on page 129.

Results

The results of the vision sessions can be found in their entirety in "Appendix 8: Raw interview notes" on page 141. The resulting vision drivers can be found on next page. All participants' statements have been scanned, and similarities and discrepancies have been identified. Participants were able to share their concerns and expectations on their future research tools.



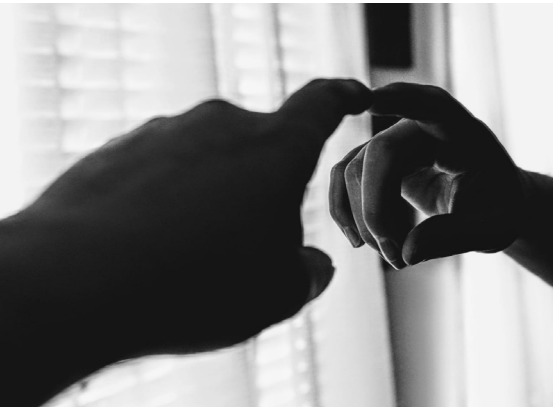
VISION DRIVERS

The statements from “Session 2: Vision mapping” on page 42 are analyzed, and generalities and discrepancies have been identified. The most critical and frequently provided statements are described in the vision drivers. The vision drivers will function as design input for the design directions and represent the user concerns in the further decision-making processes.



Natural interactions

Every researcher states that it is necessary to observe the user doing tasks as he would do in real life. The tool should be unobtrusive and comfortable. The same applies to the haptic feedback that is provided to the users. The more realistic and believable the virtual interaction is, the higher the quality of most experiments. Depending on the usecase, the interpretation of a natural interaction can vary.



Integration

Especially for researchers with a non-engineering background, integrating a product within their system is perceived as a significant problem. Manual changes to software and hardware keep them from their relevant work. The future vision describes a research platform that works well with existing lab setups and blends in with the rest of the equipment. Besides, the tool itself should be an integrated design. Researchers expect that technologies will be blend more in everyday objects, such as wearables integrate technologies in accessories.



Co-studying

According to the researchers, projects that involve overlapping fields or research will be much more critical in the future. Being able to validate or support findings by research in other fields, research results get more tangible and create a better vision of the potential of a technology or principle in a later stage of development. For example, a device that has been developed by an engineer to simulate textures is much more relevant when an expert on simulations demonstrates that this feature improves the efficiency of a training simulation.



Comfort



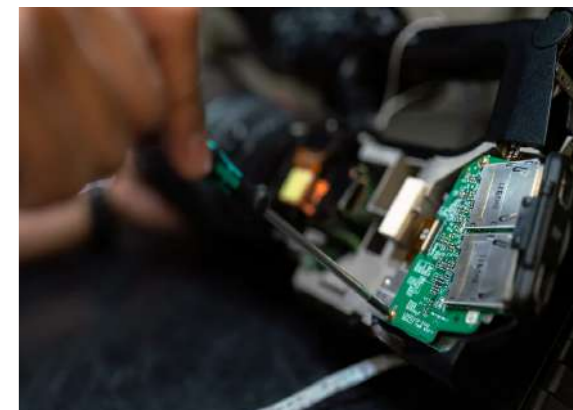
Where new technologies are mostly embodied rough and volumous prototypes, researchers expect that SenseGlove-like tools will develop further towards a more wearable product. They expect, that when product like this hit the industrial- or even consumer market it will look more like wearable than a prototype. However, researchers still expect that the products consist of hard and rigid materials to conduct forces and vibrations. Without these rigid materials and exoskeleton structures, the overall performance of the tool would decrease.



Flexibility



Engineering researchers like to have the freedom to test new hardware and software ideas themselves. When an engineer has an idea, he would like to put it to the test by changing his research setup, sometimes up to component level. Non-engineering researchers want an easy to integrate a tool that enables them to discover and prove new principles. Besides, a tool that can be used for multiple kinds of experiments is preferred over a one-time-use tool.



Industry driven



The researchers seem highly influenced by industry stakeholders, who are often an important source of resources. The tool should leave a professional impression, be state-of-the-art and demonstrate potential applications within the industry.



SESSION 3: PARTICIPATORY DESIGN

Goal

The future visions from individual researchers are collected and compared, and generalities and discrepancies have been identified. These insights could already be used for ideation towards initial design directions. At the same time, some core characteristics in the future vision, often describing a product quality, are open for interpretation and should be further explored and defined before design decisions can be made. In addition, it is still unknown how the researchers relate to vision drivers that are defined by researchers with other backgrounds

Research questions

- According to the target users, what product appearance fits the future vision best?
- According to the target users, what functionalities and product features represent the future vision best?

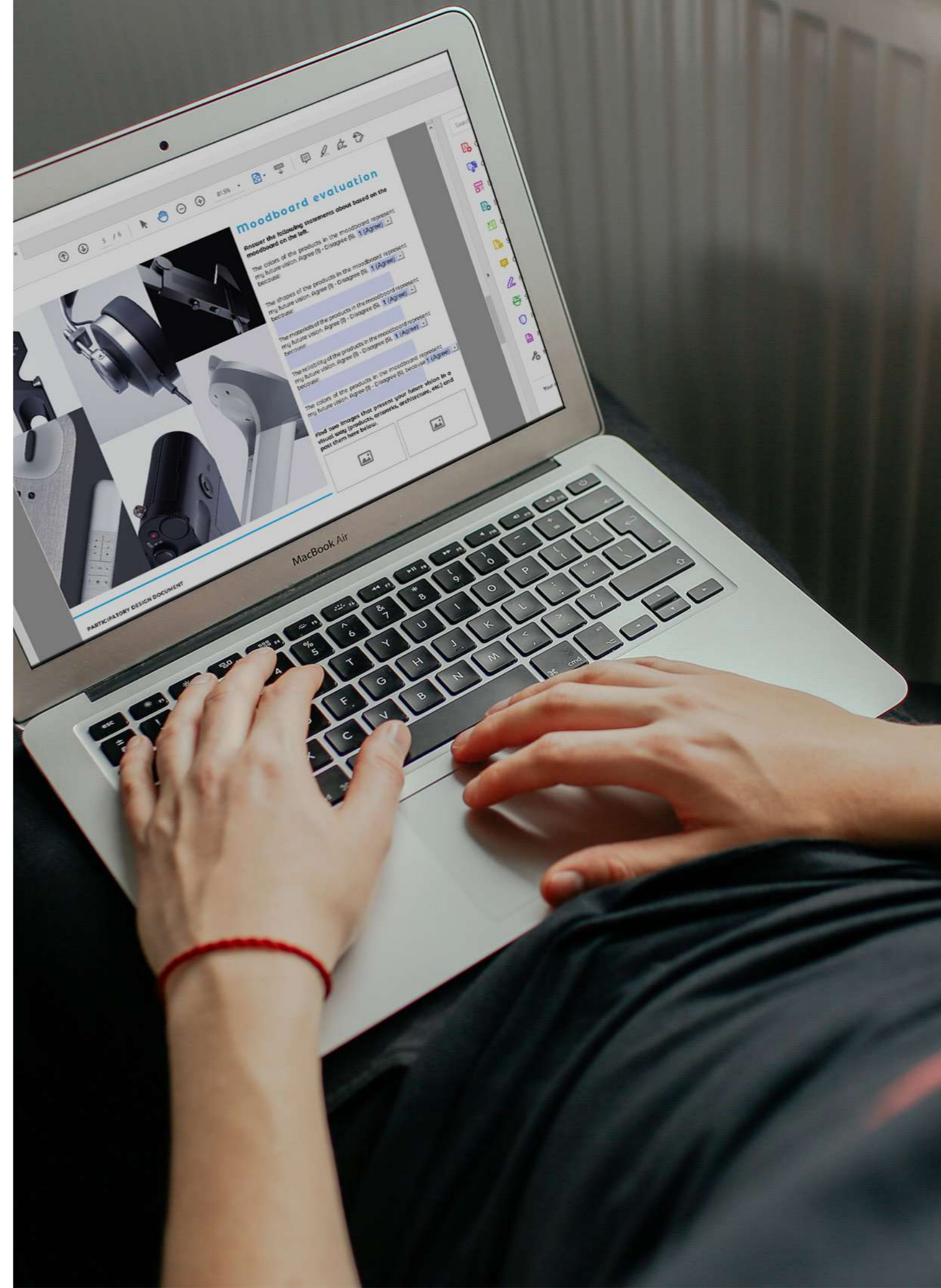
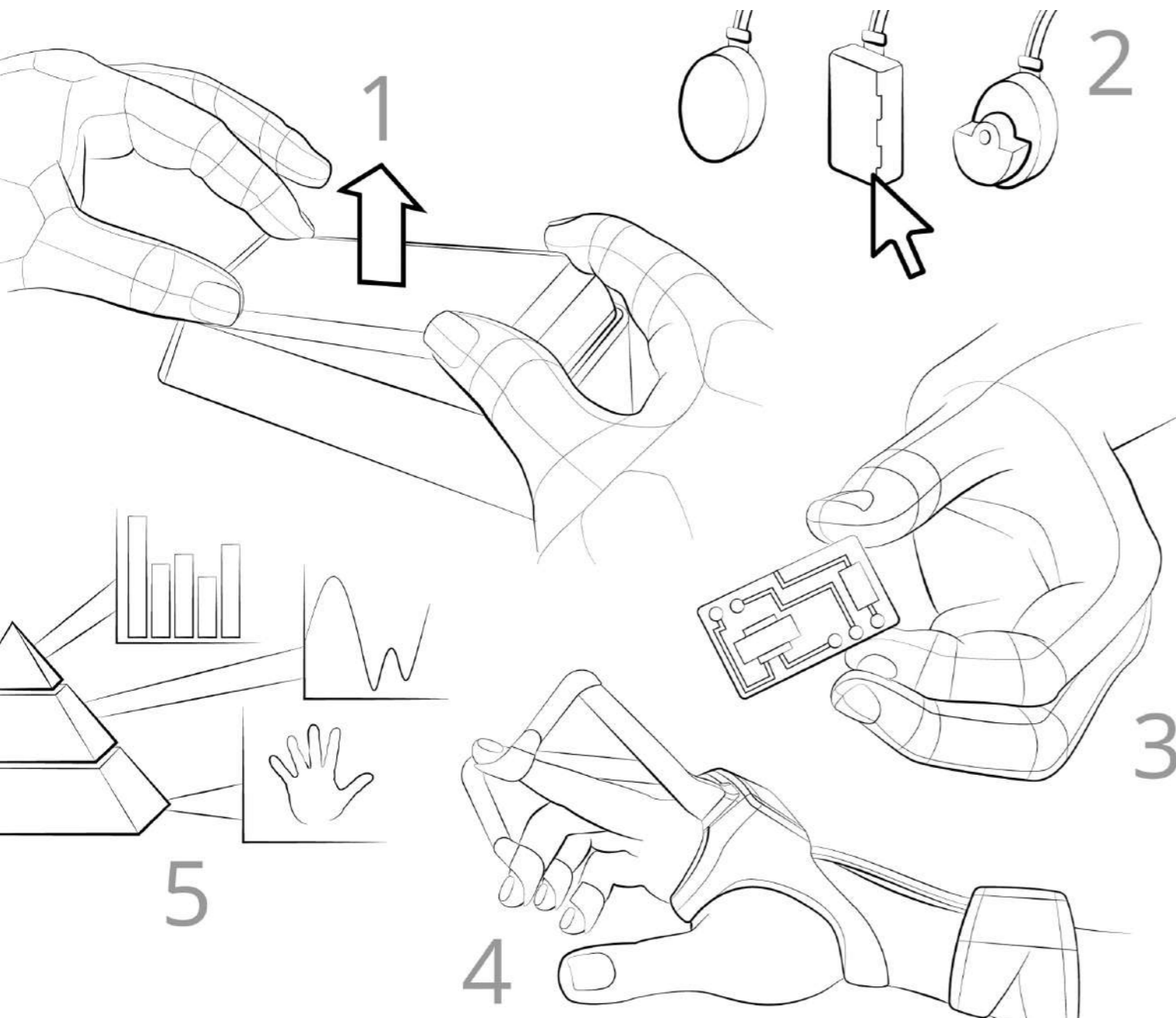


Figure 23 Some of the ideas presented in this session

Approach

In order to gain rich information and stimulate discussions about future design directions, the path of expression theory (Sanders & Stappers, 2012) was used. According to Sanders, peoples past and present experiences will influence their future desires and dreams. By applying the right techniques in the user session, the creativity of the participants can be stimulated to extract ideas based on underlying needs for today, but also aspirations for the future.

Research techniques to explore people's experiences can be divided in three categories: Say, Do and Make (Sleeswijk Visser et al., 2005). By studying what people say, do or make different levels of knowledge can be accessed (see figure 14). By interviewing people and finding out what they say and think, you can gain explicit knowledge. By letting them do or use things and observe these actions you gain observative knowledge. By allowing the participant to actively engage in problem solving, you can gain tacit and latent needs and discover what people know, feel and dream. In this case, it helps the designer in confirming the earlier identified vision characteristics, and allowing the user to elaborate how a future product can improve to fit the vision.

Method

The session consists of 4 stages. In the first stage of the document, the participant is presented with vision drivers that are derived from previous session. The participants are asked to select either "agree" or "disagree" and their motivation for their answer. Lastly, the participants are asked provide a theme or challenge they think are missing in the overview. Their answers will be used to evaluate the future vision, and create an overview of the differences between certain user groups.

In the second stage of the document, the participant will be presented with post-it's that contain the challenges derived from the future visions. Since the document is an interactive PDF, the personally defined challenges from the first stage will be presented as well. The participants will fill the blank post-its with solutions for each design problem. This information represents viable solutions in the eyes of the end-user.

In the third stage of the document, the participant will be presented with a series of design dilemmas. These design dilemmas are identical to the ones that are used to define the

In normal circumstances, such generative sessions are conducted in a creative environment where different stakeholders participate at the same time. The advantage of such a set-up is that the participants can stimulate each other and discussions can lead to interesting insights. In addition, the goal of the session is to let the participant create a physical artefact, which represents their interpretation of the product.

Unfortunately, due to the COVID-19 measurements it was impossible to meet the participants in person, and meeting the participants in a digital meeting environment. This means that guiding them through the process of making a physical artefact becomes way harder. The same applies to working together with other participants and starting discussions to understand their thought process. To solve this, a virtual booklet has been assembled, that runs the participant through various problem-solving stages. This way they can create their own document that represents their concerns, ideas and feedback while discussing the topics with the interviewee.

desired brand language during the creative session at SenseGlove. The participants pick a value from 1 to 5, to define the characteristics the new concept should contain to fit their future vision. From this data, it will be clear what the expectations for the product are on an embodiment level, and similarities and differences between preferences of the company and the user can be identified.

In the fourth and final stage of the document, the participant has presented a series of functionalities and features that were generated in an ideation session by the designer. The participant rates the features from 1 to 5 and motivates their rating by text. After rating the design input, the participant is asked to explore the internet for three images that represent their future vision. The participants can include captions to highlight and clarify their picks.

FILL IN THE YELLOW POST-ITS WITH IDEAS AND SOLUTIONS

VISION EVALUATION:
According to your specific use-case, what are important features of a future research platform? Sort them from most valuable (1) to least valuable (6).

Robustness
Flexible & comfortable
Allows me to cooperate with other fields of research
Allows me to cooperate with industry partners
Allows participants to interact in a natural manner
Trustworthy & reliable

(most valuable)	Rank 1	Trustworthy & Reliable
	Rank 2	Trustworthy & Reliable
	Rank 3	Trustworthy & Reliable
	Rank 4	Trustworthy & Reliable
	Rank 5	Trustworthy & Reliable
(least valuable)	Rank 6	Trustworthy & Reliable

Since you are the target-user, you have the most important saying in what the future SenseGlove should be. Fill the gap in the following sentence: In a short statement, the SenseGlove should be...

MOODBOARD EVALUATION
Look at the moodboards on the left. Evaluate the moodboards based on their appearance. Prioritize them based on the fit with your vision of a reliable, robust and trustworthy research platform.

The moodboard that fits my user vision most is: Moodboard 1
The moodboard that fits my user vision least is: Moodboard 1

IDEA EVALUATION
On the left side of the page, various ideas are presented.
1. Modules with haptic functionalities can be swapped for repair, upgrades or different functions.
2. When purchasing the SenseGlove, you can select the exact hardware that is integrated in the glove.
3. Developers can share their own haptic hardware that can be integrated in any SenseGlove. This stimulates cooperating between various fields of research.
4. Hardware is moved from the hand to the arm, making the glove smaller and lighter to use.
5. Data can be presented on various levels of complexity, making it easy to share results among stakeholders with different levels of expertise.

You are asked to rank the ideas. Rank the features that you value the most on the highest place, and the features that you value the least on the lowest place.

Rank 1 (Most value)	Idea 5
Rank 2	Idea 5
Rank 3	Idea 5
Rank 4	Idea 5
Rank 5 (Least value)	Idea 5

Pilot study

A pilot study was performed to check whether the participants were able to successfully complete the form. In addition, the quality and usability of the results has been reflected upon. This led to the following changes:

- The participants found it hard to answer questions that required them to choose between true and false. The questions have been reformulated, and now require the user to rank the options to the extent they meet their future vision.

- The task that required the participant to actively search for images that represent the participants vision was too difficult. The participant was not sure what to do, and it did not serve him as a way of effectively present his thoughts. For that reason, three moodboards have been created by the designer, and are included in the form. All moodboards include product qualities described in last session, but all of them in a different way. By ranking the moodboards according to the fit to their vision, it can be identified whether researchers share the same expectations on appearance.

- By allowing the participant to rate the generated ideas from 1 to 5, product ideas end up having the same rating. By ranking the product ideas relative to each other, it becomes way more clear what the preferences of the participants are. In addition, this way of ranking is in line with the changes to the rating of the vision drivers. Matching both ways of ranking the options adds coherence to the document as a whole.

Participants

The three participants of this session all have a research position at the TU Delft. The researchers have different backgrounds:

- Human-robotic interaction control
- Perceptual Intelligence
- Haptic Interaction Devices

Results: product features

The user session allowed the users to use their problem solving capacities to contribute to the ideation. Their suggestions were later visualised and considered for concept directions. The qualitative feedback on the ideas presented to the users helped in converging the ideas towards concept directions.



“By matching the temperature of a product to the body, the user is less aware of the actual product being there”



“Being able to share my own hardware solutions to clients and colleagues will definitely drive some of my projects”



“Why not also capture the actual output of the actuators, instead of just driving them?”

Results: Product form

During the session the users evaluated three collages, including products that in some way or form represent the vision drivers defined earlier. By speaking out their preference, the designer can refine his interpretation for what a sufficient product looks like according to the user vision. In other words, it decreases the chance of misinterpretation of the user vision.

The shapes in the chosen collage can be described as quite geometric. Sometimes they transition towards more organic shapes, but the shape is always defined by strong continuous lines, which ensures closure and repetition in the form.

As can be seen in “Figure 24” on page 56, when highlighting the lines that define the shape, only a few lines are required to describe the overall shape of the product. Many lines flow in the same direction, contributing to the feeling of continuation and repetition. Even when lines end, it tends to continue after a small “gap”.

Changes in materials and parts do not influence the contour of the product. The different parts fit seamlessly on each other which again, contribute to the closure of the design. Different materials often have a different color, adding some contrast to the overall product. Choices in colors, materials finishes and forms tend to follow the functionality of the parts. Parts that touch the body are soft and rounded, where functional parts look sharper and harder.

The products find a balance between typicality and novelty by finding the most minimal form that fits the functionality of the product. Stripping the product till basic geometry is left, makes the product look robust and functional. This way it differentiates itself from typical products in the product category, while the typical functionality of the product can be clearly recognized.

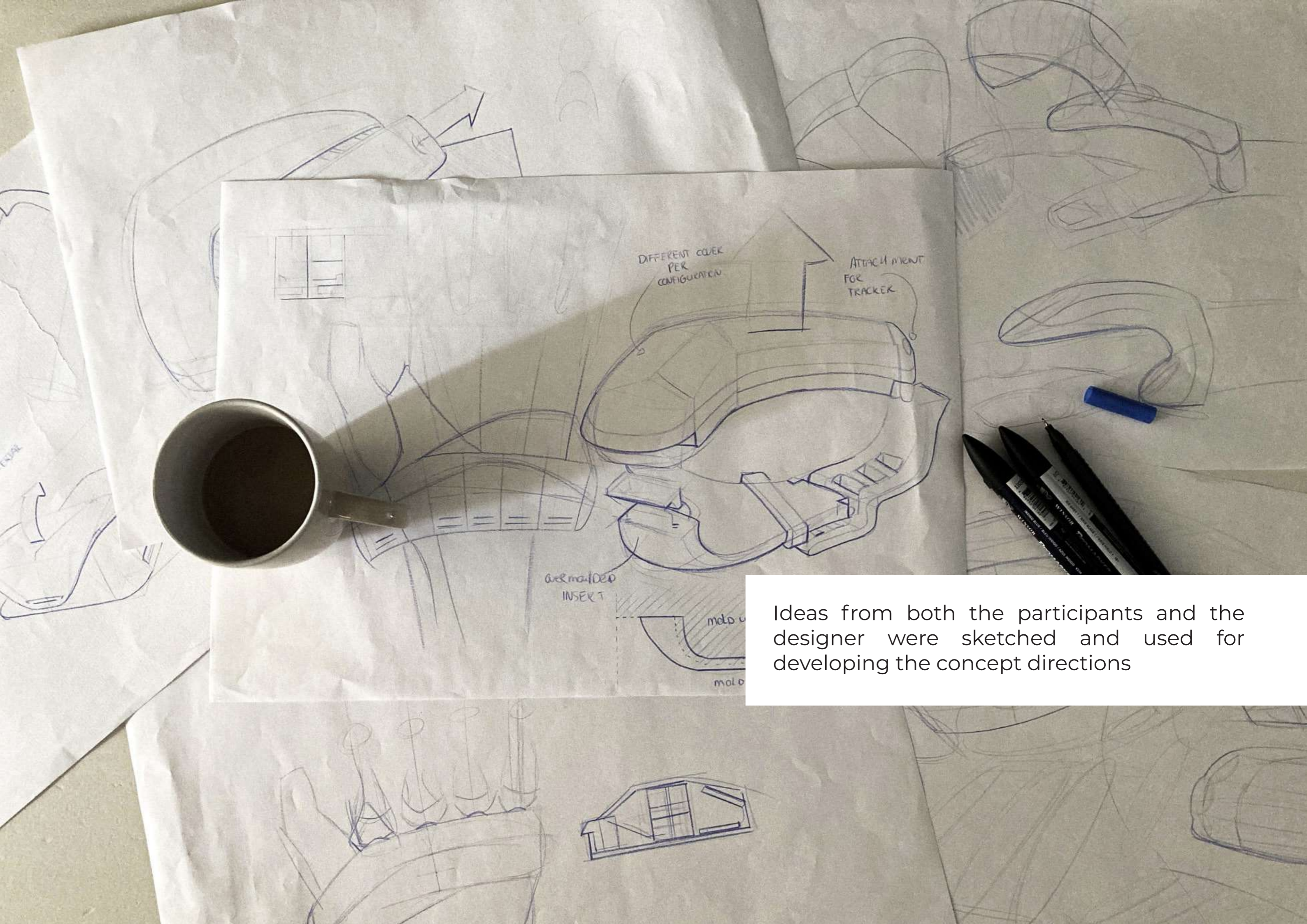
The features in the selected products have been analysed according to the principles described by Hekkert (see “2.8 Design principles” on page 24), and have been used in forming the final product concept.



Figure 24 Looking closer to the form



Figure 25 Collages presented to the users, top: preferred products



Ideas from both the participants and the designer were sketched and used for developing the concept directions

05

Concept Direction.

This chapter describes the process of transitioning vision drivers into a concept direction. Using ideation techniques and user interviews, initial ideas will be generated, selected and ranked based on insights from the user the context.



CONCEPT DIRECTION 1: LAGOD

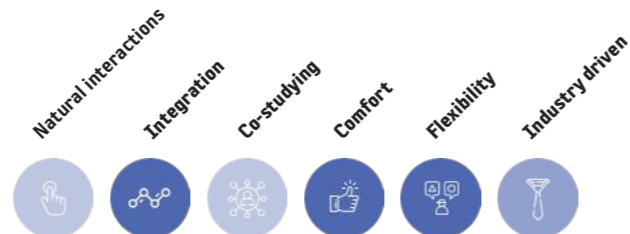
Design drivers

Lagod is mainly driven by the vision-drivers that describe an integrated and compact research platform. Although the current product requires a large enclosure to contain the force-feedback actuators, there are ways to reduce volume by eliminating unused voids.

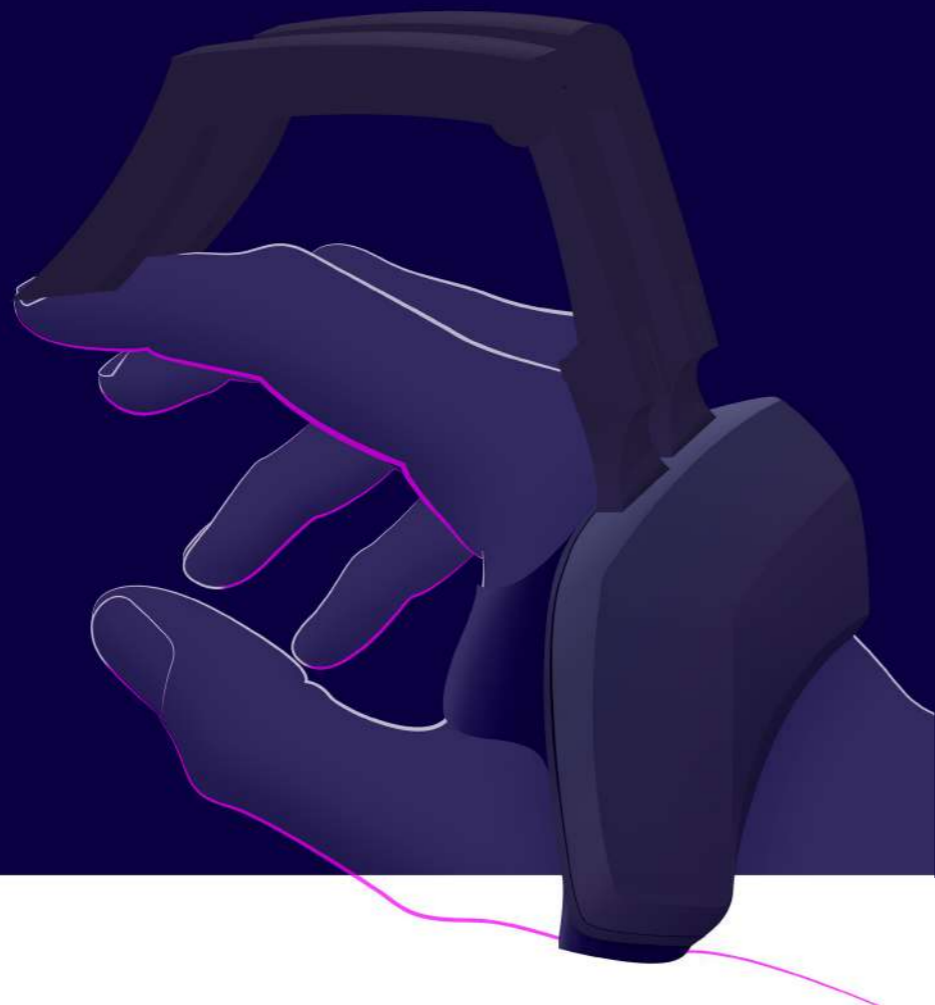
This concept allows SenseGlove to pack the researchers' individually selected functionalities in a small and compact enclosure. This way, the researcher can select the product features that fit his research requirements. By assembling different fingers with each a unique haptic- and tracking functionalities, the capabilities of the glove can be changed by simply assembling the glove with a different kind of finger. Each sort of finger corresponds with its own hub enclosure. This means that fingers with a smaller volume (for example, only motion tracking) can be housed in a smaller enclosure. Since only the top cover of the hub changes for each configuration, SenseGlove can offer various set-ups without the struggle of high customization costs. This way, each configuration matches the requirements of the researcher, as compact and integrated as can be.

Inspired by wearable consumer electronics, the palm strap of the glove is seamlessly connected to the hub. This makes the shape of the glove transition continuously from the hub to the strap. This aspect can enhance the "enclosure" of the shape and should enhance the overall aesthetic quality of the product.

The strap itself is made from TPU plastic, which is over-moulded on a hard ABS insert. This insert enables the TPU strap to be easily replaced by the user for different sizes, repair, washing, or upgrades.



The strap includes a buckle, which allows the user to change the size of the strap to fit comfortably to the hands size. The shape of the enclosure is lightly curved to the shape of the dorsal side of the palm.

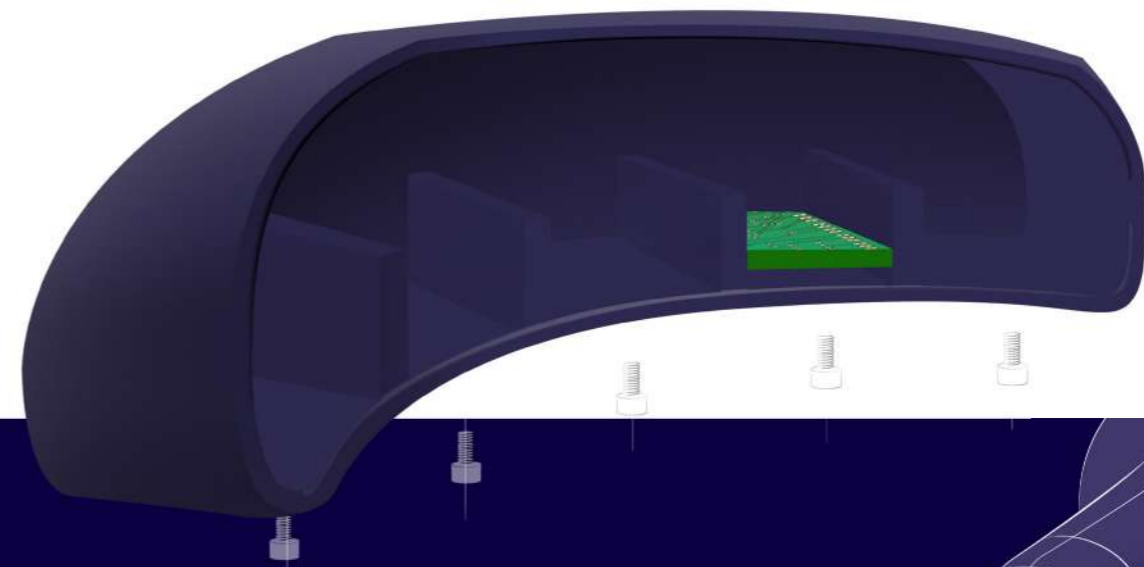
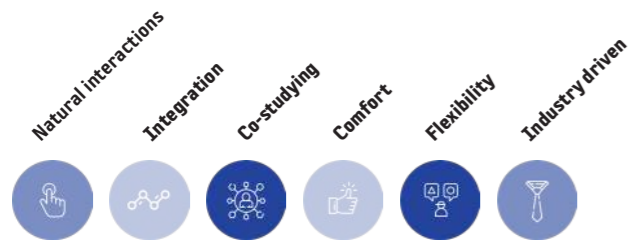


CONCEPT DIRECTION 2: CONSCIO

Design drivers

Just like Arduino became a sandbox platform for basic electronics, Conscio offers engineers a platform to experiment with new actuator- and driver technologies. Just like the current version of the SenseGlove, Conscio is a fully equipped SenseGlove that is ready to use for any use case that requires motion tracking and haptics. Haptic researchers that prefer to develop haptic stimuli themselves can open “the hood” of the device to insert their custom driver boards to control actuators of their choice. This way, the flexibility in terms of use-cases and product specifications is improved drastically. SenseGlove provides the user with breadboards that interface with Conscio, to make the prototyping process as easy as possible.

This customizability feature does not add any complexity for non-engineers, who are not interested in customizing themselves. However, they can request engineering researchers in their network to put their hands together on developing haptic interfaces for their project or industry interest. This way, Conscio stimulates co-studying in overlapping fields of research. It allows researchers to actively direct the execution of a project in the direction that is foreseen by the industry stakeholders.



CONCEPT DIRECTION 3: MOTUS

Design drivers

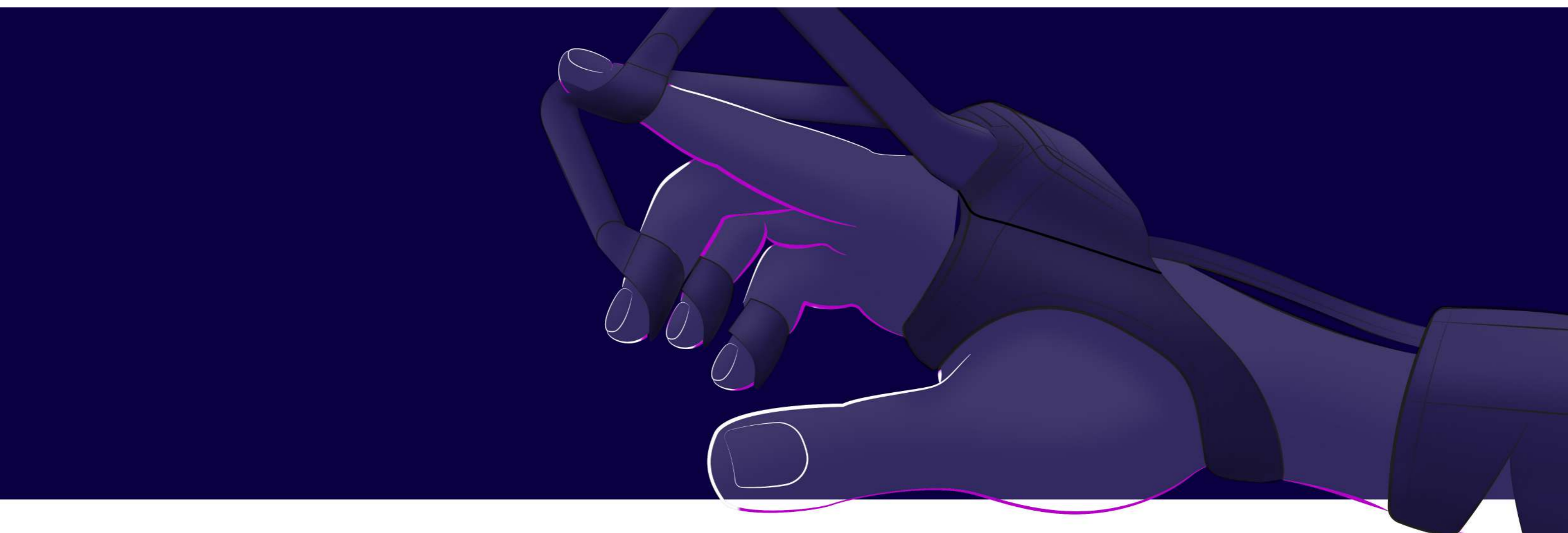
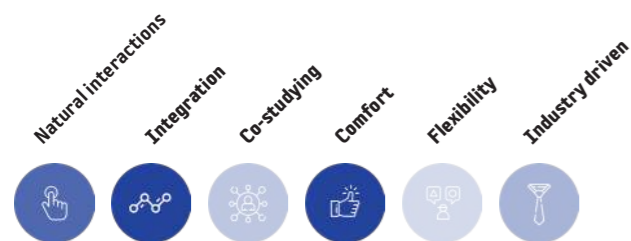
Motus is driven by the desire to create a tool that excels in comfort and ease of use. By relocating the majority of hardware to the arm of the user, the glove itself can drastically be reduced in size and weight. Due to the reduction of components and complexity in the glove, the complete area on the palm can be reconfigured, allowing for the use of flexible materials. Since the weight on the hand itself has been decreased, the whole product should be way easier to manoeuvre, decreasing the user's workload. Where traditional SenseGlove products were used with a wireless kit, Motus includes a Bluetooth connector in the arm's enclosure. This means that wireless products

become the new standard, always allowing the user to interact with objects without the impediment of cables running to a computer. The rubber material of the strap around the palm runs all the way through over the hub. The material will close gaps around the joints and prevents dust and liquid from entering the enclosure. This makes the product easy to wash and can absorb shocks more efficiently than most hard plastics. This contributes to the overall reliability and robustness of the design.

Evaluating the concept directions

In four short virtual meetings, all concept directions were presented to users in the fields of telerobotics, perceptual intelligence, haptic devices and applied ergonomics.

Each researcher's preferences, combined with qualitative feedback on each concept, have been taken into account in the decision-making process in next section.



WEIGHTED OBJECTIVES

Introduction

The weighted Objectives method is an evaluation method for comparing ideas, directions or concepts based on the overall value. This method is especially beneficial when this overall value consists of multiple factors. The directions are rated on a scale of 1 to five for all factors, where 1 represents a negative score, and 5 a positive score. In addition, a weight is assigned to the factors, representing its importance and influence on the final score. After all factors are rated for each direction, a total score for each direction can be calculated.

The ratings assigned to the factors are a combination of the results of user interviews and company evaluations. The outcomes are discussed with the project stakeholders, who agreed on the results.

User vision

Because the user vision is one of the core pieces of this project, it has the highest contribution to the total score of the directions. Each concept driver that was formulated in previous chapter contributes to the score of the future vision.

Development

The development factor indicates the amount of development resources that SenseGlove has to invest for the embodiment design. The more complex and amount of new features the concept direction has, the lower the rating on this point. On the other hand, a realistic and more traditional design will improve the rating.

Costs

The costs factor indicates the expected retail price for the product direction. During user session 1, it has already been found that researchers are willing to invest in more expensive product, if it provides them with a more valuable product. For this reason, the weight of this factor is only 1. At the same time, it is important to take costs into consideration, since a cheaper product will always be preferred to save a lab's financial resources.

Portfolio

The portfolio factor indicates the way the concept direction fits within SenseGlove's foreseen portfolio. The product should be in line with the rest of the company's strategy, and clearly differentiate from products developed in parallel projects. In addition, being able to use existing SenseGlove accessories, such as the wireless kit, would be an advantage.

Market

The market factor indicates the way the concept direction fits a (sub)target group, and whether there are other products in the field that could be a threat. Concept directions with a strong value proposition for a broad audience score better. So does a concept direction that outperforms competitors.

Usability

The usability factor indicates the product's ease of use. Subjects that can influence the ease of use are donning/doffing procedures, accessibility of various parts, ease of repair etc.

FEATURE DESCRIPTION	WEIGHT	LAGOD	CONSCIO	MOTUS
User vision	5	3.3	3	3.8
Natural Interactions		3	3	4
Integration		4	3	5
Industry driven		3	5	4
Flexibility		4	5	2
Comfort		4	3	5
Co-study		2	5	3
Development	3	5	4	2
Costs	1	4	4	2
Portfolio	3	4	5	2
Market	2	3	4	4
Usability	3	5	4	4
TOTAL		4.0	4.1	3.0

Conclusion

As can be seen in the table above, Lagod and Conscio both outperform Motus. Despite Motus rates highest on the factor of user vision, the concept was evaluated by the client company as complex. Too many radical changes are required compared to the already existing glove. Developing a concept like this would take too much time and resources to succeed. Also, the concept direction is quite similar to the FINO, a product that will be launched simultaneously to the concept designed in this project. SenseGlove thinks that this could cause the products to compete with each other, neglecting other potential areas in the market.

Lagod and Conscio reached a score of 4 and higher, indicating that both concept directions are strong. After discussing the directions with the engineers, it is decided that the final concept direction can include features of both concepts. Since the overall configuration of the concepts is similar, this decision does not bring up any foreseeable complications.

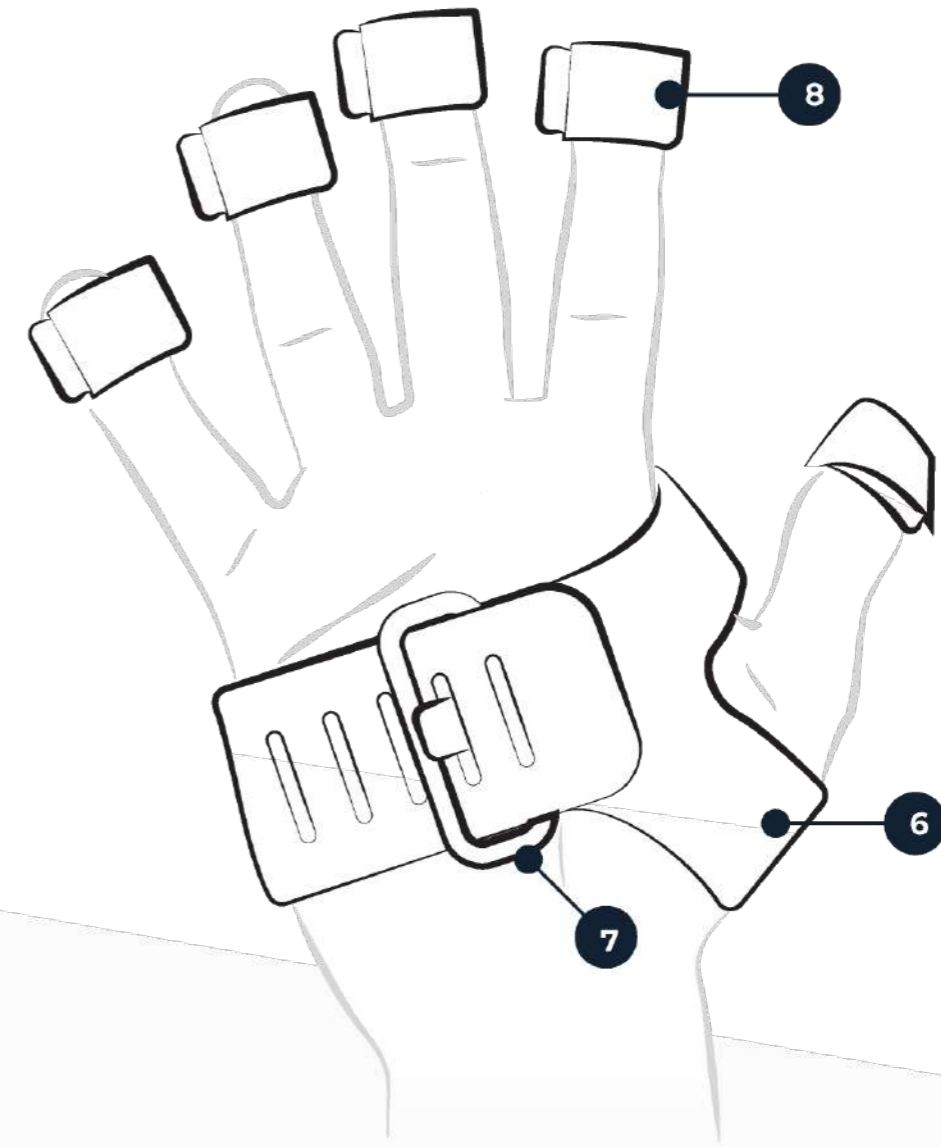
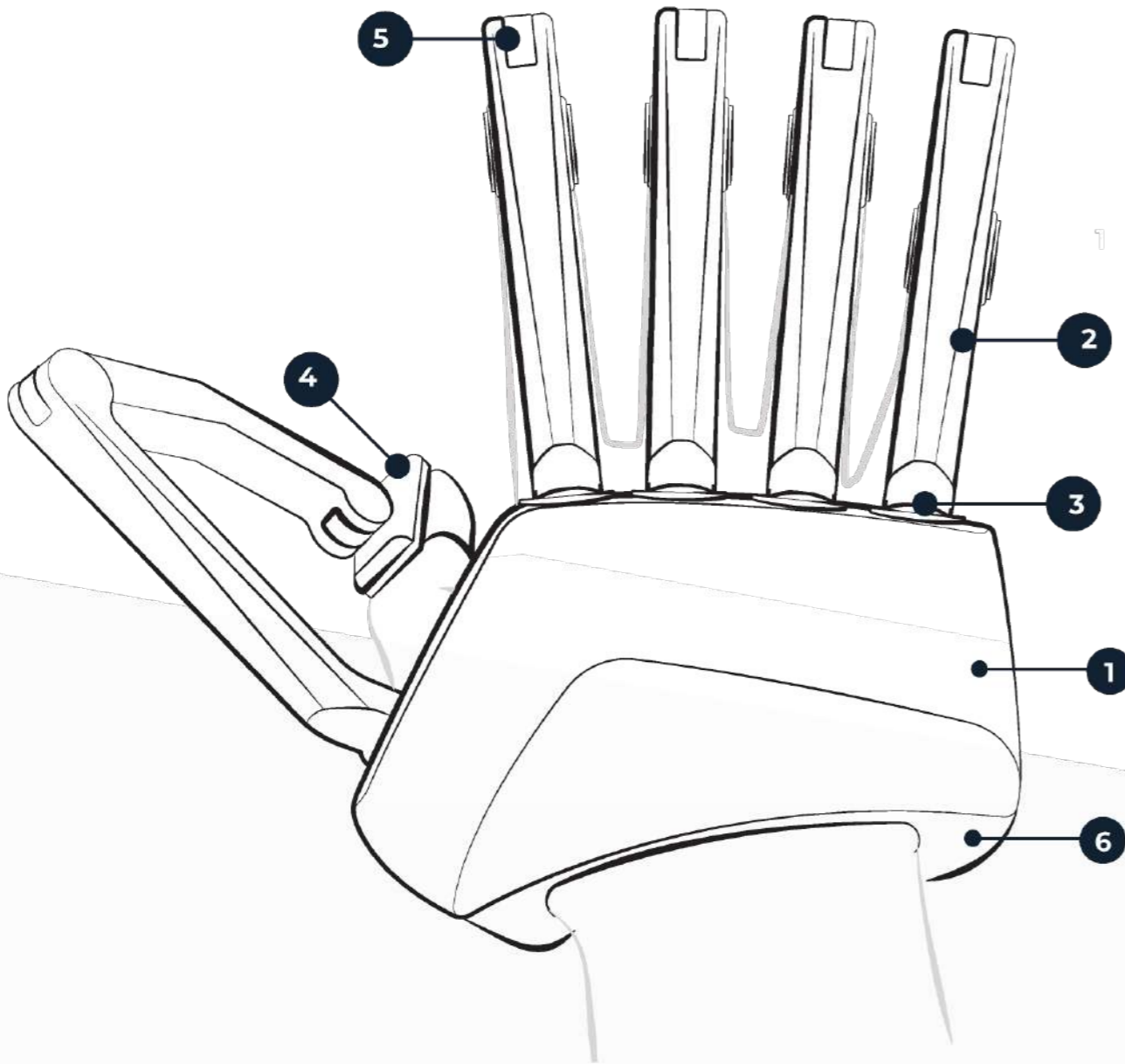
According to SenseGlove, the concept direction "Conscio" offers the best narrative and best fits the company. Keeping up with the developments in the vibrotactile hardware seems like a huge benefit to the product. Also, enabling researchers to develop hardware themselves is a great advantage, and serves as an excellent tool to target users. SenseGlove has not been able to target right now. Especially users in the market of telerobotics should get extra attention since the traditional products were never able to target market segments such as telerobotics. Formulating the product's narrative towards these users is a great way to target this new market, while also including segments of non-engineering researchers.

Concept Development .

This chapter describes the development process from concept direction to concept product. Each of the distinguishing features of the product is implemented to meet the vision in a way that is feasible and realistic for further embodiment. In this chapter is described how constantly iterating with feedback from SenseGlove engineers has helped me in defining a future-proof concept.



GLOSSARY



Nr.	Feature	Nr.	Feature
1	Hub	5	Singular joint
2	Finger	6	Palm strap
3	Universal joint	7	Buckle
4	Thimble	8	Velcro

MANAGING EXPECTATIONS

In case the findings in this project are relevant, the goal is to implement the project results in a product that can actually be launched by SenseGlove. For that reason, it is of high importance that the concept meets the expectations of various stakeholders within SenseGlove. At the beginning of the concept development phase, various SenseGlove employees have been approached to discuss what their priorities are regarding the completion of the project. These factors are used in making the planning and setting priorities during the last phase of the project.

Mechanical engineer

As a mechanical engineer, Johannes Luijten requires insights on the assumptions, conducted experiments and outcomes. By understanding how these factors influenced the final product concept, he can further develop the product preserving the strengths of the concept. For Johannes a physical prototype is of high importance. By using, wearing and experiencing a mockup, the experience the product should evoke is better described than with words.



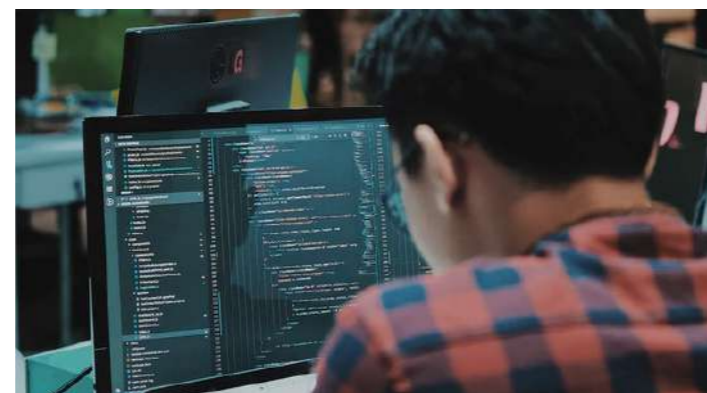
Electrical engineer

As an electrical engineer, Chun requires insights in dimensioning the type of mechanical connections that the components use to communicate signals. The configuration and location of electronic components within the product should be defined. These take-aways are even more important when components are interchangeable. Chun likes to be already involved during the design process, since unachievable features from an electronics perspective are easily overlooked.



Software engineer

As a software engineer, Max should be informed on what components are used and what the general flow of data will look like. This way, Max can identify what processes should be run within the firmware of the glove, and what processes should be run by the software in the PC. By understanding the configuration and components, he understands what coding language and signals should be used to drive the actuators and sensors.



The haptic module

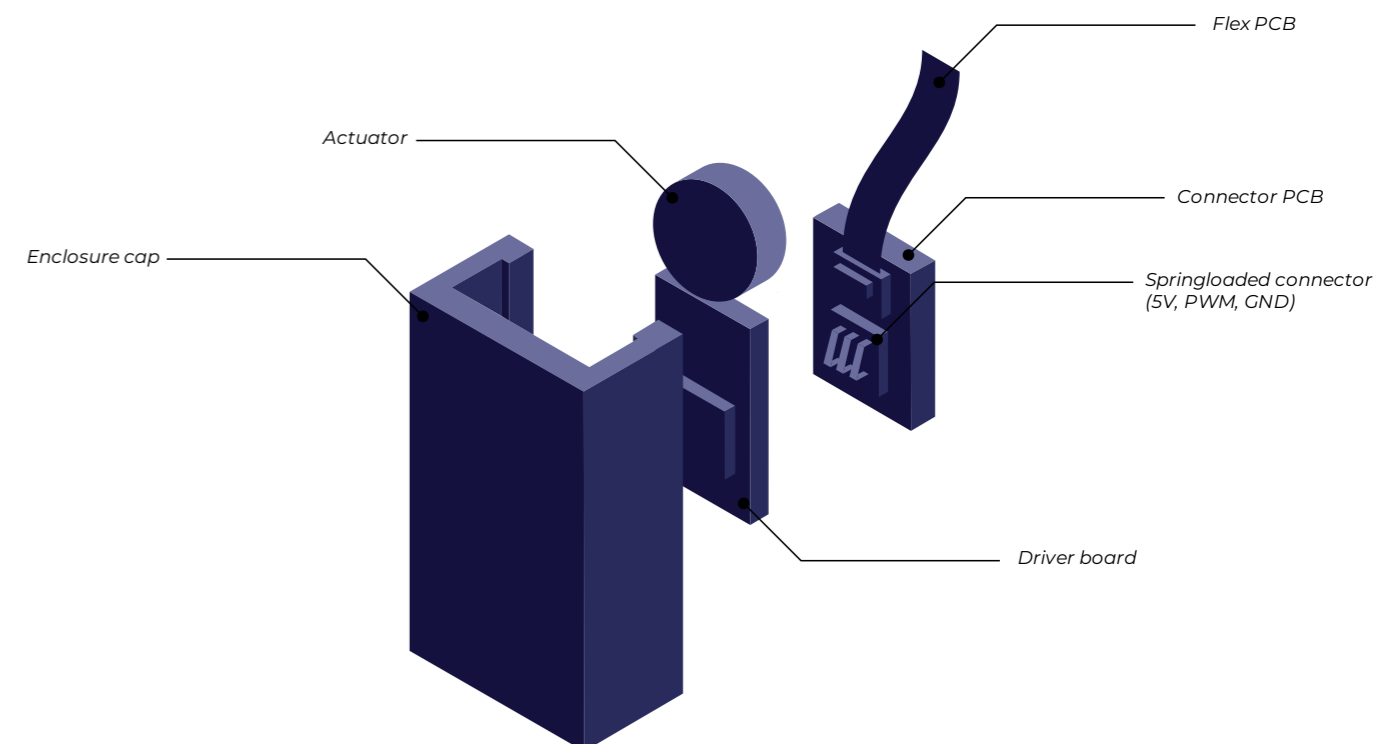
The haptic module, as earlier described in the Conscio concept, enables researchers to customize the vibrotactile actuation for each individual finger. In order to make a vibrotactile stimuli, there are a couple of hardware components that are required: an actuator, a driver, a PCB/breadboard and an enclosure to mount the assembly to the rest of the glove.

When the product is bought by the user, it will be equipped with a "standard" module that provides the vibrotactile functionality that SenseGlove is known for. This means that this module will contain the G1040003D LRA by Jinlong (Jinlong Machinery & Electronics, 2020). This actuator works with a resonance frequency of 175 HZ, which is suitable for simulating discreet interactions like finger contact and clicks.

The driver that is selected to drive this actuator is DRV2605L by Texas Instruments. The DRV2605L device is a low-voltage haptic driver that includes a haptic-effect library and provides a closed-loop actuator-control system for high-quality tactile feedback for ERM and LRA (Texas Instruments, z.d.). This driver improves acceleration consistency, start time, and brake time and is accessible through both I2C or PWM input signal. More information on the signal types and PCB tracing can be found on next page.



In order to make this module as compact as possible, the actuator will not be mounted directly on the surface of the PCB. Instead it will be pressed in the enclosure next to the PCB. This way the thickness of the module can be minimized and create a continuous volume when attached to the finger.



CONCEPT DEVELOPMENT

As explained in “2.2 Vibrotactile feedback” on page 19, vibration motors can have different working principles, and therefore the way the actuator is controlled can vary. Since the concept should enable the user to experiment with these actuators, the haptic module should support the majority of vibration motors. This means that each sort of signal will add one trace on the flex-PCB and connector on each finger from an embodiment perspective. Thus, it is essential to carefully select the required signals to find a balance between complexity (costs) and usability.

To gather information on possibilities and preferences from an electronics hardware perspective, I met with Chun Lam, the electrical engineer at SenseGlove. Chun has been involved in the embodiment of the SenseGlove from the first generation, and has experience in testing and integrating a wide variation of haptic actuators. Although this meeting gave me insights into the technical aspects of driving haptic actuators,

information on the relevance and haptic experience is still required. For that reason, a meeting with Michelle Corten (MSc candidate biomechanical engineering in haptics) has been set up. In this meeting, Michelle provided information on the quality of haptics and the relevance for researchers of each way of driving a haptic actuator.

The simplest way of driving vibrotactile actuators is by connecting it to both a positive and negative current. Simple ERM's rotational speed depends on the number of pulses it receives. Connecting such a motor to a voltage (for example, 5V) turns on the motor and starts driving it. By continually switching the motor on and off, which is controlled by the firmware in the SenseGlove, the rotational speed can be controlled.

Pulse Width Modulation (PWM) is a modulation technique that supplies a square wave of which the up and high time can be controlled.

Audio signals are currently the most complex signals that can be used to drive haptic actuators. Because of the complex waveforms, audio signals can provide detailed and vibrant vibrotactile feedback. On the downside, the signal itself is so complicated that it requires significant amounts of data to be transferred and extra hardware components in the hub of the glove to process it. Thus, equipping each finger with an audio-driven actuator decreases the feasibility from a hardware electronics perspective. Also, according to Michelle Corten, audio signals are currently not the preferred signals used by haptic researchers. This means that the costs of supporting audio-driven actuators within the

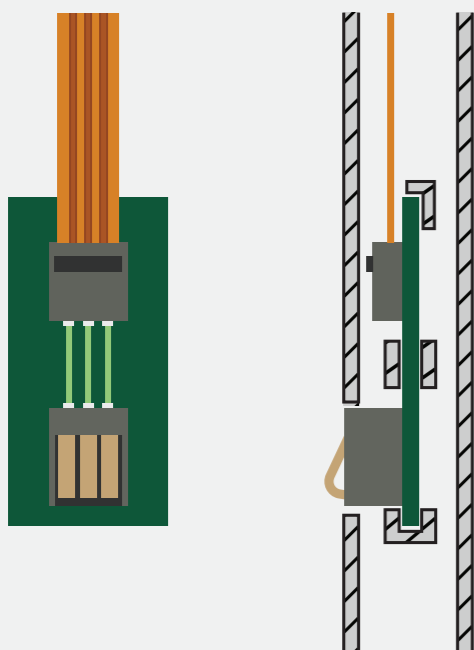
Connectors

glove outweigh the benefits.

Since the amount of required traces towards the module has been defined, the way the module is connected to the finger of the glove should be formulated. In this design decision three factors come into play: usability, feasibility and reliability. To gather information on the possible solutions and their benefits, a meeting has been set up with SenseGlove's mechanical engineer (Dan Shor) and electrical engineer (Chun Lam).

The first possibility would be to let the user connect the module himself through soldering it directly on the (flex)PCB in the finger. This way of connecting the module is cheapest, since no extra connectors or rigid PCB parts increase the BOM costs. On the other hand, this method discourages non-engineering researchers from actively adapting other researchers' modules, since soldering is an activity that not all users might be comfortable with. At the same time, constantly soldering on the same surface can damage the part over time. The (Flex)PCB is not easily repairable, which means that damaging this part should be avoided at all time.

Spring based electrical connectors make it very easy for the user to replace the module. Spring based connectors have the benefit that they automatically press themselves to a conductive surface, which means they're function well when exposed to vibrations. There are various kinds of spring-based connectors on the market. The most common connectors are: pogo pins and butterfly connectors.



Hub enclosure

When it comes to designing the shape of the hub, there are two possibilities. The bottom can be designed as a flat plane or a curved plane. A curved plane has as an advantage that its shape can be formed to the shape of the hand, which prevents high pressure concentrations that could cause discomfort. In order for a curved bottom enclosure to work, the part gets more complicated for various reasons. Due to the MOQ injection molding will be the preferred method of manufacturing. This means that the geometry of the part should include draft angles. This becomes a problem when taking a closer look at the holes for the fingers of the exoskeleton (see "Figure 17" on page 76). Every finger is connected to the PCB with a mechanical connector, which means that they're always mounted in a perpendicular angle to the PCB. Even with a curved split line that splits all fingerholes, the draft angles will cause a problem for the draft angle. In addition, the required draft angle causes the enclosure to be larger than necessary.

Again, the components will be mounted perpendicular on the PCB, which means that they will be tilted among the curve. The bigger the angle and the components, the more volume is wasted in preserving the moldable geometry (see "Figure 27" on page 79). In addition, adding unnecessary volume is in contrast with the user vision, which describes an integrated research platform.

As stated in last paragraph, a flat bottom part of the hub enclosure avoids complications in the geometry. In order to keep the product comfortable and integrated, the geometry of the strap will have to connect seamlessly to

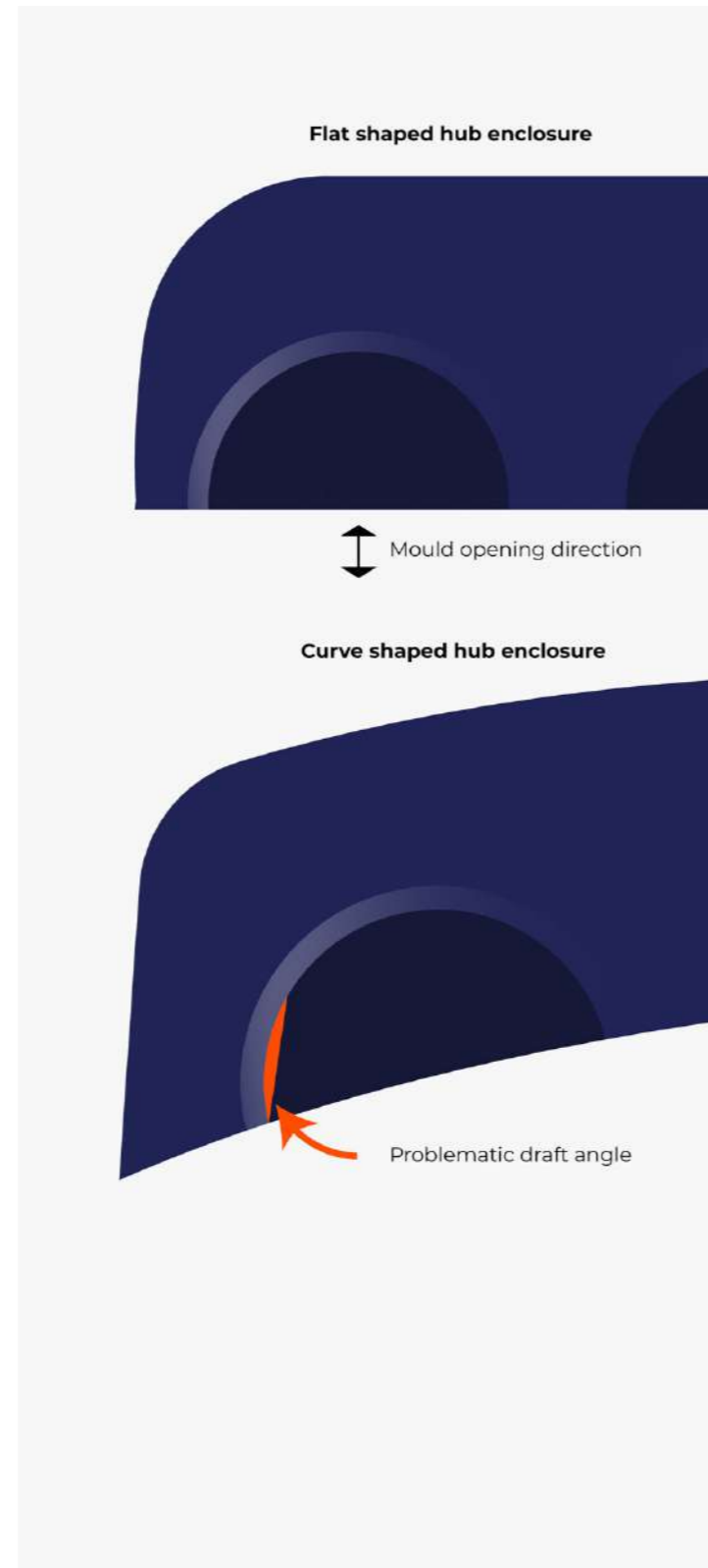


Figure 26 Problematic draft angles

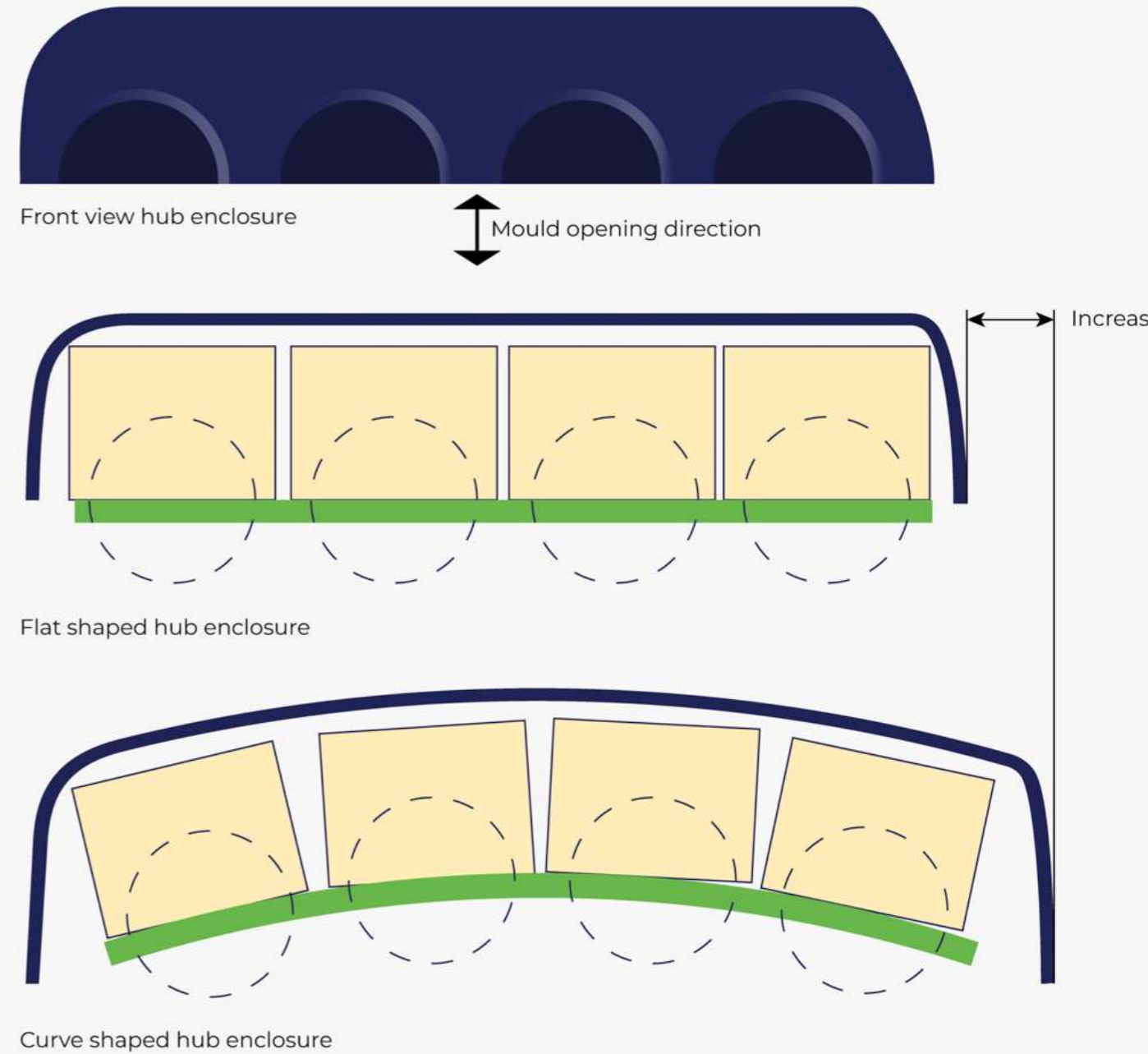


Figure 27 Increasing volume for curved hub

The palm strap

The palm strap is the interface between the exoskeleton and the palm user's hand. The part ensures that the hub enclosure remains stationary on the user's palm. This means that the strap should have a firm grip around the hand of the user. At the same time, the strap should be comfortable to wear, avoiding pressure concentrations, obstruction and heat-trapping. A significant factor that influences the comfort is its size. With a difference in hand circumference of around 60mm between a P5 female and a P95 male (TU Delft, 2020), hand sizes are challenging for designing a generic product. The strap should also be cleanable with detergents since it gets in contact with sweat and grease repelled by the hand.

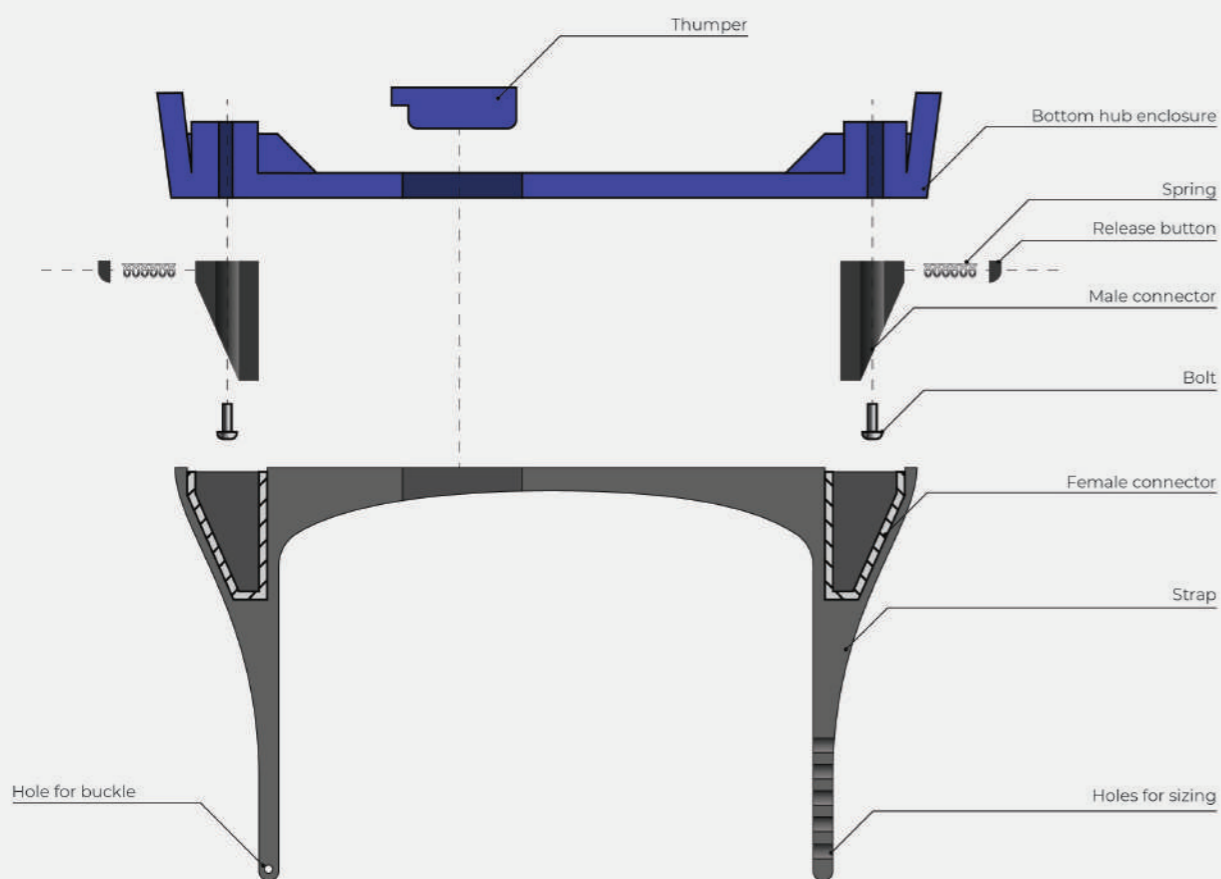
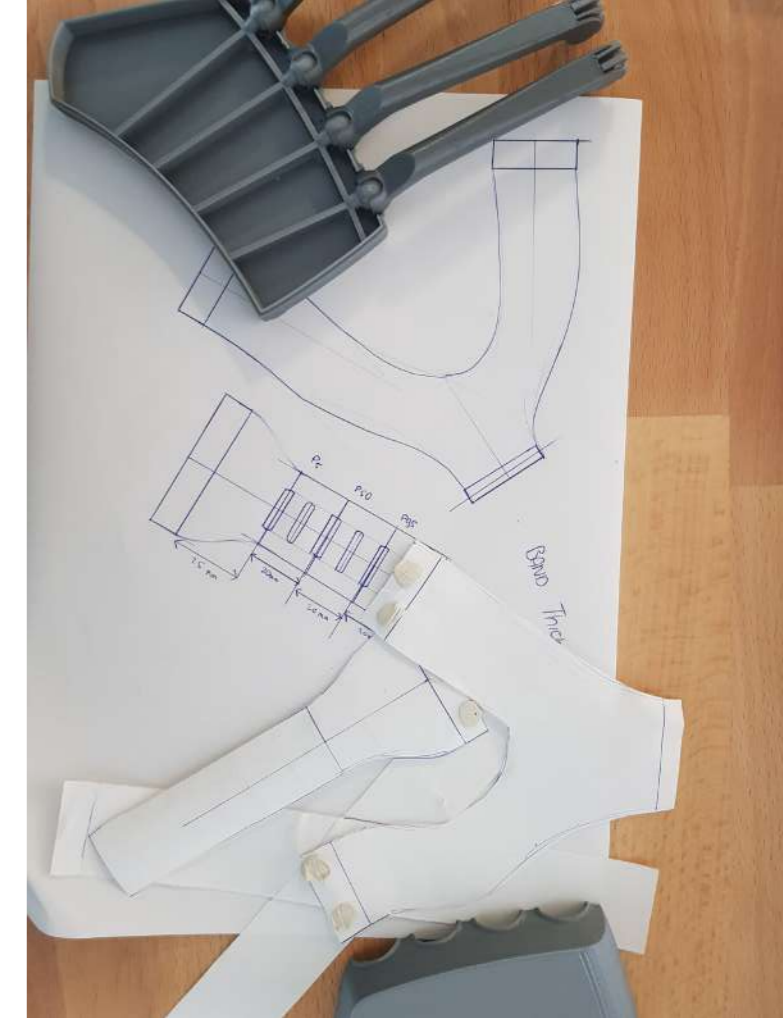
The current version of the SenseGlove straps the exo-skeleton to the hand through two Velcro loops. Although Velcro is a great solution to cover a wide variety of hand sizes, it can provide discomfort by sliding the hand across the sharp edge of the loops. Velcro is not a durable solution since, after a small number of uses, the quality of the grip decreases rapidly. Thus, the straps are often described as a "cheap" feature of the current product, which does not match the

desired image and user-vision. The current straps are connected to the hub through three slots positioned on the outside of the hub's sides. These slots are fragile and do not blend in with the rest of the product.

Inspired by wearables from the consumer electronics industry, a new strap has been designed. As many smartwatch bands, the strap itself is injection-moulded TPU, which can be a non-stretchable but highly flexible plastic. Within the soft strap, three ABS inserts are positioned. The ABS parts are injection-moulded separately, and over-moulded as an insert in the mould to integrate them with the TPU strap. Those inserts create a cavity that can be used for connecting the strap to the hub using a spring-based connector. The TPU is slightly over-dimensioned relative to the ABS and will get compressed when connected to the hub. This compression will create a neat split line between the hub and the strap. The form of the complete product at this split line will continue, as the shape of the strap can be completely controlled due to the injection moulding process. The used plastics are resistant to detergents and

can easily be cleaned. In order to simplify this process, the strap can be detached in its entirety. The size of the strap can be varied through the use of a buckle. The size of the strap in this concept design is defined by designing a paper strap that fits the model of a P65 hand. The dimensions of the resulting pattern are scaled accordingly to roughly fit a P30 female and P60 male hand (TU Delft, 2020). For hand sizes outside this range, other sizes straps should be used.

The shape of the strap contributes to the comfort of the product. Since the bottom part of the hub enclosure was designed as a vertical plane (see "Hub enclosure" on page 78), the strap is shaped with a small curvature, spreading pressure among the top of the hand and preventing pressure concentrations. In the thicker parts of the strap, a combination of ribs and cavities can influence the part's hardness. This can be optimized in the future to find a balance between stability and comfort.



Dual-axis joint

SenseGlove's current DK1 tracks the user's movement by measuring the rotation in each joint of the exoskeleton's fingers. In order to do so, a small pin-shaped magnet is pressed against a hall-effect sensor. This sensor measures the rotation of the magnet and communicates the corresponding value to the software to calculate the rotation in each joint.

Abduction and adduction of the finger are measured at the first rotational point from the hub. The flexion and extension at the knuckle are measured in the second rotational point from the hub. Two additional rotational points to track the bending of the phalanges are positioned outside of the hub assembly in a box-shaped plastic part. Since the finger rotates in 2 directions in this part, a gap in the enclosure is required to allow the finger to move freely. These holes expose the technology and could allow dirt and liquids to damage the electronic components inside.

This method is expensive since many plastic parts are required to keep the two joints in place. This complex subassembly feels complicated and fragile and counteracts the goal to make this product as integrated and straightforward as possible.

Biomimetic design

An example of a joint that enables rotation in two planes is the metacarpophalangeal joint (MCP) in our bodies (see "Figure 29" on page 83). This is the joint that connects the finger to the hand, also known as the knuckle. The MCP is a condyloid joint, which allows for flexion, extension, adduction, abduction and circumduction. In other words, this joint allows us to bend/flex and spread our fingers, exactly the rotations that the exoskeleton should measure in this part of the product.

A ball-and-socket joint is a joint in which a ball-shaped surface of a rounded bone fits into a cup-like depression of another bone. However, a joint like this provides the required rotation but does not present a solution to measure it. A product feature that is inspired by a ball-and-socket joint is the analog stick (see "Figure 30" on page 83). Since analog stick allows rotation in two planes, it feels like the stick works precisely like a ball-and-socket joint. In reality, two potentiometers that each enable movement in one direction each. Together they can both measure and facilitate the movement across two planes. The controller's enclosure prevents the joint from "overextending" and keeps the analog

stick within measurable limits. This is precisely what the joint in the finger of the SenseGlove requires.

On the downside, off-the-shelf analog stick components frequently include a preload in both rotational directions to keep the stick centred when it is not being used. If these components are integrated into the SenseGlove, it means that the resistance can be felt when moving the finger, which is undesirable in a haptic glove. The finger should also be able to facilitate a maximum hyperextension of -35 degrees and flexion of 90 degrees. Although the range of motion of most analog sticks theoretically covers the required range, there is a chance that this is not the case in practice. Since the component is quite significant, it will be moved further back in the enclosure, which means that the enclosure's opening will decrease the range. Also, the force feedback cable should be able to move freely through the joint center, which is not possible with this component.

Universal joints, as can be seen in "Figure 28" on page 82, are known for their two rotational degrees of freedom. After exploration by sketching, a possible configuration using the familiar hall-effect sensors was constructed. After further research, a published research paper presenting a similar joint is presented (Wang, Meydan, & Williams, 2017b, p. 770). In this paper, the researchers used optical sensors and LEDs to measure the rotation instead of hall-effect sensors and magnets. The paper shows that this working principle can be used to cover the full range of motion of the finger. It also demonstrates that the rotation can be measured quite accurately (± 0.3 degrees) with an astonishing range of motion of 180 degrees.

SenseGlove should develop a new plastic component that uses hall effect sensors to measure the rotation in two directions. The component should be small enough to be positioned close to the opening of the enclosure. It should have a hole in the center of rotation so that the force feedback cable can be led. A plastic cover in the shape of a sphere moves with the finger and covers the gap, preventing dust and liquids from entering the enclosure. Most used plastic materials for these sorts of parts are nylon and Teflon. The material properties of both materials are quite similar, besides the heat resistance (in which Teflon is a clear winner), most material properties are quite similar. In this case, nylon (PA) is recommended, since its material costs are almost twice as low as Teflon (HDFE).

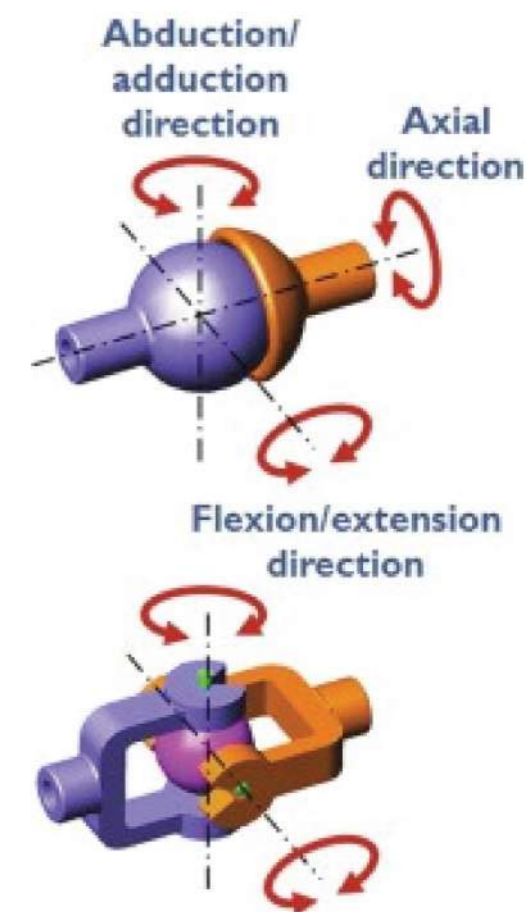


Figure 29 MCP joint compared to Universal joint

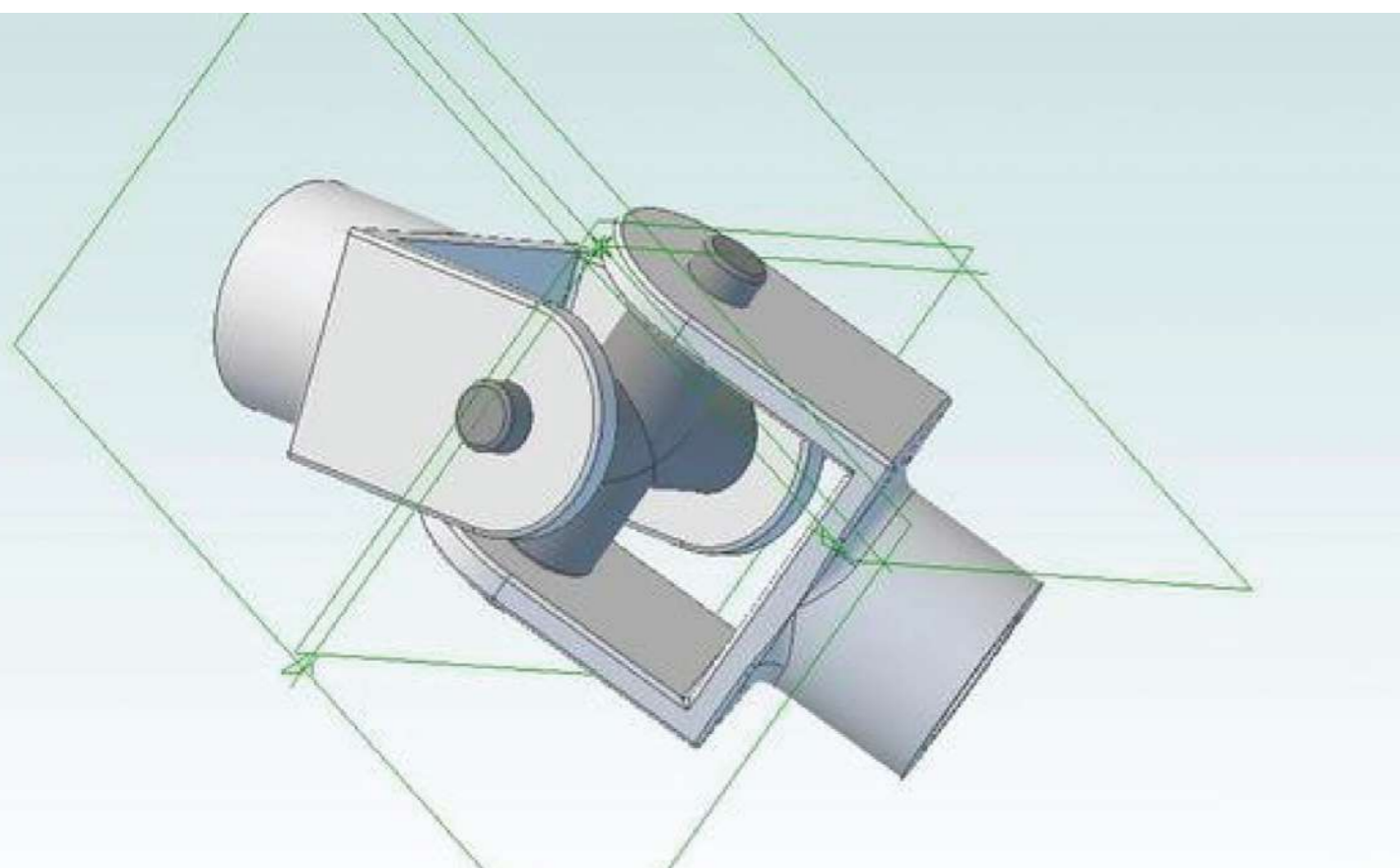


Figure 28 An universal joint that can has two degrees of freedom



Figure 30 Thumbstick on gamecontroller

Non force-feedback configuration

The user interviews showed that not all researchers are in need of force feedback capabilities. For use-cases such as ergonomic evaluation, motion-tracking and vibrotactile feedback are a great set of functionalities for the researcher. Just like explained in “Company drivers” on page 32, using the same product framework for various configurations could be a great way to include more use-cases within the target group.

The hub enclosure consists of a bottom part and a top part. The bottom enclosure is used to mount all components in the glove. The top enclosure is only meant to hold the trackermount and as protection of the components inside. The force feedback actuators are by far the biggest and heaviest components in the glove. Not including those actuators, allows for a way smaller top enclosure. In addition, the weight reduction would improve the products manouvrebility and comfort significantly.

Offering this configuration enables SenseGlove to target a group of users that could otherwise choose for an non-force feedback alternative. Combined with the USP’s of the tracking accuracy and modular thimbles and vibrotactile haptics, the product would actually be able to compete

with motion-tracking alternatives. This level of “modularity for manufacturing” does require resources in the development of alternative fingers. For the reason, SenseGlove should quantify the target group that could be interested, to be able to tell if this feature would be worth the investment.

Trackermount

The position of the complete hand in the virtual environment is tracked through an external tracker. Like other VR tools, the tracker is mounted on top of the device through a trackermount. The most common way of attaching a trackermount is through a 1/4” screw with 1.27 mm pitch, just like professional cameras are fixed on a tripod (see “Figure 32” on page 85).

The position on which a tracker or trackermount can be attached is on the topside of the enclosure (see “Figure 33” on page 85). A threaded insert will be covered by a rubber cover, which can be found as input covers at DSLR cameras (see “Figure 34” on page 85). By peeling the cover aside, the user can screw in a tracker of choice. If no tracker is used, the rubber part covers the thread nicely.

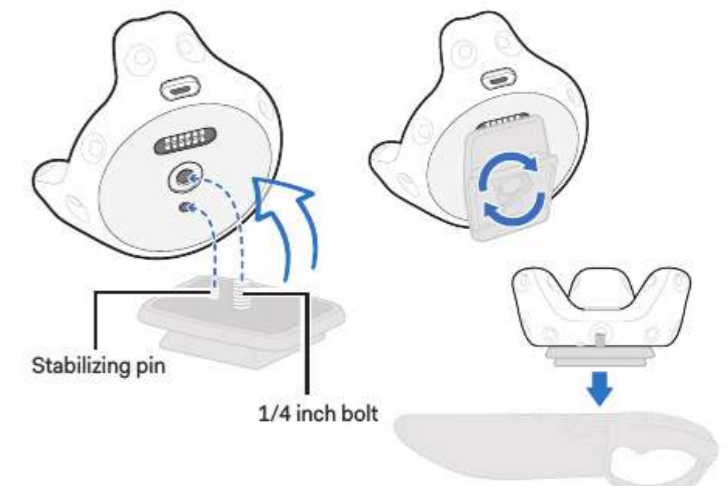


Figure 32 Attaching a tracker using a 1/4 screw



Figure 34 A rubber cover used by cameras

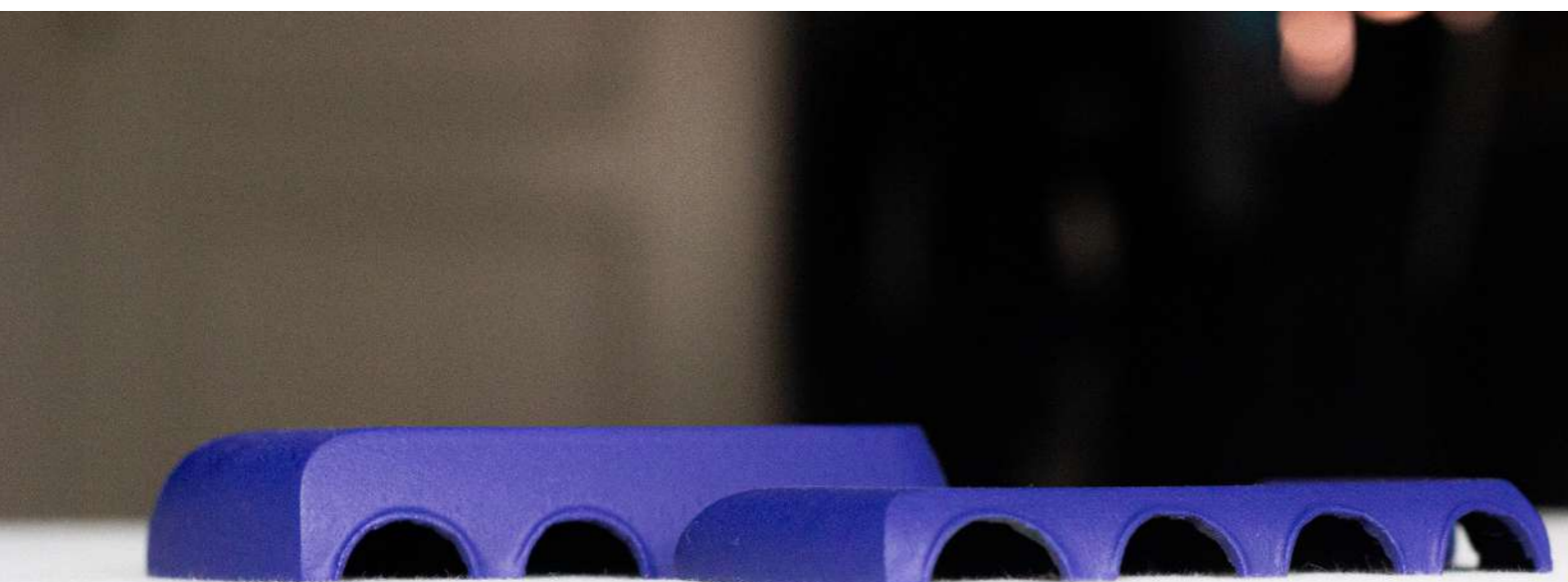


Figure 31 The two different top enclosures compared



Figure 33 Location of the trackermount connector

Swappable thimbles

The traditional thimble design was one of the weaknesses of the product. Critically evaluating the user drivers, the thimble design did not meet the expectations of comfort and flexibility.

A new thimble design has been integrated into the product concept (see “Figure 35” on page 86). The new thimble is entirely passive, which means that there are no electronics integrated. The thimble slides into a part that holds the thimble in place and rotates the exoskeleton for motion-tracking and haptic feedback. This sliding mechanism makes the thimble modular. This has various advantages compared to a permanent connection (see “Figure 36” on page 87).

The traditional thimble uses a velcro strap that straps around the finger. This is a great solution when different users use the glove since the size is easily adaptable. However, sweat tends to be absorbed by the velcro, decreasing the hygiene of the glove. Since the velcro could not easily be attached from the glove, it could not be cleaned. Making the thimble modular allows it to be washed or replaced after each use.

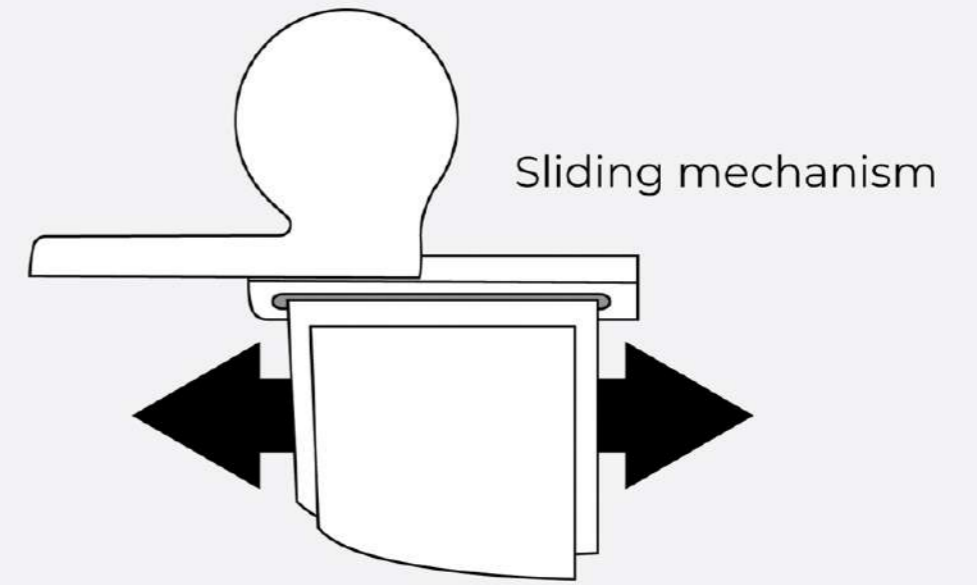
The swappable thimble also allows SenseGlove to launch additional thimble designs. The comfort and performance of the glove can be optimized when the thimble fits the fingertip better. Releasing various thimble sizes boosts the performance, and could decrease the don/doffing time in case the thimble is mostly used by a single user.

Some researchers work with physical mockups in their simulation. By launching a thimble design that partly exposes the fingerbed, the haptic- and motion-tracking capabilities of the glove could be combined with physical mockups. This allows the user to explore materials, textures and weight of objects.

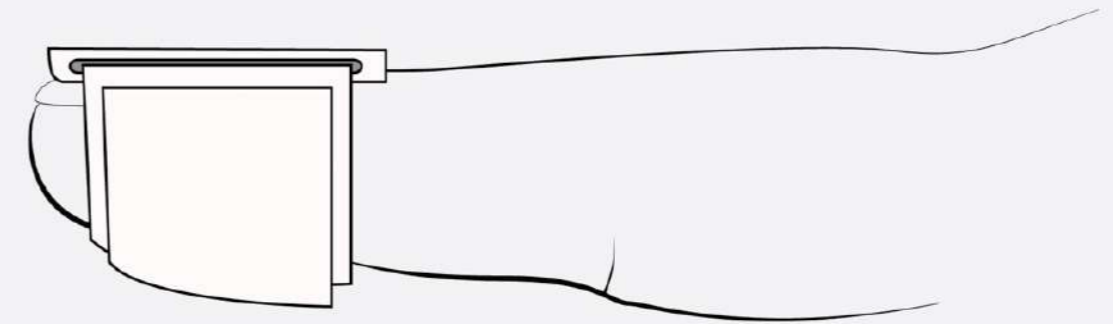
The researchers could even experiment with thimble designs themselves. 3D-scanning becomes more accessible by the day. Custom thimbles could be designed and 3D-printed to fit the users’ fingers perfectly.



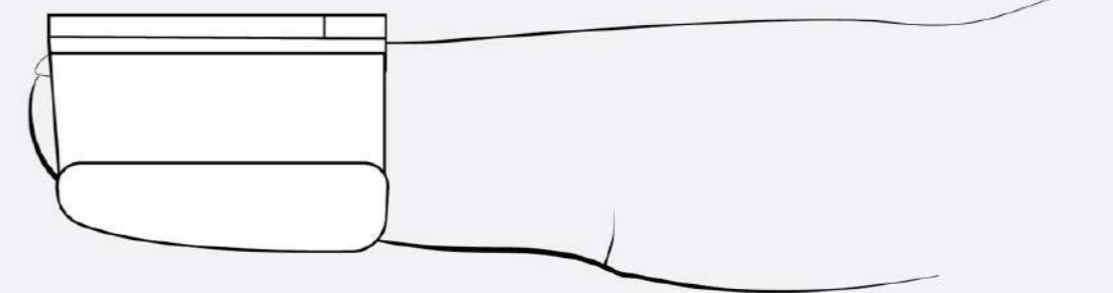
Figure 35 The swappable thimble integrated in the prototype



Washable velcro thimble



Fixed sizes



Fingerbed exposed

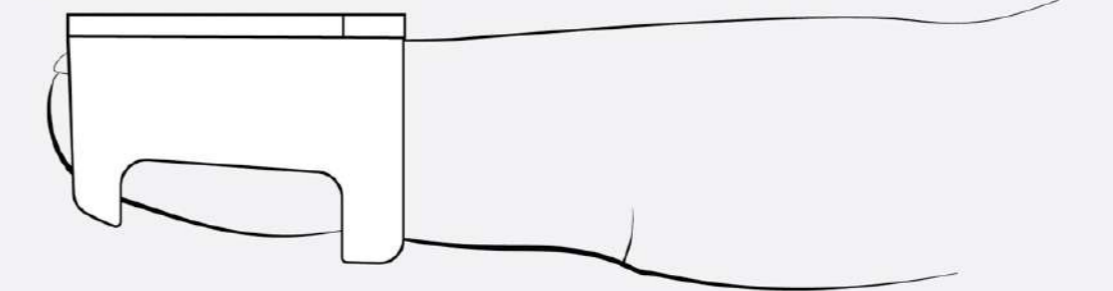


Figure 36 The thimble mechanism has various advantages

Color selection

Colour selection is a process that is used in all kinds of design disciplines. Each designer approaches colour selection differently, varying from soft and humanistic to opinions grounded in logic, reason and commerce. Whether the process is applied to the design of a physical product or a digital interface, it comes down to scoping the user group and basing your colour selection on the way you like to position yourself for them compared to competitors. In most cases, mapping the options and decision-making is based on emotion and gut-feeling by the designer himself.

BresslerGroup shared their method for selecting the “right” colour in product design (Murray, 2018), developed with Reiko Morrison, a CMF consultant at BLINK-id. They describe that any meaningful colour selection process for physical products should begin with an understanding of how specific colours can connect attitudinally and functionally with their users. Colour preferences tend to be defined by consumer attitudes, which can obviously be quite varied even within a well-scoped user group. The material and finishing in this approach represent value tiers within this approach. The colours can be derived from different consumer attitudes, where material and finishing communicate the user’s different value perceptions. The used method is not a formula, and the designer’s skill is still necessary for proper selection and decision-making. This tool guides the designer through the colour selection in a more rational and structured manner.

Four quadrants of users

The user group will be divided into four quadrants representing four different attitudes – youthful/expressive, youthful/understated, mature/expressive, and mature/understated. The already existing personas (see “Appendix 7: Personas” on page 136) will be further expanded and positioned within the quadrants in such a way that the quadrants represent the attitude of the users within.

When looking back at section “2.5 The SenseGlove Identity” on page 33, keywords that SenseGlove would use to describe their desired are neutral, serious, calm, lean etc. This character has a complete matches best with the mature/understated quadrant. The youthful/expressive quadrant will be ignored, since it has a complete mismatch with the target user and the SenseGlove Identity. The two remaining quadrants will be explored to identify potential strong colour palettes since they can all be included to some extent to secondary target groups.

Assigning colors to quadrants

The user personas are described by characteristics that match the users within the quadrants. These sets of characteristics are now called the attitudes, the “personality” of each quadrant. By matching each attitude with associated color trends, we get a first glimpse how specific groups of users can be targeted with colors. Each quadrant has a different associated color scheme:

The youthful-understated quadrant distinguishes by contrasts between whites and blacks. The quadrant is often referred to as the “Apple quadrant” because of the use of pale greys. While the overall color scheme remains fresh and calm, small controlled areas of low saturated color accents bring a lively character to this quadrant. The use of these color is often in hidden in details or not directly exposed parts, striking the user when discovered.

The mature/understated quadrant has a way safer character. With blacks, greys and silvers the quadrant is serious and neutral. The lack of (saturated) colors gives the quadrant a functional character. The palette feels strong and powerful, and is suitable for mass appeal because no striking statements are made.

The mature/expressive quadrant uses dark colors to create an elegant and chic character. Using bright highly saturated colors communicate a clear brand identity.



Category norm restrictions

The landscape of colors that is used by the competitors is researched. In "Figure 37" on page 90, the colors used by each competitor are mapped for their logo, website communication and physical product. It is interesting to know that the landscape of hand controllers is dominated by blacks and dark grey colors. In color psychology, black represents protection from the outside world, and the concealing of emotions (Becerra, 2016). Black is also a classic neutral color that people often wear to feel slimmer or to fit right in. It is striking to see that these dark colors more dominant in the physical product compared to the website communication. Considering that hand-based controllers always require another device, the choice for black makes sense. The market of HMD's (head mounted displays) is largely dominated by black hardware devices. By picking a similar color, the designer can increase the chance that their product fits right within the system of the user. To still differentiate from the other hardware, but still blend in with the dark colors, a dark blue color will be used.

The current version of the SenseGlove is bright blue with black details. Opposite to neutral tones, bright colors are associated with lower cost materials such as plastic, polyurethane, rubber and paint, which are quick and easy to

manufacture and to discard (Becerra, 2016). On the other hand, Beccera explains that in some cases bright tones are utilized by premium or luxury product categories as trim details or as iconic branding elements. Taking this into consideration, it makes most sense to keep the bright blue that SenseGlove is identified with, but implementing it as a trim detail or branding element.

Color study

In a color study many color variations are visualised. As can be seen in "Figure 37" on page 90, Bebop uses a dark blue in their website branding. In addition, both VR Gluv and DextaRobotics use blue/green tones in their branding. To differentiate from these competitors, the final color will include hint of purple. Currently purple is already been used in the senseglove website, so it seems like a logical color to differentiate from "standard" dark blue tones.

The selected color is RAL 5022 (Nightblue). As discussed with engineers from Kellpla, RAL colors are the industry standard when it comes to manufacturing plastic parts. The same color is used for the spraypainted prototype.

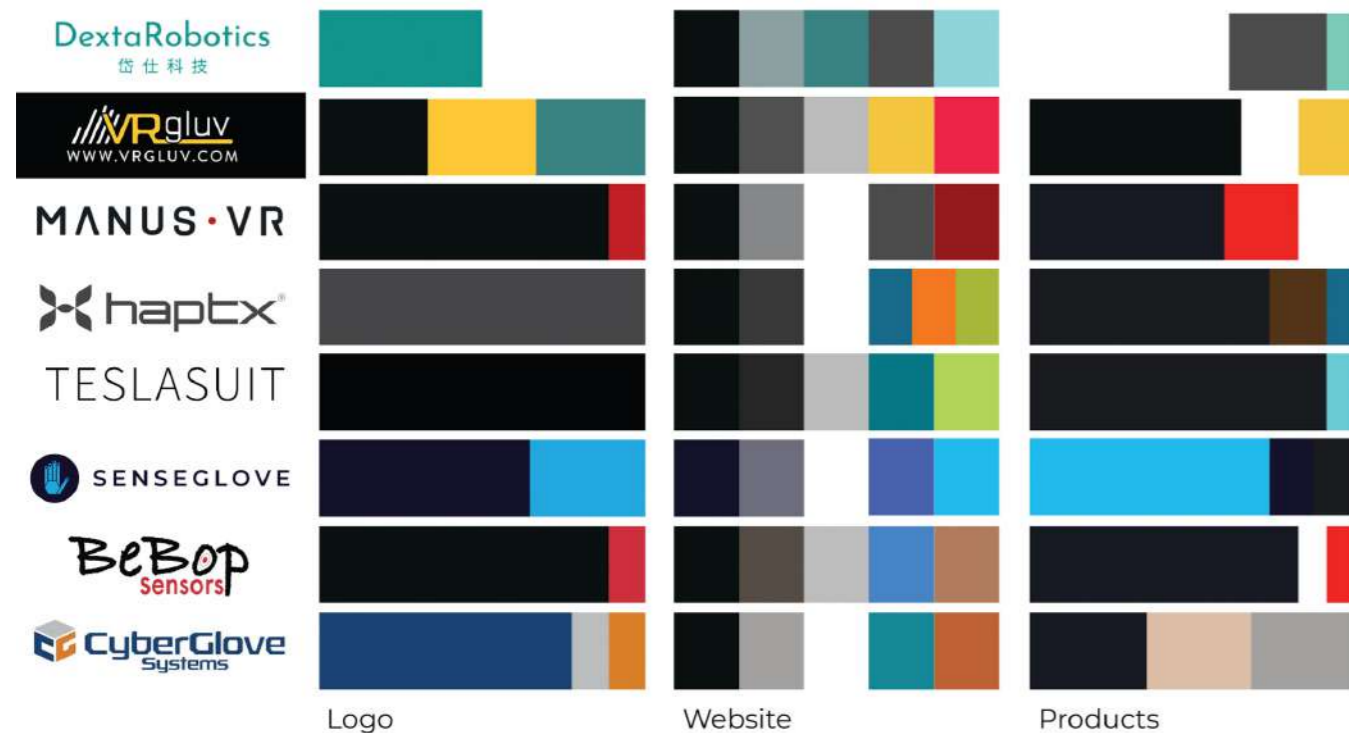


Figure 37 The use of colors by competitors

Prototyping plan

The prototype is one of the three essential project deliverables. The goal of the prototype is to demonstrate the client company and future users what the final product concept could be. Since the project's scope does not allow me to build a fully interactive prototype, the product must be a clear visual representation that communicates the product features clearly. Since aesthetics play an essential role in the new concept design, the shape, colour, and finishing of the prototype should be as close to the foreseen product concept.

The prototype will play an essential role in the evaluation of the product concept. In the final phase of the project, the product concept will be presented to target users whose feedback will indicate the quality of the project approach and result. In addition, the prototype will play a major role in presenting the project results for the client company.

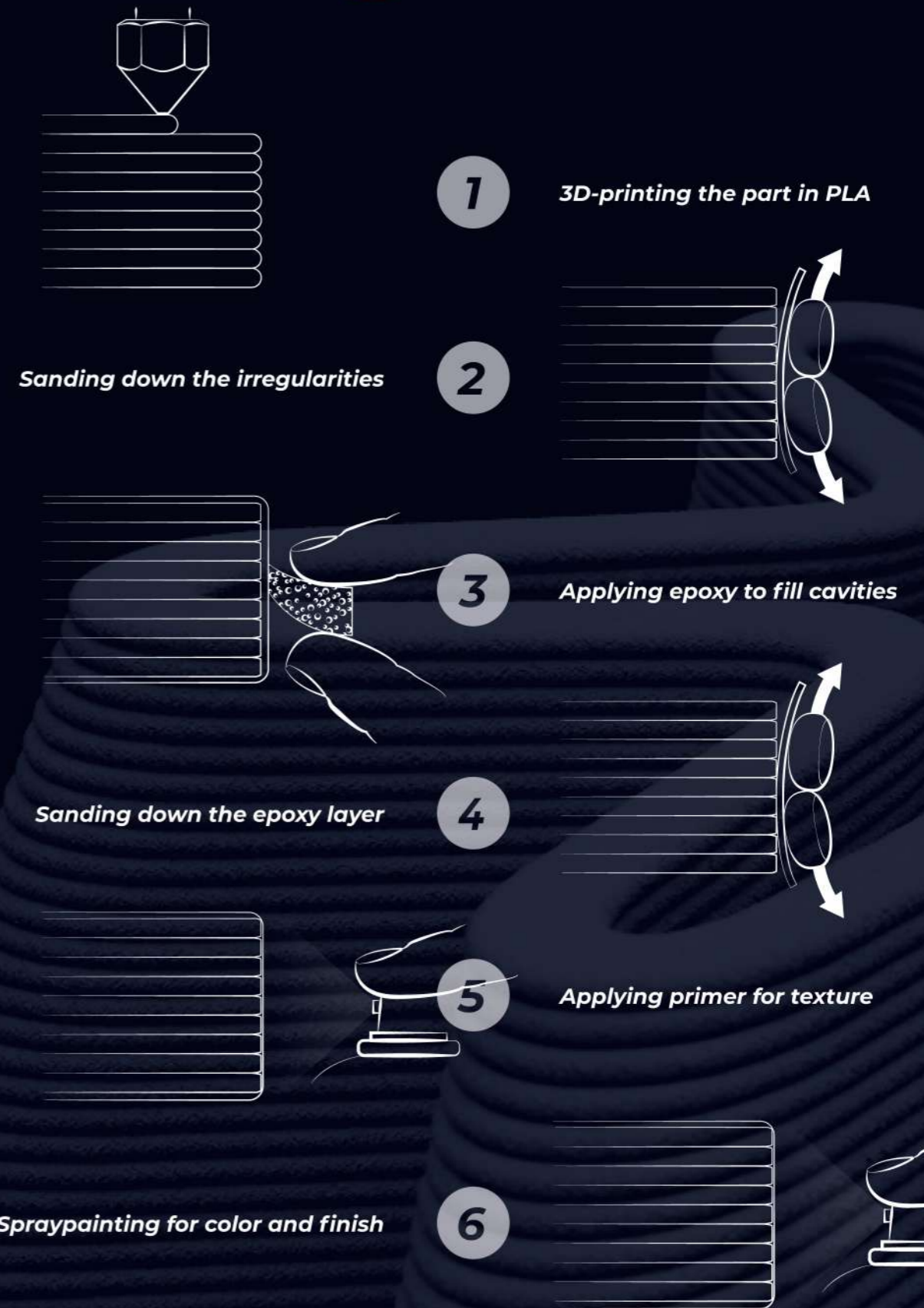
The hard plastic parts of the concept are 3D-printed in PLA on an Ultimaker 2+. After printing all parts, they are sanded down till no major surface imperfections are visible. After sanding and carefully cleaning the piece, it will be treated with epoxy. After preparing the epoxy, a thin layer can be applied to the part. When the epoxy is drying, it distributes itself over the piece, filling all imperfections equally. If necessary, another layer of epoxy is applied. When the epoxy is dried, the surface was sanded with fine sandpaper to create a surface on which the primer filler can bond. Now a primer filler spray is used to create a rough but continuous surface suitable for painting. After the whole part was covered in a sufficient primer layer, the ultra matte 2K spraypaint was applied to the piece. Components that require a glossy finish are finished with a couple of layers of clear coat spray.

When all parts were thoroughly dry, the fingers and thimbles could be assembled through bookscrews. Those screws kept the pieces tightly together while allowing them to rotate freely. The universal joint, which was prototyped as a simple ball-socket joint, could be form-fitted into place. In case some pieces didn't fit at once, they were sanded down carefully till they did.

The palm strap was initially 3D-printed using a dual-extrusion Ultimaker 3. Due to its complexity, it has been simplified to a two-dimensional cutout, printed in TPU on an Ultimaker 3. The pieces were fixed into place by using a fast adhesive. The buckle for the strap was 3D-printed in PLA and held in place by clamping around an RVS rod.



Prototyping plastic parts in 6 steps









07

Evaluation Session ■

This chapter describes the session in which users from the target group are evaluating the project result. The session leads to a general impression of the quality of the work and suggests areas of further development in the future.



EVALUATION

Goal

The goal of this interview is to evaluate on the effectiveness of the vision-centered approach and the quality of the product concept; the main project deliverable.

Research questions

- Can the future vision approach lead to a product concept that satisfies customer needs?
- What are areas of improvement for the presented product concept?

Method

The interview will be conducted digitally in Zoom, where a slideshow presentation will be presented. In total, lab representatives of three different labs are participating in this evaluation session. Interviewing the participants directly is preferred over a questionnaire since discussions on the given answers can lead to interesting qualitative results. During the interview, the audio will be recorded to review the research outcomes. The participant will be informed and will provide permission for making and using the recordings. This will be done through verbally agreeing to the use of their statements for this graduation project.

During the introduction, the interviewer tells about his background and shortly elaborates on the background of the graduation project. The participants are encouraged to answer questions as honest and complete as possible to get the most valuable insights as possible. The participants should feel free to speak their minds without any expectations. The participants will be allowed to introduce themselves and tell about their the current field of research and projects.

In a short pitch, the interviewee will be informed of the final product concept. This will be done

by showing product photos, sketches that illustrate product use and the unique selling points generated by the user drivers. Then the participant is asked to answer some questions that require a qualitative response. The questions that are asked are:

- What is your first impression of the product concept?
- Is this product in line with your expectations of a research tool?
- How would you use this product? Can you walk me through a use-case?
- What problems can you foresee with this product concept in practice?
- Do you think this product can add value to research activities in your field?

In addition, the participants are required to rate the product concept on a couple of statements. The scale will be from 1 (fully disagree) to 10 (fully agree). The statements that the participants will rate are:

- This product enables researchers in my field to do their work (functionality)
- This product represents the way I would like to use tools in the future (usability)
- The features of this product concept seem feasible (feasibility)
- In general this is a product that I would like to work with (general appeal)

Results

In general, the participants were satisfied with the quality of the final product concept. All participants rated each scale with an eight or higher (see “Figure 21” on page 102), which means that they rated the concepts’ functionality, usability, feasibility and overall appeal as positive. This suggests that the vision-centred approach resulted in a sufficient product. Since the project scope only allowed a small number of participants to participate in this research, similar research on a more substantial scale is advised to make sure the findings are significant.

The lab representative who researches in the field of Industry 4.0 gave the following qualitative feedback:

“Seeing **this concept makes me excited**; it all looks really good. I can tell that **you have a very good understanding researcher’s needs** because I can relate to everything you bring up.”

“You already worked a lot on the embodiment of the product itself. Combined with the described service features, **it would be a complete package**. I would really like to work with this product.”

When providing the researcher with some standard scripts, it might be **useful to match them up with some standard questionnaires**. There is a selection of common questionnaires that researchers use to reflect on the quality of a tool or interaction. Taking those into consideration could improve the workflow of the researcher even further.

The lab representative who researches in the field of telerobotics gave the following qualitative feedback:

“A tool like this would be **an essential element** coming years for telegrasping. This concept would be something I can easily adopt in my setup.”

“I really like the design. I like the improvements compared to the first version of the SenseGlove. **It looks more finished, more robust**. The original glove looks like someone just build it as a prototype, and could break down. The new concept **communicates reliability and seems further developed**. It is a product you could sell to someone and be confident about it.”

The lab representative who researches in the field of Applied Ergonomics gave the following qualitative feedback:

“I can already tell the features of the changeable thimbles **will be a game-changer** for me. This product will allow my users to explore real-life materials and textures in a simulation. Something that other products simply cannot.”

“**I can totally relate to the struggle** of re-engineering a product. It would be great if I could work together with engineers who can actually help me optimize my product. Researchers with a non-engineering background like me would love to work together in that area. **I can already imagine some use-cases** I could use this product for. For example, exploring the reachability of my participants in a partially virtual environment.”

Aspect	Telerobotics	Industry 4.0	Applied Ergonomics	Mean
Functionality	8	8	8	8
Usability	9	9	8	8.6
Feasibility	9	9	9	9
Appeal	8	9	8	8.3

Figure 38 The ratings by each lab representative

Recommendations & Project conclusion ■

This chapter concludes the findings in this project. Based on the evaluation session and findings in the process, a set of recommendations is composed. Also, to successfully continue developing the product concept after the concept design phase a features list is included.

CONCLUSION

This research aimed to design a future proof haptic glove using a vision-centred approach. Based on the analysis of various qualitative interviews, individual future visions of target users have been collected, compared and synthesized to vision drivers. Serving as the main design driver, the vision drivers guided the development of a new product concept. The outcome has been evaluated in a series of user interviews. The results indicate that the product concept meets the users' concerns and fits most individual future visions.

The so-called vision-centred approach has been chosen due to the complex scope of the target group; the academic industry. Researchers are experts in their field and work in a future-oriented industry. Contrary to traditional design methods that enable the design to create his vision, using the users' future vision seemed like a more efficient way of quickly defining user concerns and expectations.

During various user interviews, the participants were asked how they envision their future research projects and suitable research platforms. They were requested to envision a scenario that is both desirable and realistic for the upcoming ten years. After collecting, comparing and synthesizing the individual visions, a set of vision drivers could be formulated: natural interactions, integration, co-studying, industry-driven and flexibility.

These were the main drivers in an iterative creative process that involved all project stakeholders, including, most importantly, the target users. The initial ideas were evaluated by the target users in a creative session. In this session, the participants were allowed to contribute their thoughts and elaborate on their preferred solutions for the concept direction. The creative session also allowed the participants to evaluate a selection of products that represented the vision drivers, according to the designer. The creative input and feedback on ideas and products directed the

designer towards fruitful concept directions.

Using weighted objectives, based on both user- and client company feedback, the concept directions have been evaluated and selected for further development. From this point, with a clear value proposition in mind, the designer was able to develop the concept direction towards a feasible concept product. This was done in an iterative process that involved company stakeholders, such as mechanical-, electrical-, software-, and haptic engineers. With their constant feedback on the progress of the development, each feature of the concept was well-defined and feasible for further development by the embodiment team at SenseGlove.

While relying on a similar technical framework as the original SenseGlove, the new concept has a set of new features that serves users in the academic industry. Both thimbles and vibrotactile haptics are modular. The introduction of universal joints makes the design more integrated and compact. A new strap design allows SenseGlove to provide a strap that is well integrated and comfortable.

A mockup of the product concept has been prototyped and was evaluated on functionality, usability, feasibility and overall liking by the target users. The results of this evaluation show that the product concept proposal has potential. It indicates that the vision-centred approach led to a product concept that meets the concerns and expectations for future research platforms.



RECOMMENDATIONS

General

- Gain insights on the size of sub-target groups for the planning of next haptic module functionalities. Besides keeping the drives up-to-date, the kind of interaction can be targeted at specific use-cases. The size, demand and value-proposition for each use-case can be specified.
- There is huge potential in playing a role in connecting developing researchers and analysing researchers. Where those two groups often work separately, they hope to work more closely together in the future. This product enables those two groups to work closer together, but SenseGlove could actually play a role in connecting the right people. After all, more research publications means more publicity for the product.

Design features

- When testing the final prototype, the design allowed all fingers to move completely freely, besides the thumb. The thumb has the full range of motion. However the rotation axis parallel to the thumb does not always follow the fingertip correctly. This can probably be solved by moving the rotational point of the universal joint slightly closer to the original joint in the hand.
- In the user interviews became clear that not every researcher requires force feedback, but would like a product with vibrotactile and professional tracking functionalities. As described in the product features, the finger in its entirety could be modular, allowing for a non-force feedback configuration. This would also decrease the overall volume of the product and result in a more compact and lighter product. SenseGlove should quantify the market, and consider whether the technical challenges are worth targeting this market segment.

Research Practicalities

- Make sure the specifications of the product are (independently) tested and defined. The more transparent SenseGlove can be on the actual dataflow and performance, the more attractive the product becomes for research purposes.
- Integrating a research tool within a system can be tricky. Preparing some standard scripts that quantify data for the most common practices could give the researchers a headstart in using the product for their project. For example, standard scripts for gesture recognition or contact time with objects. For each field of research, there are a sets of standard questionnaires that are frequently used. There is potential in integrating variables of those specific questionnaires to make the datamining process easier.

Further development

- An overview of tasks for further development of this product concept is attached in "Appendix 8: Feature list" on page 139. It indicates tasks I could identify after finishing this project. Each task has been appointed to the right department within SenseGlove. In addition, the risk and priority for each task has been indicated. In a meeting with the upcoming product owner of the project, the features list served as a medium to kickstart the planning of the project.
- The findings in this thesis are mostly grounded by qualitative research. To avoid unnecessary risks, performing quantitative market research, proof of concepts and user tests are recommended to reduce the risk.

The image shows three overlapping 'Product feature list' documents for the Rembrandt project. Each document is a table with columns for Task, Priority, Risk, and Responsible. The tasks listed include: Universal joint development, Strap design, Vibrotactile modules, and Hub shape. The priorities range from High to Low, and risks range from High to Low. Responsible parties are listed as Johannes (mechanical dept.), Anne (product design dept.), and Max (software dept.).

Task	Priority	Risk	Responsible
Universal joint Development of a joint that enables dual-axis rotation Integration of motion tracking capabilities using hall-effect sensors	High	High	Johannes (mechanical dept.)
Compatibility of force feedback with the universal joint	High	High	Johannes (mechanical dept.)
Design cover to protect the joint from pulling forces and dust	High	High	Johannes (mechanical dept.)
Integrate a non-measured rotational degree of freedom	High	High	Johannes (mechanical dept.)
Make necessary changes in software scripts for changes in sensor positioning	High	High	Max (software dept.)
Strap Task Design for anthropometrics, define sizes and interface positions with the hub Design for comfort, define exact materials, shapes and textures Design spring loaded mechanism for modularity (female) Optimize buckle mechanism don/doffing	Average	Average	Johannes (mechanical dept.)
Vibrotactile modules Task Designing a well-integrated standard configuration Quantifying potential areas for expanding the module portfolio Hardware design of standard configuration module Defining placement details standard driver/actuator combination standard configuration	Average	Low	Johannes (mechanical dept.)
Hub shape Task Define exact footprint based on positioning of universal joint and strap anthropometrics Develop and integrate male connector for strap module depending on finger modularity and non-force feedback configuration, make interchangeable top cover	Average	Low	Johannes (mechanical dept.)

REFLECTING ON THE VISION-CENTERED APPROACH

Reflection

Using a user-vision centered approach to feed the design process is not a typical method in product design. Despite the workflow shares some of its research methods with value-driven user-centered, using a user-vision as main design driver is unique. This means that a thorough reflection on the approach and its effectiveness is value for designers that might want to use a similar approach in their future projects.

When to use a vision-centered approach?

In many known design methods, such as VIP (Vision in Product Design), FIXME and FIXME, the designer conducts research to gather knowledge to create his own vision of what the product should be. This approach can be very effective, as long as the amount of information that is required to form a desired and realistic vision can be obtained within the duration of the project. In my case, designing for highly specialized and educated experts in a variety of fields, the amount of information that is required to form a high-quality vision by myself was not obtainable within the given timespan. This means that traditional design methods would not be effective approaches for this specific design case.

The vision-centered approach is highly effective when it's the designer's task to design for a professional and future-aware target-group. By relying on the expertise from the target-group, time and effort can be saved on trying to understand the in-depth knowledge of complex use-cases. Since my target users were highly informed and willing to share their insights, their vision was a great fundament for the design direction of my product.

Obviously, the approach requires a selection of users that are both representative of the full target group and willing to share their insights and concerns when it comes to their use-case. Since this project is a graduation project at a technical university, finding representatives for the user-sessions was no problem. In projects in which the target users cannot be included in the

Technical complexity

user-sessions, the vision-driven will probably not be an effective approach. The client within this project is a highly-technology driven company. The technical framework they laid out for this product at the start of this project was highly complex and not flexible. This means that while driven by a user-vision, the product was to some extent still defined by its technical framework. In my personal experience, technical restrictions and vision-driven design directions can lead to complex challenges. Changes in product features, in this case driven by the user-vision, often demand changes in the technical framework. In my project, this could be resolved by working in close relation with electrical- and mechanical engineers. By frequently and clearly presenting each iteration, the experts were able to provide

Recommendation on method

me with technical advice to make sure the direction would lead to a feasible final concept.

My recommendation is to use this vision-centered approach for projects in which technical framework is either flexible or defined by the designer after creating the concept direction. Using this approach to add value to a product of which the technical framework has been formulated is possible, but requires insights and advice from technical experts to confirm the feasibility of design solutions. After all, the result of the vision-driven approach should be the starting point for embodiment design, which means that the concept is technically feasible to manufacture.



REFLECTING ON THE LEARNING GOALS

Product ownership

The first learning goal I set for myself was the improvement of skills in product ownership. Although this product does not allow me to direct the development by a team, I managed to give myself enough tasks that involve product owner skills in an individual project. This project's experience confirmed that product ownership is a responsibility I would like to take in my future career. It made me more comfortable with a product owner's responsibilities and made me identify in what areas I could further improve myself.

The first task was managing the expectations of all stakeholders involved in the project. As became very clear in the project approach, the target users provided me with the main drivers. This automatically meant that protecting the "raison d'être" from a user perspective was already included in the general approach. During the user sessions, I found that users find it way easier to provide feedback when comparing a proposal to alternatives.

When it comes to company stakeholders, I learned that it was essential to manage the expectations of the involved colleagues. First of all, as a designer, you want to be up-to-date on the engineers' requirements. Simultaneously, the engineers should be informed on the project's scope so they can give valuable insights that can impact the project in a positive way. Limited input can have a minor impact on the project, while extensive input can take away the design freedom. Always informing stakeholders allows them to balance the right amount of feedback.

Like with the end-users, regularly pitching the latest ideas and concept features provided me with valuable insights, keeping the concept realistic and viable.

At the end of the project, I presented the final product concept in a SenseGlove project kick-off meeting. After this meeting, I finalized the project with a feature list and initial planning, indicating risks and priorities for further development of the product. Also, my final concerns and user feedback are concluded in a set of recommendations.

UX-methodologies

The second learning goal I formulated was to engage in new UX-methodologies. Honestly, when critically reflecting on this learning goal, I made quite a slow start. I managed to apply some of the UX-tools I was familiar with, such as experience mapping and storyboarding. However, the tools I applied were kind of forced in the process and did not directly justify their use. Although insights were gained, I needed to reflect on my challenges and think of approaches that fit organically within the problem definition.

From that moment, I explored more methods of design road mapping and allowed myself more freedom to define my own "custom" design methodology, driven by the user vision and inspired by other UX tools and methodologies. After doing so, I found more valuable insights and drivers for the concept design. I also got more enthusiastic by each step I took in the process, since it felt more like personal achievement, instead of the result of a recipe I followed.

This project allowed me many times to communicate with users in various user interviews directly. First of all, I got more comfortable interviewing end-users. At first, I found myself nervous about the quality of the interview, my proposal, or my impression on the participant. After lots of practice, I managed to engage the participants by gaining their interest. I managed to identify underlying themes and real user concerns effectively. I feel like I improved in listening and understanding the user, by asking the right questions and following up on interesting statements. Concluding, my skills in qualitative research have improved.





CMF design

One of my learning goals was to explore the subject of Color, Materials and finishes (CMF). CMF contributes to the complete aesthetic experience of a product, and could be used as a tool to direct the product concept towards the future vision.

During my project I learned new methodologies and tools that guide the process of color selection (See "Color selection" on page 88). Being able to select a color through a guiding process does not only speed up the process, but it also makes decisions in CMF easier to clarify to others.

In addition to learning new methods, I closely studied products that are, in my opinion, well designed in terms of CMF. I tried to learn from those products, and implement design features in my concept that seemed valuable in my context.

At the stage of color selection, I got in contact with Kellpla. Kellpla is Senseglove's manufacturing partner in injectionmolding. Their engineers learned me some in's and outs when it comes to manufacturing plastic parts, the influence that manufacturing can have on CMF, and the possibilities in terms of finishing and colors. Being able to talk to industry experts gave me insights on what the possibilities of CMF are from a manufacturing perspective.

Lastly, I want to state that prototyping on a detailed level where CMF results are presented really helped me reflecting and understanding the influence of the decisionmaking on the final product. This project was the first occasion where I made prototypes on CMF level.

Prototyping

Around the mid-term milestone in my project, it became clear that my prototype should communicate product features and details in such a way that simply 3D-printing would not be sufficient. Throughout my experience as a designer, making prototypes has always been one of my weaknesses. I feel way more comfortable when designing digital products or product renders. Making a prototype that goes this much into detail was something I had to get around.

I made sure to do lots of research on prototyping and finishing plastic to find the right steps that led me to the quality I was looking for. Luckily, some of my peer students had experience making prototypes like this, which gave me some guidelines to work with.

Graduating during the pandemic forced me to work from home. Since I have no garden or balcony, I often found myself sitting on the doorstep in front of my house. However, the hard work paid off, and I am delighted with the result and my personal growth on prototyping. I feel like I've learned more in the four weeks of prototyping during this project, than in the rest of my time at IDE.

I learned that when making a prototype, it is okay to make simplifications compared to the product concept. Especially when working with soft plastics which are tricky to prototype. As long as the prototype serves the goal, it is almost impossible to make it perfect.

ACKNOWLEDGEMENTS

This project wouldn't be the same without some amazing people around me. I want to thank the following individuals:

Andre

Thank you for your dedication and constant support during the project. Your curiosity and interest kept me sharp throughout the project. Thanks to you I always explored the boundaries which got my project to the next level.

Derek

Thank you for challenging myself. From the beginning of the project you showed me how to approach complex problems in efficient ways. You dared me to not always take the easy way. Your coaching challenged me not to just make a great product, but led me to an interesting approach.

Dan

It has always been a pleasure working together, and this project was no exception. Thank you for managing the project from a SenseGlove perspective. You kept both my feet on the ground, and allowed me to design a concept that could make potentially a real impact.

Johannes

Thank you for always being available for crazy discussions about new ideas. Your feedback gave me the assurance I needed to take the next steps in the development.

SenseGlove

Thank you for making this project possible. Thanks for all the possibilities and responsibilities in the last years. It has always been a pleasure working with such a driven team. I've learned so much from you guys. It was an experience I'll never forget.

Sven

Thank you for keeping my mind off the project, and listening to my crazy stories about my new ideas. Apologies for the mess at home during the prototyping phase.

Karolina

Thank you for the constant support throughout this project. The pandemic has not been the most fun period for both of us, but we got through. Thank you for the amazing food and always being there for me.

Britney

Thank you for your support! Your achievements triggered me to get most of my own work. Let's finish our studies together!

Mom & dad

Thank you for the support throughout my whole career. Without you guys this wouldn't be possible. Thank you for all the great advice! It won't be the last time I need it.

REFERENCES

- Boeijen, A., Daalhuizen, J., Schoor, R., Zijlstra, J., van Boeijen, A., & van der Schoor, R. (2014). Delft Design Guide. New York, United States: Macmillan Publishers.
- Buiga, A. (2012). Investigating the Role of MQB Platform in Volkswagen Group's Strategy and Automobile Industry. *International Journal of Academic Research in Business and Social Sciences*, 2(9), 391–399. Retrieved from https://www.researchgate.net/publication/285838018_Investigating_the_role_of_MQB_platform_in_volkswagen_group's_strategy_and_automobile_industry
- Culbertson, H., Schorr, S. B., & Okamura, A. M. (2018). Haptics: The Present and Future of Artificial Touch Sensation. *Annual Review of Control, Robotics, and Autonomous Systems*, 1(1), 385–409. <https://doi.org/10.1146/annurev-control-060117-105043>
- Hale, K. S., & Stanney, K. M. (2004b). Haptic rendering - beyond visual computing - Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. *IEEE Computer Graphics and Applications*, 24(2), 33–39. <https://doi.org/10.1109/mcg.2004.1274059>
- Hekkert, P. (2006). Design aesthetics: Principles of pleasure in design. *Psychology Science*, 48(2), 157–172. Retrieved from <https://www.semanticscholar.org/paper/Design-aesthetics%3A-principles-of-pleasure-in-design-Hekkert/8392cba309bc4477718713baf5dabef938699865#paper-header>
- Hekkert, P. (2016). *ViP Vision in Design*. Zaltbommel, Netherlands: Van Haren Publishing.
- Inkwood Research. (z.d.). Global Haptic Technology Market. Geraadpleegd op 7 juli 2020, van <https://www.inkwoodresearch.com/reports/haptic-technology-market/>
- Jinlong Machinery & Electronics. (2020, January 23). G1040003D. Retrieved May 5, 2020, from <https://www.vibration-motor.com/coin-vibration-motors/coin-linear-resonant-actuators-lra/g1040003d>
- Kim, J. R., & Tan, H. Z. (2014). A study of touch typing performance with keyclick feedback. 2014 IEEE Haptics Symposium (HAPTICS), 227–233. <https://doi.org/10.1109/haptics.2014.6775459>
- Lin, C.-C., & Luh, D.-B. (2009). A vision-oriented approach for innovative product design. *Advanced Engineering Informatics*, 23(2), 191–200. <https://doi.org/10.1016/j.aei.2008.10.005>
- Mihelj, M., & Podobnik, J. (2012). *Haptics for Virtual Reality and Teleoperation*. New York, Verenigde Staten: Springer Publishing.
- Murray, C. (2018, August 10). Four Steps To “the Right” Color in Product Design. Retrieved May 6, 2020, from <https://www.bresslergroup.com/blog/four-steps-to-choosing-the-right-color-in-product-design/>
- Precision Microdrives. (2018, November 28). Linear Resonant Actuators - LRAs. Retrieved from <https://www.precisionmicrodrives.com/vibration-motors/linear-resonant-actuators-lras/>
- Precision Microdrives. (2018, November 28). Vibration Motors. Retrieved from <https://www.precisionmicrodrives.com/vibration-motors/>
- Pugh, S. (1991). *Total Design*. Zaltbommel, Nederland: Van Haren Publishing.
- Roozenburg, N., & Eekels, J. (1998). *Productontwerpen, structuur en methoden* (2nd ed.). The Hague, Netherlands: Boom Lemma.
- Sanders, E. B. N. and Stappers, P. (2012): *Convivial Toolbox: Generative Research for the Front End of Design*, BIS Publishers, Amsterdam, The Netherlands (pp. 15-31)
- Sharp, J., & Macklin, C. (2019). *Iterate*. Amsterdam, Netherlands: Amsterdam University Press.
- Simonse, L., Iwanicka, B., & Whelton, J. (2018). *Design Roadmapping*. Zaltbommel, Netherlands: Van Haren Publishing.
- Texas Instruments. (n.d.). DRV2605L. Retrieved May 5, 2020, from <https://www.ti.com/product/DRV2605L>
- Valkenburg, R., & Sluijs, J. (2016). *Images of design thinking* (1ste editie). Den Haag, Nederland: Boom Lemma.
- Wang, L., Meydan, T., & Williams, P. (2017). A Two-Axis Goniometric Sensor for Tracking Finger Motion. *Sensors*, 17(4), 3. <https://doi.org/10.3390/s17040770>
- Wang, L., Meydan, T., & Williams, P. (2017b). A Two-Axis Goniometric Sensor for Tracking Finger Motion. *Sensors*, 17(4), 770. <https://doi.org/10.3390/s17040770>
- Xbox. (2013, 7 augustus). Xbox One Wireless Controller [Videobestand]. Geraadpleegd van https://www.youtube.com/watch?time_continue=13&v=T4FV2wfDVeY&feature=emb_logo

APPENDIX 2: USER MAPPING

USER CONCERNS - INTERVIEWS

Goal

The goal of this interview is to obtain contextual information about the target group, product use and opinions about existing products and experiences. The interview can be performed with both individual and multiple participants, encouraging discussions to highlight similarities and differences between the them.

Research questions

- *What are the main drivers for the target group and their research activities?*
- *Which qualities should a research tool contain for academics and R&D workers?*
- *What similarities and differences in mindset can be identified within the target group?*

Participants

The participants of the interviews are academia and/or R&D workers.

The environment

The interview is performed in a relaxed atmosphere without distractions. The participants are offered refreshments to remain comfortable and satisfied during the interview.

Introduction (5 - 10 minutes)

During the introduction the interviewer tells about his background and shortly elaborates the background of the project. In case of multiple interviewees, the participants will be able to introduce themselves and tell about their fields. The participants are encouraged to answer questions as honest and complete as possible in order to get the deepest insights possible. The participants should feel free to speak their mind without any expectations.

Statements (20 - 25 minutes)

The participants will be presented with certain statements, and should fill in or answer the statements based on their background and past experiences. The first statements describe topics around the participants and their personal drivers, and will slowly transition towards topics around research activities, equipment and experiences.

This way the users can “warm-up” by providing information close to them, and provide deeper and more complex insights later during the interview.

Experience mapping (10 - 15 minutes)

The participants will be asked about experiences and expectations on the use of products within their lab. First, they're asked to provide insights on common frustrations and benefits they encounter in product use. Then the participants are asked to further elaborate and highlight moments of product experience in the customer journey. Lastly, after discussing many elements of product use, the participants are asked to name the three characteristics that the ideal research tool should embody. To trigger the participants, a list of random characteristics will be presented. The participants can, but are not limited and to, choose characteristics from this list.

Results

After reviewing summarising notes and transcripts, conclusions can be drawn. The results of this interview can contribute to the creation of user personas and to get an initial impression of the target group and their opinions and experiences.

APPENDIX 3: VISION SESSION

USER VISION - INTERVIEWS 1.1

Goal

The goal of this interview is to obtain insights on the future vision from the target group's perspective, on the developments within HCI- & haptics research platforms and their direct context. The interview is performed with individual participants, enabling the interviewee to steer and discuss as a response to specific thoughts and statements.

Research questions

- What is the future vision on HCI- & haptics research platform in 2030 according to researchers in that field?
- What should be, according to researchers, the most important changes of these research platforms to remain relevant?
- What trends and technologies influence these changes?
- What attitude do researchers have towards those differences?

Participants

The participants of the interviews are academia and/or R&D workers. A minimum of three sessions, and thus participants, are required for this research.

Research setup

The interview is performed in a relaxed atmosphere without distractions. The participants are offered refreshments to remain comfortable and satisfied during the interview. During the interview audio will be recorded to review the research outcomes. The participant will be informed and will provide permission for making and using the recordings. This will be done through signing a consent form.

Introduction (5 - 10 minutes)

The participant is informed about audio recordings and their purpose. The participant is asked to sign an agreement on the recording and use of audio material. During the introduction the interviewer tells about his background and shortly elaborates the background of the graduation project. The participants are encouraged to answer questions as honest and complete as possible in order to get the most valuable insights as possible. The participants should feel free to speak their mind without any expectations. The participants will be allowed to introduce themselves and tell about the current situation within their field of research and projects.

Interview questions (20 - 25 minutes)

- How would you describe your future vision on haptics/HCI research platforms in 2030?
- What are the most important changes compared to current platforms?
- Why do you think those changes impact the world positively or negatively?
- What trends and technologies will contribute to these changes?
- Can you run me through a typical use cycle in which you use such a platform? How do you interact with the platform, and how does it interact with its environment?
- What value does this platform bring you compared to current platforms?
- What does this new platform look like?

When interesting answers or opinions are given by the participant, the interviewer is encouraged to ask the participant to further elaborate their answer. In this way the interviewer can get a deeper and better understanding on the participants thoughts and motivations.

Expected outcomes

A change in the way research platforms look and work and their role in the experiment of a researcher. A shift in the way the research platform is interacting with its environment. A shift in what the expectations are for future research platforms. Clear insights in the most relevant changes of the research platforms and the attitude of the researcher towards them.

Results

After reviewing summarising notes and transcripts, conclusions can be drawn. The results of this interview will be summarized in an universal future vision; a statement of a maximum of three sentences. This vision represents the expectations and values of the participants in this research. The vision will be supported by a couple of paragraphs which further elaborate the vision and drivers. The results will be documented in such a way that its suitable for evaluation and design drivers. The results will be used in the decisionmaking in later stages in the project.

Evaluation

During the next phase within the project, the vision will be evaluated by performing another research. This evaluation will give insights in five categories: **Accuracy, Completeness, Feasibility, Likelihood and Clarity.**

APPENDIX 4: PARTICIPATORY DESIGN

USER CONCERNS - INTERVIEWS

Goal

The goal of this interview is to obtain contextual information about the target group, product use and opinions about existing products and experiences. The interview can be performed with both individual and multiple participants, encouraging discussions to highlight similarities and differences between the them.

Research questions

- *What are the main drivers for the target group and their research activities?*
- *Which qualities should a research tool contain for academics and R&D workers?*
- *What similarities and differences in mindset can be identified within the target group?*

Participants

The participants of the interviews are academia and/or R&D workers.

The environment

The interview is performed in a relaxed atmosphere without distractions. The participants are offered refreshments to remain comfortable and satisfied during the interview.

Introduction (5 - 10 minutes)

During the introduction the interviewer tells about his background and shortly elaborates the background of the project. In case of multiple interviewees, the participants will be able to introduce themselves and tell about their fields. The participants are encouraged to answer questions as honest and complete as possible in order to get the deepest insights possible. The participants should feel free to speak their mind without any expectations.

Statements (20 - 25 minutes)

The participants will be presented with certain statements, and should fill in or answer the statements based on their background and past experiences. The first statements describe topics around the participants and their personal drivers, and will slowly transition towards topics around research activities, equipment and experiences.

This way the users can “warm-up” by providing information close to them, and provide deeper and more complex insights later during the interview.

Experience mapping (10 - 15 minutes)

The participants will be asked about experiences and expectations on the use of products within their lab. First, they're asked to provide insights on common frustrations and benefits they encounter in product use. Then the participants are asked to further elaborate and highlight moments of product experience in the customer journey. Lastly, after discussing many elements of product use, the participants are asked to name the three characteristics that the ideal research tool should embody. To trigger the participants, a list of random characteristics will be presented. The participants can, but are not limited and to, choose characteristics from this list.

Results

After reviewing summarising notes and transcripts, conclusions can be drawn. The results of this interview can contribute to the creation of user personas and to get an initial impression of the target group and their opinions and experiences.

APPENDIX 5: CONCEPT EVALUATION

USER VISION - INTERVIEWS 1.1

Goal

The goal of this interview is to obtain insights on the future vision from the target group's perspective, on the developments within HCI- & haptics research platforms and their direct context. The interview is performed with individual participants, enabling the interviewee to steer and discuss as a response to specific thoughts and statements.

Research questions

- What is the future vision on HCI- & haptics research platform in 2030 according to researchers in that field?
- What should be, according to researchers, the most important changes of these research platforms to remain relevant?
- What trends and technologies influence these changes?
- What attitude do researchers have towards those differences?

Participants

The participants of the interviews are academia and/or R&D workers. A minimum of three sessions, and thus participants, are required for this research.

Research setup

The interview is performed in a relaxed atmosphere without distractions. The participants are offered refreshments to remain comfortable and satisfied during the interview. During the interview audio will be recorded to review the research outcomes. The participant will be informed and will provide permission for making and using the recordings. This will be done through signing a consent form.

Introduction (5 - 10 minutes)

The participant is informed about audio recordings and their purpose. The participant is asked to sign an agreement on the recording and use of audio material. During the introduction the interviewer tells about his background and shortly elaborates the background of the graduation project. The participants are encouraged to answer questions as honest and complete as possible in order to get the most valuable insights as possible. The participants should feel free to speak their mind without any expectations. The participants will be allowed to introduce themselves and tell about the current situation within their field of research and projects.

Interview questions (20 - 25 minutes)

- How would you describe your future vision on haptics/HCI research platforms in 2030?
- What are the most important changes compared to current platforms?
- Why do you think those changes impact the world positively or negatively?
- What trends and technologies will contribute to these changes?
- Can you run me through a typical use cycle in which you use such a platform? How do you interact with the platform, and how does it interact with its environment?
- What value does this platform bring you compared to current platforms?
- What does this new platform look like?

When interesting answers or opinions are given by the participant, the interviewer is encouraged to ask the participant to further elaborate their answer. In this way the interviewer can get a deeper and better understanding on the participants thoughts and motivations.

Expected outcomes

A change in the way research platforms look and work and their role in the experiment of a researcher. A shift in the way the research platform is interacting with its environment. A shift in what the expectations are for future research platforms. Clear insights in the most relevant changes of the research platforms and the attitude of the researcher towards them.

Results

After reviewing summarising notes and transcripts, conclusions can be drawn. The results of this interview will be summarized in an universal future vision; a statement of a maximum of three sentences. This vision represents the expectations and values of the participants in this research. The vision will be supported by a couple of paragraphs which further elaborate the vision and drivers. The results will be documented in such a way that its suitable for evaluation and design drivers. The results will be used in the decisionmaking in later stages in the project.

Evaluation

During the next phase within the project, the vision will be evaluated by performing another research. This evaluation will give insights in five categories: **Accuracy, Completeness, Feasibility, Likelihood and Clarity.**

APPENDIX 6: LIST OF REQUIREMENTS

Area	Nr.	Demands	Source	Page	Nr.	Wishes
1. Performance	0				0	
	1	The product must be able to provide a minimum Force Feedback to the users fingers of minimum 30N.	CTO		1	The force feedback should be as powerful as possible.
	2	The product must be able to provide vibrotactile feedback to the users fingers. The product must be able to track the motion of the user's hand and fingers. The motion tracking solution should	CEO		2	The vibrotactile feedback should be as clear as possible.
	3	cover a flexion of 90 degrees, and an abduction/adduction/hyperextension of 30 degrees for each finger.	CEO		3	The motion-tracking must be as accurate and precise as possible.
	4	Standard position trackers should be mountable on the final product concept.			4	The components take as little time and effort as possible to replace.
	5	The product should enable the user to interchange all finger-tracking and haptic feedback components.	Users			
	6	Hand-to-product alignment is the same for each user (+5mm).	CTO			
	7	The fixation to the fingers is stable, allowing the capturing of every movement the finger makes.	CTO			
	8	The shape of the product avoids trapping heat, and therefore avoids sweating.	AED			
	9	The product simulates virtual interactions with haptics in a believable way.	CEO		5	The haptic interactions are as clear and realistic as possible.
2. Environment	10	Non-haptic related parts do not trigger sensations that can be mistaken for haptic cues.	DAN			
	11	The product must be able to be stored and used in temperature conditions of 30-65°C.	CTO		6	The product must be resistant to the widest range of temperature as possible.
3. Life in Service	12	The product must be able to be stored and used in humidity conditions of 5%RH-85%RH.	CTO		7	The product must be resistant to the widest range of humidity as possible.
	13	The product can be used in sessions of maximum 120 minutes each.	Users		8	The maximum time for continues usage is as long as possible.
4. Maintenance	14	The performance of the product does not decrease after multiple back-to-back sessions.	Users			
	15	Every part of the product should be able to be repaired or replaced.	CTO			
5. Target Product C	16	New parts can be ordered and replaced by the user.	Users			
	17	Parts that are in frequent contact with the users skin, are directly replacable.	DAN			
	18	Any textile parts can be detached and washed.	Users			
	19	The enclosure of the product can be rinsed using wet wipes.	Users		9	Grooves and cracks in which dirt can accumulate are covered/avoided as much as possible
6. Transport	20	The maximum production costs are €1250,-	CEO		10	The production cost should be as low as possible.
	21	The user should be able to transport the product after initial set-up.	Users		11	Repacking and moving the product is as convenient as possible.
7. Packaging	22	The packaging should protect the product from mechanical damage.	Research		12	The packaging protects the product from as much mechanical damage as possible.
	23	The packaging should work for all component configurations available.	Research		13	The packaging can be used for as many future generation products/components as possible.
8. Quantity	24	The product has a total MOQ of 1000 pairs in the first year.	CEO			
	25	The product has a total MOQ of 6000 in the first three years.	CEO			
9. Production Facili	26	The product can be assembled manually.	CTO		14	Assembling the product is as convenient as possible.
	27	Majority of modules should be manufactured in a shared mold.	Research		15	As little as possible changes to the mold are necessary to produce all parts.
	28	Varous configurations can be assembled on the same base enclosure.				
	29	No manual sewing for textile parts is required.	CTO			
10. Size and Weight	30	The weight of the product must be 300 grams or less.	Research		16	The weight of the product must be as little as possible.
	31	The size of the product is maximum 100x100x50 mm.	Research		17	The size of the product is as small as possible.

11. Aesthetic, Appe

- 32 The aesthetic, appearance and finish should fit the user's future vision. Research
- 33 The products appearance stands out from its competition. Research
- 34 The product represents the SenseGlove brand. CEO
- 35 The aesthetic of the product represents the four aesthetic principles by Hekkert Research

12. Materials

- 36 Given the weight and MOQ, the enclosure must (will) be made from plastic. CTO
- 37 Where fabric is used in contact with the skin, breathable fabric is used.

13. Product Life Spa

14. Standards, Rule

15. Ergonomics

- 38 The maximum set-up time after unboxing is 5 minutes. Research
- 39 The user should be able to wear the product in first time use within one minute. Research
- 40 The user should be able to use the product for 120 minutes without discomfort. Research
- 41 The product allows the user to move all the parts of the fingers independently. CTO
- 42 The product is usable for users with long fingernails. Research

- 18 The set-up time is as little as possible.
- 19 First time use is as intuitive as possible.
- 20 The product can be worn as long as possible before causing discomfort.
- 21 The movement of the hand and fingers is as little restricted as possible.

16. Reliability

17. Storage

- 43 Storage does not take up more than 500x400x300mm. Research

18. Testing

19. Safety

- 44 Wearing the product should inflict no rashes or discomfort on the skin.
- 45 The hand of the user can not be stuck or pinched between parts while wearing it.
- 46 The product does not have sharp edges that can inflict pain or damage.

- 22 The product is as safe as possible.

20. Product Policy

21. Societal and Pol

22. Product Liability

23. Installation and

- 47 The second glove can be "donned" while wearing the another glove.
- 48 The user can wear the product without assistance of others.

- 23 Donning and doffing is as convenient as possible.

24. Reuse, Recyclin

- 49 The product's lifetime can be increased by replacing/upgrading modules.
- 50 The product can be disassembled to separate different materials up to part level.

- 24 Replacing/Upgrading modules inceases the valuable lifetime of a product as long as possible.
- 25 As many different materials can be seperated for recycling.

APPENDIX 7: PERSONAS



MICHAEL PhD student

"I do not want to worry about equipment and the safety and well-being of my participants. They should behave as natural as possible."

INFO

Age: 25-33
 Profession: PhD candidate
 Income: 2800 - 3100
 Family status: Partnership
 Field of studies: Applied Ergonomics

ABOUT

The PhD candidate is, that engages in a field of study for a 3-4 year traject. Within this traject, the PhD candidate collects credits by presenting and publishing relevant scientific work. This work will be related to the theme and research questions which are formulated at the start of the PhD traject. For that reason, most of the experiments will be within the same area, but develop and change in goals and outcomes over time.

FRUSTRATIONS

- Constantly building up and tweaking equipment keeps me distracted from my important work.
- To make my research relevant, I want to benchmark my equipment to the "golden standard".
- Lack of itransparancy of my hardware disables me to draw conclusions

GOALS

I want to find new principles and mechanics within my studies. I want to contribute to the **community** of scientists. I want to **develop myself** as a person and learn more about the world by travelling and working in **different places**.

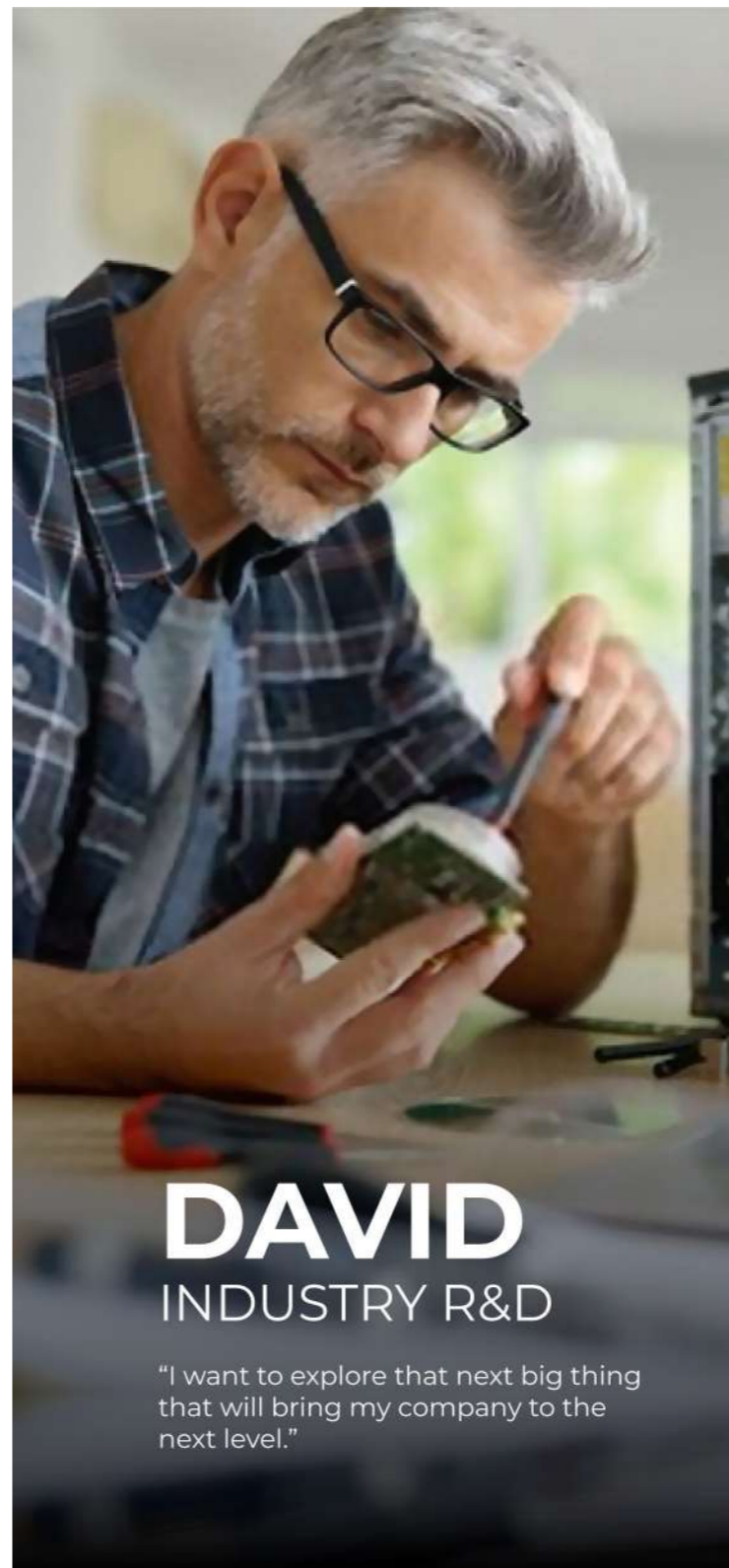
CONCERNS

The tool does not influence the participants **natural behaviour**. The tool is precise and **helps me understand** unknown principles. The tool is **easy to work with**, and does not require my effort to work. The tool is **completely safe** and **comfortable** in use.

PERSONALITY



EXPLORE DEVELOP SOCIAL CURIOUS FREEDOM



DAVID INDUSTRY R&D

"I want to explore that next big thing that will bring my company to the next level."

INFO

Age: 35-65
 Profession: R&D Engineer
 Income: 3000 - 5000
 Family status: Married & Daughter
 Field of studies: Training and maintenance

ABOUT

As an In-house R&D engineer, David plays a major role in optimizing training and maintenance processes. As his company is transitioning towards virtual trainings, he is responsible for having the greatest understanding of new developments. He is looking for a great tool that helps him develop and understand new possibilities for implementation.

FRUSTRATIONS

- The functionality of many products is too narrow for my project.
- Whenever I purchase a new product, a product with better specifications gets released by another company.
- Many products do not represent my professional use-case.

GOALS

I want to **test and implement** new functionalities in my system. I want to **integrate** solutions in the long-term. I want to **innovate** the system within my company. I want to get **recognized** for my effort and achievements.

CONCERNS

The tool gives me the **freedom** to explore and experiment. The tool enables me to leave a **great impression** among my managers. The tool is precise and **helps me prove and develop** new assets. The tool is **comfortable**, since I will use it myself everyday.

PERSONALITY



DEMONSTRATE EXPLORE TEST DEVELOPMENT



KAREN PROFESSOR

"Benchmarking with the golden standard? No, want to work with the golden standard!"

"I do not care what it looks like, as long as it does it's job, good!"

INFO

Age: 40-65
 Profession: Professor & Lab Owner
 Income: 5000 - 7000
 Family status: Married & 2 children
 Field of studies: Human-Computer Interaction

ABOUT

As a professor & lab owner, Karen is responsible for all the equipment in the lab. In this role, she engages industry partners in her research trajectory. While guiding and motivating her researchers, she tries to push the boundaries of her field of research. Investing is rarely a problem, which gives her the opportunity to work with state-of-the-art tools. This ensures quality of her research, and trust from industry partners.

FRUSTRATIONS

- Moving my equipment from and to different stakeholders is quite a hassle.
- I always need to re-invest in equipment to keep using the state-of-the-art tools in the lab.
- Lack of transparency of my hardware disables me sometimes to draw conclusions.

GOALS

- I want to **motivate** my labmembers towards achievements.
- I want to **contribute and guide** the community of scientists.
- I want to **innovate** in the industry and world around me.
- I want to get **recognized** for my effort and achievements.

CONCERNS

- The tool is **robust** and does not break down during use.
- The tool is reliable and **helps me understand** unknown principles.
- The tool is **easy to work with**, and does not require adaptations.
- The tool is **state-of-the-art** and gets recognized as such.

PERSONALITY



MOTIVATE ORGANISE PROVE RESPONSIBILITY

APPENDIX 8: FEATURE LIST

Product feature list Rembrandt

Universal joint			
Task	Risk	Priority	Responsible
Development of a joint that enables dual-axis rotation	High	High	Johannes (mechanical dept.)
Integration of motion tracking capabilities using hall-effect sensors	High	High	Johannes (mechanical dept.)
Compatibility of force feedback with the universal joint	average	average	Johannes (mechanical dept.)
Design cover to protect the joint from pulling forces and dust	average	average	Johannes (mechanical dept.)
Integrate a non-measured rotational degree of freedom	average	average	Johannes (mechanical dept.)
Make necessary changes in software scripts for changes in sensor positioning	Low	Low	Max (software dept.)

Strap			
Task	Risk	Priority	Responsible
Design for anthropometrics, define sizes and interface positions with the hub	Low	High	Anne (product design dept.)
Design for comfort, define exact materials, shapes and textures	low	low	Anne (product design dept.)
Design spring loaded mechanism for modularity (female)	average	average	Johannes (mechanical dept.)
Optimize buckle mechanism for don/doffing	Low	Low	Anne (product design dept.)

Vibrotactile modules			
Task	Risk	Priority	Responsible
Designing a well-integrated standard configuration	High	High	Anne (product design dept.)
Quantifying potential areas for expanding the module portfolio	average	average	Dan (haptics dept.) Niels (strategic dept.)
Hardware design of standard configuration module	Low	High	Chun (electronics dept.)
Defining placement details for standard configuration	High	High	Dan (haptics dept.)
Select driver/actuator combination standard configuration	High	High	Dan (haptics dept.)

Hub shape			
Task	Risk	Priority	Responsible
Define exact footprint based on positioning of universal joints and strap anthropometrics	average	average	Anne (product design dept.)
Develop and integrate male connector for strap modularity	average	average	Anne (product design dept.)
Depending on finger modularity and non-force feedback configuration, make interchangeable top covers	High	High	Anne (product design dept.)

APPENDIX 8: RAW INTERVIEW NOTES

Force feedback/fingers			
Task	Risk	Priority	Responsible
Design mechanical/electrical interface for the force feedback assembly	Average	Average	Johannes (mechanical dept.)
Define level of modularity between in the finger/force feedback assembly	High	High	Johannes (mechanical dept.)
Integrate an interface PCB that interfaces with the vibrotactile module	average	average	Johannes (mechanical dept.)
Define exact lay-out and footprint for interface PCB	High	High	Chun (electronics dept.)

Passive thimble			
Task	Risk	Priority	Responsible
Extensively test the performance of the sliding connection, and optimize accordingly	High	High	Anne (product design dept.)
Integrate the "active part" within the design of the finger	average	average	Anne (product design dept.)
Develop a "passive" Velcro thimble that interfaces with the finger	Low	Low	Anne (product design dept.)
Quantifying potential areas for expanding the thimble portfolio	Low	Low	Niels (strategic dept.)

Participant

Michael Wiertelwski

Position

Assistant Professor - Cognitive Robotics

Background

Biorobotics - Haptics

Future vision – Future use

Michael likes to explore the underlying processes that make him understand the sense of touch. He starts by thinking of a model and a certain principle he would like to explore. Then, Michael builds a custom haptic stimulus to put this principle to the test. He constantly keeps developing and fine-tuning the stimulus till it reaches a high level of performance and reliability. This process is beneficial for Michael, since he feels like he is in control and able to work flexible.

This does not mean that Michael does not limit himself to custom build equipment. On a part level, many components are off-the-shelf, such as actuators, sensors, fasteners etc. Although Michael prefers to build stimuli himself, he finds himself having problems finding a solution for motion-tracking of the fingers. Considering the various use-cases Michael works on (surface haptics, vibrotactile stimuli, etc.) a high-end tracking solution that can be combined with his own stimuli would serve him best.

From the one hand Michael wants to be able to get into the deep specifics of a study and its research platforms. On the other hand, he wants stakeholders from other fields to be able to use and work with the same platform. It is difficult to find solutions that are usable for people with different backgrounds and knowledge. Michael notices that cross field research cooperation is becoming more and more important, and expects this trend to develop further in the future.

What does it look like?

When Michael describes the ideal research platform of the future as a wearable device which is embedded into everyday objects. Curved and soft, you can interact with it in general practice, not as artificial as with a touchscreen. Natural interactions, as we know them in our daily life, will be the way to go.

At the same time, Michael is realistic and realizes that the product won't be all soft in the near future. To propagate acoustic waves in there (like ultrasound) rigid and flat materials have to be integrated.

Participant

Luka Peternel

Position

Assistant Professor - Cognitive Robotics

Background

Human-Computer interaction

How do I use it?

Luka's research is positioned within the field of telerobotic interactions. He specifically focusses on the impedance¹ of the robot. Impedance is the ratio between the force applied and the motion of an object. In tele-operation, it should be carefully decided what the motion of the robot will be, based on the input of the human. The tele-impedance is an important factor in this interaction. At this point he is focused on exploring the relevance and effects of impedance control. In 2030, he expects to research the same topic, but in a more applied context within the industry. A good example of a research question for Luka would be:

How can the impedance of a robot during a tele-robotic operation semi-autonomously be controlled?

Experiments that work towards this research question will always involve the user input, especially his response to the visual and haptic cues he perceives. Luka stated that high quality force feedback is a clear benefit for these interactions. To capture the user's input, high quality motion tracking and possibly gripping force detection, are required. Vibrotactile cues are also a way of providing the user with cues, but Luka was skeptical of this method for high fidelity interactions (such as feeling edges and textures).

What does it look like?

Luka prefers the new research platform to be wearable. He wants the interaction to be as natural as possible, which means that product is as comfortable and unobtrusive as possible. The product provides kinesthetic feedback, and therefore some sort of physical coupling that applies forces to the user. An exoskeleton would do the trick, if it does not apply dominating parasitic forces.

What has to change?

The current SenseGlove's functionalities seem to be in line with Luka's expectations. Luka is quite skeptical about the impact of vibrotactile stimuli alone, and would definitely prefer a high-performing force feedback technology. Luka thinks that the force feedback should mainly transfer information to the user, and not significantly influence the movement of the hand. For this reason the performance of the force feedback on low power could be improved.

1. Impedance is the ratio between the force applied and the motion of an object. In tele-operation, it should be carefully decided what the motion of the robot will be, based on the input of the human. The tele-impedance is an important factor in this.

Participant

Jim Tolman

Position

Project Engineer – Virtual Reality and HCI

Background

Human-Computer interaction & Design

How would I use it?

Jim's responsibility is to get new technologies implemented in the validation of progresses and manufacturing within Scania. He envisions that this human-computer interface can be part of a digital test assembly line, where problems can be identified.

Jim's main concern involves the end-users within my project. The product is used by mechanics, management and myself. I find that these kind of hardware products in the future are comfortable and way easier to use. He currently works with SenseGlove because he was astonished by the Force Feedback technology. This haptic sensation really adds a new dimension compared to other VR technologies. He expects the level of haptics to improve overtime. Because in the end, he would like to have a device that provides a haptic sensation that is a copy of the real-life equivalent.

Another concern is that the product is not easy to integrate with the software he is using. Since my engineers mostly work with Catia (which works in VR), and not in VR software such as Unity.

In order for these kind of hardware products to get integrated in the company, I have to be able to present the solution to management in an effective way. Currently, we have a team photo in our office, including the SenseGlove. This photo gets people curious and excited about the technology. It would be great to have some more ways to spread the word and get colleagues excited about the technology we're working with.

What does it look like?

Actually, the product currently looks quite bulky, but futuristic. He would envision the future glove to look as futuristic, but maybe a more integrated coherent whole. The product will be much smaller, as all technologies become more compact over time. He sees that new headsets enter the market that can switch from AR/VR back to real life. Jim can imagine a future where they use a glove that enables use in VR, that can "transform" back into a normal every day-use glove.

Jim doesn't expect a future product to be completely sleek and "Apple"-like. The context in which we use the product does not require a designer focused product. Imagine a mechanic, with some stains from the workplace on his clothes, using the product.

What has to change?

After some use, the SenseGlove starts hurting my hand and fingers. This will be unacceptable ten years in the future. The product has to become more comfortable to wear for longer periods of time. Jim wants his participants to Donn/Doff the product in as little time as possible. The haptic sensation is the greatest strength of the current SenseGlove. He expects the level of haptics to be at least as good as it is now, probably even better. It would be great if he could be provided with (visual)material that presents the glove to its full potential for the use within my company. The ideal product would be easy to integrate within the software they're using.

Participant

Karina Driller

Position

PhD candidate – Perceptual Intelligence

Background**How would I use it?**

Karina her goal is to discover new principles in human perception in the field of haptics. She analyses new interaction platforms. By testing new technologies, she aims to discover ways to use the technology to its full potential. She does this by testing the haptic stimuli with participants, defining the characteristics of the platform and discovering new relations between the platform's output and human perception. An example of a research question could be:

What is the perception threshold for mid-air ultrasonic stimuli?

Since Karina is directly testing equipment with participants, many of her concerns involve usability. She is aiming to find correlations between input and perception, which means that the tool should not interfere with the actuation of the signal itself. The participant should always be comfortable during her experiments. Karina works with a large quantity of participants, which means that the ideal tool allows her to switch between participants fast and frequently.

To reach a significant result, the consistency of the hardware is of high importance. Her experiment should be repeatable and consistent, since human perception is a complex thing to measure. To get full control over the input, she needs to be able to drive the actuators herself via a program like MATLAB. Since Karina her study only involves the sense of touch, the research platform does not need to be integrated in a system.

What does it look like?

As already mentioned, the product should be unobtrusive and not interfere with the signals or movement of the user. Karina imagines the ideal research platform to be made of a soft and flexible material, which is worn by the user.

What has to change?

There should be a more effective way of preparing users for an experiment. Donning/doffing takes a long time, and users their natural behavior can be influenced by the discomfort of the glove. Making the glove lighter and more comfortable would boost the performance.

Generalities	explanation
Flexibility	The participants envision a research platform that is wearable and made from soft and flexible materials. A flexible tool brings value to the user, since it seems more comfortable and less noticeable while using.
Professional impression	In future projects, the participants expect to work in close relation to industry partners or management. Working with the research platform should impress and inform a spectator in a professional way.
Reliable and robust	The ideal research platform can be trusted by the researcher, and won't easily break down. The results and input/output values are consistent. The research platform does not fail when unexperienced users are involved and possibly use the product in a wrong way.
Natural interactions	All participants use the research platform to facilitate or capture natural interactions. For this reason, the product should not be obtrusive or influence the wearers behavior significantly.
State-of-the-art	The research platform is state-of-the-art and, performs at least as good as novel alternatives.
Transparency	All participants expect to be informed about the capabilities and performance of the research platform. Examples are data-sheets, data on wear, etc.
Integrated design	All participants expect the research platform to be a coherent integrated design that fits the way it is used. In addition, all participants expect their future research platform to be smaller, since the footprint of certain technologies get smaller and smaller. Especially for wearable solutions, reduced size and weight is valuable.
Discrepancies	explanation
Off-the-shelf vs. Do-it-yourself	Most researchers with a non-engineering background prefer an easy to integrate product, where some researchers with an engineering background would like to have full control and possibly change parameters. This last group probably uses the SenseGlove for motion tracking only to test a custom stimulus.
Comfortable	All researcher agree that a comfortable platform is always beneficial. At the same time, researches that involve end-users or
Future technology	When it comes to defining relevant future technologies, opinions can vary for each researcher. Two researchers with an engineering background disagreed whether vibrotactile stimuli will be a relevant medium for the future.
Easy to use	Of course, all participants mentioned that it's always a good thing that a product is easy to use. Some researchers mentioned that that the usability for them is inferior to the functionality and performance. They mentioned they're willing to spend extra time setting up an experiment, if it pays off in the results.

Integration	Researchers with a non-engineering background find themselves having problems integrating the hardware in their experiment set-up or software. Researchers with an engineering background find it easy, since they have a bigger experience in engineering custom solutions themselves, as long as the raw input-output values are accessible.
Challenges Concept	
Wearable vs. hardware	The next design should contain both soft and rigid parts that allow functional wave propagation. The product should be designed to form a coherent whole.
Off-the-shelf functionality	The product's functionality should be relevant for the majority of use-cases. Product use in combination with passive mock-ups or custom stimuli should be a possibility.
Professional impression	The product should leave the researcher's/developer's stakeholders with a professional impression. Besides actually performing well, it should look like it does.
Reliable and robust	The product is designed in such a way, that it's reliable and robust. The look and feel of the product represent that.
Appearance	The product's appearance resonates with the target-group, but also represents SenseGlove's brand identity and the position within the product portfolio.
Manufacturing	The biggest company driver in the future vision is scalability, and for that reason manufacturing. The main point of improvement is the assembly of the glove, since the last design was focused on pure technical functionality. Many processes can be improved and parts can be integrated. The concept design should be "manufacturing proof", but does not have to be fully embodied.
Upgrades	The concept design should enable SenseGlove to introduce new add-ons or upgrades at the launch of the product. This means that completed and successful R&D projects can directly be applied in the concept. The possibility to integrate upgrades
Challenges marketing	
Challenges technical development	
Tracking only functionality	The development of thimbles that allow interaction with external stimuli should be started.
Collecting data sheets	Testing actuators, define wear and error in readings
Software integration	Access to raw data output/input, C# compatibility (tele-robotics), Unreal compatibility, Catia (design/manufacturing assessment, MatLab (general research purposes)
Challenges customer service	
Communicate data sheets	Grant access to datasheets for clients in academia

Meeting Michael:

"What is common around here, I build everything myself. A lot of things I plan to do is, I come up with a new way of interacting. It takes a lot of time, but I think its also valuable to learn about the small steps it takes when going from 0 to 100. What I'm trying to do with this approach is gaining a deep understanding of the input-output relationships. If I create a voltage somewhere, create a stimulus somewhere, that stimulus triggers something in the brain of the participant. I want to know what this chain looks like."

"The holy grail for haptic stimuli is a tool that stimulates the skin, as interactions in real-life would do. When the participant is exploring objects there is skin deformation and he'll notice kinematic constraints. It is capable of communicating different textures and shapes to the user."

"The current general view on haptics is quite misguided. Existing platforms like VR didn't just exist out of nowhere. I remember working on a shitty bulky greyscale screen, which already did a great job on displaying simple images. These solutions take a long time to develop, but you always start with something useful. It will go the same way for haptics. We have to ask ourselves, what is the most useful stimulus you can get out there."

"When you get products from the market, you often can't find the right specs."

"One thing I'm pursuing, which I think will be more and more important in the future, is to get my technology in the hands of more people. Whether it is people with a development background or with a use-case. The principles I research can be applied to various sub-areas, not only within academia, but also within the industry. "

"From the one hand you want to be able to get into the deep specifics of a study and its research platforms, on the other hand you want stakeholders from other fields to be able to use and work with the same platform. It is difficult to find solutions that are usable for people with different backgrounds and knowledge. "

"If I would have to describe the ideal research platform of the future, it would be a wearable device which is embedded into everyday objects. Curved and soft, you can interact with it in general practice, not as artificial as with a touchscreen. "

"First of all, there are physical problems in the embodiment of this ideal platform. If you want to make something soft, you can't really propagate acoustic waves in there like ultrasound. We have to find out how we can get that working without the use of flat and rigid materials."

Keywords

Usability Reliable, no delay, performance, flexible

Meeting Luka:

B Statement that describes the future. It is somewhat realistic, so based around developments and trends in the field. But it is also Idealistic, so what would I like the future to be? So feel free to throw in your own opinion and thoughts on certain subjects. So, do you have a future research platform in mind? What would it look like, what kind of product would it be?

L You mean in terms of hardware?

B Yeah, could be!

L I'm not sure because currently I work in teleoperation, mostly on what is called tele impedance. So, I try to make the robot to control the impedance parameters, based on what the human is trying to do. So, the human can command it directly through some interfaces. Or you can have a robot do it semi-autonomously. So far tele-operations are done by a position controlled rigid robot. If you have a fragile object, you could easily break it if there is a sensory mismatch or your feedback is not good. So, you estimate the position of the object incorrectly. That is what we're trying to do, we're trying to do it for the past eight years now. Of course, we're trying to propose some projects so we can push this from the scientific environment to the industry. Of course, your subject is more about feedback. Initially this tele impedance is done without force feedback. We showed that you can perform the task, if you have the ability to control the impedance of the robot in real-time. Well of course then we went on, and we also included classical bilateral teleoperations on top with force feedback. And of course, it's then much easier to control the impedance, because if you're feeling it you can adjust it more naturally. Because otherwise if you don't have force feedback, you have to use cognitive capabilities to devise the strategy. Okay I see an object, I see a table,

B The tests you are performing, are you only performing those in the lab, or also within the industry you described. Are they expert users or random research participants?

L So far it is mostly us researchers as expert teleoperators. Because it is very difficult to get expert teleoperators. The field is really novel, so it is really meant to validate certain concepts.

B What does such a piece of hardware look like? Is it a joystick, is it a glove or maybe an optical based solution?

L Initially we used a motion-capture system for the arm to transfer the motion to the robot.

B Okay, how do you capture that motion?

L Visually, either we have passive or active. We have passive markers that reflect light to detect a position. Or you have an LED that actively emits light to track the motion.

B Is that accurate enough?

L Very accurate! But when we started using force feedback, we switched over to other haptic devices.

B You mentioned that the implementation of haptics recently got introduced. Do you think, given the latest developments, that this will remain an important element in the future?

L Force feedback is always nice. The problem is that often companies, let's say, da Vinci, they probably did not want force feedback to be there. It could be dangerous. If it would become unstable, they would probably be responsible and not the surgeon. They rather just have the position controlled using this scaling factor. They then use their cognitive capability and dexterity to

perform the surgery without force feedback. Of course, force feedback, when its really good feedback, it makes the task much easier. So far, force feedback we use it at the level of the endpoint. So, let's so your hand or wrist gets some forces, but not the extra tactile on the finger. That would be one of the steps forward.

B And in terms of, when you have this product that you wear or have in your hand. How will it change to be in your research environment in the future? What are the points of improvements? How do you think it would develop?

L The problem with tele operation is that it is quite a niche market. It is not like other fields, something you can easily fit in other scenarios. You rather use it in disastrous scenarios, where you send a robot where a human can not go. And then you tele-operate it. Or for example surgery, where you can increase the precision of the surgeons to reduce the negative effects of tremor and shaking.

B So you would say that the tools that are available to you, they have to be so specifically focused on the niche you're working in? Does that make it also difficult to find the right equipment, or do you rather engineer equipment yourself?

L So far, regarding the impedance control interface, you somehow need to command the impedance to the remote robot. Let's say you have reference motion plus the stiffness of the robot, that would be two commands going parallel. For the motion its easy, you have a haptic device that can measure the motion, but impedance is a bit more novel. Initially we used EMG that measures the muscle activity of the teleoperator, and then we can estimate the approximate the impedance of the human arm, which you can map on the impedance of the robot. We knew from the very beginning the **novelty of EMG which is impractical**, so later we tried to develop more practical interfaces such as the gripping force, or more external devices such as push buttons. Of course, they might be bit less natural than EMG, because using EMG you naturally perform the task.

B Is that something you think is important, when you look at the future of interaction devices? Should they be as natural as possible?

L Yes. And no. Because humans are extremely adaptable creatures. Maybe when you grab a computer mouse for the first time it feels strange. However, you quickly adapt this in your body scheme, and now its like a piece of you hand. I think that even if the interface is not the most natural, it could become useful with enough training.

B You mentioned that at this point you're in the very beginning and experimenting with certain techniques and interactions. Over time it would slowly move to an industry standard. How would those tools have to change to make this transition?

L I think we are now more in a transition stage, so we have the ideas, we have the scientific studies and research, prototypes, but now we want to actually want to go to the stage where we develop the technology. So maybe this is not still the stage where it will be implemented in the industry or for an end user, but we still need to develop equipment that potentially will be used. Of course, the best way is to do it through a project which can get funded. Let's say the government or European commission would fund it so we can develop this technology further.

B Based on your current knowledge; So, what would be the best direction in which you will be developing those products. Let's say you have to propose the three best products right now. What would it look like, what would have the most potential?

L I would say the stiffness or impedance command interfaces. That has to be really something applicable and intuitive and ergonomic. And of course, there comes a part where you integrate it with force feedback. The whole system has to be **compact and usable**.

B Does that apply to both the product and the system you hook it on to? The controlling interface is of course one part, but the other part is for example the robot arm. Would you expect that in 10 years those two will be same system? Or would they still be two clearly separate products?

L In our case integration is easy, because we have on one side the robot, and on the other side the interface for the teleoperator. You can switch the remote robot with another robot easily. Since you have a simple ethernet connection you can send commands. Of course, if it's a bigger robot, you can increase or decrease the motion depending on the size of the robot. But it's just a matter of constrained what you're sending. The use-case is important. You can use one interface for a robot, but maybe different interfaces are more suitable for other use-cases. We're now proposing one European project where **we get end users on board**, so they can tell us what they expect and what they need. What are their requirements?

B We talked about some positive changes you would need to reach the ideal product. Are there any negative changes around there, of which you think is pushing it into the wrong directions?

L There are always risks that things you're doing is a dead end, and no one wants to use it. On paper tele impedance has many advantages compared to classic human controlled operations. Maybe the position control operation is enough for this niche market. My primary field is physical human-robot interactions where you have tasks with which the robot physically helps you. Now I work in the distance, with tele-robotics. You really have to look at the functionality of a technology. Subjects might sound cool, but they **must be also applicable** in practice.

B I have one last exercise. If we have that Ideal research platform. What do you expect it would look like? Feel free to design and fantasize!

L I would prefer it to be **wearable**. But unfortunately, there were some researchers that tried to do the vibrotactile in each direction. **But this is not natural**. When you're interacting with some objects, you feel the forces. The object pushes you hand, or your arm to feel that interaction. If something just vibrates there, you can just say that it is not the same. So, I am still afraid that **there still should be some physical coupling**, some kind of interface or robot that pushes you.

B So you expect that just a wearable on its own would not make it for the level of immersion or realism that you need. It will always be tethered to a computer or stationary device.

L For the finger interaction vibrotactile is enough, but for end point interaction, or the whole are dynamics and interactions, vibrotactile is not enough. Therefore, it probably cannot be wearable. **Maybe an exoskeleton**, but also an exoskeleton produces some parasitic forces on some other parts of your body. And then again it feels unnatural.

B Are there any developments you notice that can influence these changes?

L Artificial Intelligence will be very important. We implement it at a low level. When you imagine AI you imagine something grand and glorified. Researchers mostly call AI that is very primitive. Any machine learning based function. When AI comes to the point that it can produce stuff as good as humans, then I don't think we even need human robot cooperation anymore.

*B Okay, that is a problem for you! *Laughing**