Redesigning a Haptic Glove for New Features and Improved Assembly

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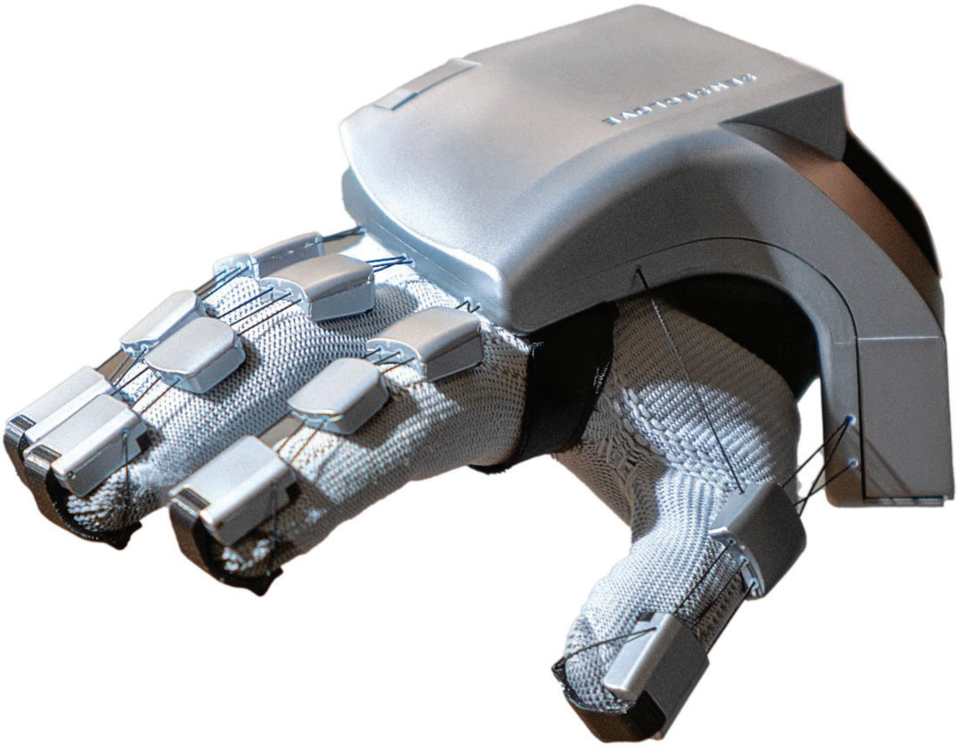

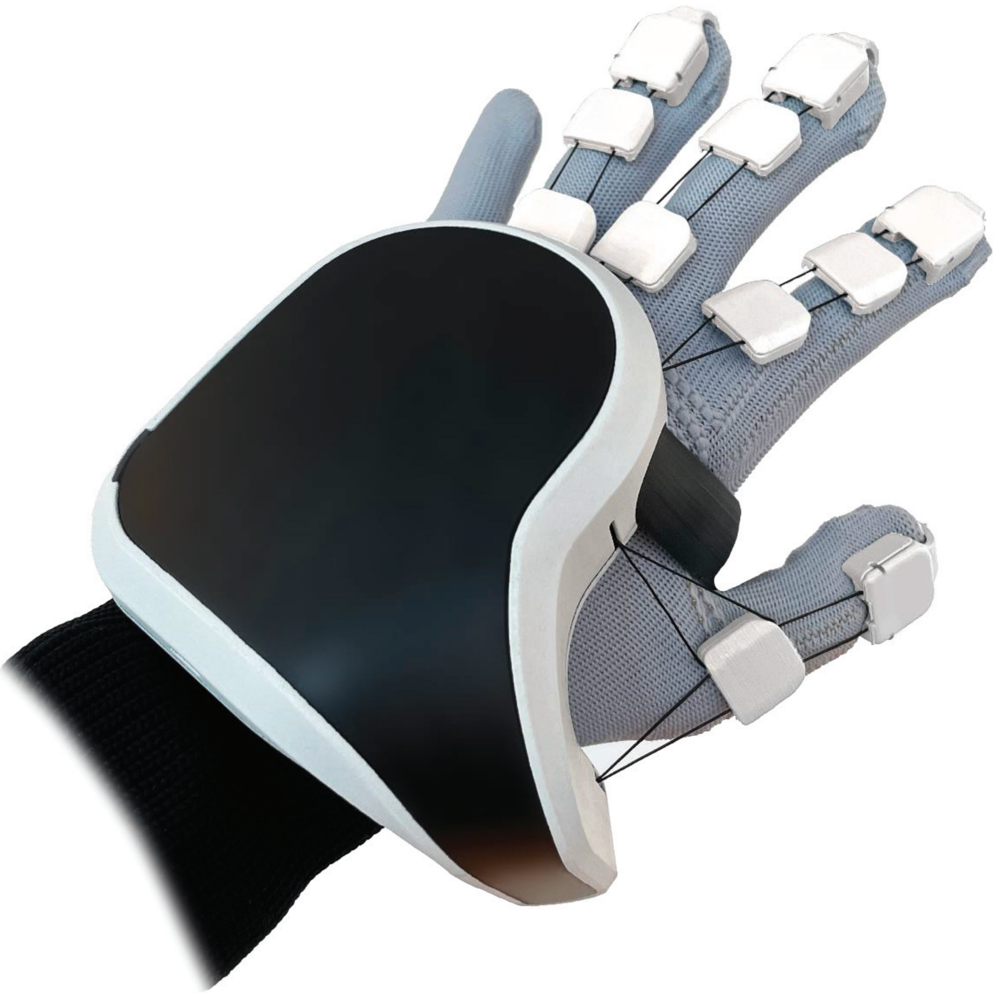

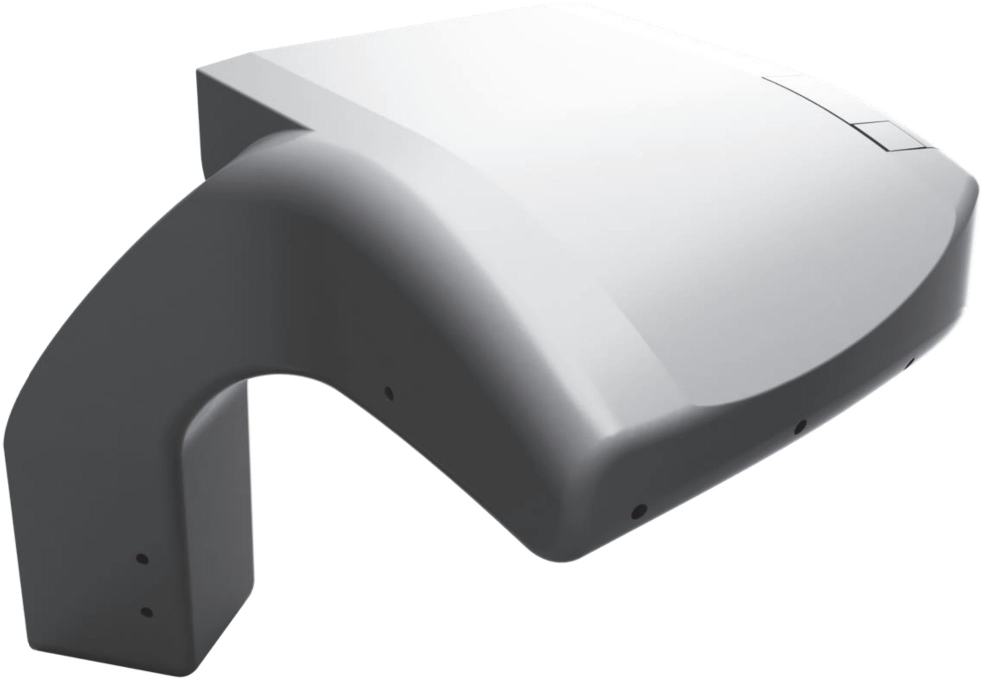

Abstract

This report describes the development of a redesigned haptic glove for SenseGlove, a Delft-based startup specializing in haptic technologies for use in Virtual Reality. Their Nova product line offers force feedback, haptics, and finger tracking to increase immersion in VR and provide intuitive interaction with virtual objects for training purposes. Driven by a desire to implement new features, communicate a new branding direction and increase production rates while maintaining quality, SenseGlove requested a full redesign of Nova's enclosure with a focus on improving assembly time.

An analysis of Nova's original assembly process and design was conducted and showed several areas in which it could be improved. Then, three focus points were defined based on principles from Poka Yoke and DFA:

Focus point 1:
Minimize the number of parts needed for subassemblies within the scope of this project.

Focus point 2:
Improve the logic of the assembly steps and make them as self-explanatory as possible.

Focus point 3:
Reduce the loss of progress that can occur from human error during assembly.

Guided by the focus points, a three-phase design process was completed in which Nova was divided into several subproblems that were individually solved, then combined into a configuration model, before finally being integrated with a new aesthetic direction that was co-developed with SenseGlove to create a Nova 2.0 concept with a new assembly process. A proposal for CMF was also provided, along with an evaluation based on assembly, aesthetics reception, manufacturability, and costs.

The Nova 2.0 concept is estimated to take approximately 53% of the original time to assemble, while eliminating the need for several assembly stations and enabling non-destructive disassembly. The new aesthetic direction fits well among other VR devices often used together with Nova but requires some refinement to meet all visual goals set by SenseGlove. The model provided in this report is not yet completely manufacturable, but with minor adjustments and implementation of recommendations should be ready for production. The new production cost is expected to be higher than the original Nova due to the implementation of new features and a redesigned PCBA, though the exact price cannot be determined as some features were beyond the scope of this project.

The Nova 2.0 concept reaches the goals set at the start of this project and SenseGlove is recommended to further develop it but is advised to keep the three focus points in mind when making changes, as design for assembly needs to be applied in all stages of development to bring maximum benefits and reduce the risk of facing issues in the future.

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Abbreviations and Terms

See below a list of abbreviations and terms related to this graduation project. Most are explained in text as well, but for reading convenience and a quick overview they have been collected here.

Term	Definition
B2B	Business to Business, between companies rather than individuals.
CMF	Color, Material, Finish. The detailed physical properties of a product.
DFA	Design for (manual) Assembly. Principles and design guidelines to improve the assembly steps done by humans by making them easier and therefore faster to complete.
FF	Force Feedback, the effect of applying a force to a body part during a simulation to mimic a real situation.
FFM	Force Feedback Module, a component within Nova that provides force feedback during use.
HMD	Head Mounted Display, headset with screens to see into virtual reality simulations.
SP	Stringpot, a module which measures a cable's extension by counting rotations of its spool.
VR	Virtual Reality, a 3D computer simulation that a person enters and interact with using an HMD.

Design Brief

Introduction

This report describes the development of a redesigned haptic VR glove for SenseGlove, a Delft based startup developing input devices for use in Virtual Reality training. Their current flagship product is the Nova, a hand-mounted device which enables interaction with virtual environments by recording the user's hand position and movements, as well as applying force and vibrations to the fingers to simulate touch. SenseGlove is continually and incrementally redesigning their product, implementing various small changes that have improved the user experience and function of Nova since its original release. However, more drastic updates such as completely new features and a refresh of the aesthetics require an overhaul of the design. As this will mean the Nova's enclosure and internals are to be redeveloped almost from the ground up, there is room to improve the assembly process and general build quality to be more in line with the ideal Vision SenseGlove has for the Nova.

This project aims to deliver a preliminary design for the next version of Nova that implements new features and optimizes some existing ones, while balancing the desires from different departments within SenseGlove, to provide an integrated design that requires little effort from SenseGlove to develop further and eventually sell.

Problem Definition

SenseGlove has the desire to bring a new version of Nova to the market, with new features and a different aesthetic direction. As the current version of Nova has been continually updated without any changes to the enclosure to accommodate them, assembly has become inefficient and unintuitive. This leads to longer assembly times and more costs than necessary, as well as a steep learning curve for new employees. Additionally, some of the fastening methods for internal components have become relatively crude compared to other examples in the industry because they were not part of the design from the start. The repairability of specific parts of Nova has become negatively affected by the use of irreversible fastening methods, which cause great loss of progress in case of an error in the assembly line.

Therefore, Nova's enclosure needs to be redesigned, combining new and existing features with a redefined aesthetic direction, focusing on optimizing the assembly time and consistency to enable larger-scale production and better build quality. To allow for repair and replacement of individual parts both during assembly and after sale, fastening solutions should preferably be non-permanent.

Design Approach

During the project, SenseGlove continued active development of several subcomponents and features of Nova. To keep the workload of the project manageable without reducing the outcome's usefulness for the company, some subjects were considered 'out of scope' (see Figure 1). Some sensitive and frequently updating components were implemented as black boxes, with only the most important features present. Most importantly, the modules providing force feedback and reading the user's finger position were considered unchanged since version 1.0, while still being developed in the background. This meant some discrepancies between this design and the most up-to-date components would occur down the line, but in discussion with SenseGlove, it was determined that this is an acceptable compromise given that the design still needs additional iterations before being ready for sale. The principles and findings from this project would still be applicable, even if some components were outdated.

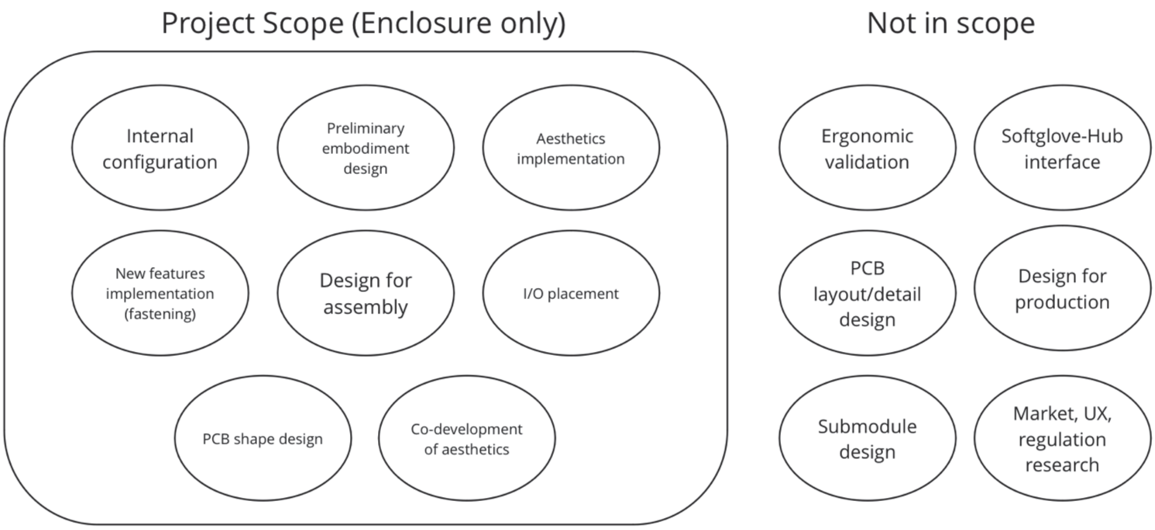
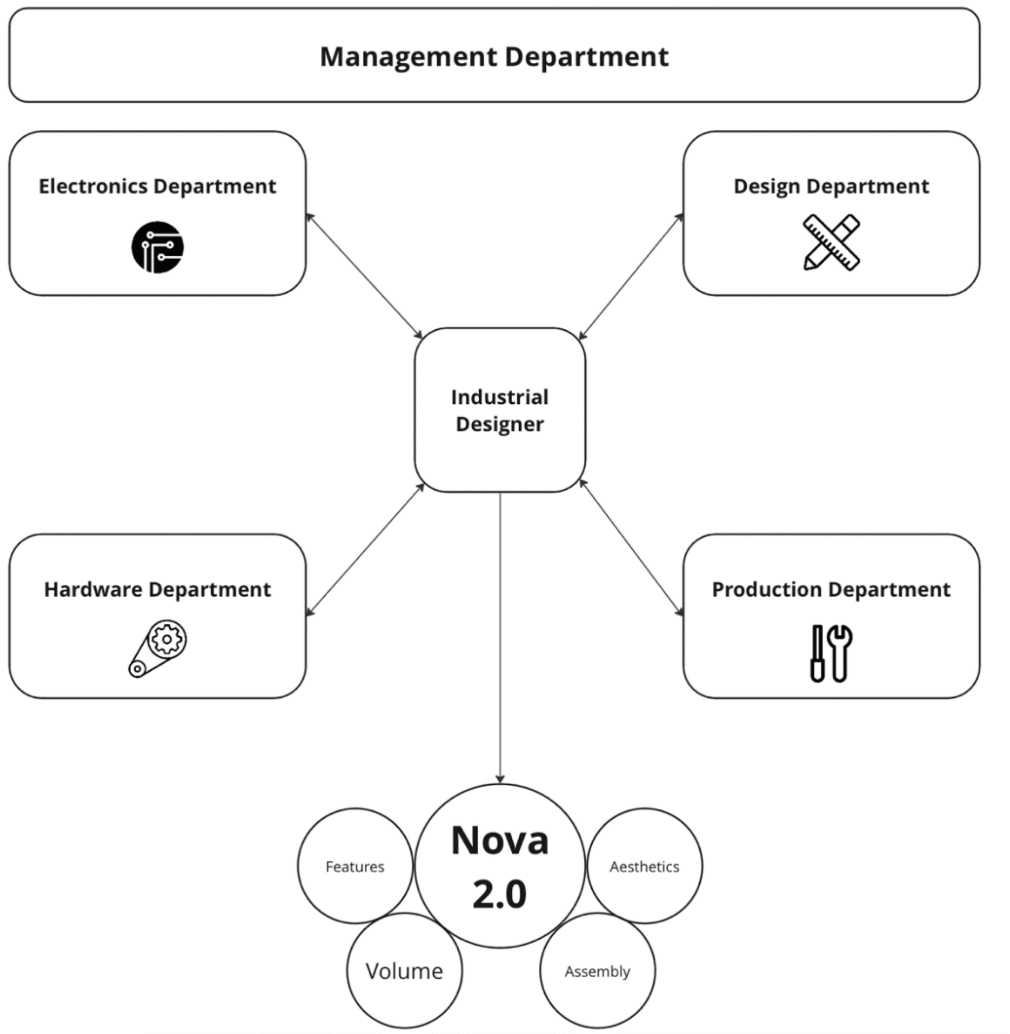


Figure 1 – Project scope.

The components that were considered in scope were divided into several subcategories, each with their own subproblems that needed to be solved (see Section *Phase 1 – Identifying and Solving Subproblems*). As this project consists largely of embodiment design, a practical approach with frequent prototyping and physical testing was used. With CAD models, analysis of existing products and discussion with employees about current issues and previous iterations of Nova, solutions to subproblems were defined and tested, until eventually integrated into a final (digital) design. A design process plan to structure the workflow during the project was created and can be seen in Figure 3.

Communication with SenseGlove during the project was handled as if this graduation was a part of their regular workflow. This meant that the work was integrated into the existing schedule and treated with nearly the same attention as other internal projects, especially near the end. The attendance of design meetings and discussions was helpful for this project in that it provided insights into the direction the design should be heading, but it also kept SenseGlove informed about design decisions, compromises and limitations that needed to be considered regarding the redesign. In essence, the project and designer were treated as part of SenseGlove, with frequent and mutually beneficial communication that allowed for a simultaneous balancing of multiple internal stakeholders. Figure 2 shows an overview of the involved departments within SenseGlove and their general desires in the project.



Electronics Department

Desires:
- High internal volume for easy PCB design
- Optimal positioning of electrical components and wiring

Main contact: Chun

Design Department

Desires:
- Smallest possible product volume
- Strong likeness to aesthetic direction
- Maximum user comfort

Main contact: Bryan

Hardware Department

Desires:
- As many envisioned features implemented as possible
- Optimal function of mechanical components
- High durability of mechanical components

Main contact: Johannes

Production Department

Desires:
- Fast and intuitive assembly process
- Low risk/quick mitigation of human error in assembly process
- Low component variation

Main contact: Floris

Figure 2 - Departments involved with the development of Nova 2.0.

This graduation project was approached like a traditional design project, in the sense that it would consist of several iterations done for a design that would follow out of research, ideation and conceptualization. This, however, proved to be a simplified view of how the project would unfold. The original design plan was to consider Nova's enclosure as one entity, but working further quickly showed that the development of Nova 2.0 was very difficult to treat as a single problem and should instead be seen as a series of subproblems that each contributed to a larger whole. Due to the complexity of Nova and the many interdependent systems within it, the redesign of the enclosure had to be treated as a series of micro-projects, each with its own exploration, ideation, prototyping and testing steps. The project was therefore divided into three Phases that occurred after initial exploration of Nova: Phase 1, where efforts were made to identify areas of improvement, define subproblems and solve them individually; Phase 2, where the solutions to the subproblems were combined into a single design which contained all the most important features of each of the subproblems, as well as considerations for production and assembly; and Phase 3, where the findings from Phase 2 were combined with an aesthetic direction that was being developed in parallel with the previous Phases, creating an integrated design covering the entire scope of the project and balancing requirements and wishes from each of the departments, making compromises where necessary and delivering a package that had more intrinsic value than the sum of its parts.

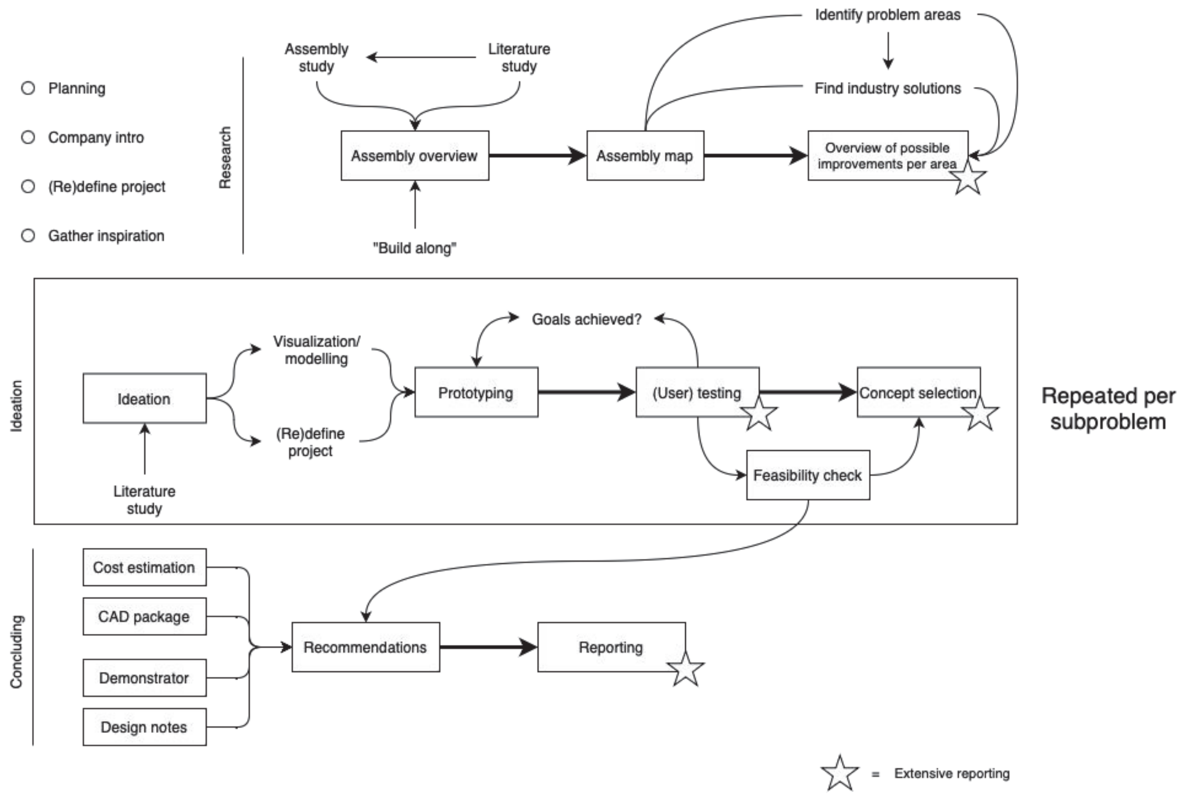


Figure 3 – Design process plan.

Context

SenseGlove and Nova

Context

Company Overview

Figure 4 – SenseGlove staff at Yes!Delft.

SenseGlove is a startup in Delft that was founded in 2017 by Johannes Luijten and Gijs den Butter as part of their graduation project at TU Delft. Their goal was to use Johannes' invented haptic feedback technology previously used for rehabilitation in another context and discover other ways to implement it meaningfully. Formerly called Adjuvo Motion, the company behind the technology now shifted their attention to using haptics in VR. The first prototype of a haptic glove for use in VR applications was SenseGlove, which later became the name of the company as it broadened its portfolio.

Today, SenseGlove works on several projects in VR, tele-robotics, and haptics research, but is best known for their Nova line of products. At the time of writing, 27 employees work divided across several departments as seen in Figure 5. Due to the recent rapid expansion of the company and the number of employees, they can be considered an early stage scaleup (Ferrati, 2021). Additionally, their business model is established and there is a focus on optimization of existing processes and expanding of production of Nova.

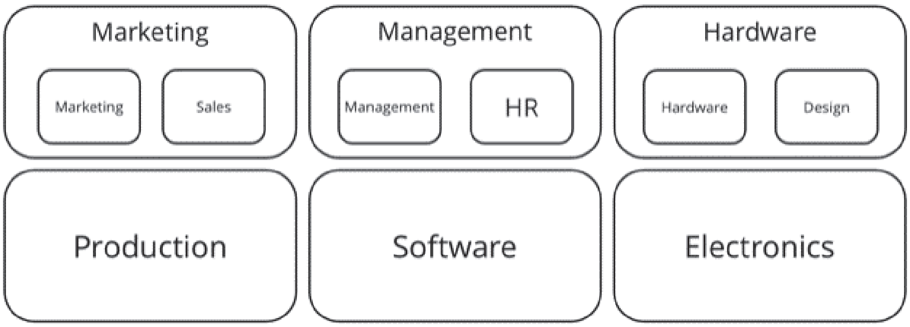


Figure 5 – Departments within SenseGlove.

The company has an active presence on social media and has been in the general spotlight several times since its inception. They have won a number of awards, the most recent of which was won during this project for being number one in the 'KvK Innovatie Top 100 Editie 2022', where they were named the most innovative Dutch startup of 2022.

SenseGlove is partially funded by Nova sales and after-sale tech support, but still most prominently by investors. They have several partnerships and industry clients, the most notable of which are Volkswagen, ESA, P&G, Google and the TU Delft, among several others. Volkswagen has been a partner from the very start, working together with the founders to make the first working prototype in 2017.

SenseGlove is a part of Yes!Delft, a startup incubator located near the campus of TU Delft. Next to office space and social areas, they provide startups with "custom startup programs, full-lifecycle services such as recruitment and funding, access to market and capital, and a community of experts, corporate partners and mentors" (Yes!Delft, 2022). They are a tech-focused organization with close ties to the university but have opened a sister location in The Hague in 2019. The SenseGlove offices can be found on the top floor in Delft and are roughly divided between the previously mentioned departments, with some departments sharing an office space. A meeting room is present to call with shareholders and hold the bi-weekly sprint review, as the team uses SCRUM for their agile project planning. Most importantly for this project, there is an office dedicated to assembly, where all Novas are produced in-house by SenseGlove employees before being shipped to resellers or directly to industry clients.

Stakeholders and Competitors

Besides partners and investors, several other stakeholders are related to SenseGlove. Of course, there are also competitors in the industry who make similar products or try to occupy the same market space. In Figure 6, an overview of stakeholders can be found. Figure 6 shows direct and indirect competitors to SenseGlove. These have been collected from various talks with staff, as well as online research and exploration. In no way is this an exhaustive list, as it is merely meant to illustrate SenseGlove's position in the world and not as a competition analysis. As this project has been involved closely with developments regarding Nova 2.0 within SenseGlove, the designer himself can be considered a part of the 'Employees (Interns)' stakeholder group.

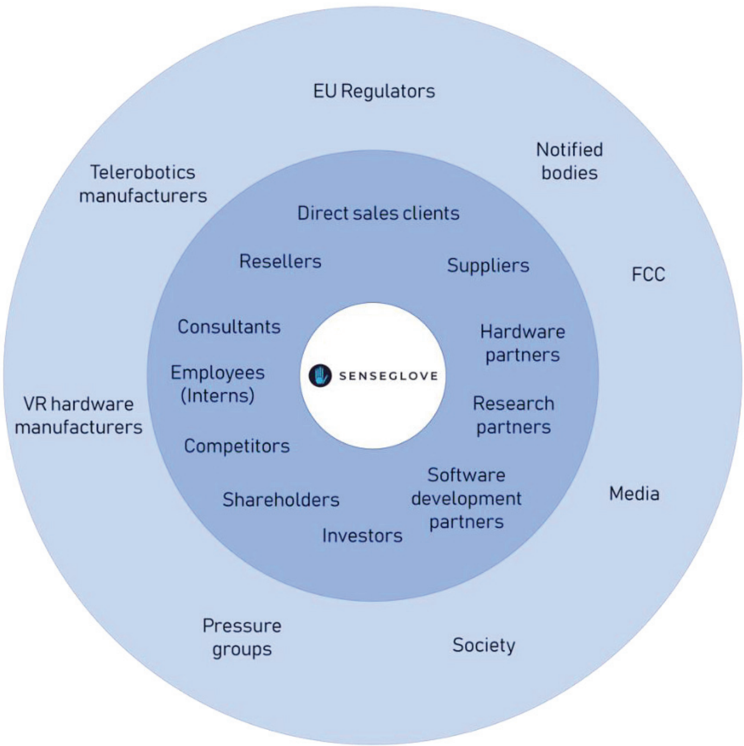


Figure 6 – Stakeholders overview.

SenseGlove Direct Competitors			
Brand	**Product description**	**Similarities**	**Differences**
HaptX	Gloves G1: Provides hand tracking and haptics in VR through microfluidic actuators on the hand, powered by a backpack with pumps and a battery.	Provides a tactile VR experience for a similar price to Nova, aimed at enterprise use.	Does not provide force feedback and instead focuses on realistic touch. Requires large backpack module to operate.
MANUS	Prime X: Provides high-accuracy hand tracking with finger-mounted vibrotactile actuators.	Provides a vibrotactile VR experience in a compact package, complete with integration into commonly used development platforms. Requires attachment of controllers or trackers to function.	Does not provide force feedback and is more focused towards highly accurate finger tracking than realistic touch.
TESLASUIT	TESLAGLOVE: Provides hand and finger tracking with force feedback and nerve stimulating actuators in the fingertips.	Provides force feedback similar to SenseGlove's DK1*. Requires attachment of controllers or trackers to function.	Provides additional electrical stimulation to simulate touch and measures biometrics during use. Starts at triple the price point of Nova.

SenseGlove Indirect Competitors	
Brand	**Competition area**
Meta/Valve/HTC	Ship controllers with their headsets but try to achieve the most intuitive user experience possible using haptics and advanced input methods. In essence try to achieve the same thing SenseGlove is, but limit complexity in favor of versatility.
Ultraleap	Offer detailed hand tracking for (among other things) VR using a vision-based system. Like SenseGlove, they seek to improve the immersive capacity and intuitiveness of virtual interactions.
Emerge Wave-1	Offer hand tracking with haptic feedback using ultrasonic waves. Has a similar goal to SenseGlove to make VR more immersive and intuitive but have a stronger focus on social interactions in VR.
Haptic suit companies	Aim to achieve immersive and intuitive VR interactions, but with a focus on a full-body experience rather than just the hands. Due to the similarities in goals but difference in focus area, can exist as competitors to SenseGlove or as parallel companies working in a similar but separated space.
High-Fi headset producers	Seek to maximize VR immersion with better image quality and higher fields of view but leave input methods unchanged. While not seeking to alter intuitiveness necessarily, the immersion of the end user can depend on any combination of image quality and input method, putting the choice between a new headset or new input device such as Nova on the table for the end user.
Telerobotics providers	Often ship proprietary input devices with their telerobotics solution, making the adoption of alternative devices such as Nova less necessary. Might try to close their product ecosystem to third party developers such as SenseGlove.

*DK-1 is Nova's predecessor.

Table 1 – Competitors overview.

Company Identity

SenseGlove exists in a developing market where different companies have different approaches to the same design space. The problem of intuitive and immersive interaction in VR is something that has been at the attention of designers since the inception of VR devices and, like many products, has eventually developed into several market segments. SenseGlove positions itself as the affordable, simple option without sacrificing quality. They want to be open and user friendly, but not to an extent where they can be perceived as informal. The focus is still mainly on B2B sales, and this requires a professional attitude that communicates added value to other companies. The branding uses bright blue colors with bold product photos to showcase Nova. Pictures of the product in use are frequently edited to show holographic projections of tools that the modeling person is interacting with, to show the value of Nova in a clear and pretty way. Figure 7 shows this on the SenseGlove website.

During this project, SenseGlove made efforts to further specify their brand identity and visual language, in part because the company is ever evolving, but also because of the development of Nova 2.0 allowing for a refresh in product looks. This process took place during a creative session where employees from the design, marketing, sales and management teams came together and performed some creative exercises to define a new direction. The session was hosted by Bryan from the design team and had the goal to generate three things: a list of experiential keywords describing the brand, a collection of product examples that communicate these experiences and finally, a collage or moodboard to be created afterwards from the previous results, that would function as an aesthetic direction for future designs. The experiential terms associated with the current and future branding can be found in Figure 8. These findings later served as the basis for further development of the aesthetics for Nova 2.0, as can be read in Section *Defining Aesthetic Direction*.

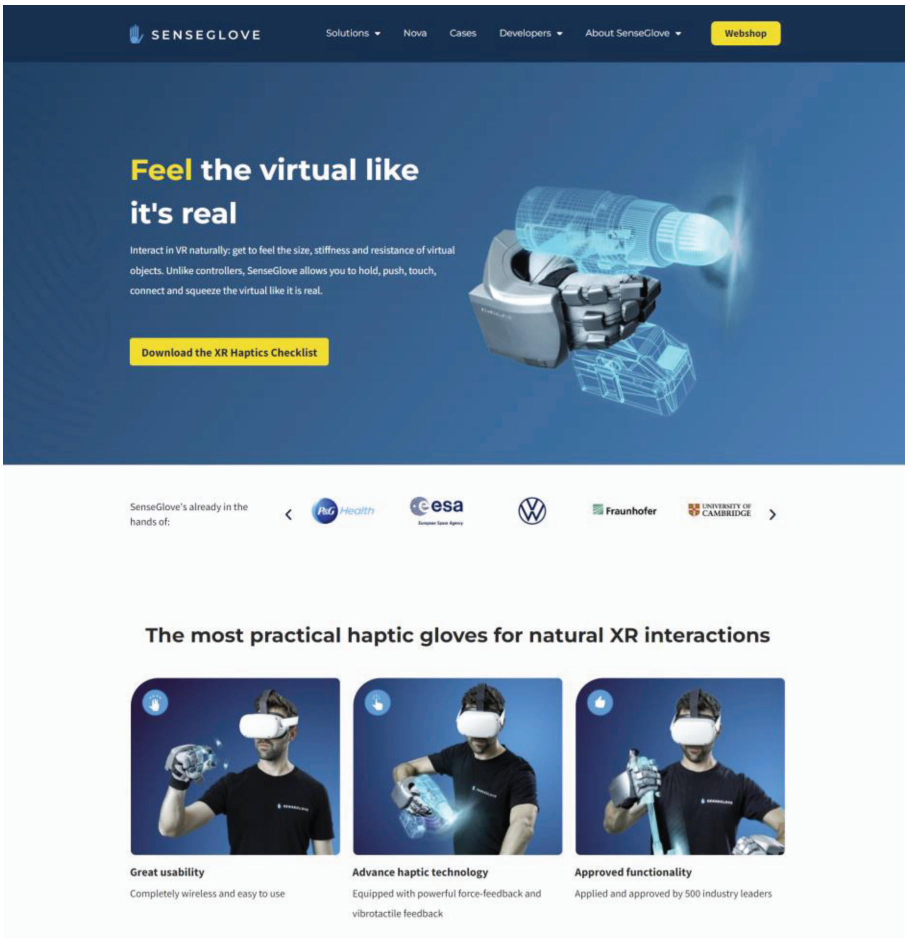


Figure 7 – SenseGlove website as of 2022.

Figure 8 – Experiential terms from the creative session.

Nova

Overview

SenseGlove's flagship product is a device worn on top of and attached to a glove for use in virtual reality. It allows for interaction with virtual environments through hand tracking, finger tracking and tactile feedback to the user in the form of vibrations and force on the fingers applied with thin cables running along the top of the fingers. This feedback and the natural way of interacting with the hands provides a more immersive experience than conventional VR input devices, which are often controllers where the user presses buttons to trigger actions (see Figure 9). According to SenseGlove, they are “on a mission to create the mouse and keyboard of the future”. Just like the keyboard and mouse are for computing, Nova should become a ubiquitous device that the average consumer uses to access virtual content in the future. Right now, it is sold for 4500 euros on their website and mostly business-to-business.

Figure 9 – Nova and conventional VR controller (Meta Quest 2).

Nova consists of three main components: the Hub, sitting atop the back of the hand and containing all the electronics; the cable guides, a collective name for the finger-mounted components which guide the force feedback cables along the fingers and to the fingertips; and the Softglove, providing an attachment point for the Hub and cable guides, as well as routing power to the finger-mounted vibration motors through the Hub interface. These come in three different sizes to accommodate most hands (P10-P90). The Hub is attached to the glove with a connector on the bottom and is held in place securely with straps that go around the user’s hand (see Figure 10). The cable guides click in place on plastic parts attached to the glove. Figure 11 shows the main components of Nova. As can be seen in the image, the Hub has some semblance to the shape of a hand, containing a distinctive ‘appendage’ near the user’s thumb that contains some components required to apply force feedback to and measure the movement of the thumb. For this reason, that part of the Hub is referred to as the ‘thumb’ as well. Following the comparison of the Hub to the shape of the hand, the part where the user’s fingers are located is designated the front of the device.

Figure 10 – Straps to hold the Hub in place.

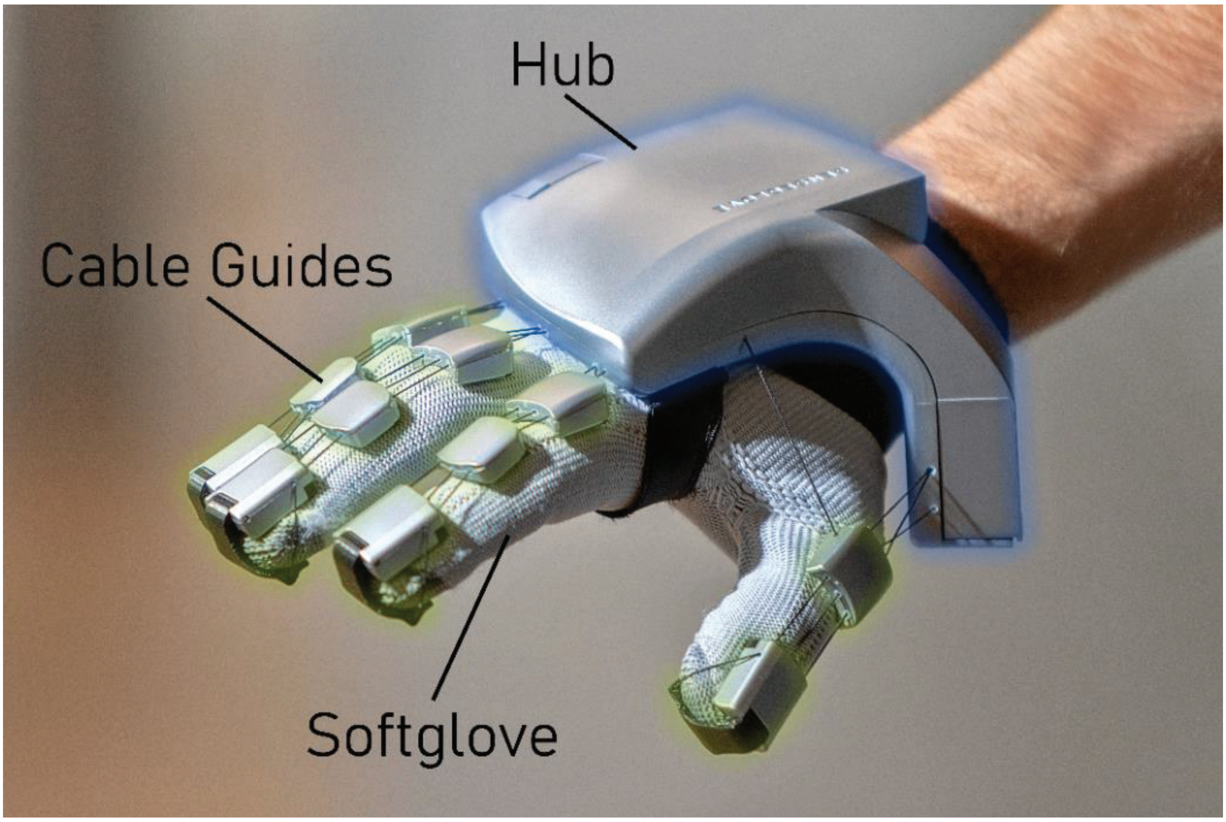


Figure 11 – Main components of Nova.

For this project, the focus is on the enclosure of Nova, which consists of the cable guides and Hub and is also referred to as the 'hard glove'. The cable guides are essential to prevent discomfort from the cables rubbing across the knuckles and make sure there is minimal friction when the cables are actuated, allowing for full freedom of movement. This style of applying force feedback is also referred to as the 'exo tendon' method. The little finger does not have any cable guides, as this finger receives no force feedback. This is due to a decision to save space in the Hub, as each finger needs its own pair of modules for force feedback, which takes large amounts of space inside the Hub. SenseGlove has also determined through testing that immersion does not suffer from this, as the other digits are more frequently used during (virtual) interactions. The thumb and index finger also receive vibrotactile feedback from vibration motors sitting in the cable guides atop the fingertips, referred to as the 'thimbles'.

The Hub contains all the components that give Nova its function as a haptic glove, as well as an LED indicator to communicate its status. As an additional source of vibrotactile feedback, a 'thumper' module is located on the bottom to provide intense vibrations when needed. Components are positioned in such a way that the center of mass sits as far to the back of the hand as possible. This is to minimize the moment arm from the wrist to the center of mass, as this reduces wrist strain when moving the Nova around when worn. The same principle applies to the product's height; a Hub sitting closer to the back of the hand causes a smaller moment when rotating the hand. Figure 12 shows an exploded view of Nova's current construction.

In Figure 11, it can be seen that the thumb of the user receives an extra cable from the side of the Hub. This is to provide it with two-dimensional tracking instead of the other fingers' one-dimensional tracking, as the thumb frequently moves from side to side, as well as flexes in natural interactions. Measuring the fingers' flexion is done by a separate module from the one that provides force feedback. This is done because the force feedback modules stop the movement of the cable to allow the user's own finger's strength to apply force to itself. This is referred to as passive force feedback. As the cables are essentially locked in place during the triggering of force feedback, an extra cable that does not lock up is used to measure when the user is performing an action that should disable the force feedback again, such as releasing a virtual object. The module that handles this is referred to as the 'stringpot', an amalgamation of string and potentiometer, as the module measures the rotation of the internal spool to determine the change in string (cable) length. Figure 13 shows an overview of the force feedback system as seen in an early patent from Adjuvo Motion. This can provide up to 20N of force feedback per finger (Source: SenseGlove).

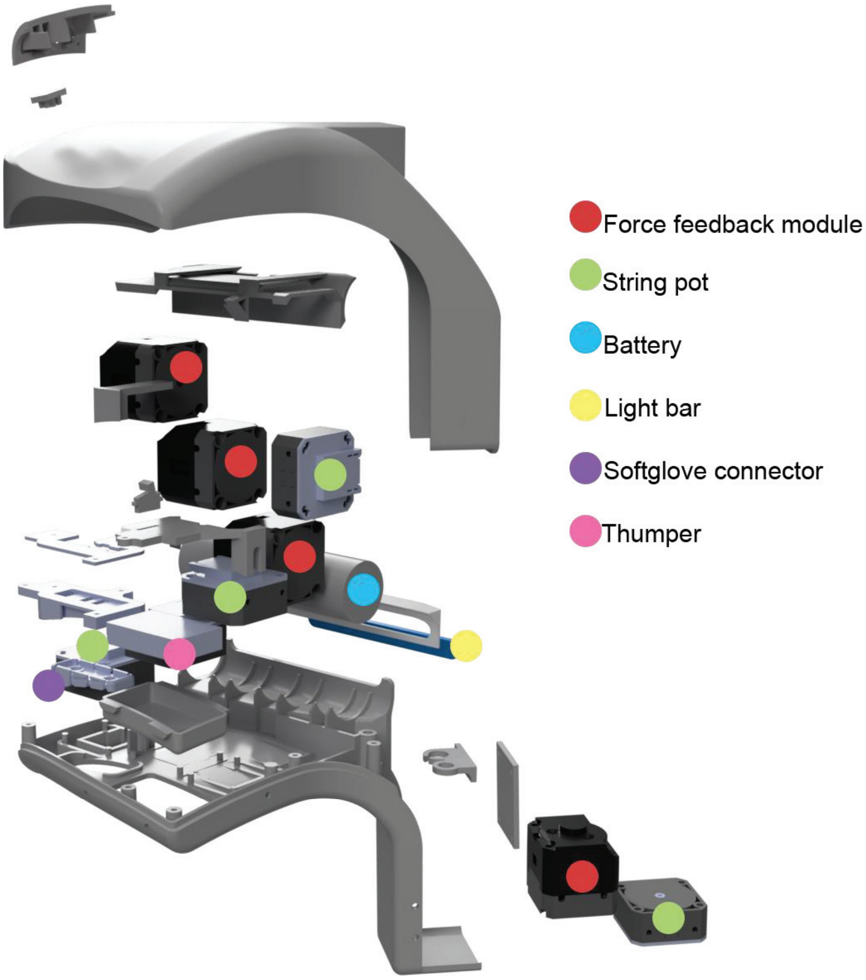


Figure 12 – Exploded view of Nova.

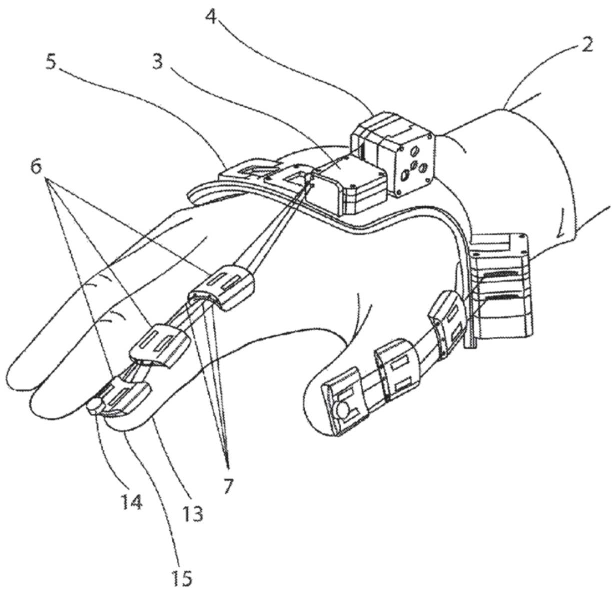


Figure 13 – Image from early Adjuvo Motion patent explaining the force feedback system. 6 shows the cable guides; 7 shows the cables, consisting of two force feedback cables on either side, with the stringpot cable in the middle; 3 shows the stringpot module; 4 shows the force feedback modu

Use cases

Training

Nova is used primarily in training applications, where a virtual environment offers a safe way for trainees to interact with potentially dangerous equipment or where the employer can save costs by eliminating the need for training materials that are sensitive and prone to damage. One application used by SenseGlove's longtime partner, Volkswagen, is to train assembly workers to use the equipment present on the factory floor and what actions to perform to properly assemble a car (see Figure 14). This equipment is both dangerous and expensive, so letting an inexperienced worker handle it is a great risk. One could imagine that a virtual environment at a fraction of the cost but nearly the same educative value would be more efficient. This is where Nova's main added value lies.

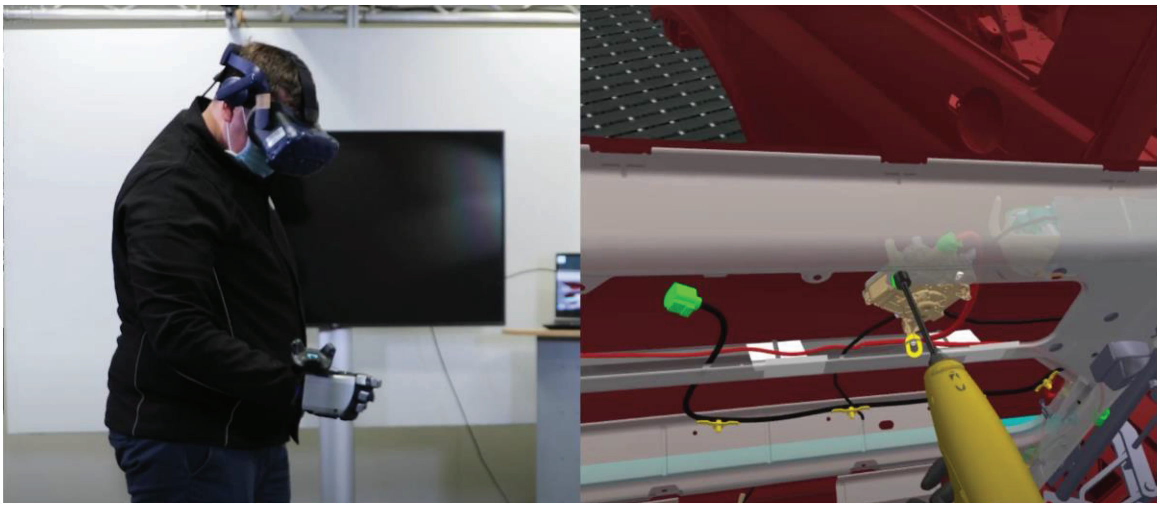


Figure 14 – Screenshot from video showcasing Volkswagen's application for Nova to train assembly workers. Left shows the trainee using an HMD and Nova, right shows what the trainee sees.

Experiences

Another application of Nova that is sometimes used is to simulate physical conditions in healthy patients. Nerve damage, partial paralysis or Parkinson's disease can all be simulated in a virtual environment, using the user's real hand movements, and altering them in VR to mimic symptoms. For example, by allowing the user to move all their fingers in real life, but disabling some in VR, the illusion can be made that those fingers do not respond to nerve impulses, suggesting to the user that they have been paralyzed. Similarly, the global position of the virtual hand can be separated from the real counterpart by introducing shaking, making the navigation around and interaction with virtual objects more difficult, suggesting symptoms of Parkinson's disease. This application is quite different from the former, being less practical and more empathic, allowing users to experience something that Is difficult to describe with words and potentially improving their understanding of specific physical conditions.

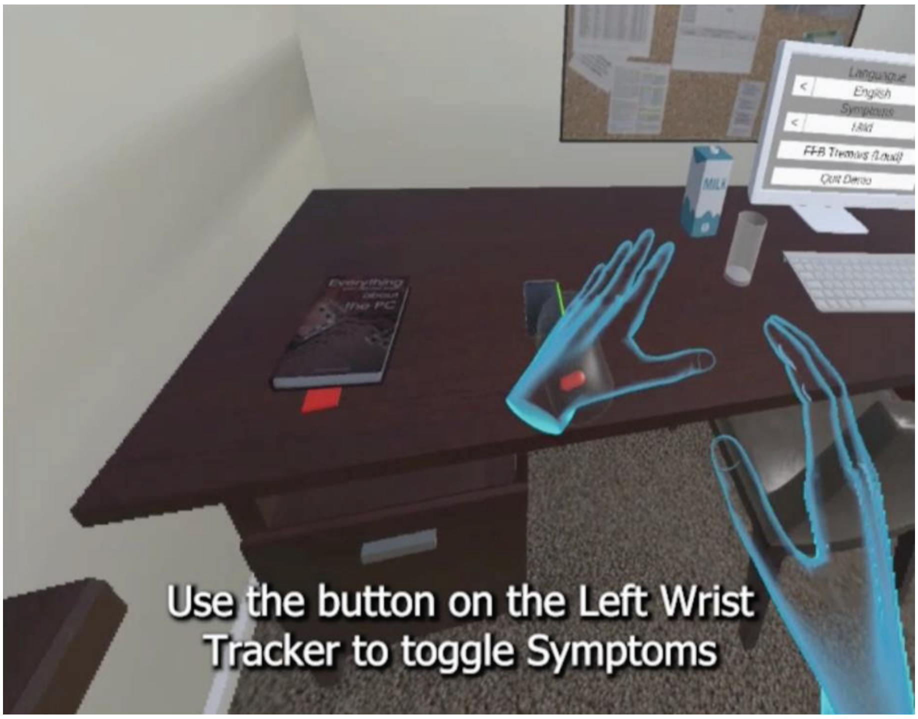


Figure 15 – Screenshot of an instructional video for a demo that requires the trainee to perform simple dexterity tasks with the option to enable various simulated nerve conditions.

Revalidation

Nova can also be used to help patients with physical conditions revalidate in an environment that is adaptive and safe. An example is SenseGlove's own kitchen demo, where the user completes several seemingly mundane tasks, such as cracking eggs over a pan, pouring tea or scrubbing dishes. However, completing these tasks for a person with a physical condition can be dangerous in real life; High temperatures, sharp objects and fragile items are everyday risks that are common in the household but require frequent interaction. To practice these interactions in a real kitchen would be dangerous and difficult to adapt to the user. With a virtual environment, not only are the risks eliminated, but the interactions themselves can also be altered to better aid the user in revalidation. For example, if a person cannot exert much force with their fingers, the act of picking up a virtual mug can be made more accessible by reducing the force feedback, but still requiring the correct finger position. This adjustment can then be gradually reduced during the revalidation process as the user progresses until full finger control is restored. A similar setup in real life would likely not be as controlled and safe for the user and, as each user's needs are different, not fully adaptable in the way a virtual environment can be.

Figure 16 – Screenshot from video explaining SenseGlove's kitchen rehabilitation demo. On the left, we see the trainee interacting with DK1, Nova's predecessor. On the right, we see what the trainee sees.

Limitations

While Nova offers many improvements over traditional VR input devices and unlocks the possibility for unique experiences, it does have its drawbacks too. Force feedback, finger tracking and tactile vibration are features that improve immersion greatly (SenseGlove, 2022), but also increase the complexity (and cost) of the device. Unlike controllers included in most VR sets, Nova requires the user to put on the glove, tighten two straps, and calibrate the device through proprietary software before it can be used in VR. Therefore, in its current state, Nova is not yet ready for the consumer market, which is a part of SenseGlove's vision for the future. Efforts are being made to mitigate these drawbacks and make Nova an attractive product for the general consumer and even those new to VR, lovingly called 'Grandma Proofing' internally, but for now, the Business-to-Business market is where Nova is most practical and affordable. There are enough use cases to learn from and gather insights to keep improving Nova and eventually make it accessible for everyone.

A limitation of Nova is that it does not offer a way to measure ad- and abduction (spreading) of the fingers. This is due to the stringpots only measuring the one-dimensional value they receive from flexion (bending) of the fingers. Additional stringpots for the fingers would allow the measuring of an additional dimension similar to what is already happening with the thumb, but this would have a significant impact on the size and weight of the Hub. For volume reasons and because the lack of abduction measurement has not proven to be a major issue among clients, SenseGlove has chosen to exclude that feature until a future version of Nova and its internals permits it.

User/Trainee

As can be deducted from the many use cases Nova is applicable to, there is a wide variety in the types of users that work with Nova. It is therefore difficult to define a single persona, but there is a clear relation with other stakeholders that define the user; they are almost never the person who purchases the Nova or develops the software that is being used. Instead, they are the person who seeks a specific experience in VR, be it educational, for research, for rehabilitation or even for entertainment. Because software developers, engineers and the instructors for virtual training are also users of Nova but are not the end users who will need to gain some form of value from it, another term might be more appropriate. Nova is most frequently referenced to be a training tool and SenseGlove's B2B marketing leans into this, so the term used to describe the 'end user' of Nova is the trainee. This of course is not accurate in all situations, but for the sake of clarity, this term will be used from here on.

The trainee is often inexperienced with VR and/or the situation they are experiencing. It is therefore not expected that the trainee knows how Nova works. They can be of any age and gender, with the only discriminating factor being the hand measurements due to the softglove sizes between P10 and P90. They are the person Nova is designed for, but not necessarily the person it is marketed and sold to. Therefore, there is a challenge in making Nova appealing to a specific group; the trainee may be attracted to the design, causing them to want to try it out and use it, but the individual making the purchase decision (likely with a management role) may not ever need to use it at all. This way, the trainee is also unlikely to be the owner of Nova in a property sense, while still interacting with it most and being most dependent on Nova delivering a good experience. Closest to the trainee is the instructor, who is a more experienced individual that manages the way trainees use Nova. Therefore, the instructor is likely familiar with the function, strengths, and limitations of Nova, and is responsible for keeping it in working order, but is not the owner of the device itself. The relation between the trainee, client (owner) and SenseGlove is illustrated in Figure 17.

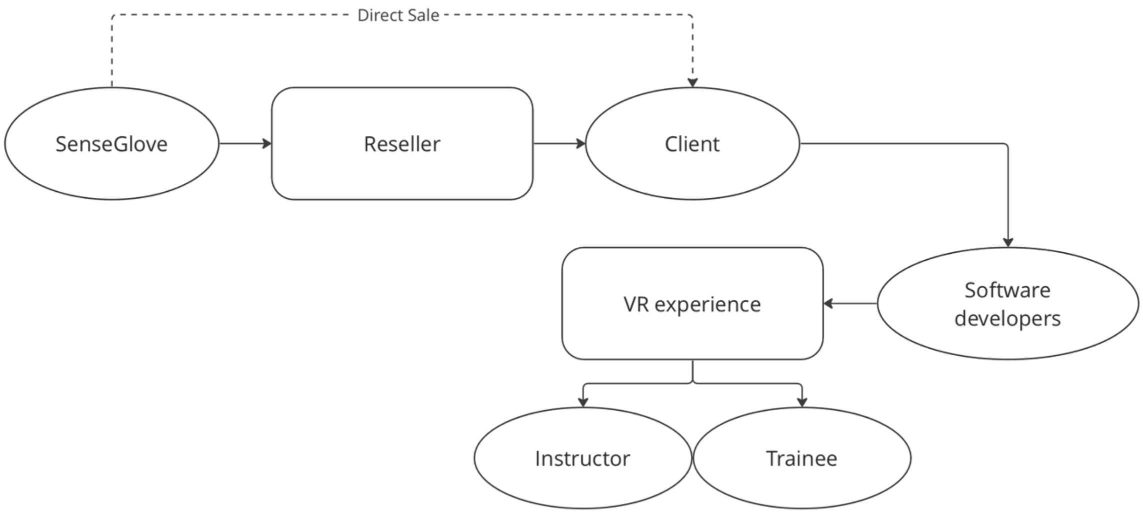


Figure 17 – Nova ownership overview.

Integration with VR

Virtual Reality hardware usually consists of a Head Mounted Display (HMD), input devices such as controllers and some form of tracking using external or internal sensors (see Figure 18). Conventional sets are either standalone, containing an internal processor that generates images on the HMD, or connected to an external computer which then sends the images to the HMD through a wire or wirelessly. Because of the former being quite common, this form of VR is usually referred to as 'tethered VR'. Figure 19 shows an overview of which headsets are used in tethered mode using the most popular VR development software, SteamVR. This is not a representation of the full market and includes both business and consumer use, but gives an indication of which headsets are most popular.

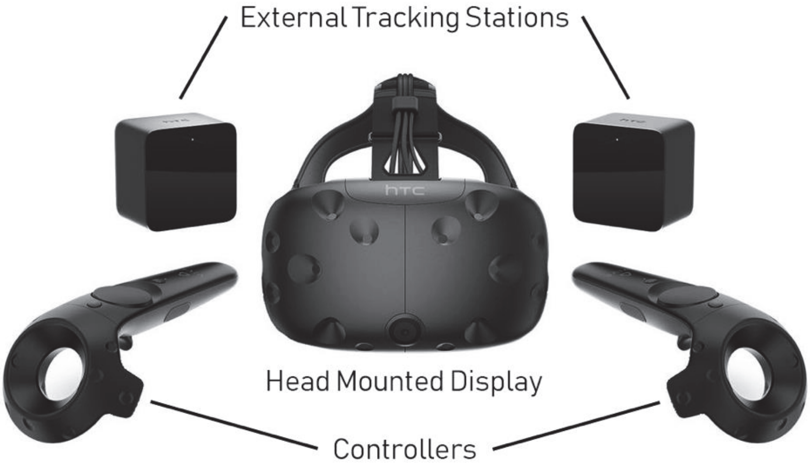


Figure 18 – VR set with controllers and tracking stations. Displayed here: HTC Vive.

Nova functions as an add-on or replacement for conventional controllers, using the tracking system of the VR hardware to determine the controllers' positions which are then attached to the Nova. SenseGlove's proprietary software reads this controller position and places virtual hands in the spots where the trainee expects their own hands to be in VR. It also measures the movements of the trainee's fingers and tells the Nova to engage the force feedback modules or trigger a vibration when specific conditions are met in VR, such as the trainee grabbing an object or touching a surface. This software translation layer is required for Nova to function properly, which is why it cannot be used in every available VR software out of the box. Developers need to implement Nova compatibility in their program using SenseGlove's Software Development Kit (SDK) for the gloves to work. As the current application is mostly in a business context with specialized virtual environments for a specific purpose, this tradeoff is not an issue among clients. SenseGlove is working on implementing a computer vision solution that utilizes camera input to determine the trainee's hand position, no longer requiring controllers to be attached to Nova. This approach requires Nova's presence and orientation to be easily recognizable by a camera and therefore influences certain decisions regarding the color and finish of the Hub. More about this can be read in Section *CMF* of *Phase 3 – Integrated Aesthetics Model*.

Figure 19 – Most used VR sets by consumers in the gaming space as collected from a November 2022 hardware survey on the Steam platform (Source: Steam, 2022).

Why 2.0?

As previously stated, the desire from SenseGlove to create a new version of Nova is largely driven by the implementation of new features and the refreshing of the product aesthetics. Besides that, it is also an important step in getting Nova ready for the general consumer market by lowering the price and increasing the consistency of quality, while increasing production amounts. In its current state, Nova is still very much a prototype product that functions mainly to be a development platform for professionals looking to get specific VR interactions out of it. To enable this, SenseGlove offers extensive tech support with personalized assistance and occasional repairs. In an ideal situation, this would be kept to a minimum with only edge cases requiring in-depth involvement from SenseGlove and when Nova arrives on the consumer market, it should mostly stand on its own. By looking into the assembly process and integration of features, even at this relatively young stage that Nova is in, many insights can be gathered that will simplify and streamline the design process in later iterations. This way, SenseGlove can act proactively on future design changes, instead of reactively, and implement those changes faster and with greater effectiveness.

Additionally, SenseGlove aims for a production rate and sale of 500 gloves per 10 months. To put that into perspective, Nova 1.0 at record pace sold 28 units in one month, nearly half as much as the goal for 2.0. To facilitate this increase in output, the production speed needs to scale along. Mass manufactured and off-the-shelf part amounts can be increased quite easily, and the manufacture of 3D printed in-house components is planned to be mass manufactured using injection molding too, so the bottleneck for increased output now sits with the assembly process. Section *Nova's Assembly* in the next part of the report explains the current state of assembly for Nova further, while Figure 20 shows the main drivers behind the development of Nova 2.0..

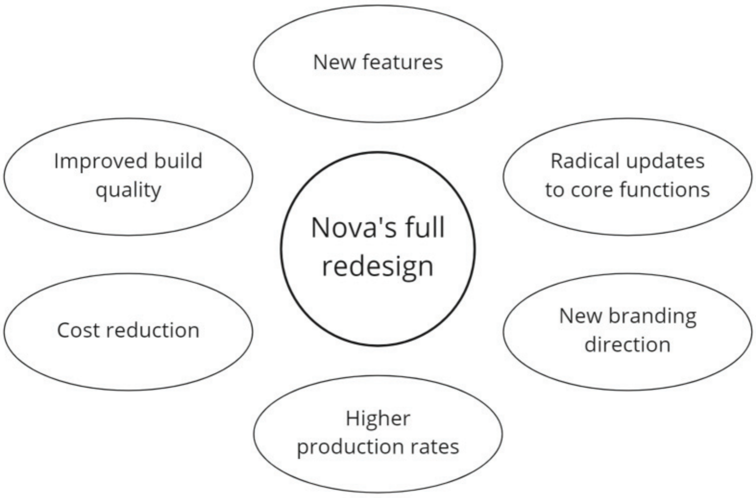


Figure 20 – Drivers behind Nova 2.0 development.

The primary new feature that is to be introduced with Nova 2.0 is the active strap, a replacement for the front strap that can tighten and vibrate to give the trainee even more feedback about their actions in VR. The active strap requires additional components to function, namely a motor to pull the strap tight, and vibration modules for tactile feedback on the palm of the hand. The way the strap is fastened to the Hub will also be fundamentally different from the previous version, as it needs to withstand its own force feedback without translating the forces to the Hub and deforming it. As the straps of the current version of Nova require minimal space (see Section *Regular Strap* in *Phase 1*), the addition of this new feature will require a reconfiguration of the internal volume of the Hub to accommodate the new components. While this part of the strap design falls within the scope of this project out of necessity, the development of the strap's function is not a part of this report. As with the force feedback and stringpot modules, it will be treated as a black box, though its fastening features and interaction with other components will be considered in the design. Figure 21 shows a concept sketch of the active strap.

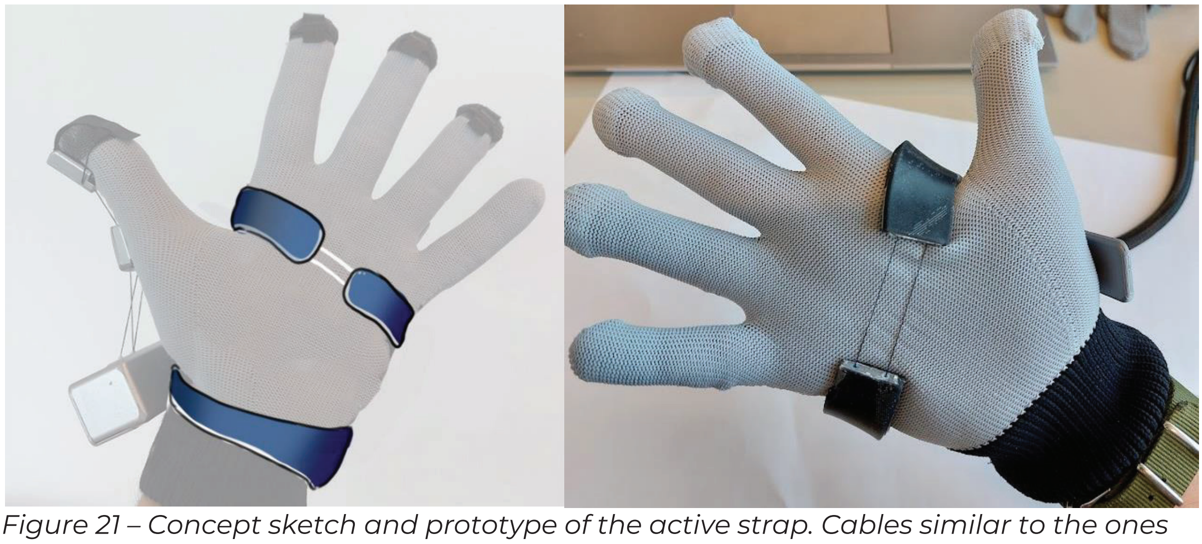


Figure 21 – Concept sketch and prototype of the active strap. Cables similar to the ones applying force feedback on the fingers will tighten and simulate the feeling of an object in the hand. Credit: Laszlo Klönhammer.

Design for Assembly,
Requirements and Process

Defining focus points for the design

Design for Assembly

Principles

During this project, several principles relating to design for assembly have been utilized and applied. In this section, they will be listed and elaborated from the most fundamental and broad to more detailed and specific. There are many ways to approach the problem of product assembly, but because this project aimed to redesign the enclosure of Nova from the ground up, the fundamentals of design thinking needed to be present from the start. Hence, the following paragraph describes the core principle that lies at the foundation of the design process.

Law of Parsimony

Also known as Occam's Razor, this is a principle in which, when faced with multiple explanations or solutions for the same problem, the one with the least parameters or complexity is preferred. This is a common principle in science, where there can be multiple explanations for the same phenomenon, but the simplest or most straightforward is likely the correct one (Math.edu, n.d.). In this design project, it is used to minimize complexity to safeguard the cost/quality ratio of the result. In essence, it is a measuring device to see which solution to a design problem requires the least parameters to effectively implement; why develop a complex, intricate solution to a problem that can be solved with a simple one if the added value is going to be the same in the end? The simpler solution is likely to contain less parts, needing less complex manufacturing and being quicker to assemble, without compromising on function or quality.

The challenge with effectively applying the law of parsimony is that the choice to go with the simpler solution should always be supported by proper arguments and a careful analysis of the risks and benefits beforehand. Blindly going for the simplest possible design choices at every step is likely to result in a product with many shortcomings, negatively affecting the value it adds to the design space. On the other hand, the designer should not be afraid to cull complexity to minimize the effort required down the line when implementing the solution. This means that this principle in practice should only be used when the choice between solutions would result in equal value and should not be depended on when faced with multiple solutions with slightly different outcomes. Other design methods would be better suited for that situation.

Poka Yoke

Originally developed as Baka Yoke (idiot proofing), but renamed out of respect for assembly workers, Poka Yoke is a principle developed in the 1960s by Shigeo Shingo, an industrial engineer at Toyota (Kanbanize, n.d.). The term translates from Japanese and means 'mistake proofing'. While Poka Yoke refers to a way of thinking and analyzing a process, it is sometimes also used as a term to describe a mechanism within a process. The goal behind Poka Yoke is to drastically reduce or eliminate the risk of human error in a process by implementing mechanisms that prevent it from happening or inform the human that a mistake is being made. It can more technically be described as a 'behavior-shaping constraint'. In assembly, this expresses itself as part features or process steps that cannot be assembled incorrectly. For example, if a component can only fit inside a housing in one specific way, the assembly worker is prevented from incorrectly placing the component by restricting them in doing so entirely; the part either fits and can be assembled, or it cannot. There is no grey area and no misinterpretation possible. This is a strong example of Poka Yoke, but there are other ways to implement it. In Figure 22, a list of the six principles of Poka Yoke (RNA Automation, 2022) can be found, along with descriptions of how they can be implemented in a product in Table 2. The principles are sorted by priority, with 1 being the most favorable and 6 being the least. As a designer, it is most beneficial to implement the highest priority principles frequently, but due to restrictions in the design this might not always be possible. Think for example of an off-the-shelf part, where the part's features are already determined. In that case, measures can be put in place that inform the assembly worker of the proper way to assemble. This can vary from something as simple as a note in the manual to specific iconography or color-coding on the part itself. If none of the preventive methods can be used, it is possible to implement safeguards that minimize the effect of human error in case it happens. In this case, something like a final check using a template or redundancies in the design can be implemented.

Like the law of parsimony, Poka Yoke needs to be applied responsibly. An analysis of risks versus benefits should always be considered when designing with this principle. In the case of this project, the ease of assembly should be optimized, but considering the effect of this on the function and aesthetics of Nova.

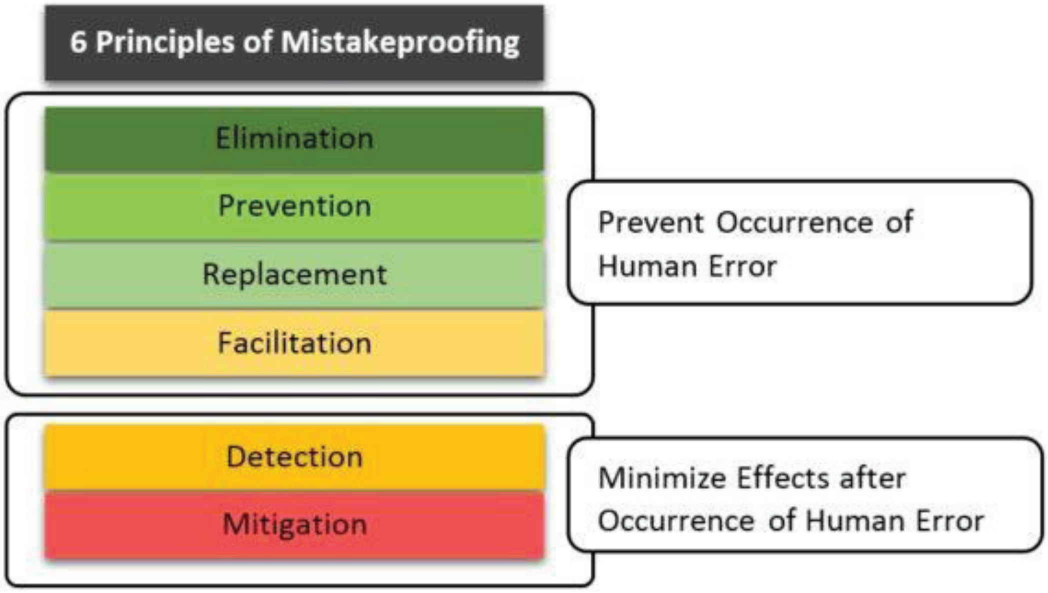


Figure 22 – Principles of mistakeproofing as pictured by RNA Automation, 2022.

Descriptions of Poka Yoke principles	
1. Elimination	Remove the possibility of error by redesigning the product so the problematic feature or tasks is no longer required.
2. Prevention	Design the product or process in such a way that it becomes (near) impossible to make a mistake.
3. Replacement	Design a better feature or process that replaces the original for better consistency.
4. Facilitation	Make work easier to perform by integrating techniques or steps that make mistakes less likely to occur.
5. Detection	Implement methods to detect when an error occurs so the worker can fix the mistake directly.
6. Mitigation	Consider the possibility of mistakes and implement techniques to minimize their effects.

Table 2 – Poka Yoke principles with descriptions (Paraphrased from RNA Automation, 2022).

Boothroyd and Dewhurst's DFA

Dr. Geoffrey Boothroyd and Dr. Peter Dewhurst developed a design method in the 1980s that provided guidelines to improve product assembly to save costs. They eventually developed this method into a software package that is used globally to improve assembly processes for major companies and is responsible for saving significant costs across many industries (Boothroyd et al., 2010). Their method has also been published in their book 'Product Design for Manufacture and Assembly' that contains additional information on how to evaluate designs and predict assembly times. The depth and detail of their method is suitable for every step of the design process and they recommend implementing it from the very start of product development. As a full implementation of the DFA method requires the consideration of every single component in a product and redesign on a fundamental level, this is out of scope for the project. However, Boothroyd and Dewhurst provide guidelines for manual assembly that can be considered during design and also serve as a simple benchmark to see if a component fits their method's general principles. Specifically, the design guidelines for manual assembly are useful during this project. These can be split in two categories: guidelines for part handling and guidelines for insertion and fastening. These are listed below and quoted from Boothroyd, Dewhurst and Knight (2010):

Design Guidelines for Part Handling

1.1 Design parts that have an end-to-end symmetry and rotational symmetry about the axis of insertion. If this cannot be achieved, try to design parts having the maximum possible symmetry.
1.2 Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric.
1.3 Provide features that prevent jamming of parts that tend to nest or stack when stored in bulk.
1.4 Avoid features that allow tangling of parts when stored in bulk.
1.5 Avoid parts that stick together or are slippery, delicate, flexible, very small or very large, or that are hazardous to the handler (i.e., parts that are sharp, splinter easily, etc.).

Design Guidelines for Insertion and Fastening

2.1 Design so that there is little or no resistance to insertion and provide chamfers to guide the insertion of two mating parts. Generous clearance should be provided, but care must be taken to avoid clearances that result in a tendency for parts to jam or hang-up during insertion.
2.2 Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost.

Implementation

As was stated earlier in this Chapter, the aforementioned design principles are listed in order from most fundamental and broad to specific and detailed. This roughly means that, per subproblem but also the project as a whole, the Law of Parsimony was applied early in ideation, Poka Yoke during the later stages of design, and DFA to embodiment design and final verification. All principles were of course considered during the entire project, but not strictly followed in order to stimulate rapid ideation and prototyping.

All principles were also used to draw conclusions and define recommendations based on the final design near the end of the project.

Nova's Assembly

Nova is assembled in-house by SenseGlove employees and occasionally students-for-hire. Mass-manufactured components such as shell parts and screws are imported and stored locally, while a small 3D printer farm produces components which are difficult to order or prone to frequent changes during incremental development (inserts or spacers for example).

The assembly office is divided into several stations, each with their own component to assemble and collect. Stations are organized with efficiency in mind, placing parts and tools within arm's reach and with clear labeling and sorting. Assembly workers can work at multiple stations per day to add variety to their work or because specific stations have higher priority at that moment. Figure 23 shows parts of the assembly office and how the stations are organized, which is further explained in Table 3.

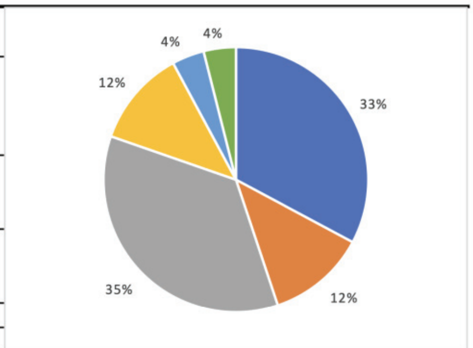
Figure 23 – Inside the assembly office. Stations are organized per task and components are placed within easy reach for the workers.

Station	**Components produced**	**Description**
Shell postprocessing	Shell parts with cable guide exit holes and threaded inserts	Shell parts are taken from the imported stack and postprocessed by drilling to allow the FF cables to pass through the appropriate holes. Vestigial features are removed, and threaded inserts are placed for steps later down the assembly line.
Cable guides and thimbles	Cable guides of types AB and BC, thimbles of types NV and VIBRO.	Imported cable guide parts, vibration motors and Teflon tubing are used to make several different types of cable guides. The halves are glued together, and excess tubing is cut by hand. The results are either placed in a rejection bin or approved and moved further down the assembly line.
Force feedback modules	Force feedback modules with tubing and cables	Custom imported brake disks and 3D printed parts are assembled into several different configurations of force feedback modules, depending on the chirality of and placement in the Hub.
Stringpot modules	Stringpot modules with tubing and cables	3D printed parts and imported Hall effect sensors are assembled into several configurations of stringpots, depending on the chirality of and placement in the Hub.
Full assembly	Fully assembled and connected Nova	Full assembly takes place in three steps, where the modules are placed in the Hub, the electronics are connected and soldered, and the cables are threaded through the cable guides and trimmed.
Quality control/finishing touches	Completed Nova ready for shipping	The Nova is checked, tested, and marked as QC passed. It is set aside and ready for packaging and shipping.

Table 3 – Assembly line stations with output and description.

SenseGlove also provided an overview of the assembly times of the current setup, which have been processed into an overview in Figure 24.

	Assembly Station/Step	**Time per Nova (mins)**
Modules	Force feedback modules	60
	Stringpot modules	65
Cable guides	Cable guides type AB	16
	Cable guides type BC	12
	Thimbles	8
	Thimbles with vibration	10
Hub Assembly	Full Assembly - Station 1	45
	Full Assembly - Station 2	45
	Full Assembly - Station 3	45
Quality control	Quality control - Check 1	15
	Quality control - Check 2	15
	Quality control - Finishing Touches	15
Postprocessing	Shell postprocessing	15
Softglove preparation	Softglove preparation (excluding curing time)	15



Total assembly time (1 Nova):
381 minutes or 6,35 hours

Figure 24 – Assembly timing ratios for one set of Novas. Based on measurements provided by SenseGlove. This chart takes an 80% working efficiency into account to provide more realistic values.

To find areas of improvement in the current assembly process, an explorative investigation was held by following along with an assembly worker and observing the steps of each subassembly. Paired with this, several questions were asked to some assembly workers regarding their experience with the way Nova was constructed. To set a goal for the investigation and to guide the visit, some points of attention were defined that were to be explored during the visit. These can be seen listed below.

Attention points for the assembly office visit:

- What assembly steps are most time consuming or take a disproportionate amount of time?
- What general difficulties are the assembly workers facing with Nova's current construction?
- Which assembly steps could be made obsolete with small design changes to Nova?
- Which assembly steps could be made easier or faster to perform with small design changes to Nova?
- What custom tooling is required for the assembly of Nova and why?

As the force feedback modules and stringpots are out of scope for this project, they have not been considered as a subassembly that can be optimized, but their placement in the Hub has been taken into consideration.

What possible areas of improvement were discovered have been considered during the further design process and have been converted into focus points and requirements that are elaborated in the next Section. The full notes from the assembly office visit can be found in Appendix A.

Requirements

Besides the observations made during the assembly office visit and the design principles gathered from literature, the design meetings, and conversations with SenseGlove employees were considered when constructing the general goals for Nova 2.0's enclosure. The complete list of requirements can be found in Appendix B, but to provide a more holistic view of the goals in this project, a list of key focus points has been created. These function as broader guidelines and directions for the design, as well as communicating multiple requirements that are often dependent on one another or exist in balance with other requirements and design decisions. They are listed below:

Focus point 1:
Minimize the number of parts needed for subassemblies within the scope of this project.

Focus point 2:
Improve the logic of the assembly steps and make them as self-explanatory as possible.

Focus point 3:
Reduce the loss of progress that can occur from human error during assembly.

Apart from the original components of Nova needing to be optimized to fit these focus points and the requirements, the new feature of the active strap needed to be conceptualized with them in mind from the start. Additionally, the cable guides have been treated somewhat as a separate entity in the project, as they are the only subproblem independent from the Hub and are therefore not as defined as the Hub is. All other components and subassemblies are directly related to the Hub and are therefore treated as part of it. Requirements are therefore written with the Hub as the main subject, while the subcomponents are redesigned to facilitate them.

Design Process

This section describes the process and results of this design project in detail, divided in three main phases and one continuous phase, being the aesthetics development. The process is described in logical order, so while most of the results will be presented in chronological order, some findings may bridge phases in terms of relevance. Figure 25 shows the process that has been followed to achieve an integrated model by the final Phase. The general design goals for this project have been defined before Phase 1, and can be found in Section *Requirements* in *Design for Assembly*.

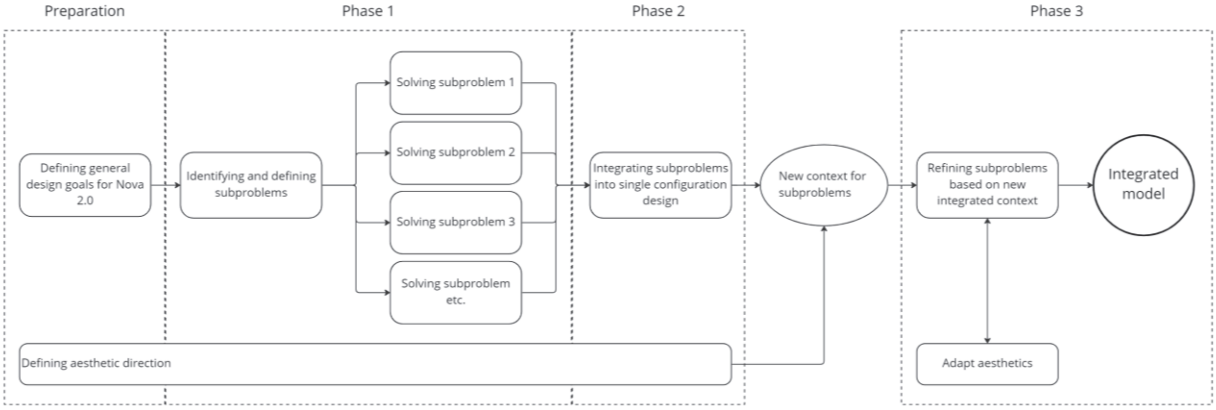
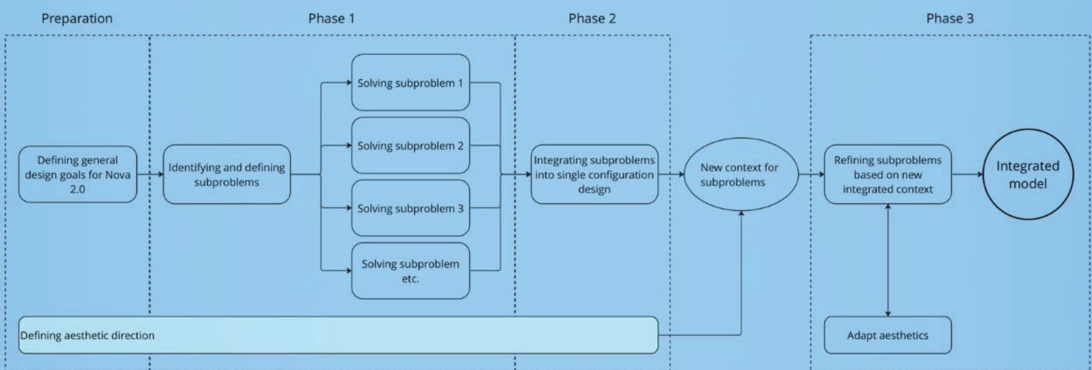


Figure 25 – Design process of Hub, divided into three main Phases.

Phases 1 - 3

Defining an Aesthetic Direction



Defining Aesthetic Direction

During this project, SenseGlove developed a new aesthetic direction for Nova 2.0 in parallel with the developments described further in this report. It is therefore difficult to elaborate on this design process chronologically. Involvement in the aesthetics design process happened frequently, with the subject being discussed during the weekly design meetings and in one-to-one conversation. While ownership of the aesthetics lied with the design department, the frequent collaboration and co-evolution of the designs justify the inclusion of this section in the report. The described process therefore does not necessarily follow any conventional design process, as the workload was shared, and topics were sometimes exclusively worked on by the design team. For clarity's sake, all results of the process will be listed, with appropriate credit to the design team where needed. All results, regardless of whether their origin was this project or the design team's efforts, were considered in the final design of the enclosure.

The first steps towards a defined aesthetics direction were made early in the project during a creative branding session. As part of this, a collection of product images was made that together closely represented the product identity SenseGlove wanted to capture with Nova 2.0. This was then condensed based on a voting process and combined into a mood board that served as inspiration for further steps (Figure 26).

Figure 26 – Collected product images and converged mood board.

To further specify what product features would fit the new aesthetic direction, a list was made that expressed this in words. This could then be referenced when using CAD software or other means to create prototypes, but also functioned as an exercise for the design team to see if they would be able to distinguish between aesthetics that do or do not fit within the established direction. This list is compiled here.

Aesthetics – Product Features

- The core shape of the product is rectangular
- The silhouette of the product is simple
- The product contains concave surfaces
- The product contains a combination of hard and soft lines, often transitioning into each other
- The corners of the product are rounded off with continuous curvature
- There is a soft contrast between the colors of the product
- The parts of the product that are meant to be touched contain darker colors than the rest of the product

Next, a series of explorative sketches was made to experiment early on with different shapes, contrast, and colors of the Hub, as this is the most eye-catching part of Nova and defines the perception of outside viewers most. It was determined early on that this part of the aesthetic design needed to be strongest, as the cable guides and softglove could be adapted easily to the Hub and would need the least amount of design work out of the three main parts of Nova. Part of the explorative sketching was done as part of this project, while SenseGlove worked in parallel. The goal here was to define general shape and feel, with quantity of ideas being more important than quality. As an experiment, efforts were also made to see if the original design of Nova could be adapted in some way to better fit the new direction. This was done with quick photo editing and sketching over the pictures (see Figure 27). Figure 28 and 29 show the exploration sketches from both SenseGlove and the designer. This process was very much a collaborative effort, with sketches being shared frequently and ideas being shaped into new ones.

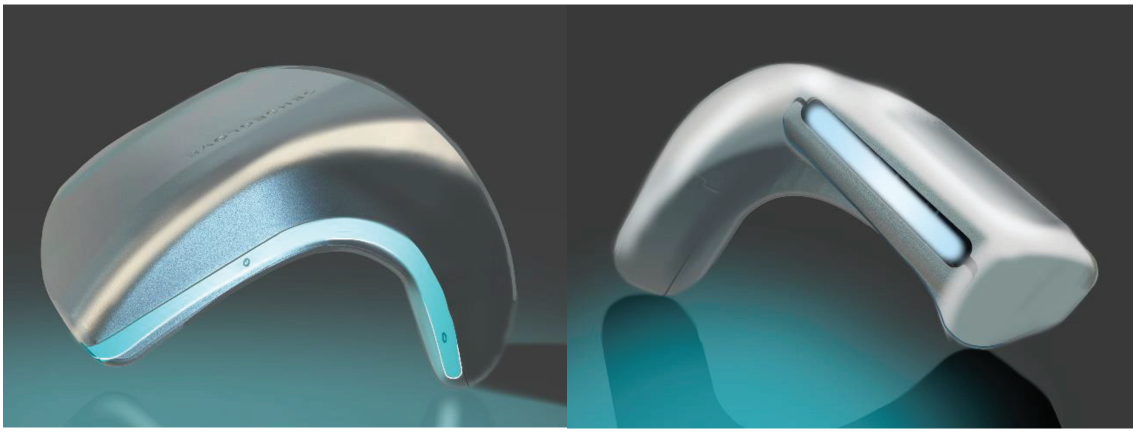


Figure 27 – Adapting Nova's original design to a new aesthetic direction.

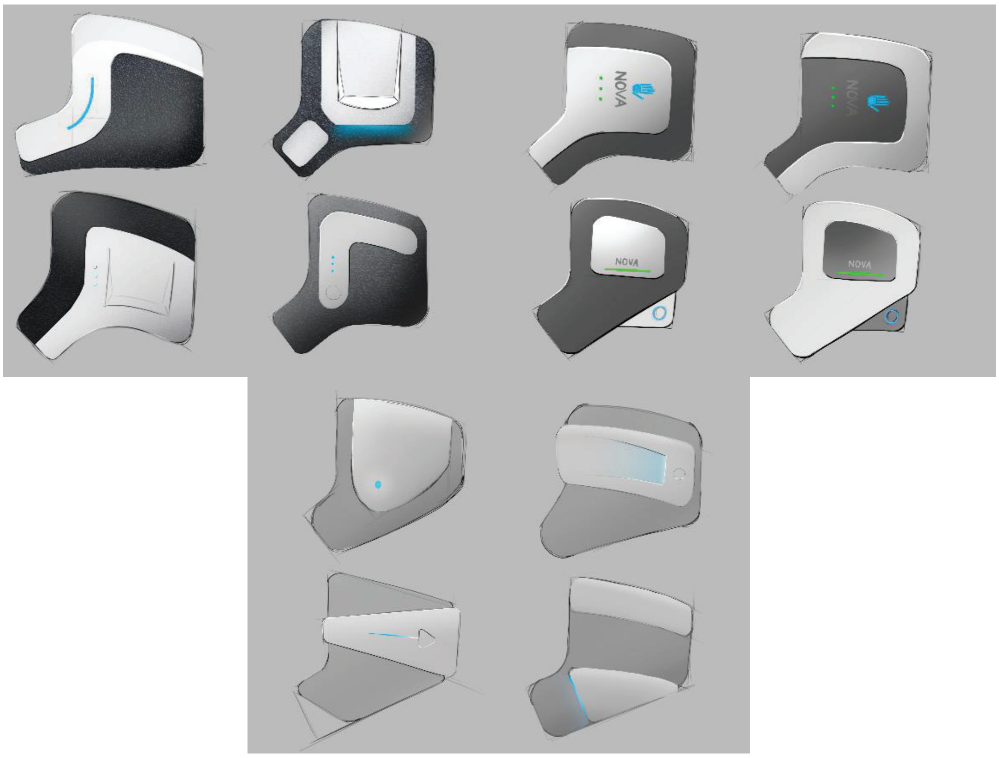


Figure 28 – Quick exploration sketches.

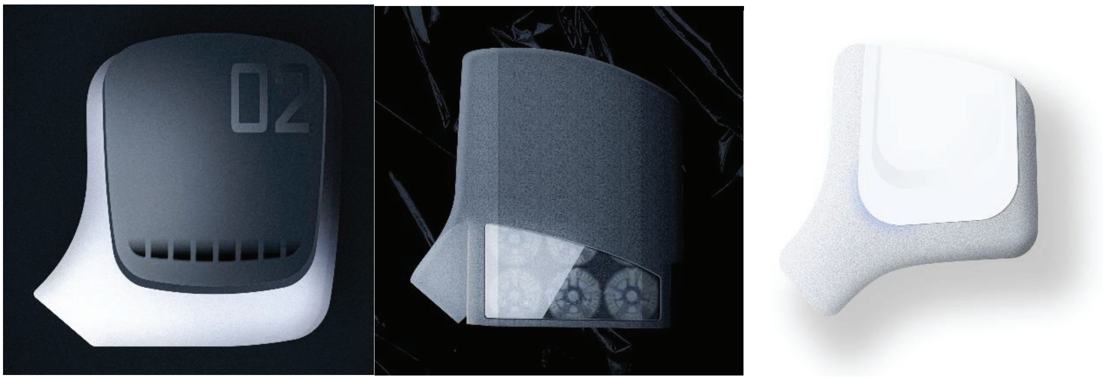


Figure 29 – Exploration sketches by Bryan Zaaijer.

Another collaboration tool that was used was Gravity Sketch, a VR design program created to enable users to work in the same virtual room and make designs in 3D. The advantage this brought over the traditional sketches is that it would generate an instant 3D view of the designs and therefore a better indication of what the volume would look like in space. A session was held where the design team, consisting of the CTO, Project Manager and Creative Director were given a short tutorial by the designer of this project to work in Gravity Sketch, followed by a session where everyone could bring their own ideas into VR and display them next to each other. For reference, 3D files from the original Nova CAD were imported into VR so that they could be used as a skeleton for the models. The result was a virtual room with a large display area for all the different ideas, which was then used to discuss findings and gather takeaways. Some of the 3D designs that were made individually before the session were also imported. Figure 30 show the results of the VR session.

Figure 30 – Picture taken during and results from the VR session.

From the session, it was determined that a specific Hub design was most attractive and in line with the mood board, so that was to be developed further. This design had been explored early in the process and had many adjustments and changes made to it. As another iteration, a concept sketch was made by SenseGlove. The general evolution of this design, as well as the concept sketch can be seen in Figure 31.

Figure 31 – Evolution of main aesthetic direction for Hub.

As a final step towards a fully defined aesthetic direction, inspiration was drawn from existing popular VR headsets that the new Nova was going to be used with. A big clash in looks between the headset and Nova might demotivate clients from buying the new version, as part of the goal of Nova 2.0 is to eliminate the image that Nova is still a prototype. Additionally, it was determined from internal testing that the latest aesthetic direction reminded of a medical device, which SenseGlove is determined not to be compared to. To have Nova 2.0 fit better into the ecosystem of modern VR, a last iteration was made that was designed to fit well with the two most popular colors for HMDs: white and black. In addition, this final design was meant to position Nova more as a sleek training device, rather than a medical one. While Nova can still be used as a revalidation device with this new look, it might be very difficult to sell as the future of VR input when it looks more appropriate for the hospital floor.

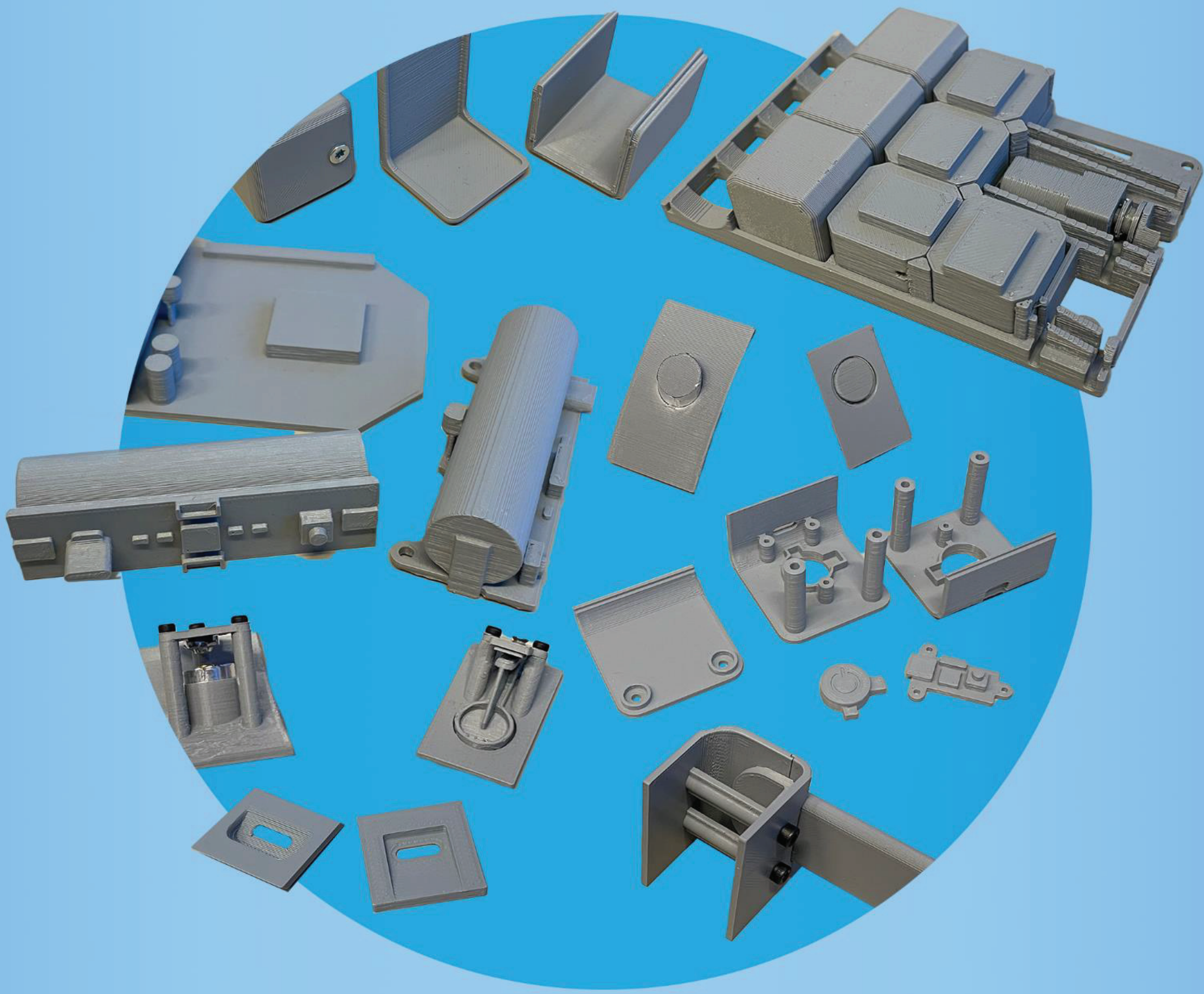
Figure 32 shows the final design besides some popular headsets. The primary inspiration was the Pico 4 HMD, which at the time of development was just released and gained popularity, but other headsets have been considered as well. This drawing also contains the primary new feature that Nova 2.0 offers, the active strap, which is elaborated in Section *Active Strap* of *Phase 1*.

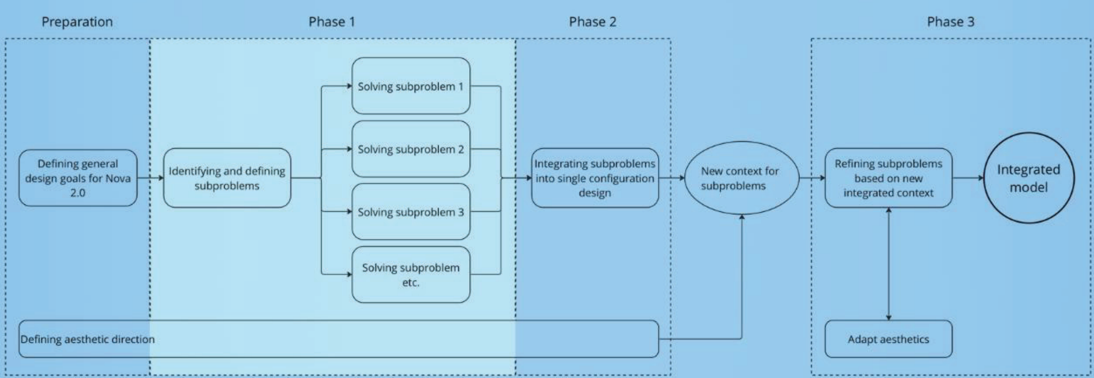
Figure 32 – Final aesthetic direction with new features compared to modern VR sets. Left to right: Meta Quest 2, Meta Quest Pro, Pico 4, Valve Index.

Apart from fitting among the headsets available in the market and looking attractive in general, Nova also needs to be ready for a possible future computer vision tracking solution. As stated earlier in this report, its position and orientation should be clearly identifiable by a regular color camera. Development of this was out of scope for the project, but Section *CMF* in *Phase 3* explains the considerations made and how they affect the final look of Nova 2.0.

Phase 1

Identifying and Solving Subproblems





Phase 1 – Identifying and Solving Subproblems

To make sure the redesign of Nova's enclosure happened in a manageable and logical way without losing sight of the bigger picture, and to provide material for the integrated design by Phases 2 and 3, the enclosure was divided into several subsections that each contained their own isolated problems. Whether something counted as a subproblem was decided based on observations of Nova's assembly, the general design goals, the program of requirements and several conversations with SenseGlove employees. In addition, a general overview of possible improvement points to the Hub was made, both in terms of subproblems and aesthetics, to provide a starting point for exploration of options (see Figure 33).

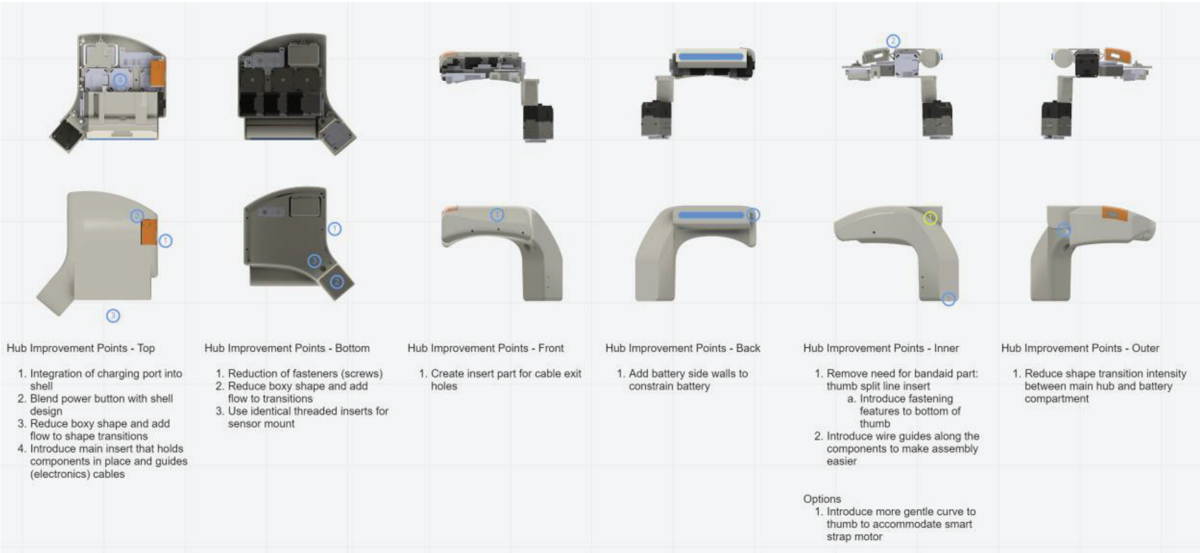


Figure 33 – General overview of possible improvement points.

While each subproblem was tackled in a slightly different way, each generally followed the conventional design cycle of problem definition, generating requirements and execution. Ideas were explored with sketching, CAD, and prototyping to determine whether aspects of assembly, volume and build quality were in line with the general goals in the project. For some subproblems, small investigations were held to verify ideas or to choose between several. The subproblems were identified early on, but development continued all the way through Phase 3. This means that the results presented in the next section are not listed chronologically and may show details from early prototypes up to the final model. They have been sorted per Focus Point in the project, but naturally, some overlap between Focus Points can occur within a given subproblem.

Part Count Minimization

Band-Aid Parts and Constraining Modules

In order to reduce the number of parts in Nova's enclosure, several changes had to be made to the pre-existing parts, either to optimize them to be multifunctional, or to integrate multiple parts into a single one. The most straightforward way to reduce the part count was estimated to be the integration of previously present "band-aid parts" into the Hub's shell. Band-aid parts refer to alignment parts or 3D printed inserts to alleviate some problem within the Hub's design. For example: The thumb part of the Hub contains a 3D printed and glued insert to prevent the widening of the split line when force is applied during handling (see Figure 34). As a metaphorical band-aid, SenseGlove decided to include this part and it can be seen as a direct result from a minor design oversight. Because of the minor nature of this oversight, the elimination of the part from the design was straightforward and simple: introducing an extra lip and groove feature to the thumb split line and adjusting its position would eliminate the need for this part and the postprocessing step required to add screw holes for it to the shell (see Figure 35). The resulting solution reduces the component count, but also eliminates steps from the assembly process and makes it more straightforward. As the current assembly process of Nova requires a whole station dedicated to postprocessing the shell parts, any redesign to the shell was to be made in a way that would require zero post-processing after manufacturing. This general guideline was followed for every subproblem.

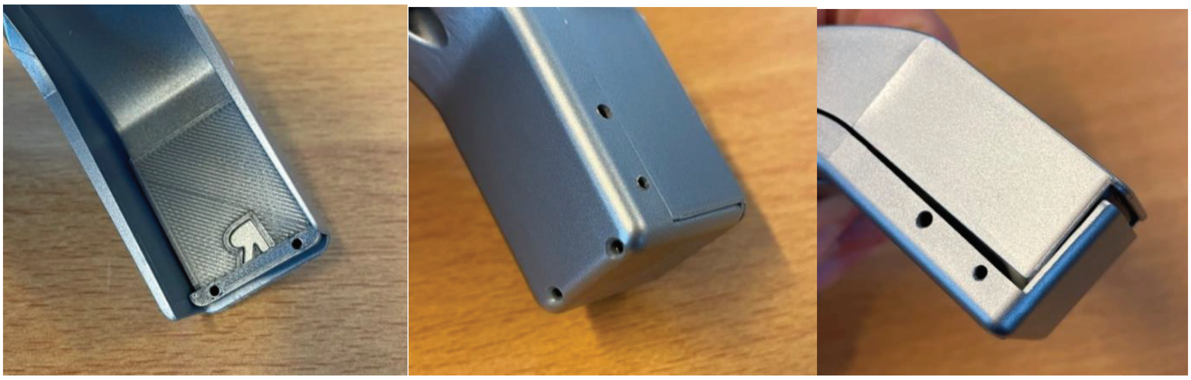


Figure 34 – Left to right: 3D printed part in the thumb part of the Hub, called the 'gap closer' among the employees; the gap closer pulls the shell halves together with screws inserted into the predrilled holes seen here; the issue the part is meant to prevent, external forces on the shell can cause a gap between the parts.

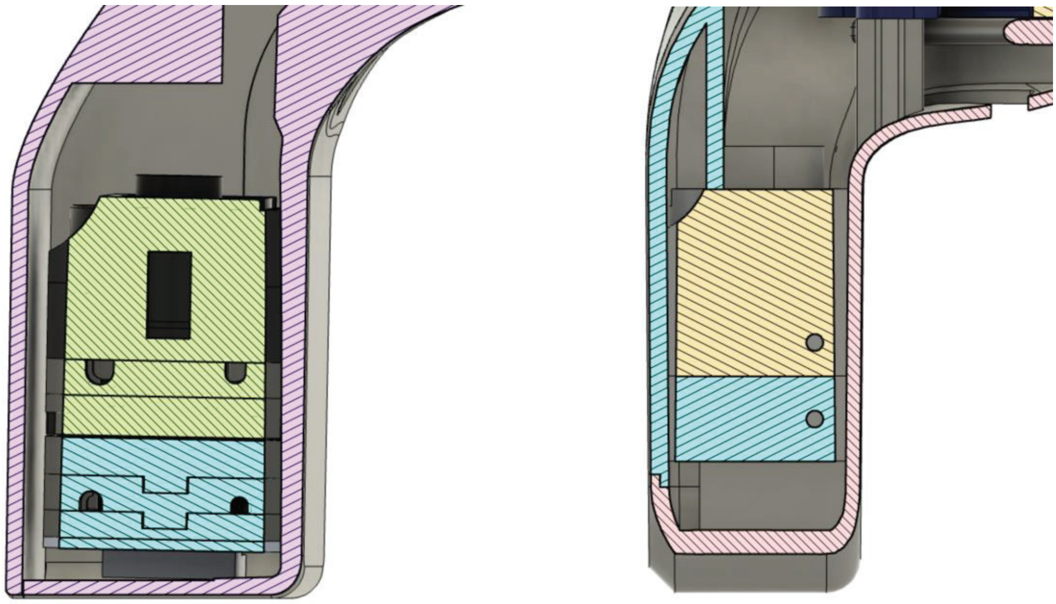


Figure 35 – Prevention of thumb gap in Nova 2.0 design, using a lip and groove to keep the shell closed when force is applied. Notice on the left that the split line between the shell halves does not contain any features to keep the halves in place, while the right shows a lip and groove that keeps the shell together. The split line has also been moved to a vertical wall to allow the lip and groove to resist forces that would cause a gap in the original version.

Similar band-aid parts are present in the rest of the Hub; the battery and FF modules are held in place by another 3D printed component, and the Thumper module as well as the Hub/softglove connector use a similar solution (see Figure 36). The similarity between these parts is that they are all mounted vertically, constraining the parts from above in a similar way that the bottom shell does from below. This leads to the fundamental idea behind most part count minimization design choices in this project, which is that the constraining of parts should be done using the Hub shell itself alongside a single, multifunctional insert instead of several smaller ones. In Figure 37, the concept for the main insert is shown. This component constrains all internal components on the horizontal plane, and requires only some features in the top shell to fully constrain them. Additionally, it guides the force feedback and stringpot cables in the right direction and prevents them from coming into contact with the other components. Previously, this function was fulfilled by several PTFE tubes attached to the modules, which had to be manually aligned in the shell before being trimmed, risking damage to the shell and the cables. With a simple test, it was determined that the force feedback cables would not be subject to increased wear from touching the plastic of the insert directly, as long as the cables were routed in a straight line from the modules and only touched the insert in one place which had been properly filleted. The full test setup and results can be found in Appendix C.

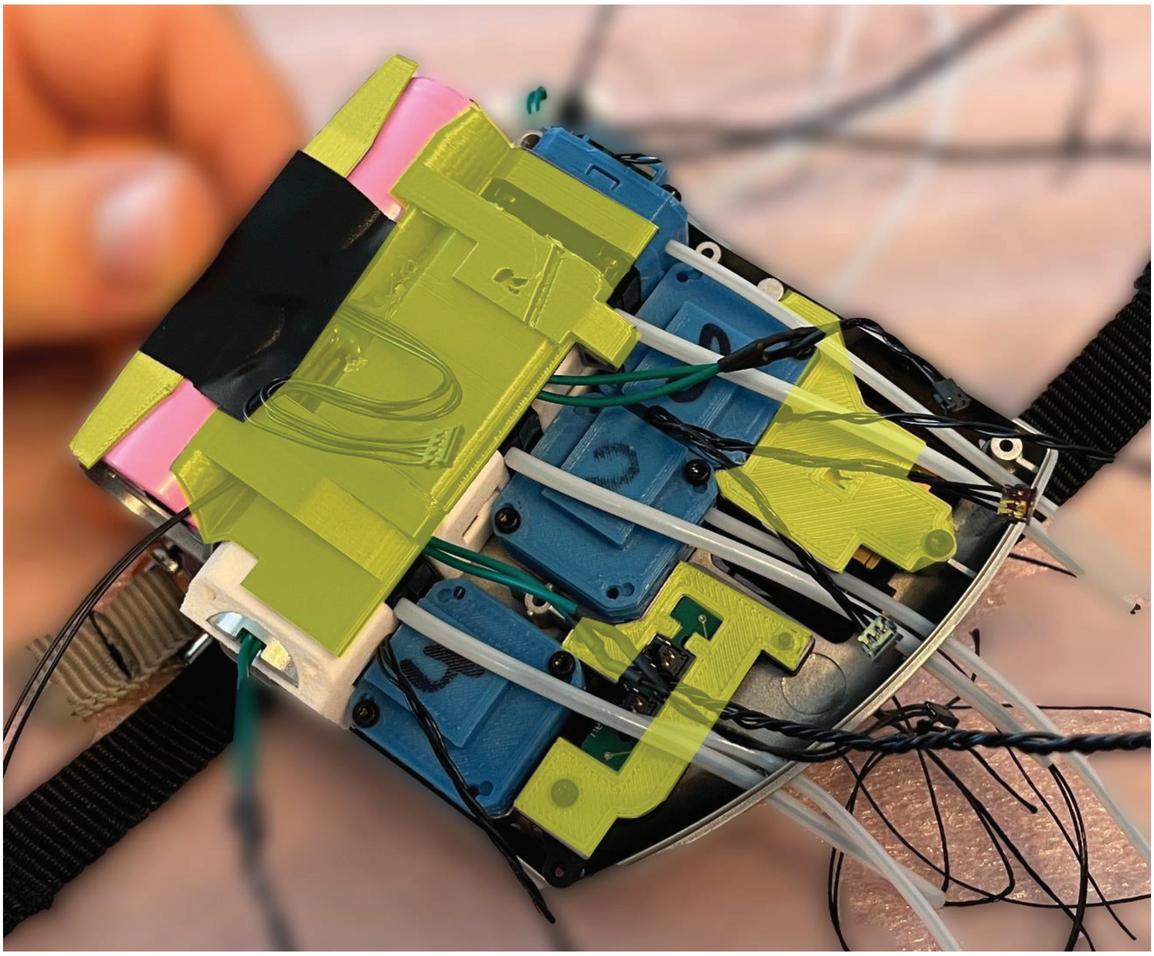


Figure 36 – Highlighted: "Band-aid" parts present in Nova 1.0, used to keep several components in place or mitigate minor design issues.

As a result, the addition of a single main insert removes the need for several other components: the PTFE tubes for the force feedback cables, the insert for the battery, and the insert for the hub/softglove connector (Figure 37). As the thumper will no longer be a part of Nova due to the integration of the new active strap, it and its inserts are removed from the assembly by default. The alignment of the battery can also be handled by the main insert, but because the tool used for this previously is not a part of the finished product, it can be argued that it does not remove that component from the assembly. What this does provide, however, is the elimination of glue from the process of attaching the battery, which can be seen as an additional component or step in the assembly process (Figure 38). Appendix D shows how the main insert was developed.

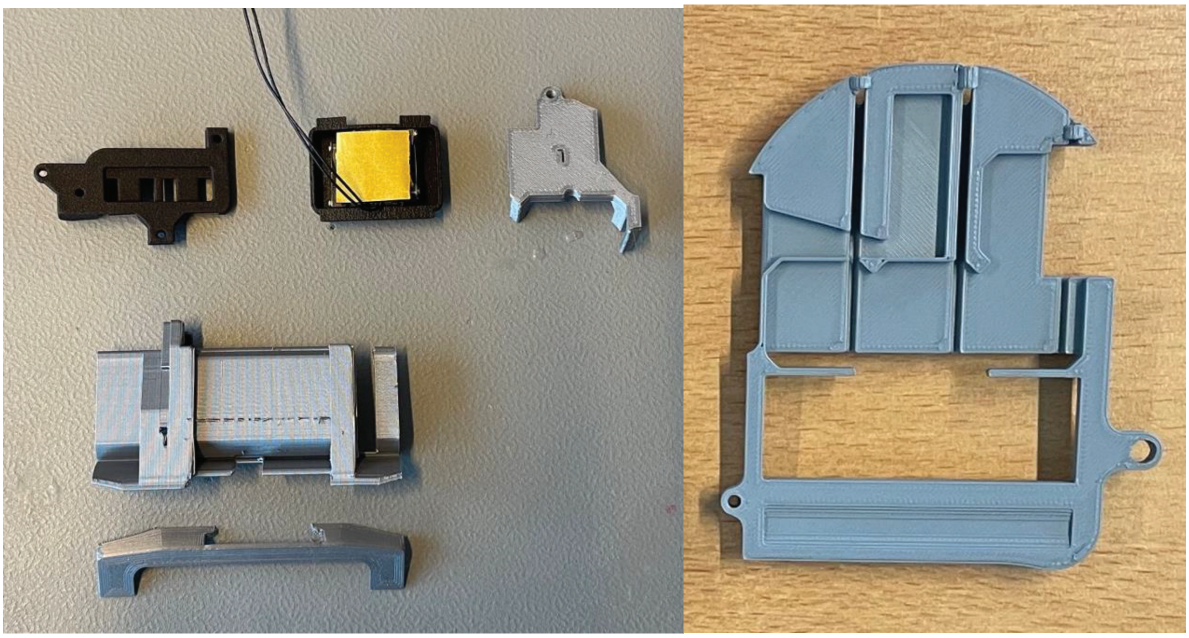


Figure 37 – Left: inserts used to constrain components in original Nova (Left to right: softglove connector, thumper casing, thumper insert, battery & FFM insert, battery/lightbar insert.). Right: single insert used to constrain battery, force feedback modules, stringpot modules and active strap motor, as well as provide channels for the FF and stringpot cables to run through. Note that the thumper and lightbar components have not been integrated as they are obsolete in Nova version 2, mainly because of the addition of the active strap and the removal of LEDs from the product. The softglove connector would sit at the bottom of this main insert, but is treated as a black box for this project.

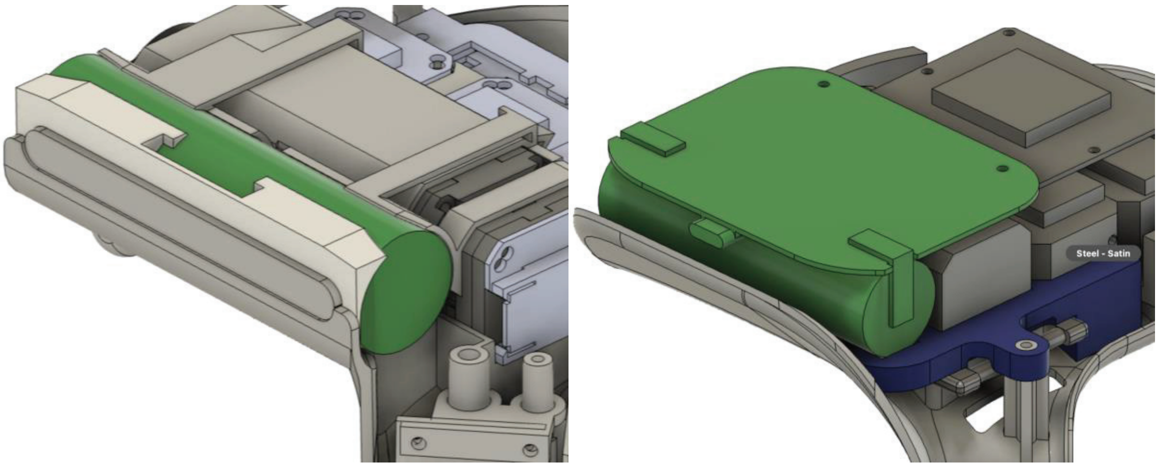


Figure 38 – Constraining the battery in the original Nova and the redesigned Nova. Note that in the left image, the battery is not constrained in the horizontal direction, allowing it to shift from left to right until the top shell is placed and fastened. For this reason, assembly workers prefer to use hot glue to keep the battery in place, risking damage to it and the shell. On the right, one can see how the main insert of Nova 2.0 contains a recess in which the battery sits during assembly, preventing it from shifting. Additionally, it is kept in place by the power PCB which is screwed to the top shell, with the screw holes' alignment being made easier by the recess in which the battery sits. Note, however, that in the redesign the battery and power PCB are placed after the top shell is already attached, making the aforementioned features function more as a means to prevent the battery from shifting during use, rather than during assembly.

Power Port

On the topic of Nova's battery, it was previously required to manually solder the battery wires to the main PCB, adding risk to the assembly process by heating the battery, as well as potentially melting part of the shell, should the soldering iron touch the sides. To eliminate this problem, a new PCB was conceptualized, that already contained the battery before being assembled and would connect to the main PCB handling the computing using a ribbon cable (see Figure 39). Combined with the new insert that handles alignment and constraining of the battery, this makes the process of inserting and connecting the battery less risky and faster to perform.

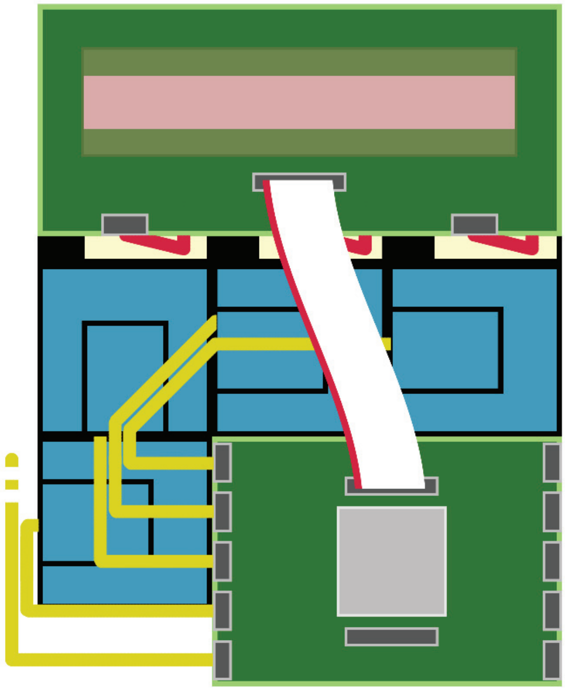


Figure 39 – Schematic for envisioned split-PCB solution.

In addition, the second PCB allowed for the integration of the power port, which in the previous version of Nova required a shell piece to be glued to the main PCB and was previously determined to not sit in a favorable spot; the power port sat on the right side of the Nova, regardless of whether it was a left- or righthanded version. This asymmetry was not only undesirable for the aesthetics of Nova, but also potentially unintuitive to the trainee or instructor. Alleviating these issues simultaneously, the power port was moved to the back center of Nova and integrated in such a way that an insert was no longer needed. To further provide symmetry, but also to comply with new EU regulations, the port was also changed to a USB-C connector, instead of the out-of-date micro-USB. The symmetric nature of the new power PCB allows it to be used in both Novas of a set, requiring only a single type for both left and right. Figure 40 shows how the power port was integrated in the original Nova, while Figure 41 shows how this has been handled in Nova 2.0. Appendix E shows the full ideation and prototyping process.

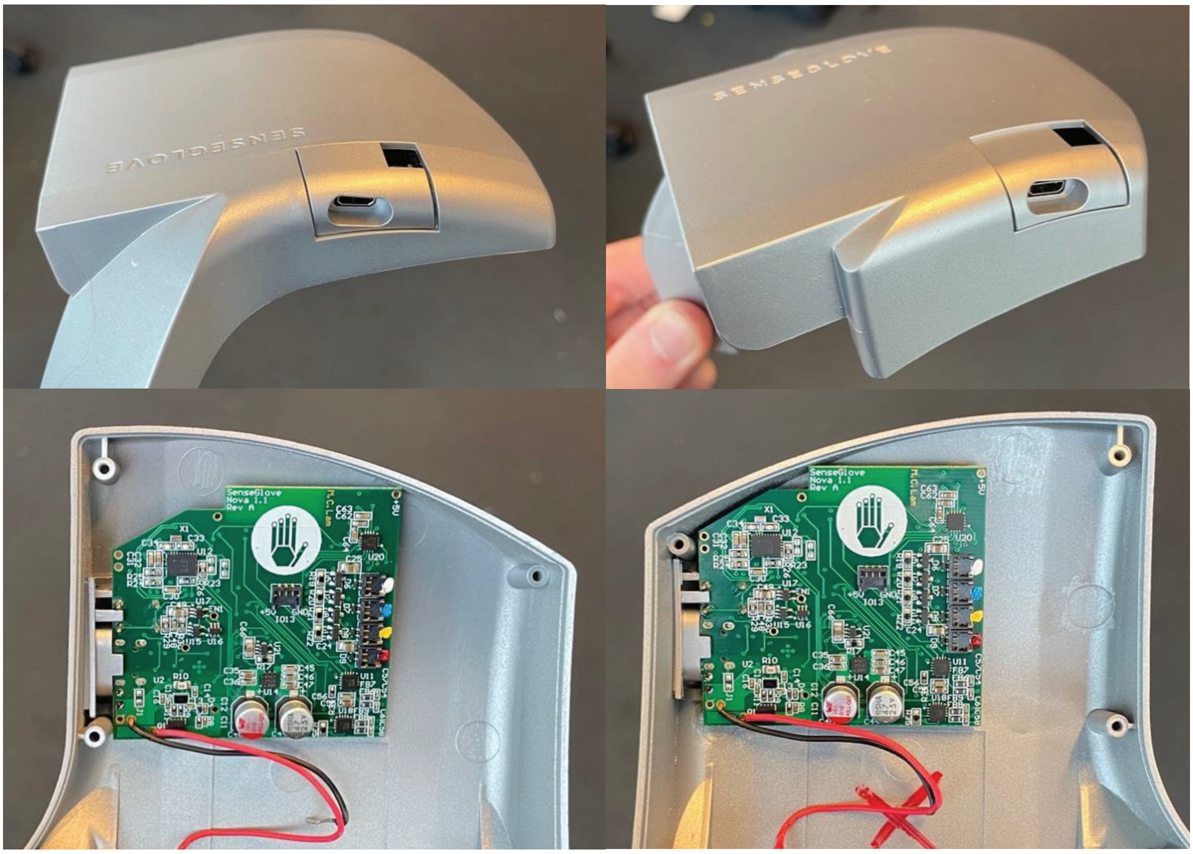


Figure 40 – Old integration of PCB and power port on a left and right Nova. Note that the PCB and power port shell pieces are identical for both. This leads to discrepancies in the internal configuration, which is mirrored apart from the PCB, requiring a different approach during assembly.

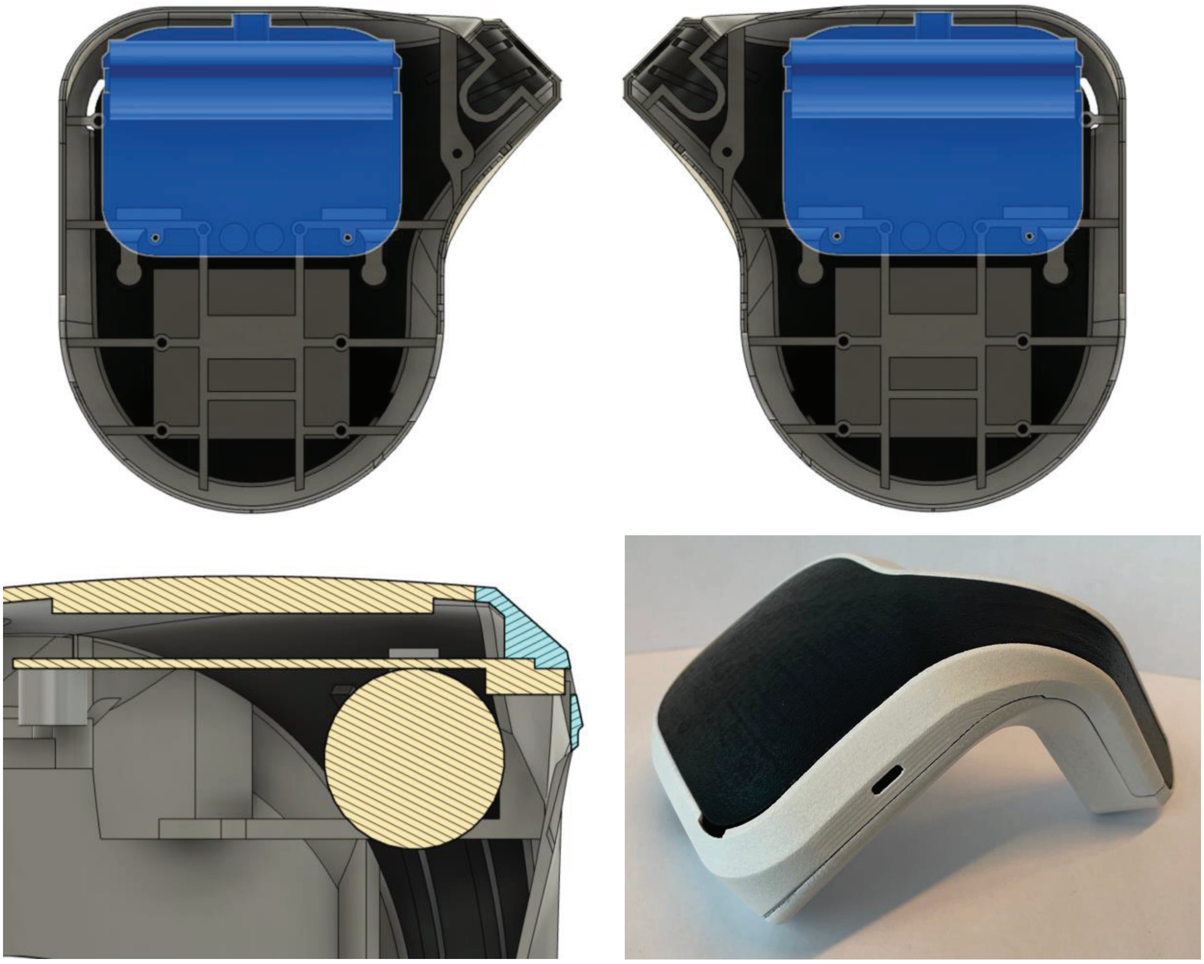


Figure 41 – Integration of power port on separate power PCB that is symmetrical and can therefore be used in both versions of a Nova 2.0 Hub. Placing the USB-C port near the surface of the shell and designing with draft angles allows for a port hole that is injection moldable without sliding mold pieces.

Power Button

As the power button was originally a part of the power port shell piece, it had to be moved when the power port was moved. A user test was conducted to identify a new, more optimal position, which was on top of the thumb part of the Hub. With further consideration and the refining of the aesthetic direction, though, the power button was eventually moved to the main PCB, where it sits below a bendy part of the shell. This way, it can be pressed like a large mouse click by the trainee, which is expected to be much easier while wearing thimbles than to try and locate a small button on the side of the device (see Appendix F). As the top of the Nova is a large surface and is intuitively found without visual aid, this new position for the power button can also be found while wearing a VR headset. To make sure the top surface does not wear from repeated presses, some considerations have been made regarding the texture of the shell in that area, which can be read in *Phase 3*, Section *CMF*.

It is also worth noting that the active strap requires some form of button to tighten during initial use. A promising concept is to have the power button function as a tightening button as well, with short presses operating the active strap, and long presses turning the power of the Hub on or off. However, this level of implementation of the active strap is beyond the scope of the project, and therefore the power button will be integrated as just that.

Thimbles and Cable Guides

One of the major assembly problem areas SenseGlove was experiencing were the thimbles and cable guides. These required relatively time intensive and risky assembly for a high number of components that did not serve a complex enough purpose to justify their assembly time. As an effort to minimize the parts required in the cable guides, as well as improve the assembly logic, these were redesigned as well. As mentioned previously, it was determined that the previously present PTFE tubes were not essential in reducing wear on the cables. For the cable guides, these were the main temporal obstacle to overcome, as each individual cable guide required up to three PTFE tubes, which needed positioning and trimming during the process. In addition, the cable guides and thimbles consist of two halves that are glued together, requiring an extra assembly step and curing time, as well as increase the risk of damaging the plastics when applied incorrectly (see Figure 42). The envisioned direction for the cable guides was therefore to eliminate the tubing and glue, resulting in only two components being needed per cable guide and four per thimble, instead of the original five and eight respectively (counting glue as a component). Using strategically placed snap fits, the design of the cable guides and their attachment to the softglove was minimally changed while providing a much faster way of assembly. By adjusting the features of the cable guides near the exit holes, it could be avoided that the cables would slip between the component halves as a result of a lack of tubing. A test was conducted with SLA 3D printed parts, which come close to injection molding in level of detail, and it was determined that the new direction was feasible. Figure 43 shows the result. The only step left would be to integrate the new Nova's aesthetics into the cable guides and give them another iteration of development before they could be implemented. A render of what a finished cable guide could look like for Nova 1.0 can be seen in Figure 44. Appendix G shows the full development process, including sketches and early prototypes.

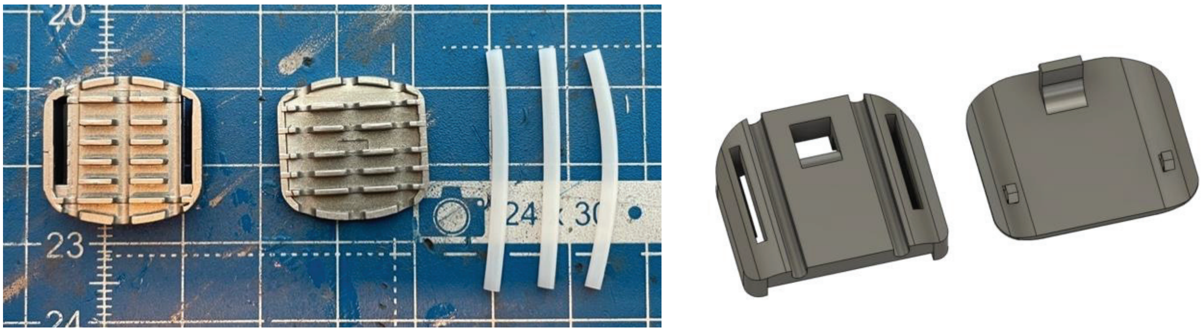


Figure 42 – Left: Old cable guides parts, fastened using glue. Right: envisioned concept parts, using snap fits to fasten the halves. Note the lack of a third channel for the stringpot cable. This is due to the cable guide concept functioning more as a proof of principle which SenseGlove could develop further, rather than a functional part.

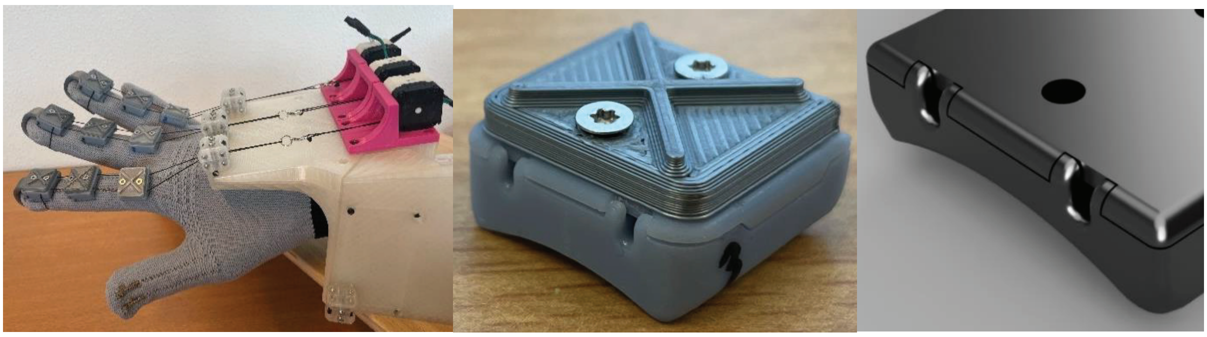


Figure 43 – Resin cable guides test showing that the cables can be guided without issues and without getting caught between the cable guide halves using special features at the end of each exit hole.

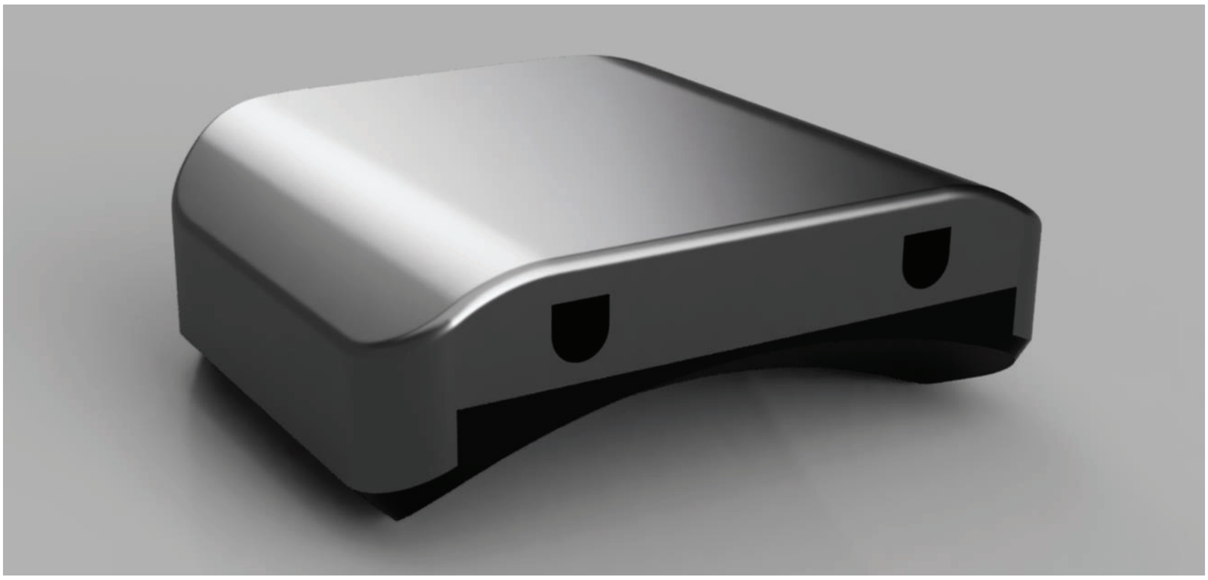


Figure 44 – Cable guide concept with integrated aesthetics. For Nova 1.0 and 2.0.

Active Strap

The addition of a new feature to Nova presented a unique challenge, namely that any reduction in components gained throughout the enclosure might be offset by the new components needed for the active strap. It was therefore important to adhere to the principles mentioned previously in this report to make sure there were a minimal number of components present from the first version of the active strap, and that it could be integrated with the rest of the redesigned Nova with minimal or no compromises to either. As the development of the function and manufacture of the active strap was done by another designer, only the integration with the Hub were of concern for this project, though some collaborative development occurred to keep both projects going in the same direction.

The active strap required a motor to actuate it, and two attachment points for it. The motor was given space in the main insert at the spot where the thumper would originally sit. As with the other components, it could sit snugly within the insert, requiring only and extra constraint from above to fully fix it to the Hub. The positioning was chosen in such a way that the cables running from the motor could run to the active strap with minimal resistance, while also aligning the motor's connection points in such a way that it lines up with the main PCB, requiring only a short cable to connect it (see Figure 45).

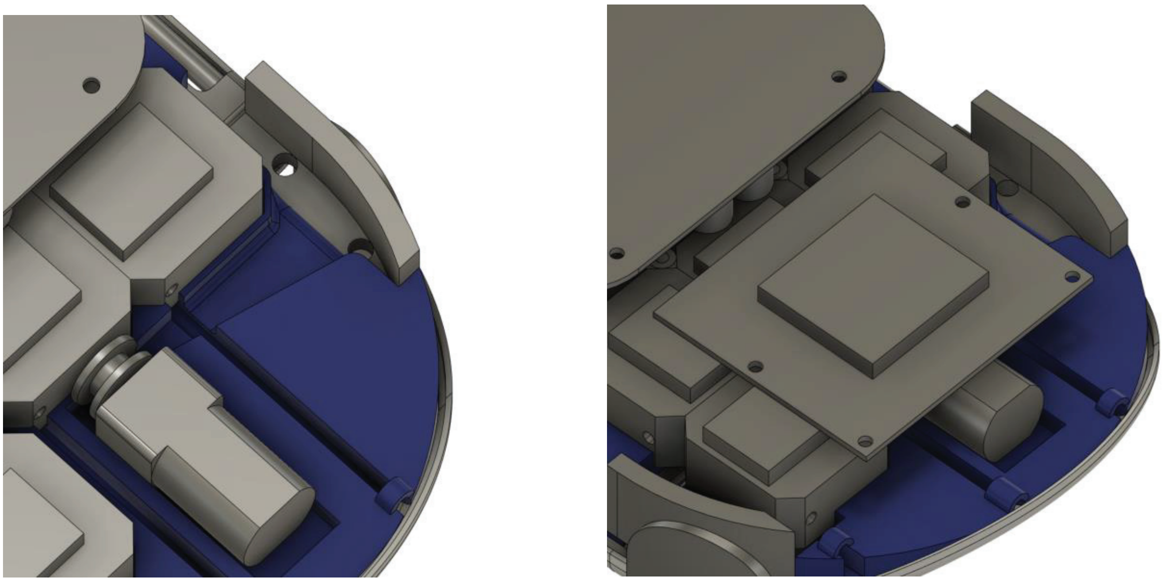


Figure 45 – The active strap motor placed in the Hub's main insert. Left: a channel has been made in the insert to guide the active strap cables between the crossing FF and stringpot cables towards the exit holes in the active strap. Right: The back of the DC motor and therefore the electrical connection are located closely to the edge of the main PCB, requiring only a short wire to attach the motor to the controller.

The strap itself was positioned in such a way that it would be located in the same spot as the original, regular strap for ergonomic reasons. Similar to with the thumb part of the Hub, the split line of the shell could be used to help in securing the strap to the shell; using only two screws to connect the strap to the bottom shell, the connection between the bottom and top shell would be oriented in such a way that a bending moment on the strap connection (as a result of the strap actuating) would self-lock the shell halves and keep the connection securely in place, without requiring an extra component to do so. Additionally, the main insert needed to make space for the active strap connections while still allowing access to the entry points for the actuator cables. The way this design was integrated can be seen in Figures 46-48, but is also visible in Section *Phase 3*, where the final design of the Hub can be seen.

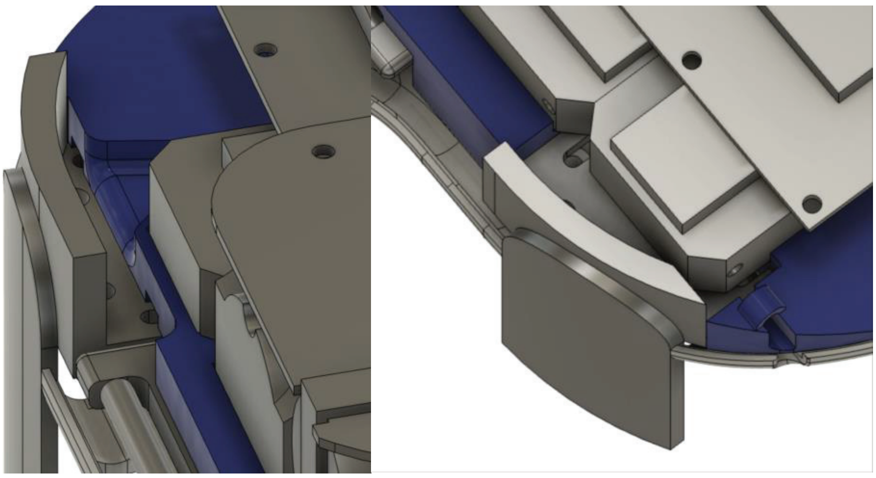


Figure 46 – Mounting the active strap in the main insert.

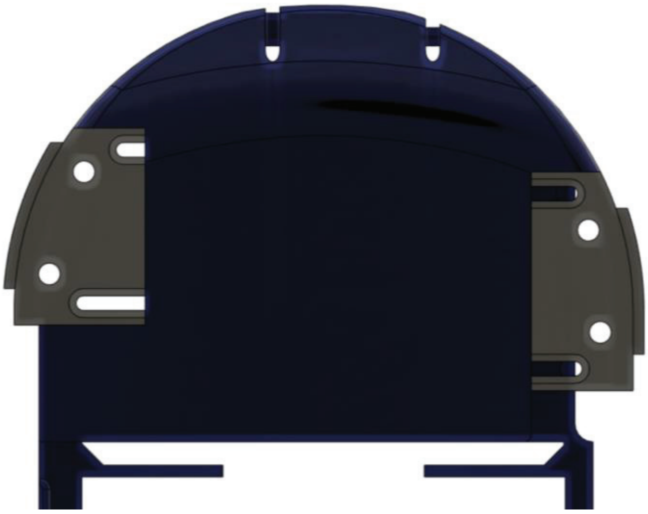


Figure 47 – Making space for the active strap in the main insert (Phase 3 model).

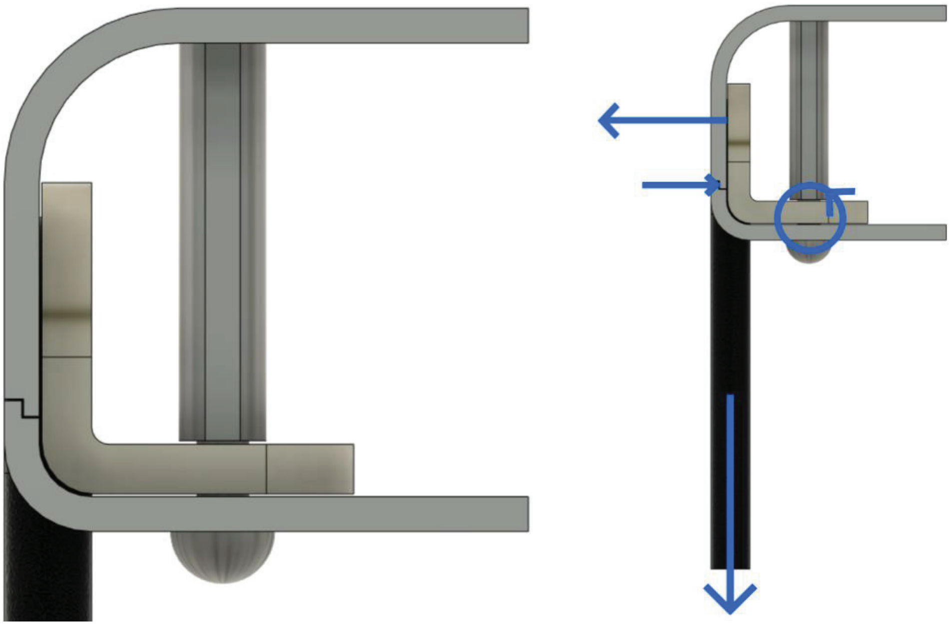


Figure 48 – Active strap self-locking shell idea. The screw was later designed to be fastened from the top, in line with the vertical assembly approach (see Section Vertical Assembly in Phase 1).

Regular Strap

Though the active strap replaces the original version of the strap, it does so only partially, leaving the strap near the wrist relatively unchanged. In the original design of Nova, this strap is attached to the Hub using some Nylon cable routed through a tube at the ends of the fabric. Though this method takes very little space internally, it requires a tedious process during assembly and suggests questionable durability and quality to the trainee or instructor. In order to remove the need to manually thread and knot these Nylon cables while minimally affecting the internal volume, the regular strap is envisioned to be connected to a single component that sits below the force feedback modules. There, it functions as a more secure but invisible attachment point for the strap, which is guided through the shell and around the trainee's wrist through holes in the bottom. Due to its position in the Hub, it also functions as an additional constraint for the force feedback modules, which sit inside the component. Though it is attached to the bottom shell with four screws for redundancy, it is also held in place by the main insert, which goes above it and is fastened to the bottom shell. The regular straps being attached to this single component is an example where actually adding a component can improve the assembly process, because the steps required to assemble it are simpler than without it. This is not a band-aid part in the sense that the others were in the previous design, as its implementation actually reduces assembly complexity while adding extra functionality like constraints for the force feedback modules. Figure 49 shows its implementation in the final model compared to the original Nova design.

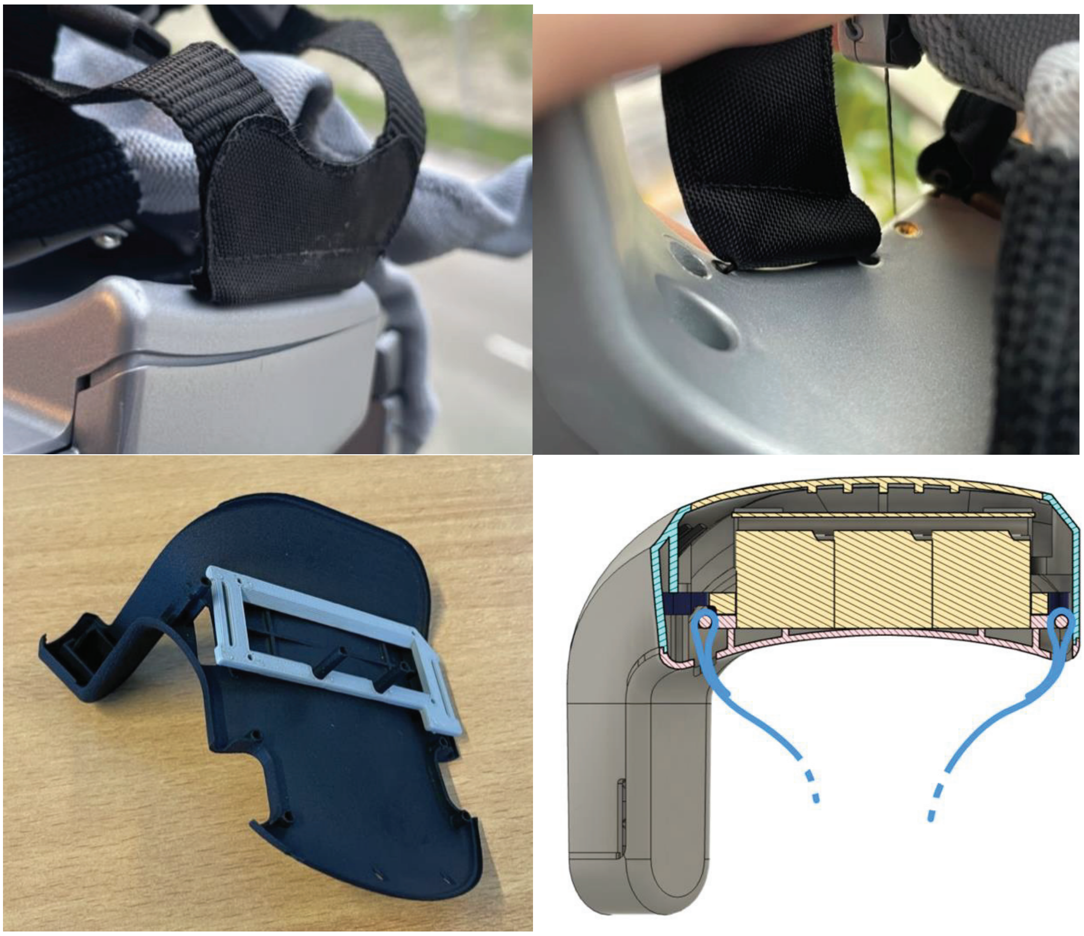


Figure 49 – Top: Original strap connection using threaded Nylon cables tied together inside the shell. While this saves on internal space, it requires dexterity and time during assembly. Bottom: New strap connection concept, with a single component below the FF modules that has the strap preinstalled and is lowered through holes in the shell before being screwed in place. Besides being easier to do, this method could also increase the strap connection's durability.

Improving Assembly Logic

Another aspect of Nova's original design that could be improved was the logic in its assembly; many of the steps require insider knowledge or a demonstration before new employees can get started, resulting in some delays and the potential for confusion during assembly. Because most of the enclosure will be redesigned for this project, there is room to implement more logic into the assembly process from the foundation of the design to more detailed features.

Force Feedback and Stringpot Modules

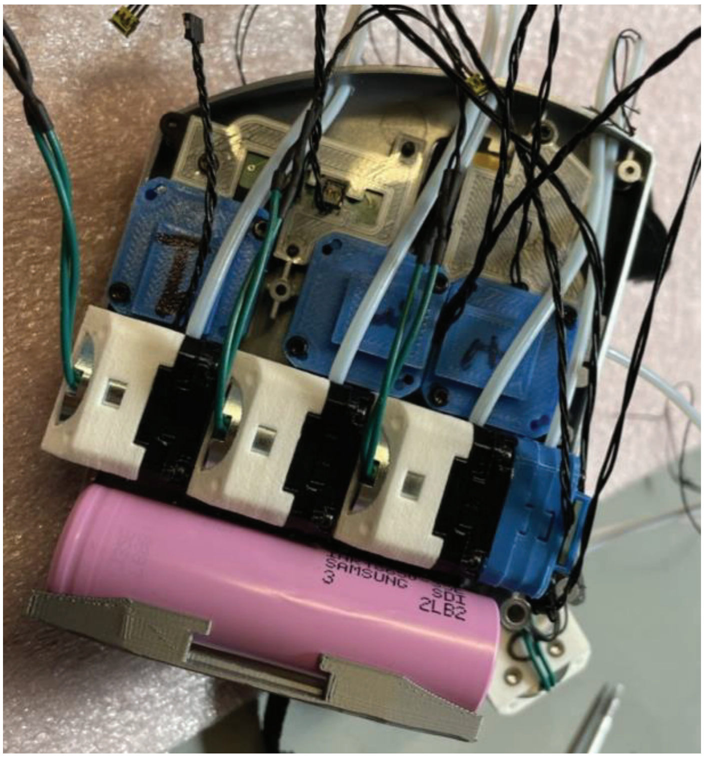


Figure 50 – Left-hand configuration of both stringpot (blue) and force feedback (white) modules inside Nova.

One method of improving the logic of Nova's assembly is to reduce the number of minor differences between components that are similar in function. The prime example of this is the force feedback and stringpot modules. In the original design for Nova, there are four different types of force feedback modules, differing only in the length of their wire connector and exit point for the cables (see Figure 50). Though this seems minor, it is something the assembly workers have to keep in mind during the making of the subassembly, but also during its assembly into the Hub. This extra cognitive load can add confusion to the process and is prone to human error in case of incorrect placement. To eliminate this issue, the redesigned Hub only contains two types of force feedback modules: three with a short wire, placed directly under the power PCB, and one with a long wire, placed in the thumb. This difference is more obvious than the previous types, and it is easily interpretable as an indication of the placement of the modules: a short cable in the thumb cannot reach anywhere, so that leaves only one module, while the rest can be placed in any order in the Hub (see Figure 51).

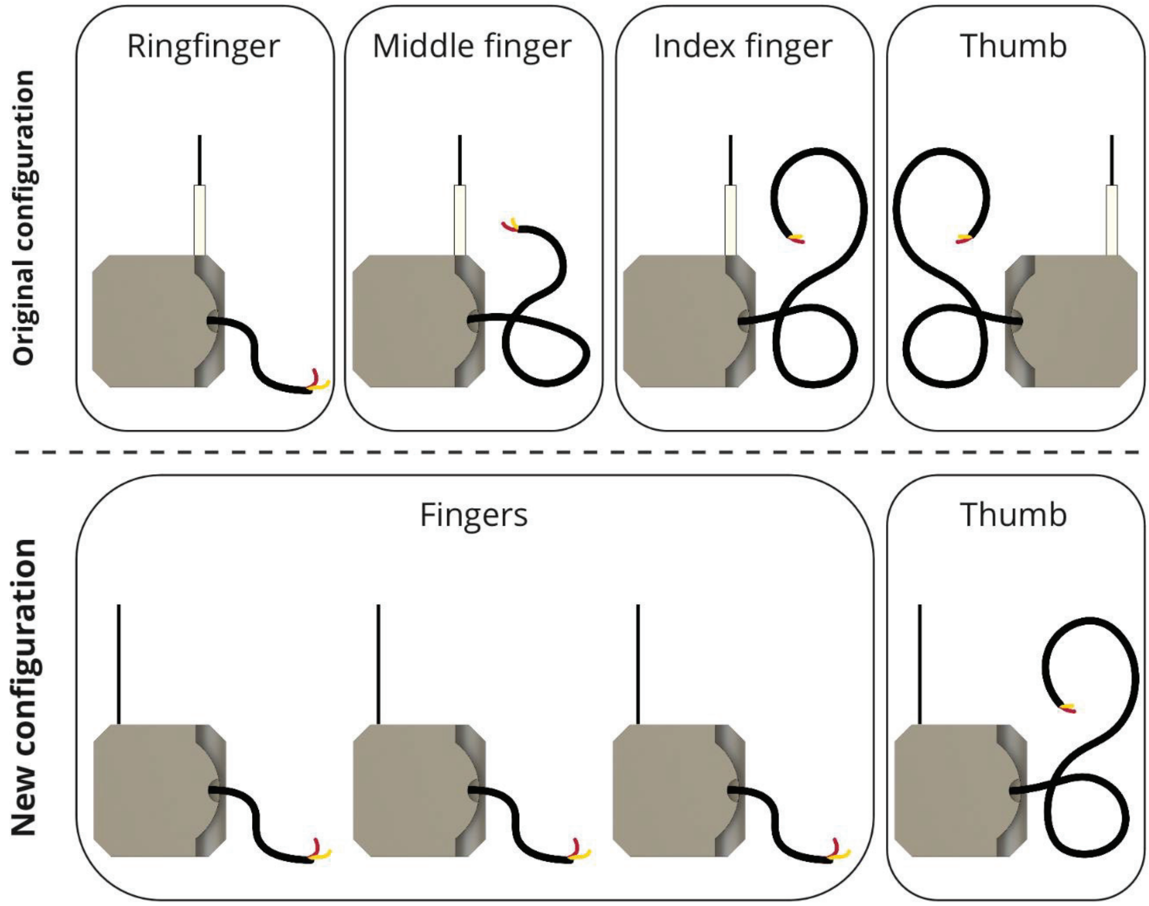


Figure 51 – Original and new force feedback module configuration for a single left Nova. By eliminating small variations, only two types of distinct modules remain, making part identification during assembly more straightforward.

A similar method was used to reduce confusion around the stringpots, which used to have five different versions per Nova, but now has three, the difference between them being only the length of cable and the orientation of the cable exit hole (see Figure 52).

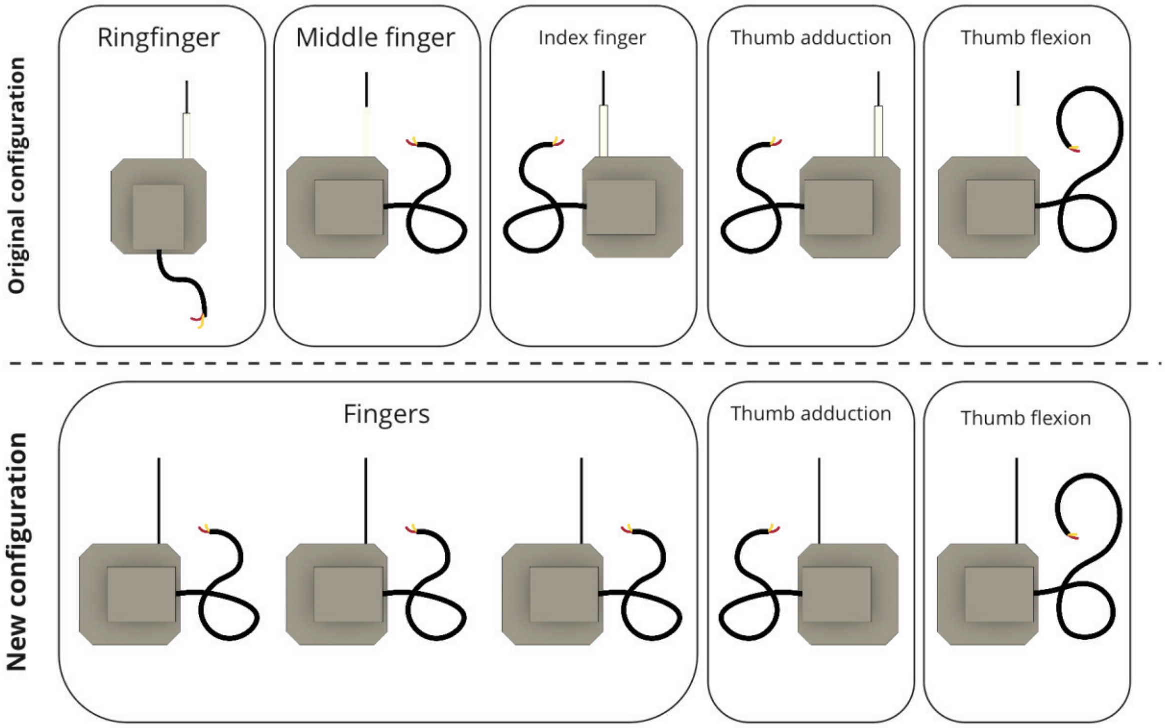


Figure 52 – Original and new stringpot module configuration for a single left Nova. By eliminating most small variations, three types of distinct modules remain, making part identification during assembly more straightforward. For reasons concerning the placement of its cable exit hole, the thumb adduction stringpot cannot be made the same as the fingers' ones. As its rotation within the Hub is also different, this helps further distinguish it.

For both modules, their left- or righthanded counterpart is an exact mirror. This makes it obvious whether a module should be in the left or right Hub, but for the stringpots there is some overlap; the thumb adduction module is identical to the finger modules from the other counterpart. This means that in essence, that type of stringpot is not an additional type at all, but simply a swap between the two different Hubs. This concept has some overlap with the previous section about component count minimization, in that it reduces the variety in components required to assemble the Hub. However, the assembly workers have stated that they are unlikely to make excess modules for left and right Novas and swap them between the two; they are more likely to just assemble the modules needed for a single Nova and make the other once the first is finished. In this case, there are still three different types of stringpot module to assemble per Nova.

Figure 53 shows a comparison between the configurations for the original design and the redesign.

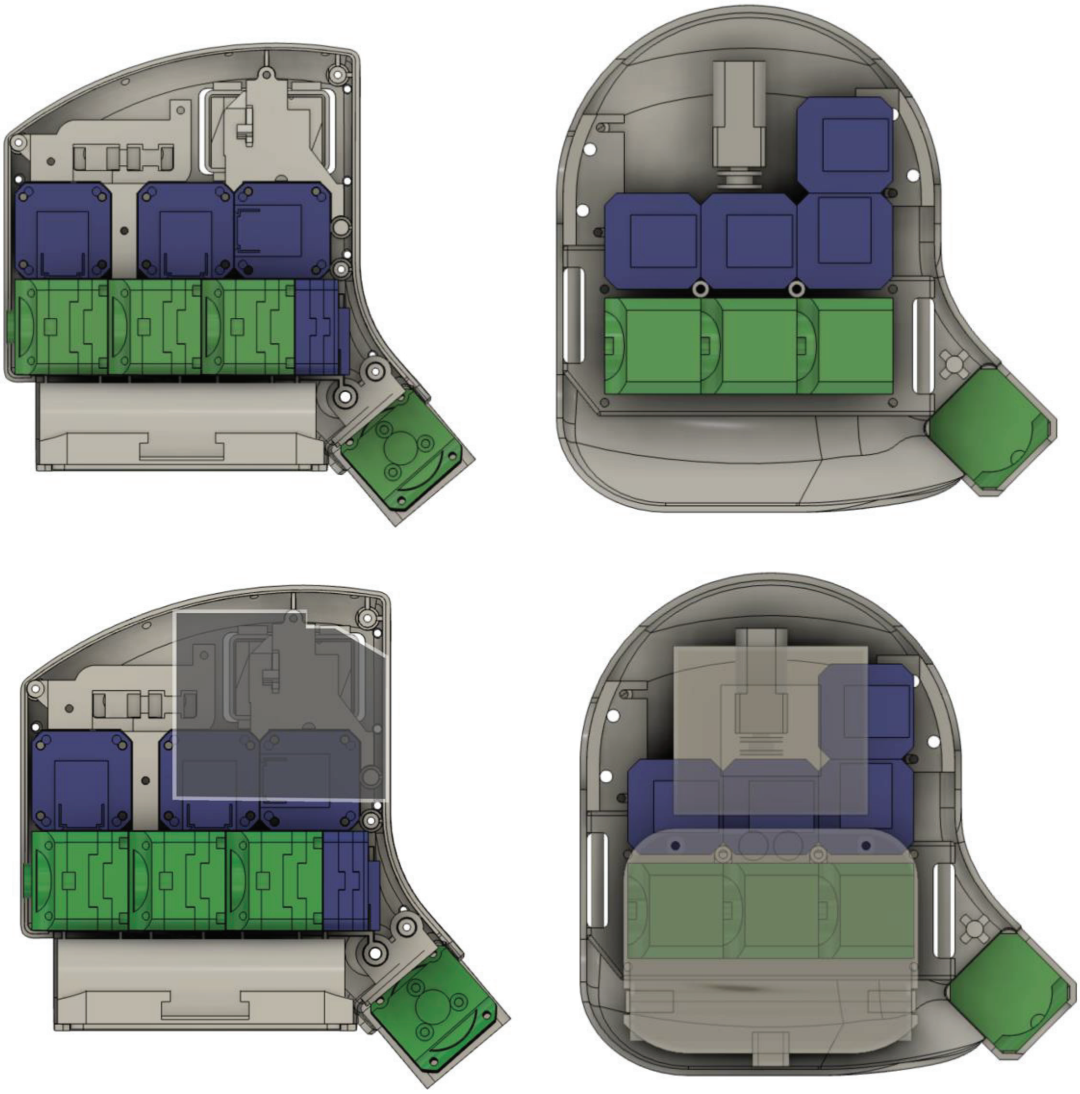


Figure 53 – Overview of new module configuration for Nova 2.0 (right) compared to original design (left). The new symmetric PCB configuration allows for modules to sit at about the same distance from their respective connectors, making the need for different cable lengths unnecessary, apart from the modules mounted in the thumb.

Vertical Assembly

On a broader level, assembly of the new Nova follows a bottom-up process, which requires less rotating of the Hub by the assembly worker during assembly. Previously, internal components would only be fixed in place once the top shell was placed, but this needed to be manually kept closed until the screws to fasten it were inserted from below. This required some dexterity from the assembly worker and could seriously set back progress if the shell were to accidentally come loose while upside down. The new design eliminates the need to rotate the Hub upside down during the process, as all screws are inserted from the top. In addition, all internal components are placed into the Hub vertically, not requiring any special actions from the worker and providing a clear overview of which steps have been completed and which still need to be done. Once the top shell is attached, all components are fixed in place and the Nova is essentially completely functional. As a bonus, this method of assembly allows all screws to be hidden inside the shell, showing no holes on the outside of the Hub. The so called 'beauty shell' (topmost part in Figure 54) is the final piece of assembly, which seals the shell and functions as a power button but does not serve any fastening purpose for the internal components. More about this is elaborated in Section *Design for Assembly* in *Phase 3*. In addition, the beauty shell is the only part of Nova which needs to be removed before the assembly workers can access any of the components inside, allowing for quick, non-destructive disassembly to be performed for repairs or troubleshooting. This contributes partially to an improved reduction in progress loss during assembly, which is further elaborated in the next Section. Figure 54 shows an exploded view of the redesigned Nova, which can be seen is completely structured vertically. Components are assembled mostly in the order shown from bottom to top (with exception of the force feedback modules, which come before the stringpots.). Though no screws are shown here, they are also added vertically and from above only.

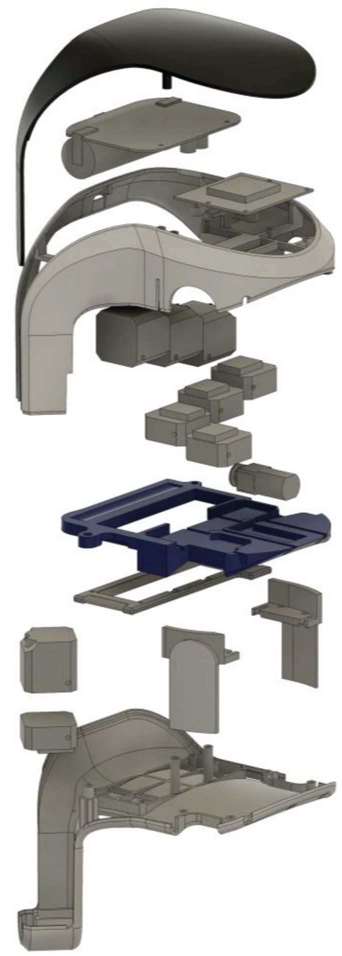


Figure 54 – Exploded view of the redesigned Nova, showing its vertical structure.

Reducing Progress Loss

As mentioned in the previous section, the vertical nature of the new Nova's assembly is that it provides easy access to components in case of disassembly. One issue that was a part of the original Nova was that a small mistake late in the assembly line could cause a significant loss in progress. For example, if the worker would accidentally cut the cables of a force feedback module during the trimming of the tubing, and it would retract into the module completely, not only would the Nova have to be (partially destructively) disassembled, but it would have to be disassembled to one of the earliest steps in the Hub assembly process, undoing almost two hours of work. This could be more if disassembly is done particularly roughly or there is no backlog of modules, requiring the assembly of a new one. This cascade effect of mistakes down the line undoing a lot of work should be minimized if Nova 2.0 is to be assembled faster. In order to achieve this, components should be able to be separately disassembled from the Hub without affecting others. It also means that disassembly should be possible nondestructively. To illustrate how this is implemented into the redesign, we can look at the process for both the original and new Nova (see Appendices H and I for a full overview), and see what the consequences are of the same error. The one that occurs most frequently and causes the biggest loss in time is a broken cable on a force feedback module during the trimming of the PTFE tubes. It is important to note, however, that this is no longer an assembly step in the redesign, so the probability of a cable being accidentally cut is extremely low. Therefore, to illustrate a worst-case scenario and to give the two designs the same scenario, we can analyze the effect of a force feedback cable breaking for an arbitrary reason after the final quality control step. First, Figure 55 shows what the consequences of this are for the original Nova, while Figure 56 shows what happens with the redesign. Table 4 compares the results.

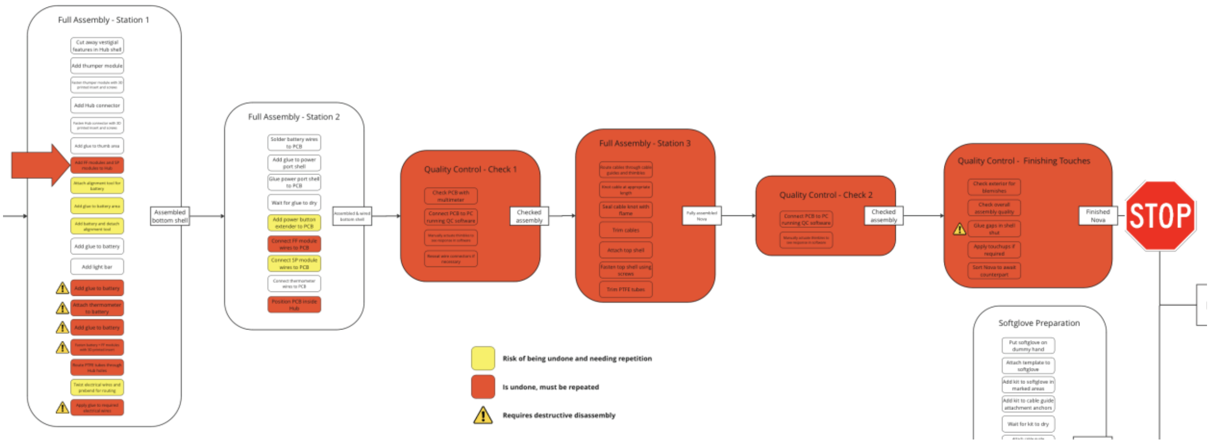


Figure 55 – Loss of progress in case of FF cable issue with original Nova.

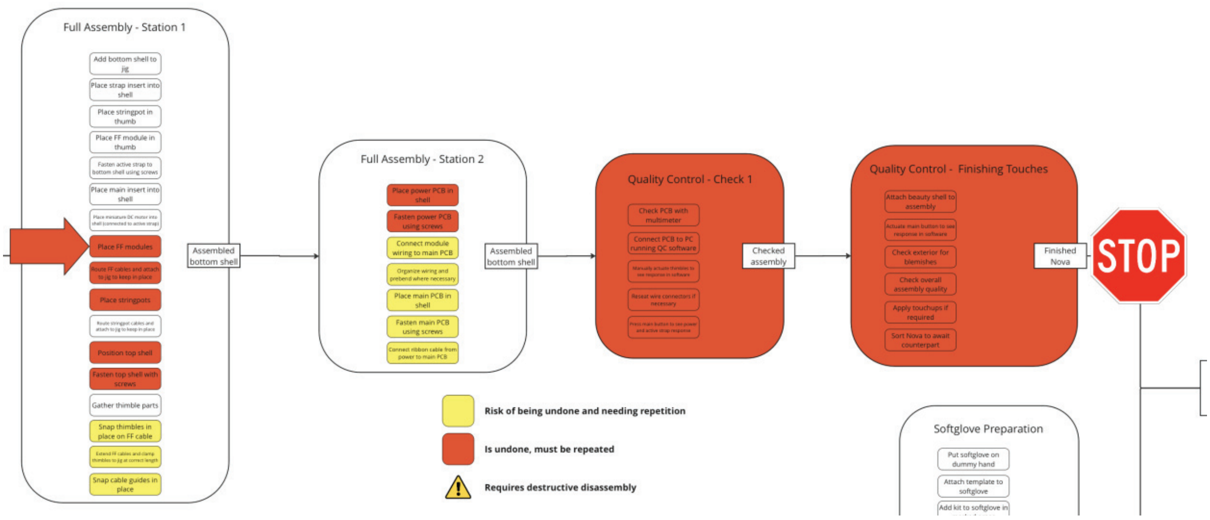


Figure 56 – Loss of progress in case of FF cable issue with redesigned Nova.

	Original	Redesign
Total step setback	40	28
Steps at risk of being undone	6	8
Steps guaranteed to be undone	27	18
Steps requiring destructive disassembly	6	0

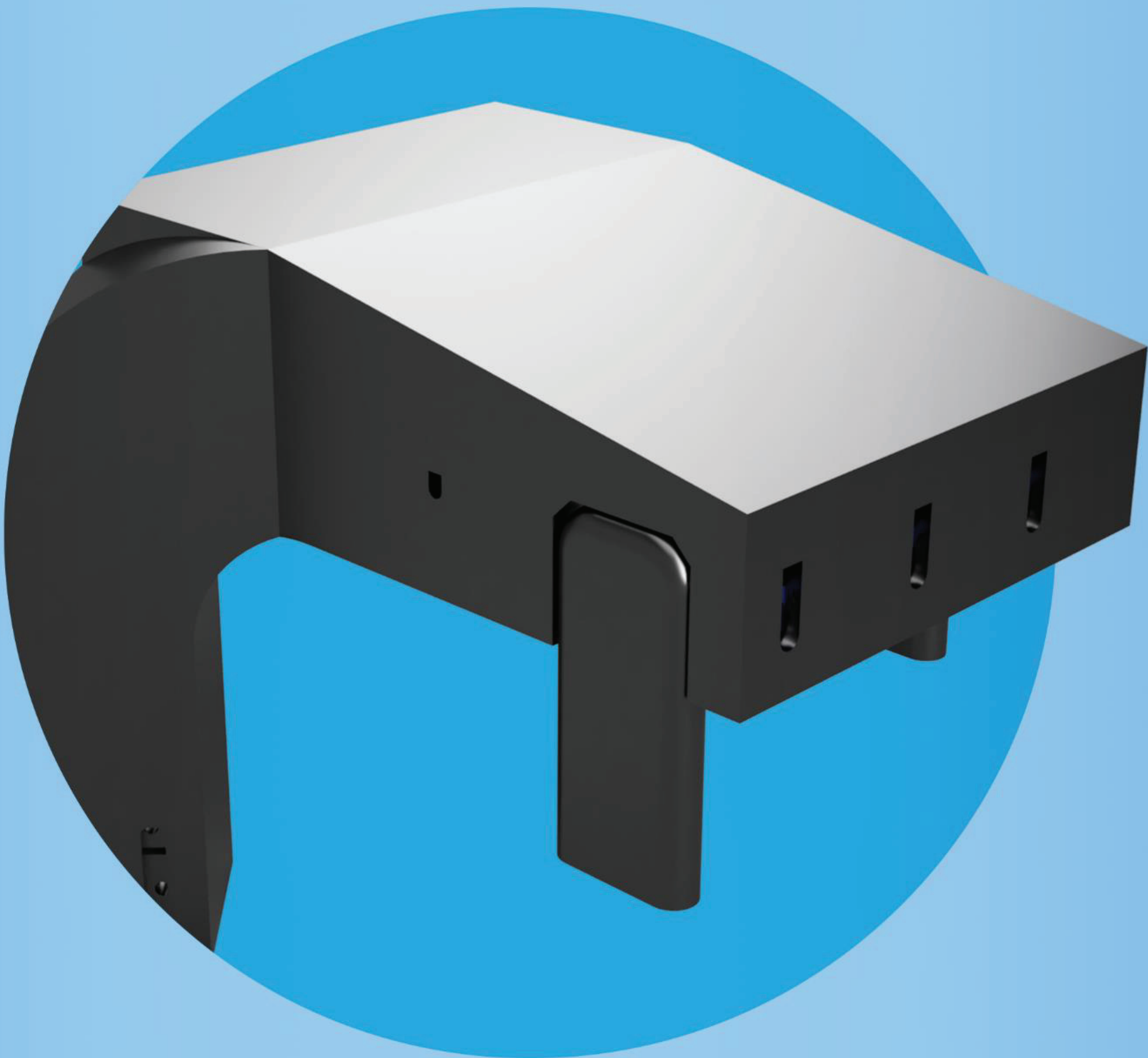
Table 4 – Loss of progress from FF cable failure between Nova versions compared.

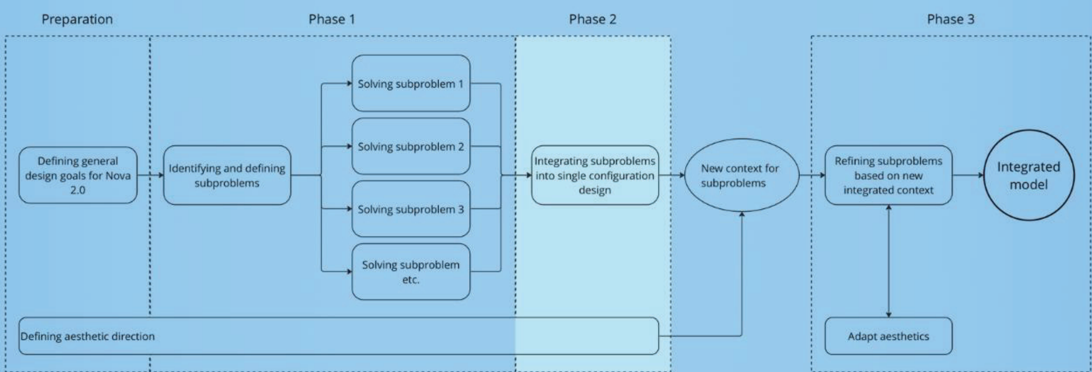
As can be seen from the previous Figures and Table 4, the consequences of a broken force feedback cable after final quality control are substantially less severe with the redesign than with the original Nova. Though there is still a loss of progress with the redesign, it should be noted that each step can be reversed nondestructively. This minimizes the risk of accidentally breaking an unaffected component and causing further progress loss. Though this is not an analysis based on actual time, it can be deducted from the fewer undone steps and lack of destructive disassembly that the redesign is better suited to handle setbacks such as this.

It is worth mentioning that the cable guides require reassembly with the redesigned Nova, unlike the original. While this may seem like an extra step that has to be redone, the snap fit cable guides are expected to take less effort than the originals, because those need to be carefully threaded and require tying a knot and sealing it. Even in the case that a cable guide breaks while disassembling the new Nova, its fast reapplication and low part count are expected to give it an advantage over the originals.

Phase 2

Configuration Model





Phase 2 – Configuration Model

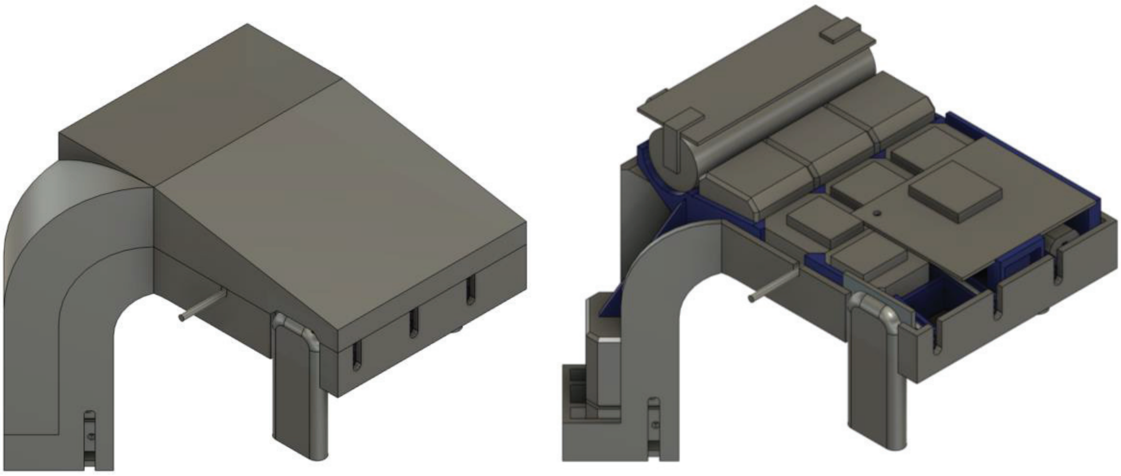


Figure 57 – Configuration model of Nova 2.0, without integrated aesthetics.

The subproblems mentioned before were solved in relative isolation, with only minor attention spent on how they would eventually come together in an integrated product that would be quick to assemble, aesthetically pleasing and compact. As a first step towards a fully integrated design, a model was made to test the configuration of all components combined and how it would impact the assembly and manufacturability.

As SenseGlove plans to injection mold the majority of components that form the Hub, the model was made with this manufacturing method in mind. This meant that, while draft angles were not yet implemented in all parts of the model, it should be easily adaptable for them. Pull direction and split lines were already being considered in this process, but not yet fully implemented with CAD, as this would cost a considerable amount of time without significantly influencing the insights that could be gained from the model.

Aesthetics were, as mentioned before, being developed in parallel with the creation of this configuration overview but were not implemented yet. Findings from this model did however provide insights in terms of possibilities regarding manufacturability and the position of features such as the new power port and redesigned cable exit holes, with the general shape still following the expected aesthetic direction, but superficial features such as curvature and color not being relevant at this stage. The model therefore gained the nickname 'Block Model' internally.

The following sections describe the model and show its most important features and the design choices involved, as well as an overview of the key takeaways that helped develop the Nova 2.0 concept further.

Configuration and Features

The configuration of the Phase 2 model was already largely indicative of the final design that would result from Phase 3; the findings from Phase 1 had shown that the layout of modules displayed in Figure 57 was near optimal, as it allowed the same functionality as Nova 1.0, but by routing the force feedback and stringpot cables underneath the internal components, friction points could be avoided, and the original PTFE tubes would become unnecessary. The main insert can already be seen fulfilling the function of keeping all the components in place, even the thumb mounted modules. Space would have to be made to accommodate the new active strap, so room for the miniaturized DC motor and the active strap attachment points would need to be cut out from the insert. To keep the main PCB in place, a single screw point was added, as well as some ribs to keep the PCB from rotating around it. The power PCB was in an early point of development, so a method of constraining it was not considered yet.

Figure 58 shows an exploded view of the entire model.

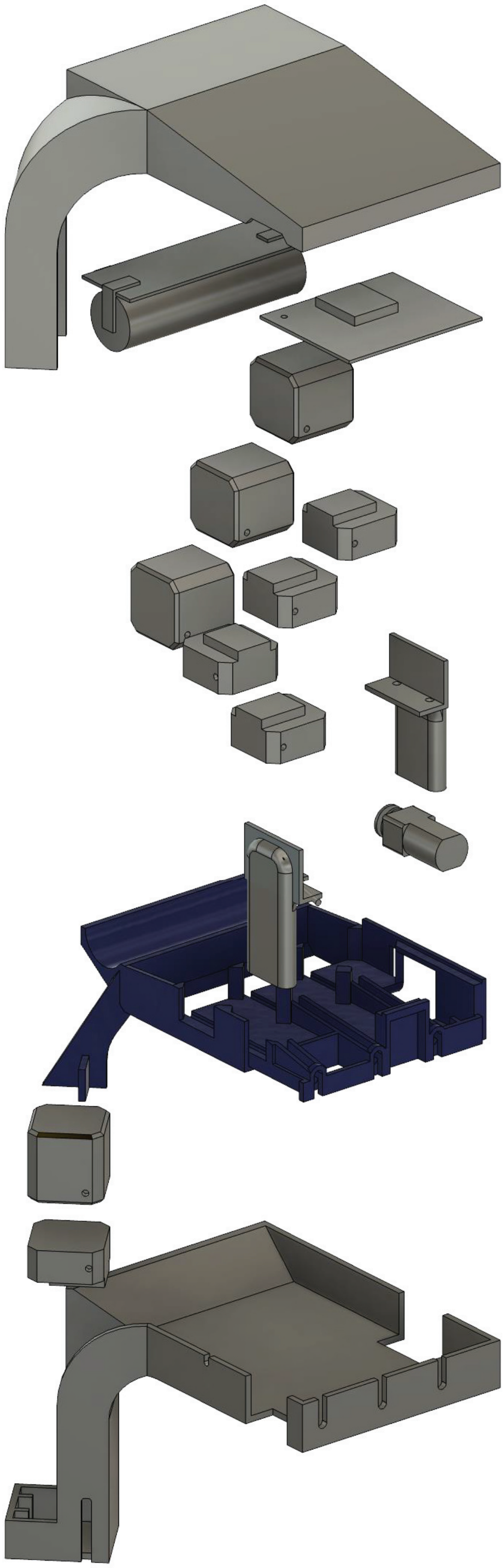


Figure 58 – Configuration of modules inside Configuration Model.

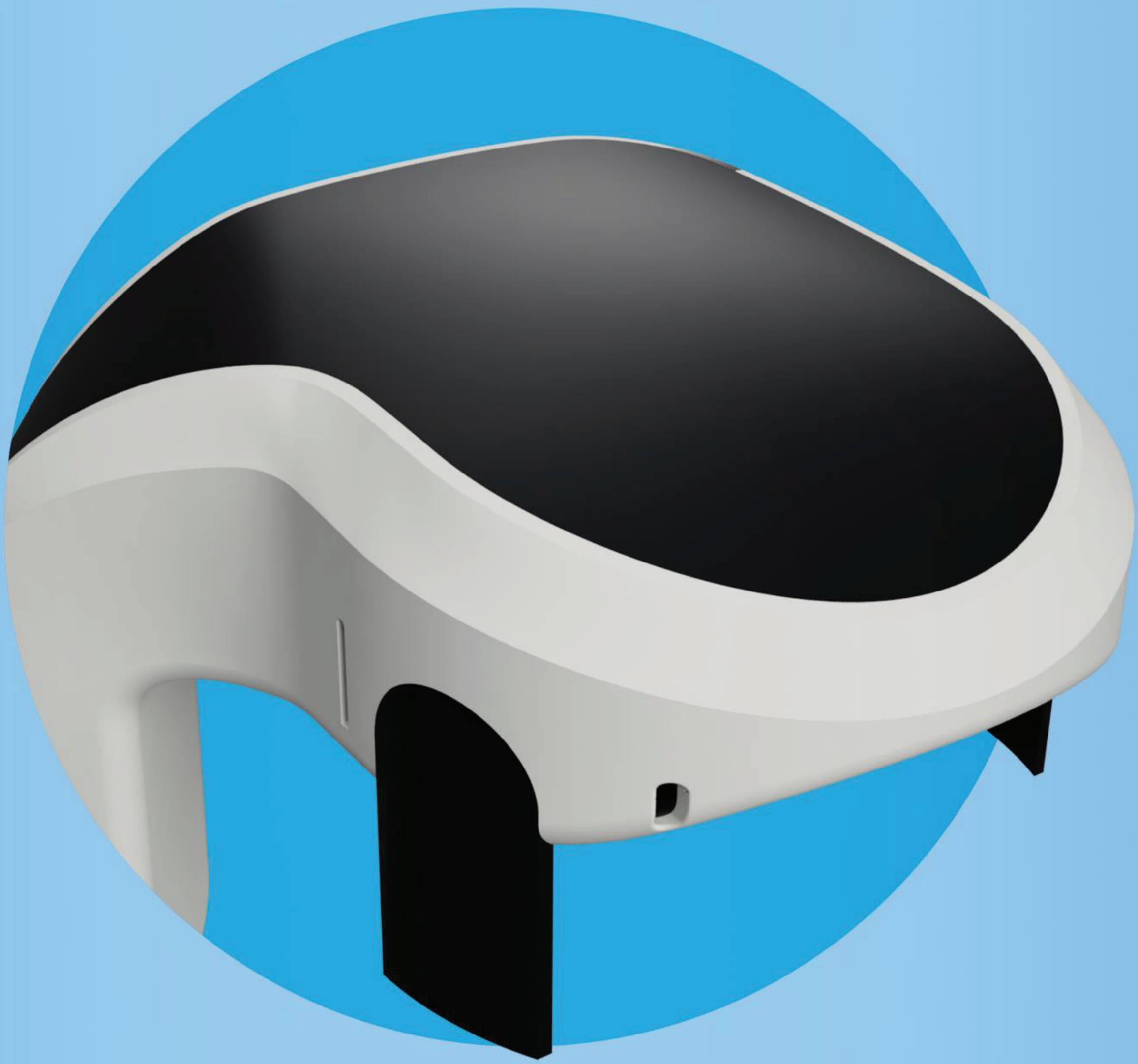
Key Takeaways

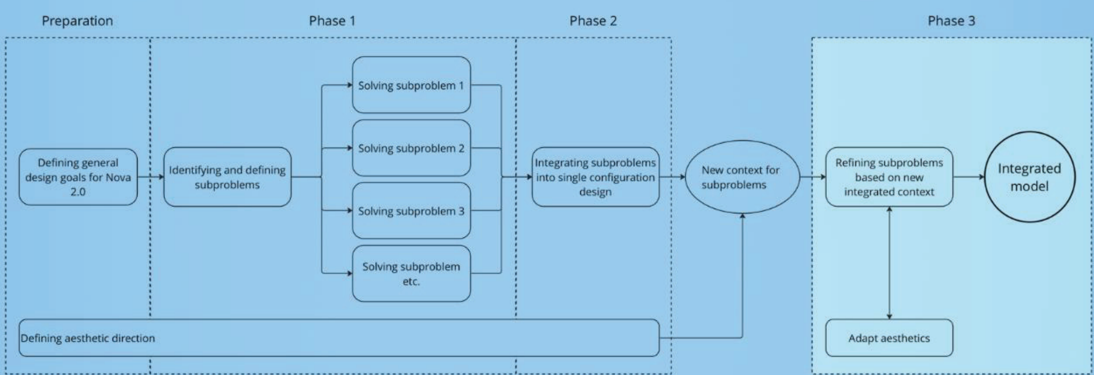
The configuration model gave a first view of how the integrated design of Nova 2.0 could look. Though many findings gave insight in how subproblems might need to be solved differently (which are already described in Phase 1) and how aesthetics would affect the configuration idea, a number of key takeaways could be listed that would advise the next steps in the design process. These were collected from reflection on the result and discussion with the SenseGlove design team.

Key Takeaways Configuration Model
Most components in the configuration model were not yet realistically constrained, missing some screw connections and shell features that would take additional space and whose position in the Hub could only be properly determined after the main form from the aesthetics development was applied.
Electrical wiring was not yet considered and was expected to take up significant additional space in the Hub.
The Configuration Model showed that a reduction in components was feasible by eliminating band-aid parts and unifying the types of modules needed per Nova.
The Configuration Model showed that the inverted force feedback module idea was feasible and desirable over the original design from an assembly perspective.
Additional symmetry could be achieved by redesigning the power PCB and main PCB layouts. This would eliminate the need for two different configurations for both Novas in a set, reducing cost and complexity.
The way the top and bottom shell would be fastened together was not yet clear, and would have to be carefully considered to keep assembly optimal and the aesthetics unaffected.
The Configuration Model was missing a power button and a way to tighten the active strap. Additional investigation of the optimal placement for this was required.

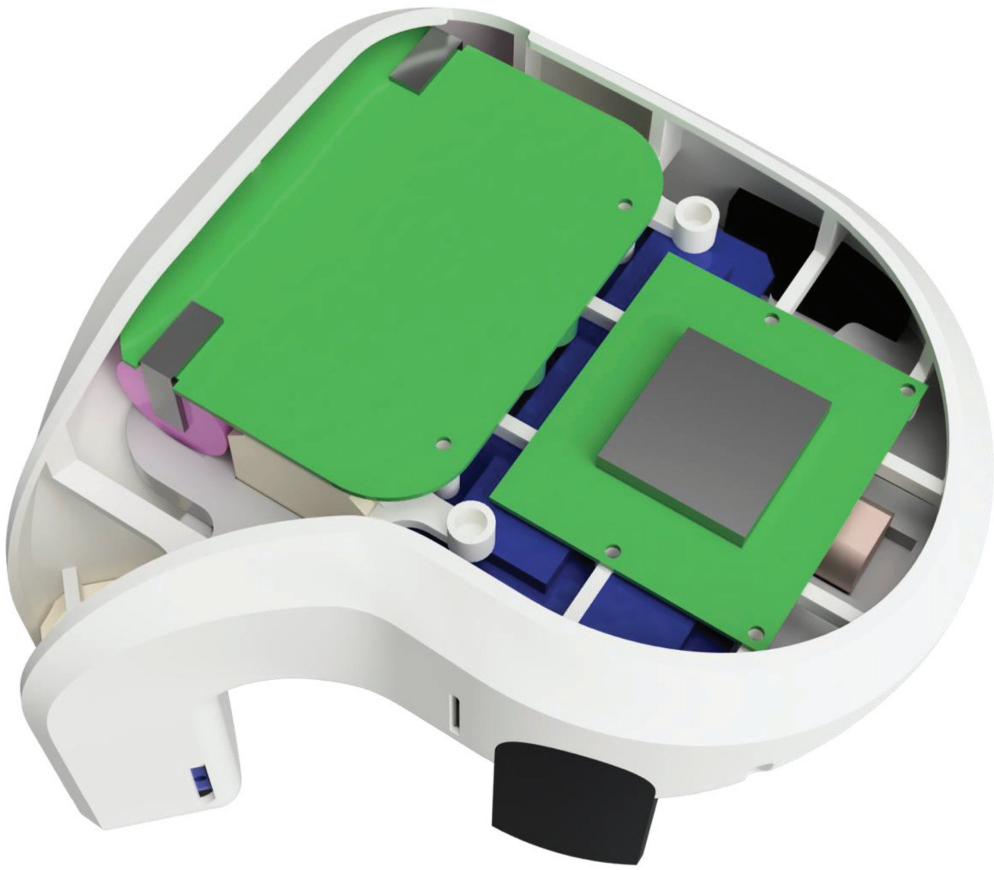
Phase 3

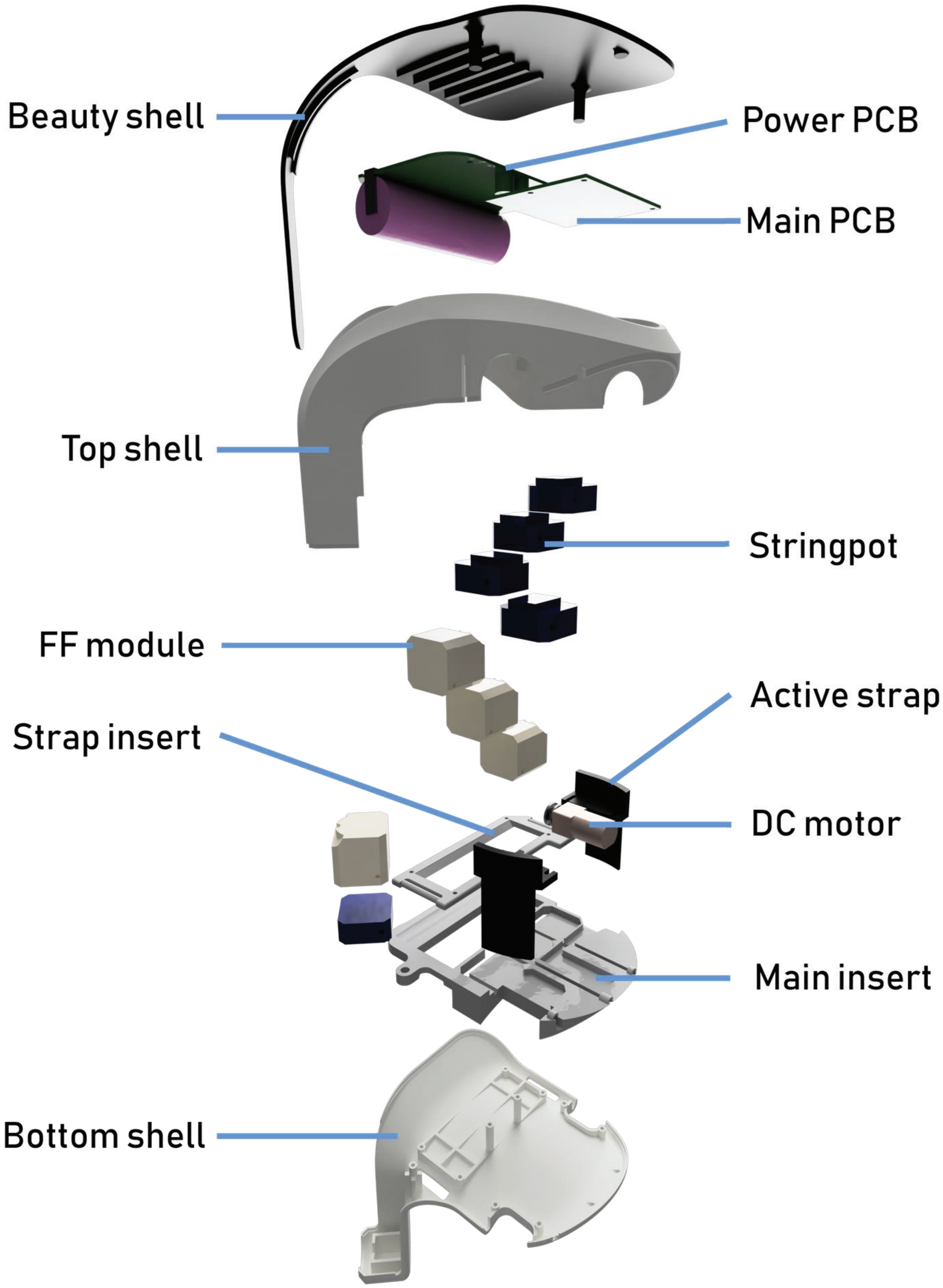
Integrated Aesthetics Model





Phase 3 – Integrated Aesthetics Model
Overview





Beauty shell
Power PCB
Main PCB
Top shell
Stringpot
FF module
Active strap
Strap insert
DC motor
Main insert
Bottom shell


mars

Aesthetics

Form

As can be read in Section *Defining Aesthetic Direction*, the overall shape of the redesigned Nova Hub is inspired by products collected during the creative branding session and VR equipment already available on the market, particularly the Pico 4 HMD. According to the Aesthetics development Phase, the device should have a basic shape that is rectangular, with both hard and soft lines integrated into the shape, specifically transitioning into each other. A combination between chamfers and fillets was used for this, with the parts most likely to touch the trainee's hands consisting of soft, rounded shapes and the top part contrasting against this with harder lines. To blend the shapes together, both rounded and sharp lines are used between them.

Some form choices were made from an ergonomic perspective; the rear of the Hub is tilted upward to make room for the trainee's wrist in the case they tilt their hand back (during a grabbing motion for example). This shape was based on the original Nova's wrist clearance, which was supported by research done by SenseGlove in the past. Similarly, the front of the device has been raised to make room for the trainee's knuckles, as the new rounded front of the Hub provides more overlap with the user's knuckles than the previous version, as can be seen in Figure 59 and 60.

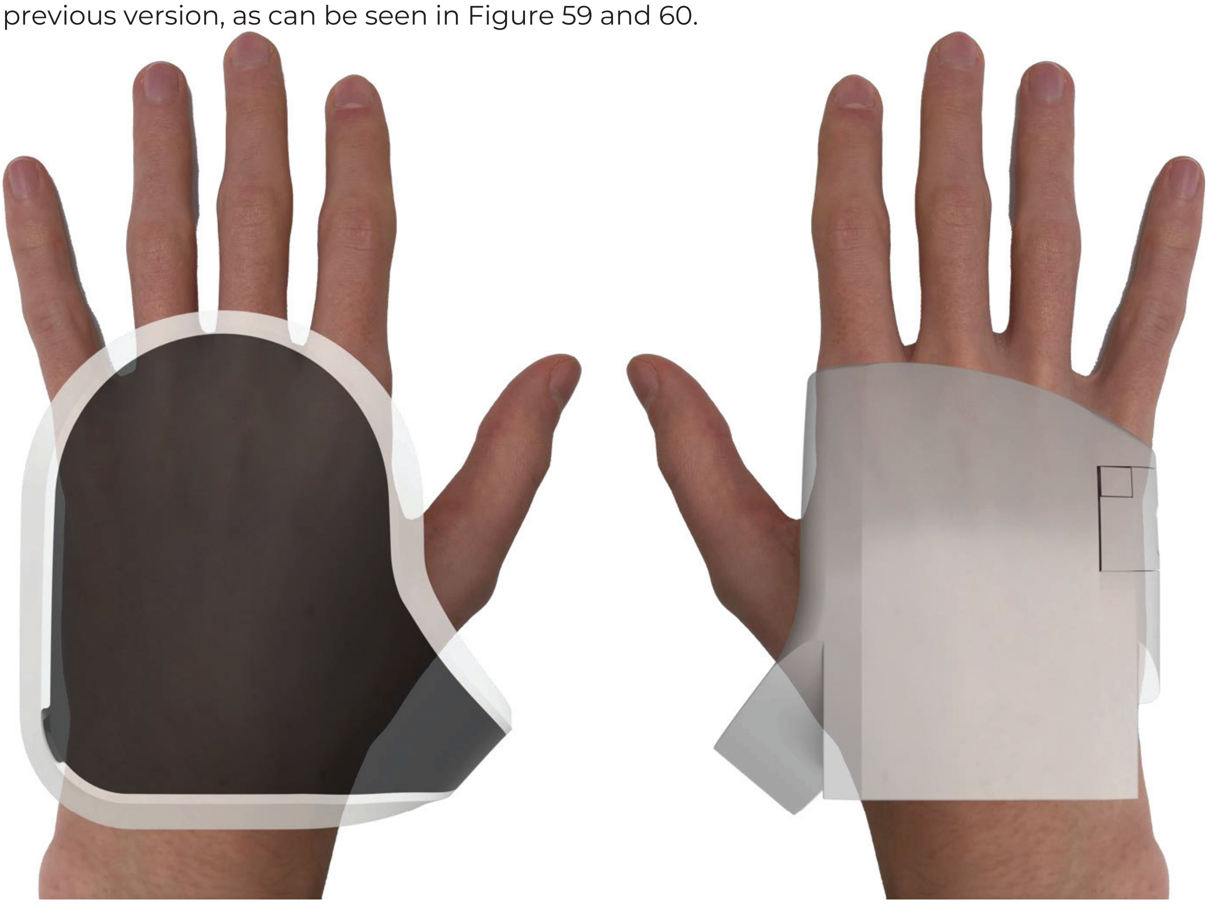


Figure 59 – Comparison of how Nova 2.0 overlaps the knuckles versus Nova 1.0. The increased length of the Hub is the result of new internal components and the rounded front as dictated by the aesthetic direction.

Figure 60 – Adjusted angles at the bottom of the Hub to make space for the trainee’s knuckles while keeping the shell’s length as required.

As the scope of this project did not extend to ergonomic research, instead, these adjustments to the overall form were made based on previous findings from Nova 1.0 and educated estimates of what would increase comfort. Some basic user testing was done to verify the ergonomics, but only internally and superficially to collect findings and work out the biggest problems.

Overall, the silhouette of the new Nova shell (Figure 61) is kept close to the original, but makes it more streamlined, suggesting a more integrated design while still being recognizable as the same product family. As with the ergonomic considerations, this part of the design process was done on a basic level to provide a general direction for the 2.0 design in order to keep the project scope manageable.

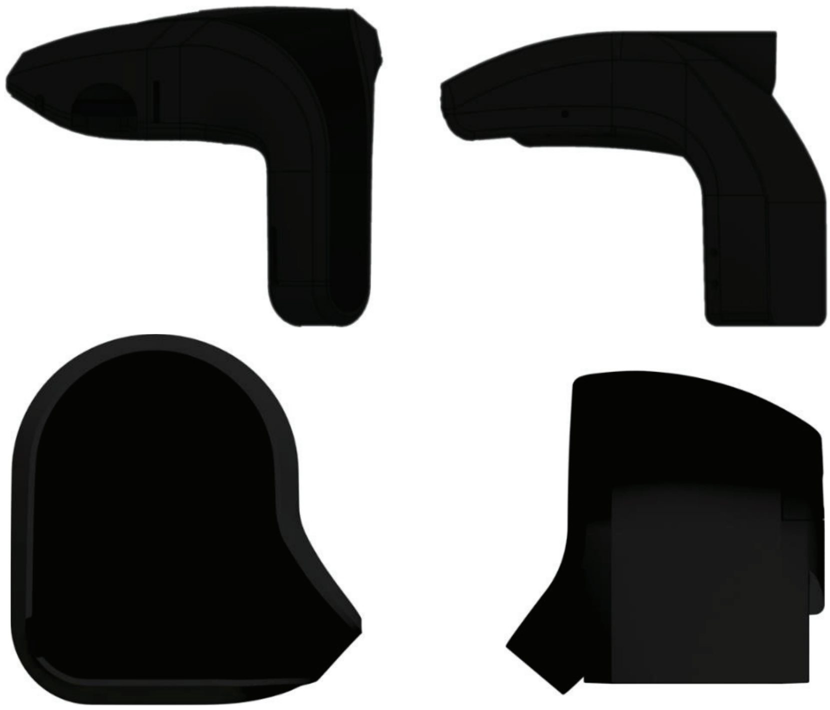


Figure 61 – Nova 2.0 and 1.0 silhouettes. In line with the aesthetic direction, the overall shape of Nova 2.0 has been kept simple and still mostly rectangular, with curvature in the corners instead of the sharp original shape.

CMF
As stated before in this report, the color, material and finish of the new Nova was largely chosen to have it fit in the market alongside other VR equipment, closely resembling the style of the Pico 4 HMD and those of other brands, sticking to the trend of either black or white being the most prominent color on those products.

In addition to fitting in alongside other products, the new CMF of Nova is also meant to represent the maturity of the design. Nova 1.0 was developed as a proof of concept rather than a full-fledged product ready to be sold and used by everyone. By approaching the aesthetics more from a user perspective, a device can be made that is both pleasant to look at and pleasant to touch. As with the colors, the finish of Nova is envisioned to bring it more in line with what is expected of a product of similar function in a comparable market segment. As Nova is meant to be the input device of the future, it is only appropriate to fit among other input devices. The next section describes the choices regarding the properties of Nova's shell.

Color
The new color direction for Nova is, like the new finish, a way to position Nova in the market as a product that is immediately recognizable as a 'device'. Especially alongside other VR devices, the strong contrast and desaturated colors are envisioned to draw comparisons to other products in a similar market segment. The goal is not to stand out as unique too much, as too much novelty may discourage potential clients from giving Nova a chance. Instead, it keeps Nova grounded in reality while showing it could look good alongside other VR equipment.

The specific colors are in this case an off-white (Signal White RAL 9003) and off-black (Graphite Black RAL 9011), shown in Figure 62. The reasoning for this is partially due to the aesthetics in the industry and preferences from the design team, but also greatly because the envisioned computer vision solution for Nova 2.0 requires specific conditions to work optimally: stark difference from the background, an easily identifiable top and bottom side, and strong internal contrast all contribute to a more reliable and accurate computer vision tracking experience. The choice to go for near-white and near-black instead of pure colors is to further offset the Nova from whatever background the trainee may find themselves in. Most walls are white, and black is difficult to track visually, as it represents the absence of light. Therefore, strong contrasting colors with a low reflectivity of the environment are envisioned for Nova 2.0. The next section elaborates on the low reflectivity of the shell, as well as what that texture might mean for user experience and aesthetics.

Figure 62 – Nova 2.0 color selection.

Material

In line with the direction SenseGlove wants to take Nova 2.0, the majority of the new components is envisioned to be injection molded. The current shell is made of ABS, as it provides good strength, stiffness and scratch resistance while being affordable. It is also a common material in the industry, being used for input devices of all kinds as seen in Figure 63.

Figure 63 – Many input devices use an ABS shell for its desirable properties and price. Left to right: Logitech G PRO mouse, Microsoft XBOX One controller, HTC Vive Pro controller.

Most components in this design project were developed with injection molding in mind, keeping into consideration the draft angle, wall thickness and pull direction, as well as features like fillets. One exception is the main insert, which, while containing moldable draft angles and pull direction, does not contain a uniform wall thickness, which would contribute to better injection moldability. This choice has been made because of two constraints: time management and relevance. The full completion of an injection moldable insert would take much extra project time that would not necessarily contribute to the functionality of the component. The main features that hold the other components in place are present, and the overall outer shape should not change much when developing the final, manufacturable version of Nova 2.0. Additionally, while the shell is not expected to be changed much, should SenseGlove implement the results of this project in their true 2.0 design, the modules are confirmed to be changed before its release. The overall configuration of the internals will remain roughly the same, but the insert will need to be adapted to the new module shape. This makes the detailed design of the insert less relevant at this stage in the 2.0 design, as the general principle and the functionality is already present. What this means for the main insert material is that it is envisioned to be made from ABS, but is likely to be 3D printed in a material like PLA for the time being. The shell comes closer to its final ABS injection molded design, but for prototyping purposes is SLS manufactured in Nylon (Figure 64).

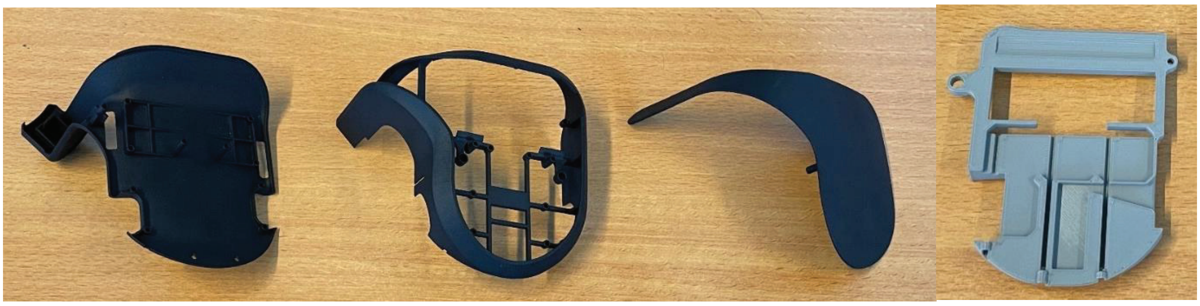


Figure 64 – Shell and main insert, prototyped using Nylon and PLA respectively. Both are envisioned to be injection molded, though the insert requires additional development before it is fully compatible with that manufacturing process.

The thimbles and cable guides are the components which received only a minor overhaul, taking into account its current manufacturing method and adapting the design to fit it. This means the material selection remains unchanged as ABS.

Finish

The main shell consists of the bottom and top shell, and will therefore be considered a single entity. In order to provide the Nova with a premium feeling outside with a pleasant touch, inspiration has been drawn from controllers used both for VR and regular computing tasks. They contain a relatively rough texture that provides grip without being uncomfortable and is not at all affected by fingerprints. Mild scratches that should occur from extensive use or an accidental drop should be difficult to spot on the texture, giving the product a long-lasting impression of being unblemished. This texture also prevents light from reflecting brightly off the surface and essentially turns it matte. This can be perceived as pleasant by observers, but also serves a purpose for computer vision, as mentioned in Section 'Color'. Figure 65 shows a product that contains the envisioned finish for the shell. This texture is estimated to roughly match MT9052, a texture that can be provided by MoldTec, SenseGlove's mold manufacturer, who has made a texture sample library available at the company for reference so the exact texture can be requested for manufacturing.

Figure 65 – Envisioned texture for Nova 2.0 top and bottom shell.

The beauty shell contains a similar but slightly less rough texture. The same qualities are relevant for this part of the shell, but for aesthetic reasons it is desirable to give the beauty shell a glossier finish without reflecting light too brightly. In this case, the component comes closer to refractivity, showing muted colors from its surroundings without reflecting objects that can confuse computer vision. As Nova might be placed upside down on a hard surface and the trainee is expected to press the power button while wearing thimbles, the beauty shell should also be resistant to scratching and mask those that do form, similar to the other shell components. The rough equivalent texture provided by MoldTec is MT-11000 (Figure 66).

Figure 66 – Envisioned finish for Nova 2.0 beauty shell.

Though the trainee does not touch Nova's exterior directly during use, the finish can contribute to a good first impression and an overall attractive aesthetic for the device. It also helps in communicating the quality of the product and draws a direct comparison to devices the trainee might already be familiar with, such as a gaming controller or remote. A good looking and feeling finish might also help sell the product to investors and clients for the same reasons and shows that attention to detail and care was put into the design of Nova 2.0, signifying a maturity in both the product and SenseGlove's design approach.

Reception

While the aesthetics for Nova 2.0 have been developed with specific goals in mind, little to no people outside of SenseGlove had seen a fully integrated visual model. As a way to verify whether the efforts in the aesthetics development process were effective, a full visual model was made and presented along with a digital questionnaire to various individuals who were fully independent from the project and had no prior experience with the Nova 2.0 model (and SenseGlove's portfolio in general).

The questionnaire was made with several goals in mind:

- Investigate whether the original moodboard was in line with the visual identity goals for SenseGlove and gather opinions on it
- Investigate whether the Nova 2.0 design was in line with the visual identity goals for SenseGlove and gather opinions on it
- Investigate whether the Nova 2.0 design matched the moodboard aesthetics, finding discrepancies between the previous two points
- Investigate whether the Nova 2.0 design visually fit amongst VR hardware commonly used in combination with it
- Gather general comments, opinions and remarks from individuals outside the project

Each goal was converted to a small collection of questions that was presented to the participants one section at a time. The majority of questions consisted of statements to which the participants could respond using a Likert Scale from 1 to 5, with 1 meaning that they strongly disagreed, and 5 that they strongly agreed. Each section ended with room for freeform responses, be it comments or explanations for previous answers. The full results of the questionnaire can be found in Appendix J, but they are discussed here.

The visual identity for SenseGlove's new Nova was first described in keywords as shown in Figure 8 of Section *Company Identity*. Though many words were listed, the most important ones were determined to be *refined, modern* and *comfortable*, as they were most directly related to product properties and easy to comprehend for participants. Words like *practical, immersive* and *sensible* are still relevant for SenseGlove's brand image, but need additional context before participants can form an opinion about them, like a physical demonstration or more in-depth knowledge about the value of Nova in the market. In addition to the aforementioned words, the desired 'wow'-factor that SenseGlove envisions for their products was tested as a 'boringness' value. The assumption here is that a product can look refined, modern and comfortable, but would still not exciting/attractive as would be perceived as boring. An optimal result would be a high score for refined, modern and comfortable, but a low score for boringness for both the moodboard and the Nova 2.0 design. The four descriptors were used to test participants' opinion about the moodboard first and any relevant input was requested as well.

Generally speaking, the moodboard was received well, being close to aligned with the optimal scores as mentioned earlier (see Figure 67). The only point of uncertainty is how comfortable the moodboard is perceived, as that score differed greatly per person. A possible explanation is that each participant had a different view on what comfortable products meant to them, or that the moodboard itself was not fully aligned in an aesthetic direction that was meant to evoke comfort due to the variety of product types displayed. Some quotes that show insight into these responses are:

"What I really like about this style is the mix of minimalism with texturized elements."

"The style looks very sleek and modern but does makes me feel like aesthetics were preferred over some functional behaviors."

"The mood board does seem like it's in line with other VR designs, but it's design seems terribly plastic-y."

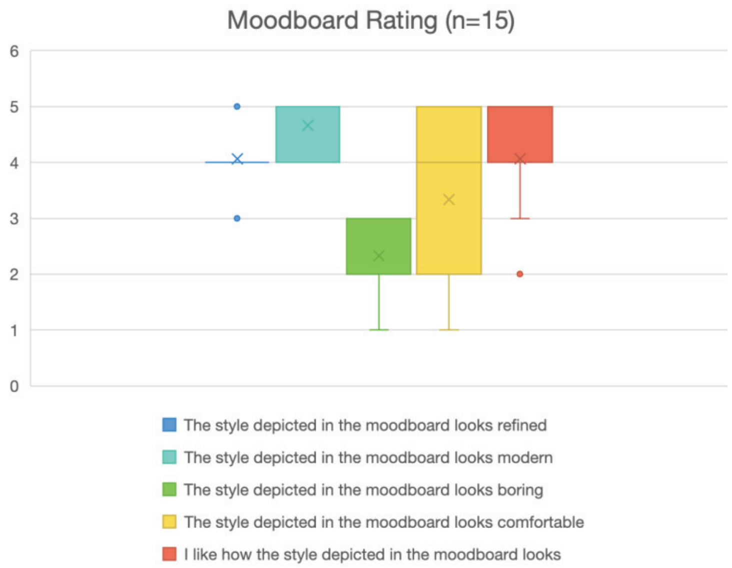


Figure 67 – Moodboard rating score.

The results for the design itself were less than optimal, with all scores dropping closer to neutral. Especially the score for modernity has spread more across the board (see Figure 68). To understand why this has happened, we can look at what participants had to say:

"Though the general shape of the solid structures is very sleek and refined. The black wires clash slightly with the clean aesthetic."

"Refinement is lost a little due to the visible strings and separate finger elements. It's the continuous flowing shapes that really emphasized refinement. Shape and color of the whole help counteract this, but not completely."

"The design for the resistance mechanism on the fingers looks sleek, but the exposed wires give the impression that they can be snagged easily when they're out in the open."

It seems the most prominent reason for a lower score are the exposed force feedback cables that interrupt the otherwise clean aesthetic of the Nova. Another point some participants mentioned is the apparent bulkiness of the Hub.

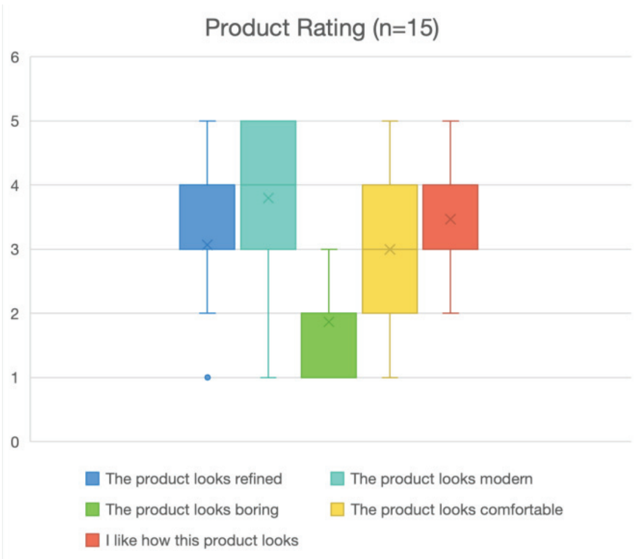


Figure 68 – Product rating score.

Looking at the points made before and the opinions participants shared about the moodboard and design, it is not unexpected that there is a discrepancy between the two that becomes apparent from the participant responses. When asked to compare the shape and colors of the moodboard and design, they rate the fit of the design within the moodboard as relatively low, more approaching a neutral opinion than agreement (see Figure 69). While this may seem like an undesirable result, it is actually in line with expectations; during the aesthetic direction development the moodboard was initially the prime source that dictated the form of the device, but in later stages it became increasingly important to have Nova fit among other VR hardware, shifting the direction away from the moodboard slightly to be more in line with what other companies in the industry chose to pursue. Some reasons given were:

"All devices in the moodboard seem wireless, the glove design has a lot of them."

"The style is mostly in line between the mood board and the glove design, however the coloring of the moodboard contains more saturated and muted types of grays compared to the stark contrast of the black/gray and white of the glove."

"The size and shape balance of the glove is different from the moodboard, but looking at the elements more individually, the shapes are the same style. The strong use of black is something that I see in the glove, but not the moodboard."

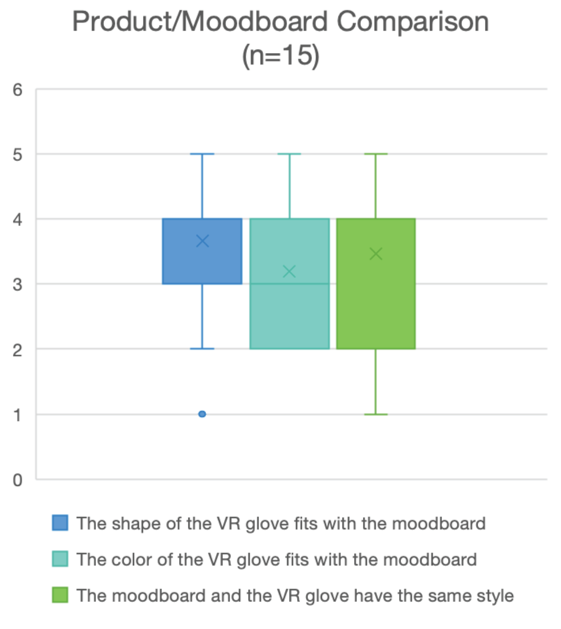


Figure 69 – Participant ratings of the design's fit in the moodboard.

The shift towards a more industry-alike aesthetic direction was expected to result in lower scores for the product-moodboard comparison, but whether it resulted in a successful implementation was to be tested. When presented with several images of commonly used HMDs along which Nova is expected to be used, it became clear that the fit was perceived as very good (Figure 70). All scores were averaged in the 4-5 range and showed high consistency, with most answers sitting around the same value. As SenseGlove desires visual compatibility with industry products and shifted the aesthetic direction there, this is a very desirable result. The participants had the following to say:

"I feel very strongly that the glove fits the design of the top right headset."

"The glove has similar dimensions, design elements and colors as the headsets. I would say it fits best with the top right headset with the color combo."

"Color and shape wise it feels like the design suits the headsets, but the headsets feel more carved out of a single shape. The glove, as stated before, feels more separate."

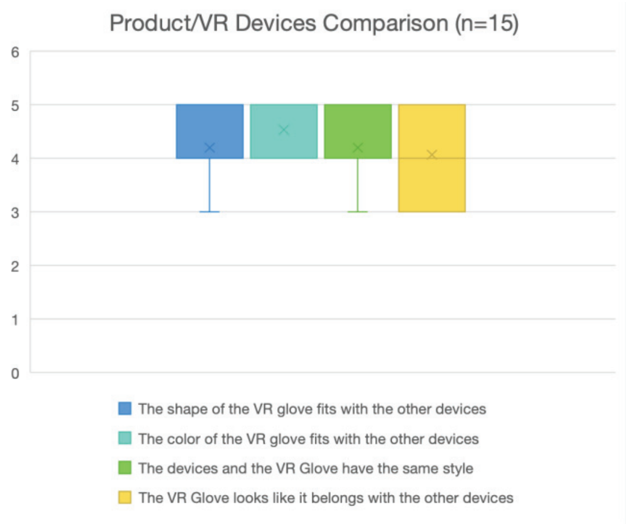


Figure 70 – Ratings from comparison with other VR devices (HMDs).

The top right headset mentioned frequently in the responses refers to the Pico 4, which is exactly the product Nova 2.0's aesthetic design was inspired by. This signals that the implementation of its aesthetics has been successful and, by the ratings of this section, that Nova 2.0 fits among VR hardware already present in the industry.

As a final request, participants were free to add any comments they might have and suggest any design changes they thought appropriate to improve the aesthetics of the Nova 2.0 design. The following quotes are most interesting to consider during the further development of Nova:

"Black wires look a bit do-it-yourself like. Maybe a way to hide them?"

"I would try and include an engraving of the name of the product/company somewhere in the black area. In small size should already be enough. Also, some lights that indicate the basic status of the product could be a great idea for ease of use and clarification for the users."

"I would reduce the size of the device on the back of the hand, it looks heavy. I would also try to integrate the white sensors of the fingers more into the glove. Additionally, the wires on the glove stand out too much against the grey glove, I would add some sort of pattern to the glove, to blend it in better."

These are all valid suggestions, some of which were already being considered as a recommendation to SenseGlove and can be further read about in Section *Recommendations*. It is clear that the envisioned refinement in the aesthetics is negatively affected by the visibility of the force feedback and stringpot cables. Several solutions to this can come to mind, but the visual requirements for computer vision may limit the design freedom in this regard. Careful consideration between aesthetic pleasantness and product functionality is needed to find a way to reduce cable visibility without compromising the visual tracking compatibility of Nova.

The results of this test show that the aesthetic design of Nova 2.0 is not entirely in line with the original direction as represented in the mood board, but still visually compatible with other VR hardware that may be used in combination with Nova. Though this may seem suboptimal, it actually shows that the change in direction during the aesthetics development is not only noticeable, but also successfully implemented, with participants across the board rating the design as highly visually compatible with the VR hardware. Though this is in line with the goals SenseGlove has for Nova 2.0, it should also be considered that participants liked the original moodboard aesthetic more than the Nova 2.0 design due to its refinement and simplicity. Especially necessary but unattractive features like the cables should be properly integrated into a final design to deliver a product that is visually appealing and in line with SenseGlove's goals.

Design for Assembly

Every subproblem described in Phase 1 has been solved with design for assembly in mind, and the Phase 2 configuration model brought the designs together into a largely integrated whole. Using the key findings from Phase 2 and some adjustments where needed, Phase 3 combined all findings and designs to make a preliminary model of Nova 2.0. Comparing the assembly process charts from Nova 1.0 and 2.0 side-by-side, one can see that fewer steps are involved, while also eliminating some assembly stations from the process completely. Figure 71 shows the charts together to compare the number of steps, but for a detailed overview please refer to Appendices H and I.

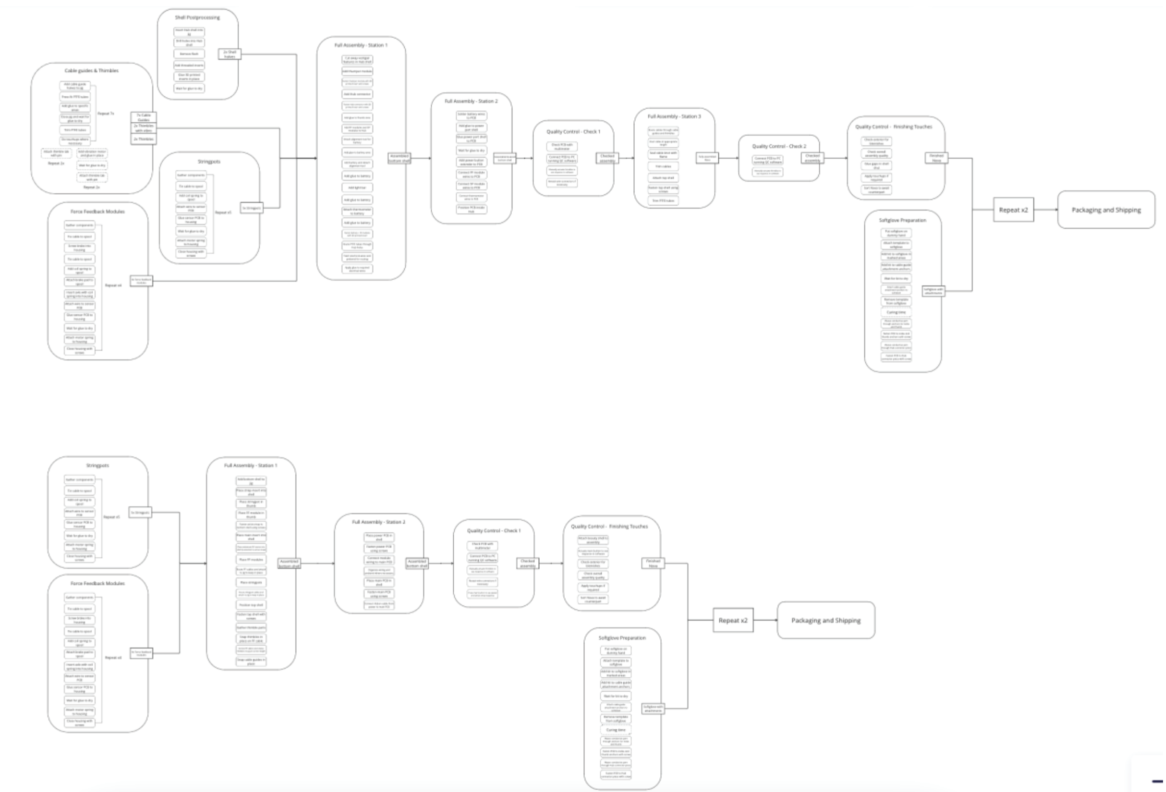


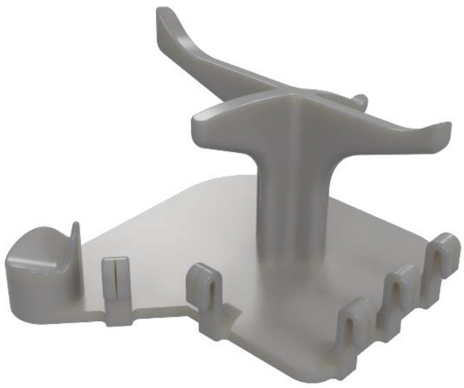
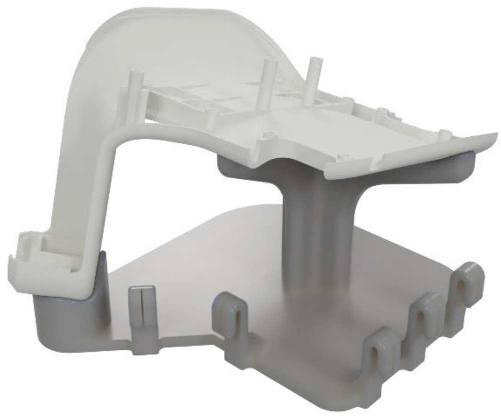
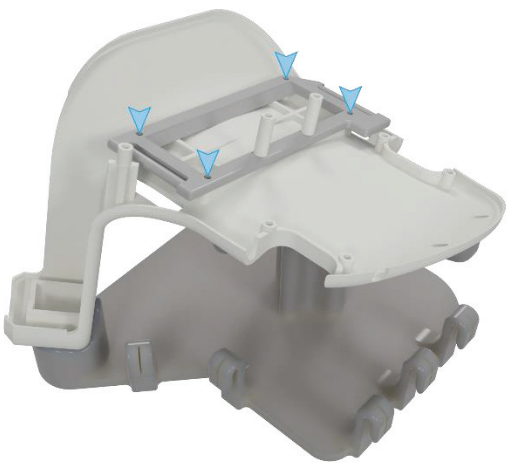
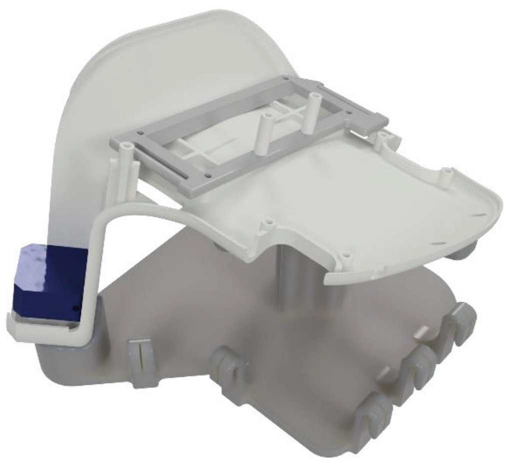
Figure 71 – Assembly process charts for Nova 1.0 (above) and Nova 2.0 (below). Note how several stations have been eliminated from the process altogether, namely the shell postprocessing station which has been made obsolete, and the cable guides & thimbles station being merged with Full Assembly. Though this image does not show the difference between the processes in detail, it is clear from a bird's eye view that fewer steps and stations are involved with Nova 2.0, potentially reducing the assembly time by a substantial amount.s

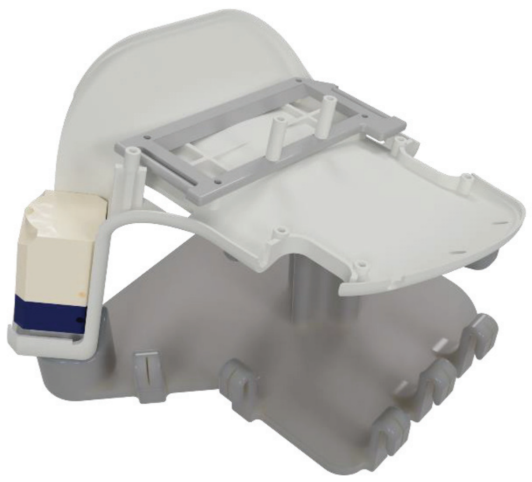
Step-by-Step Assembly

To facilitate easy and consistent assembly, a jig was designed that keeps the Hub in place while the worker places the internal components. In addition to keeping the Hub at a desirable angle (to prevent components from falling out before being fastened and to allow easy visual access to the inside of the shell), the jig contains several hooks behind which the worker can attach the force feedback and stringpot cables. This allows easy attachment of the cable guides and thimbles, as the hooks are designed to tension the cables in the correct order, requiring only the placement of the cable guide components over them. By mirroring the design, a right-hand counterpart can be produced. It is expected that the jig is 3D printed using the FDM machines present in the assembly office, likely from PLA or PETG. Because they are required in small quantities only, this is a suitable manufacturing method. Though the design is currently not optimized for FDM 3D printing, it requires only some support to be manufacturable. Further optimization can be done, but in order to prioritize the usefulness for assembly over FDM manufacturability, this has been minimally taken into account in this first iteration. In Figure 72, a render of the jig can be seen and it is used physically in the rest of the assembly overview in this Section.

Figure 72 –Assistive jig to keep the Hub in place and tension FF and stringpot cables during assembly.

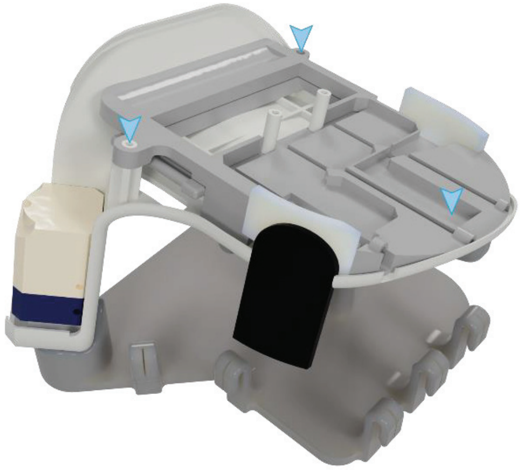
The rest of this section shows a visual overview of the assembly process in the Full Assembly stations 1 and 2 step-by-step. Where relevant, the Quality Control stations are indicated. As their assembly process is not relevant for the scope of this project, the modules are presented preassembled. *For clarity, cables and electrical wiring have been omitted, except for steps where they are specifically referenced.*

<table>
<tr><td colspan="2">Not pictured: Force Feedback Modules Assembly</td></tr>
<tr><td colspan="2">Not pictured: Stringpots Assembly</td></tr>
<tr><td colspan="2">Start of Full Assembly – Station 1</td></tr>
<tr><td></td><td></td></tr>
<tr><td>The assembly jig is placed on the table.</td><td>The bottom shell is added to the assembly jig.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>The strap insert is placed into the assembly jig and fastened with four screws. The strap comes pre-attached to the insert and is routed through the holes in the shell.</td><td>The thumb stringpot is added to the bottom shell. It is kept in place by form-fitting ribs in the shell.</td></tr>
</table>

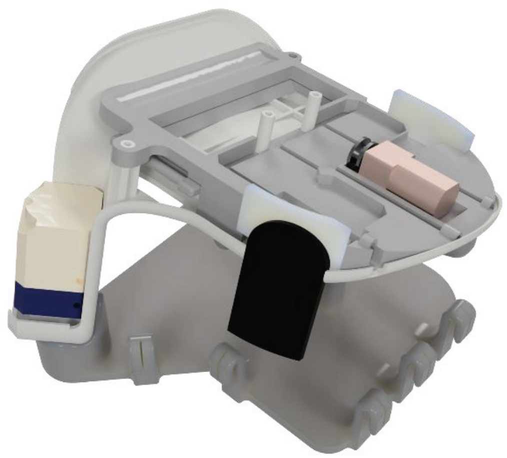


The thumb force feedback module is added to the shell. Through the slight tilt to the jig, gravity allows it to stay in place.

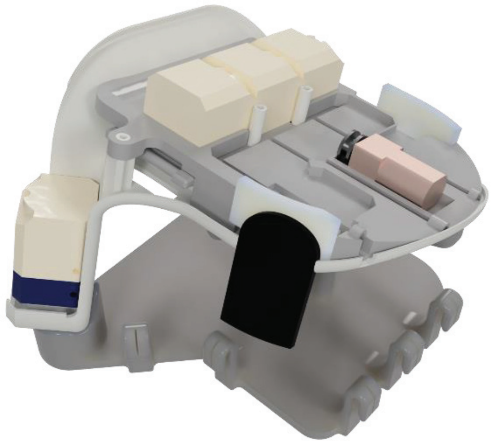
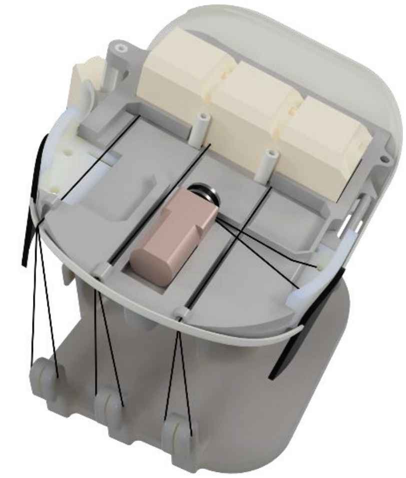
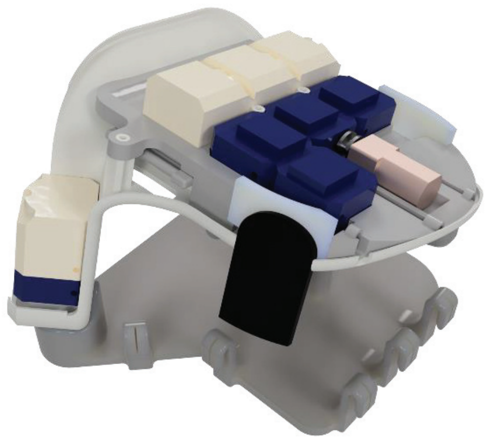
The active strap is added to the shell and fastened with four screws.

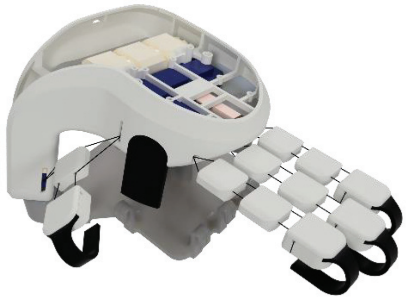
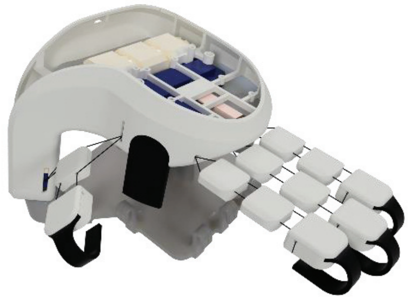
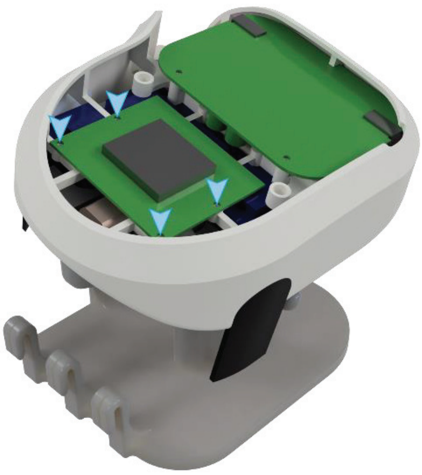


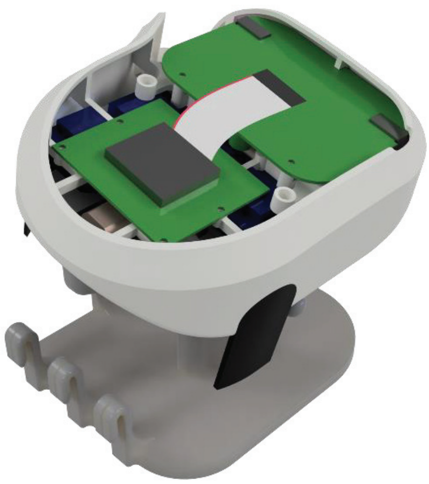
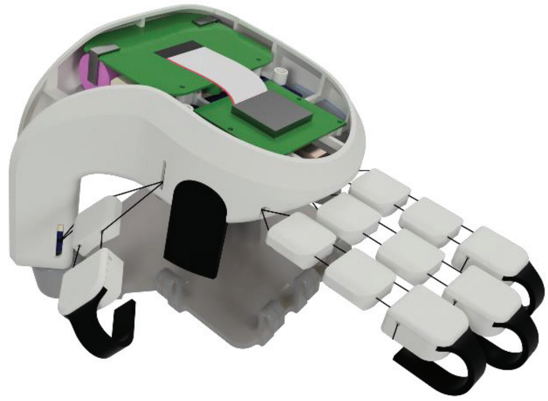
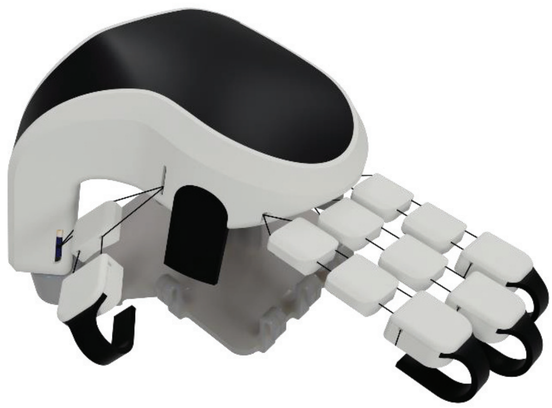
The main insert is added to the shell and fastened with three screws.



The miniature DC motor is added to the main insert whilst connected to the active strap with cables.

	
The force feedback modules are placed in the main insert.	The force feedback cable loops are routed through the main insert and kept in place by the hooks at the bottom of the jig. Note also that the active strap cables are routed to the miniature DC motor.
	
The stringpots are added to the main insert, facing the correct direction.	The stringpot cables are routed to their respective exits, being held in place in the middle of the hooks from small knots at their ends.

<table>
<tr><td></td><td></td></tr>
<tr><td>The top shell is added and fastened with four screws. Electrical wiring is organized through the shell and pre-bent where necessary.</td><td>The initial cable guides are snap-fit to the cables. Once they are on, the cables can no longer retract into the shell.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>The rest of the cable guides and thimbles are snapped in place.</td><td>End of Full Assembly – Station 1</td></tr>
<tr><td colspan="2">Start of Full Assembly – Station 2</td></tr>
<tr><td></td><td></td></tr>
<tr><td>The power PCB is placed in position and attached with two screws.</td><td>The main PCB is placed and attached with four screws.</td></tr>
</table>

<table>
<tr><td></td><td></td></tr>
<tr><td>Electrical wiring is connected to the appropriate PCB and a single ribbon cable is added to connect both PCBs together.</td><td>End of Full Assembly – Station 2</td></tr>
<tr><td colspan="2">Not pictured: Quality Control – Check 1</td></tr>
<tr><td colspan="2">Start of Quality Control – Finishing Touches</td></tr>
<tr><td></td><td></td></tr>
<tr><td>The beauty shell is attached, sealing the shell. Quality Control is performed.</td><td>End of Quality Control – Finishing touches.</td></tr>
<tr><td colspan="2">The Nova is finished.</td></tr>
</table>

Assembly Time

To determine the assembly time for the Nova 2.0 design, the prototype made in Phase 3 was equipped with non-functional but dimensionally accurate dummy models of all internal components except for electrical wiring and screws. Additionally, the jig concept as described in Section *Step-by-Step Assembly* was 3D printed. These models were then used in a time estimation test in which the designer and the head of assembly from SenseGlove went through the new assembly process step by step while comparing it to the original and physically replicating the actions required. The time specific steps took was recorded and in cases where it seemed reasonable to do so, extra time was added to the total to account for possible difficulties in the process or steps that could not be replicated with the prototype. As the Nova 2.0 assembly process consists of both new and reused assembly procedures (e.g., module assembly), some timings were derived directly from the original Nova process. In addition, several notes were made on possibilities for improvement, problematic steps and redesigns of the process. The full collection of notes can be found in Appendix K, though the content has been processed in the Discussion, Conclusions and Recommendations further in this report.

With the new time estimations as gathered from the test and the previous measurements from SenseGlove, a spreadsheet was made to calculate the totals, as well as apply margins where appropriate. These were specifically applied at the steps for Full Assembly stations 1 and 2, as these were completely new to the process and could not be derived from Nova 1.0's data. For Quality Control 1 and Finishing Touches, stations consisting of both existing and new steps, the original time was added to the estimated new time, as the process remained identical apart from the addition of the active strap feature to check. Based on the advice and experience from the head of assembly, a margin of 80% work efficiency was used to generate more realistic assembly times, as workers might choose to socialize or be involuntarily interrupted in their workflow during the day. As this factor was already taken into account for the original times, these did not need to be adjusted. Figure 73 shows to which parts of the new assembly process the factor was applied and Appendix L contains the full spreadsheet with times and calculations. As the times are meant to be estimates and cannot be measured with full precision until the design is manufactured and assembled in its final state, some values are rounded to allow a better overview.

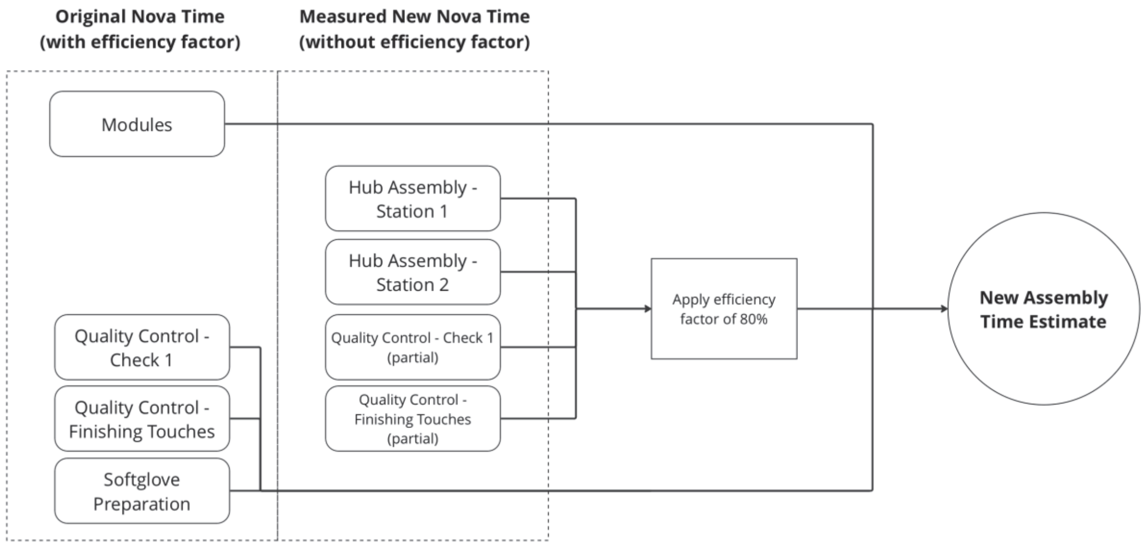
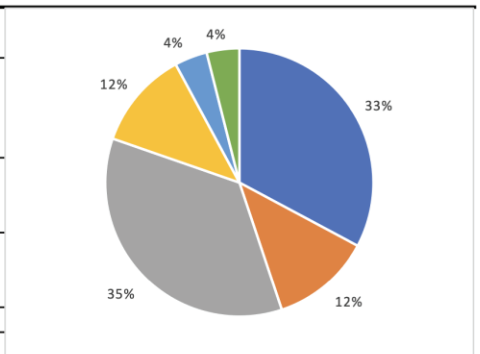


Figure 73 – Method for applying efficiency margins to generate realistic time estimation values for Nova 2.0 assembly.

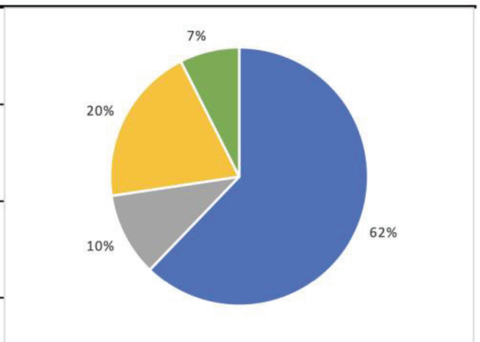
With the estimated times calculated, they were categorized and visualized in the same way as in Section *Nova's Assembly* for Nova 1.0 (Figure 74 shows a copy of this for clarity). As a result of design efforts as described in Section *Thimbles and Cable Guides* of *Phase 1*, the station for cable guide/thimble assembly was assimilated into the Full Assembly stations and Postprocessing was eliminated from the process completely. Figure 74 shows the new times and ratios per category compared to the original.

	Assembly Station/Step	Time per Nova (mins)
Modules	Force feedback modules	60
	Stringpot modules	65
Cable guides	Cable guides type AB	16
	Cable guides type BC	12
	Thimbles	8
	Thimbles with vibration	10
Hub Assembly	Full Assembly - Station 1	45
	Full Assembly - Station 2	45
	Full Assembly - Station 3	45
Quality control	Quality control - Check 1	15
	Quality control - Check 2	15
	Quality control - Finishing Touches	15
Postprocessing	Shell postprocessing	15
Softglove preparation	Softglove preparation (excluding curing time)	15



Total assembly time (1 Nova):
381 minutes or 6,35 hours

	Assembly Station/Step	Time per Nova (mins)
Modules	Force feedback modules	60
	Stringpot modules	65
Hub Assembly	Full Assembly - Station 1	12
	Full Assembly - Station 2	9
Quality control	Quality control - Check 1	20
	Quality control - Finishing Touches	20
Softglove preparation	Softglove preparation (excluding curing time)	15



Total assembly time (1 Nova):
201 minutes or 3,35 hours

Figure 74 – Above: Original Nova assembly times and ratios. Below: Nova 2.0 estimated assembly times and ratios. Both display the times estimated for one Nova.

As can be seen in Figure 74, the elimination of several stations and the time reduction in Hub Assembly seems to have significantly improved the required time to assemble one Nova. As a result, the ratios of time have changed, with the modules taking approximately 62% of the total time, over the previous 33%. To see the differences per station category, please refer to Figure 75.

Assembly Category	Nova 1.0 Time (minutes)	Nova 2.0 Time (minutes)	Difference (minutes)
Modules	125	125	0
Cable Guides	46	0	46
Hub Assembly	135	21	114
Quality Control	45	40	5
Postprocessing	15	0	15
Softglove preparation	15	15	0
Total	381	201	180
Ratio	100%	52,76%	

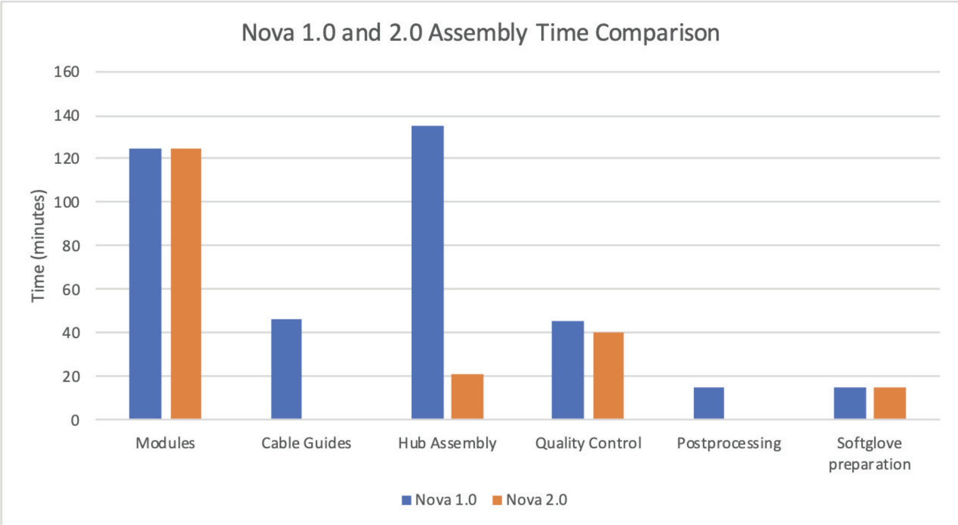


Figure 75 – Comparison between original and new assembly times per assembly station category.

As can be seen in the above Figure, the most significant improvement sits with the Hub Assembly time, with an estimated reduction to about 16% of the original. Combining this with the elimination of the second Quality Control, Cable Guides and Postprocessing stations, the new assembly process is estimated to take about 53% of the original time.

Benefits of DFA Principles

It is estimated that the largest gains in assembly time are won with the Poka Yoke principle of elimination, both through direct and indirect design choices. Eliminating time consuming steps such as gluing and soldering has removed several tedious tasks from the assembly process without sacrificing product function. The removal of the internal PTFE tubing for cable routing has simultaneously resulted in a simpler internal configuration with a clear vertical structure that is quicker to assemble, but also eliminates the requirement to manually guide the tubes around electrical wiring, which can be time intensive. These are directly designed changes to the Hub, but there are also some choices that have indirectly but beneficially impacted the assembly time. An example is the thimbles and cable guides, which have been adjusted for faster and easier assembly, but as a result of this can be added to the Hub during Full Assembly Station 1, eliminating the need for a separate station. This was initially not an intended improvement, but during the development of the new process, this became apparent as a desirable option. To put into perspective how much time this can save: the full assembly of the Hub including cable guides is now expected to take half the time it took to originally assemble the cable guides only.

Additionally, the elimination of band-aid parts and post processing as a result of design oversights has a great effect on the Hub assembly time; the old process of predrilling holes into the shell and adding the gap closer component as mentioned in Section *Part Count Minimization* saves approximately 15 minutes. The substitution of several smaller inserts with one large multifunctional one is also expected to be a time saver that simultaneously makes the internal configuration easier to comprehend for assembly workers. The three-part shell concept also allows the workers to run Quality Control tests on the Nova before it is closed and made inaccessible. This removes the need of an additional QC check before closing the top shell, as the Nova is fully functional after Full Assembly Station 2 while still allowing access to the main and battery PCB. The addition of the beauty shell is considered a part of Quality Control – Finishing Touches as this is an almost entirely cosmetic component that allows the trainee to easily access the power button but is not required for Nova to function properly. In theory, Nova 2.0 is finished on a functional level after Full Assembly Station 2 and only needs to be checked before being ready for packaging.

Not considering the time improvements, the new process still contains valuable benefits: the vertical assembly should be easy to comprehend and allows for minimally intrusive repairs without any destructive disassembly. As Section *Reducing Progress Loss* showed, even a worst-case scenario force feedback cable malfunction can be repaired with relative ease when compared to the original Nova process. This might improve assembly time in the way that there is less time spent on repairs, which then becomes available for increased production.

One field in which the assembly could still be improved is the internal modules. In the current design, these are assembled in an identical way to Nova 1.0, albeit with a slightly altered configuration per glove. Their method of assembly and the required management of electrical wiring during installation is expected to be a bottleneck where a lot of time can still be gained (this takes 62% of assembly time with the new design). Due to the scope of this project, this has not been addressed yet and would require additional design efforts. Though the improvement of the modules can be done separately from the Hub design, it is important to remember that the Hub and its assembly process are largely dependent on both the dimensions and configuration of the internal modules. Any change to this would likely require either adjustments to the shell and main insert or a full bottom-up redesign to keep the beneficial assembly principles gained with the current concept in place.

Considerations and Preliminary Conclusion

It is important to note that these time estimates are the result of a single session with two individuals, one of which had extensive knowledge of the assembly process for this particular design, and contains a combination of time measurements and estimates based on previous experience with Nova's assembly. While the values represented here are rounded up where possible and have an additional efficiency factor applied, they are not based on a working, finished product and are representative to the extent that they offer a general estimation of the new assembly time, not a definitive measurement.

The aforementioned considered, the results do show that the goal to reach 60% of the original assembly time is expected to be realistically achievable, if not a guarantee with this design. Of course, if the final Nova 2.0 based on the current proposal has been manufactured, a second test with functional components needs to be conducted to verify this and see if there are any previously unknown factors that affect assembly time. In any case, the adjusted process as a result of DFA choices for Nova 2.0 clearly shows improvement over the original.

Manufacturability

While Nova 2.0's concept has been designed with easy adaptability for manufacturing in mind, a more in-depth analysis of the CAD package was required to draw valid conclusions about its manufacturability and find areas that needed improvement before a final version can be developed. As the design of the modules is out of scope for this project and the main insert is not embodied to the point where such a test is relevant yet, the manufacturability analysis was conducted with the most complex injection-molded component of the design: the shell. With input from SenseGlove's CTO (responsible for Nova 1.0's factory-ready design) and the use of SolidWorks' analysis tools, several minor and critical improvement points have been identified that need addressing before the shell components can be manufactured. The full transcript of the session is available in Appendix M.

Before the start of the session, several questions were composed which were related to the requirements for good injection molding design as referenced early on in the project from Hubs' Injection Molding: The Definitive Engineering Guide (n.d.). Specifically, material flow, cooling, draft angles, and placement of ejector pins were the main points of interest, but additional comments and a price estimate were also discussed.

Material Flow and Cooling

While the creation of the shell was done with injection molding rules-of-thumb in mind, before manufacturing this process would need to be redone with emphasized care to follow the molding design guidelines. While the basics of injection molding compatible design have been implemented, on a detail level the model would not be manufacturable in its current state. Looking at material flow and cooling rates, a main issue became apparent in the analysis of the shell; where ribs were placed to add stiffness or connect features, the wall thickness would often be constant, causing the transition between walls to have an inappropriate thickness that can result in non-uniform cooling and therefore warping. This can happen on a visible level, but also introduce invisible internal stresses that may cause issues when assembling the device or when an unexpected force is applied. Though the rules-of-thumb approach has resulted in a model with a mostly desirable wall thickness across the larger areas of the design, internal ribs and features proved in need of small adjustments before being properly manufacturable. This counted for the beauty shell as well. Figure 76 shows a screenshot of the wall thickness analysis for the bottom shell.

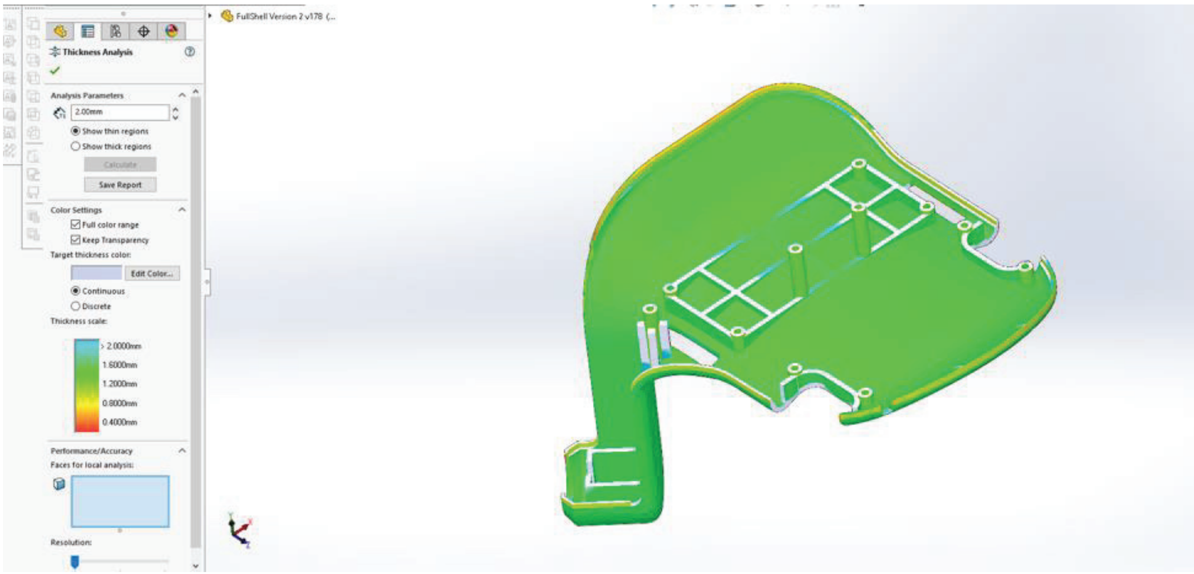


Figure 76 – Wall thickness analysis of the bottom shell, containing the most prominent ribs. Green surfaces indicate a desirable wall thickness of 1.5mm, while white and blue surfaces indicate possible problematic areas that are larger than that. Note that the transitions between walls contain the most problematic regions, as their combined thickness exceeds the optimal dimension by a significant margin.

In areas where a reduction in wall thickness would not be possible, the expert recommended removing material to maintain part stiffness while ensuring proper material flow and cooling could take place. The top shell in particular contained such areas, which are shown in blue in Figure 77.

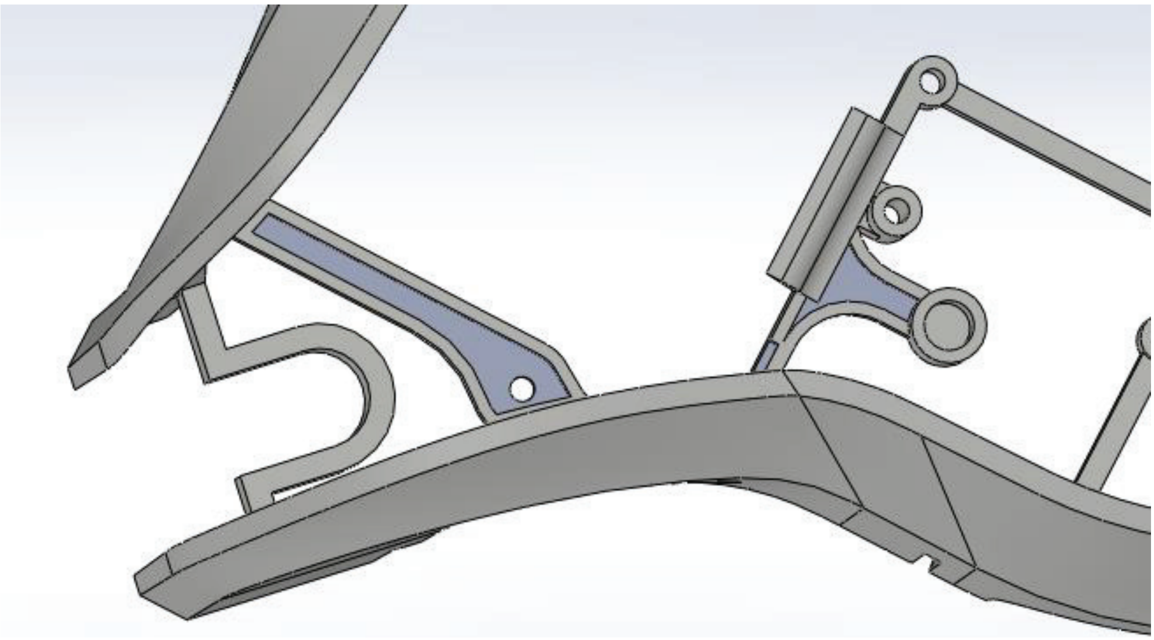


Figure 77 – Marked in blue: some areas where material might be removed to improve wall thickness while maintaining structural integrity.

Draft Angles

As stated before in this report, the CAD model of Nova 2.0 was meant to be realistically adaptable for injection molding, but not directly compatible. This is also the case for the draft angles; care has been taken to prevent overhangs and undercuts, but specific draft angles have been omitted, instead leaving walls perpendicular to the pull direction so they can be adapted or recreated easily before manufacturing. Like the thickness analysis in the previous section, a draft analysis was conducted by the expert and comments were collected as recommendations for the next design iteration.

The draft analysis showed that the majority of each of the parts was draftable, but some areas showed problems that would make manufacturing in the current state impossible. Namely, the curvature from the top of the Hub to the thumb part showed to cause some issues, as the lofted feature there generated some spots with negative draft angles (see Figure 78). A second design iteration could eliminate these issues, but due to the complexity of the curvature and the length of the thumb part, this might take some clever design to achieve. The bottom shell would be fully draftable, apart from a miniscule area near the back part of the component, caused similarly by the shape transition between the Hub and thumb area (see Figure 79).

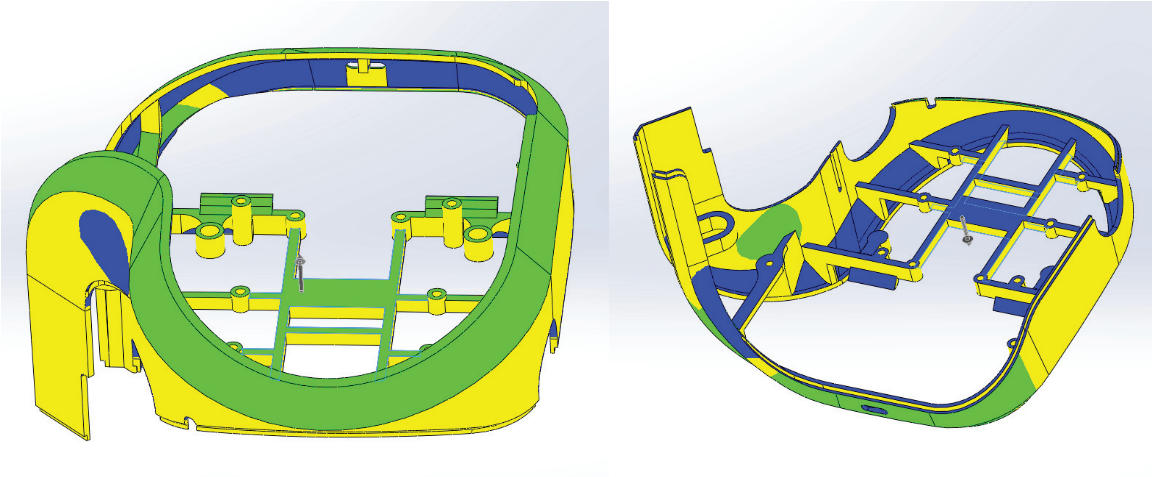


Figure 78 – Draft angle analysis of the top shell. Based on an upward vertical pull direction, green areas mark positive draft angles, yellow marks perpendicular areas (no draft angles), and blue marks negative angles. Note the spot of opposite colors near the front of the thumb; this is a non-draftable area.

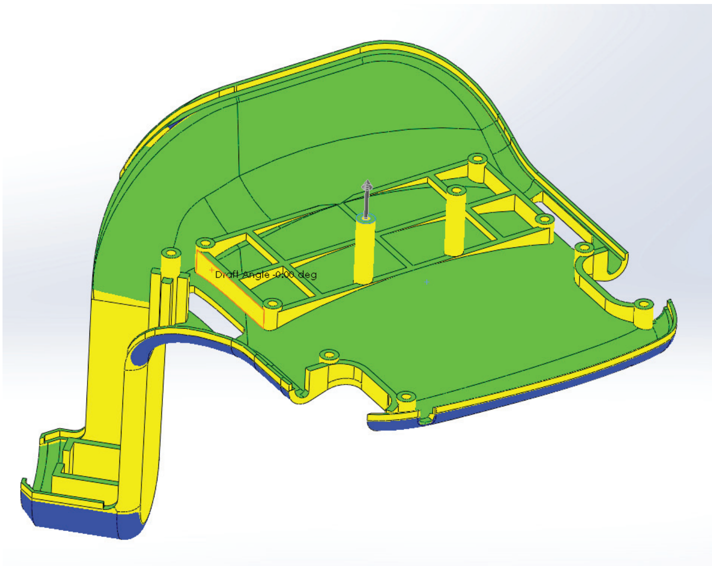


Figure 79 – Draft angle analysis of the bottom shell. This component would be fully draftable (with adjustments) save for the small area indicated in blue near the back of the component.

Ejector Pins and Gates

Assuming the design would be fully manufacturable, the placement of ejector pins and gates in the mold would still require some consideration. The only critical problem with the current design regarding this subject was identified to be the lattice structure at the center of the top shell. This serves the purpose of constraining the internal components and adding insertion points for screw fasteners, but the thin-walled structure combined with the large outer part of the shell might put risky levels of stress on their connection points. Though this could be solved with clever placement of the ejector pins and proper draft angles in the lattice, a simpler approach might be to replace the lattice structure with a single wall that contains the proper constraining features and screw insertion points, essentially adding a 'roof' by which the component can be ejected. The problem this poses for the designed assembly process and the reason the lattice exists in the first place, however, is that the management of electrical wiring might be significantly more difficult with more shell material obscuring the internal components. To find a balance between improved manufacturability and assembly, a middle ground might need to be found during an additional design iteration. One possible option is a cutaway part that only serves the purpose of adding strength to the lattice, but removing this will require postprocessing, which is undesirable for assembly.

As for the gates, these can be placed on any face that is not visible to the client during normal use and should not be exactly dimensionally accurate (such as the lip and groove on the split line). According to the expert, component faces can be excluded from the placement of gates in communication with the mold manufacturer. They then have specialized software and previous experience to help determine the best location for gates to provide optimal material flow. This would be the best approach after the design has been made fully injection molding compatible.

Cost

As this project aimed to deliver a detailed concept with embodiment design, determining an accurate final cost for Nova 2.0 might be difficult, but based on the findings so far, a high-level estimation of price influence factors can be determined. In this Section, key areas of the design are each discussed qualitatively to provide insight into what kind of changes to the cost price they bring to Nova 2.0.

Shell – Equal cost

From the manufacturability analysis session, it became apparent that the redesigned shell would likely be less costly to manufacture than the Nova 1.0 counterpart. This is due to the lack of sliders required to make the shell components. In SenseGlove's experience, the addition of sliders to their molds would increase the cost, as the low production amount means the sliders must be manually operated by the factory workers instead of by an automated process. This labor cost affects the part price significantly. The estimated price for a shell component mold is €6000 according to SenseGlove, with the price per unit coming to €3.03 in its current state. Though the new shell has one component more than the original, the offset from the lack of sliders lowers the price per mold. In addition, the production rate for Nova 2.0 is envisioned to be doubled, further lowering the cost per unit. For this reason, it was concluded by the expert during the manufacturability session that the initial cost for Nova 2.0's shell production would be equal to that of Nova 1.0. Estimating based on the original mold costs and assuming any modifiers to the price cancel each other out, this would result in around a €12000 investment for the shell molds, with a price per component below €3.

Thimbles & Cable Guides – Reduced cost

As a result of the efforts to reduce the component count and component variety in the thimbles and cable guides, it is expected that their cost per Nova will also drop. Currently, Nova 1.0 uses four different types, while the 2.0 concept uses only two. What this allows is for a reduction in the variety of injection molds and therefore initial production cost. Additionally, with well-designed runners and sprues, multiple cable guide components can be molded at once. Due to the symmetry and low variety in the thimbles and cable guides, it is expected that only two molds are needed: one for the cable guides' bottom and top components, and one for the thimbles' bottom and top components. In theory this could all be done with a single mold, but this would introduce additional complexity and introduce dependencies into the process; should the molding fail, then all components are lost, instead of those of just one type. Because the bottom and top parts of each type are assembled together and therefore needed in the same quantity, it is okay for them to be dependent on the same mold. Though the final decision may be influenced by advice from the mold manufacturer, from a design perspective it is recommended to combine the bottoms and tops of each type of cable guide, and then make one mold for each type. Assuming the same thought process was applied to the original Nova design, this should reduce the mold costs by half, as only two types are needed instead of four. As the number of needed components per type therefore increase, the price per component may fall as well, though whether this is significant must first be determined from an updated quote from the manufacturer. It should also be considered that this might mean the molds experience increased wear and must be replaced more frequently, so it might be worth ordering more durable (and more expensive) molds, should the production quantity require it.

Modules – Equal cost
As the modules remain mostly unchanged in the Nova 2.0 design, their material and assembly cost are expected to stay identical. It is possible that the new configurations as described in Section *Force Feedback and Stringpot Modules* (*Phase 1*), which require more of the same length of electrical wires, results in larger bulk orders for a lower variety of wires, lowering the price per unit. It is uncertain, however, by how much this will be and whether it is a negligible change. Due to the minimal changes to the modules and their assembly, their price is assumed to remain the same as with Nova 1.0 based on SenseGlove's own estimates:

FF modules: €23 material and €12,25 assembly cost per unit, totaling €141 per Nova.
Stringpots: €7,74 material and €11,07 assembly cost per unit, totaling €94,05 per Nova.

PCBs/Electronics – Increased cost
As Nova 2.0 will contain an additional PCB for power management and FF module control, the cost for silicon is expected to increase relative to Nova 1.0 due to the larger surface area required for both PCBs. The components mounted on the boards are expected to remain largely the same, but due to the addition of the active strap, requiring both power and signal, additional components are required. Additionally, the power PCB requires the cylindrical battery to be soldered on with precise alignment, raising the cost from either the factory delivering this presoldered or in-house soldering using machinery. In the current design this is assumed to be done by the factory, but regardless of whether this will be the case for the final version, its added cost should be considered.

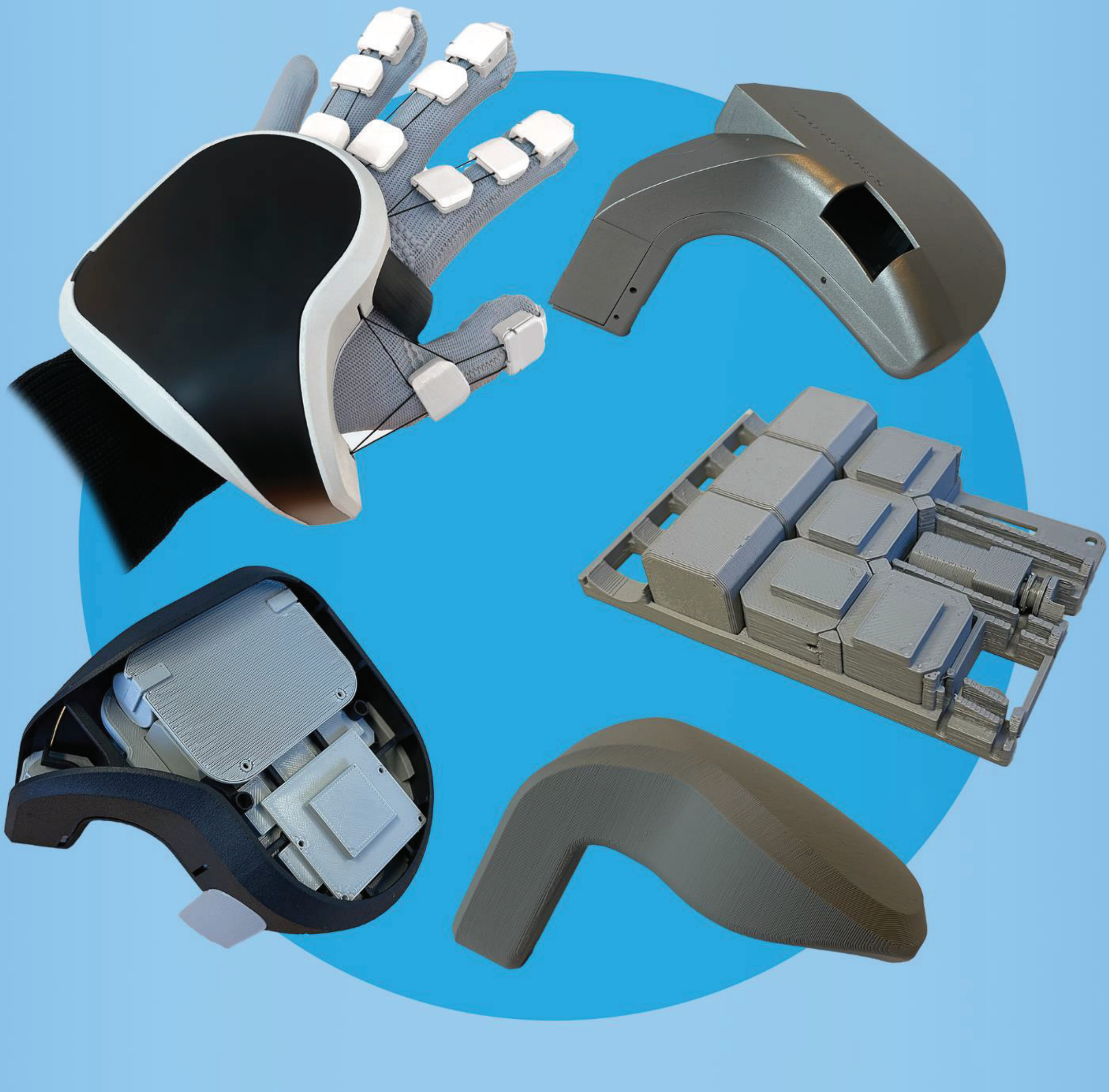
Considering the PCB surface area is expected to nearly double, but the component count is not, a price increase of 1.5x is chosen for simplicity. This would result in a new cost price of about 1,5 x €45 = €67,5 per Nova.

Additional Costs
The largest increase in production cost is expected to be the active strap, which introduces new components manufactured in a previously unused way by SenseGlove and requires the addition of power and signal processing on the PCBs. Though the design and embodiment of the active strap is outside the scope of this project, it is safe to say that its addition will increase the production cost for Nova 2.0. As it is made using silicone overmolding, a first for SenseGlove, a new manufacturer needs to be found which can provide the machinery and materials required. This new relationship might not offer the best deal possible at first, but as production increases and good relations are maintained, the price is expected to eventually fall. First though, the active strap is expected to increase the Nova 2.0 production cost significantly.

Total Cost
All the aforementioned considered, Nova 2.0 is expected to increase in material price compared to Nova 1.0, with the main causes being the additions of a power PCB and the active strap. However, assembly needs to be considered too, as manual labor plays a significant role in the cost price for Nova. The price for the modules will remain identical, but the Hub assembly can be done much faster as several time-consuming steps have been eliminated from the process. With the estimates described earlier in this report, the labor costs based on time for Nova 2.0's assembly are expected to be nearly half that of the original Nova, which was about €50 for everything except the modules (SenseGlove estimate). Considering this, it is expected that the cost price for SenseGlove will still be

slightly higher than that of Nova 1.0, as the cost for the addition of new components is expected to be higher than the savings with faster assembly. To reduce the cost price significantly, further optimization of the modules is needed, as these still form the greatest bottleneck for both the assembly time and material price. Due to the active strap development being out of scope for this project while still affecting the cost of Nova 2.0 significantly, a numerical estimate cannot be given, but with all previously mentioned factors considered, it is estimated to be higher than with Nova 1.0.

Evaluation



Discussion, recommendations, conclusion and reflection

Evaluation

Discussion

As previously mentioned in this report, the main deliverable from this project would be a preliminary embodied design for Nova 2.0. This goal has been met, and SenseGlove has been using the principles and design directions in this report throughout further development that both happened parallelly and will happen in the future. However, due to the limited scope of this project and the ever-evolving vision for the final version of Nova, some compromises had to be made in order to deliver a completed project. The main discrepancy that has occurred between the design presented here and the actual direction for SenseGlove are the properties of the internal modules. At the start of the project, the modules were envisioned to remain mostly identical to the previous versions. However, due to new insights and a desire to improve their functionality, SenseGlove has decided to redesign the modules from the ground up, resulting in new dimensions and even a new configuration. Though the 2.0 design can be easily adapted to fit modules of a different size (though that would perhaps require some scaling of the shell), the changes to the number of modules in the Hub may have consequences for the benefits this design offers, mainly in assembly: in order to design for optimized assembly, the product essentially needs to be developed from the ground up, considering assembly in even the earliest design choices. In this project, this happened during the three Phases presented earlier; while Phase 3 was completed last, its general direction (vertical assembly) and limitations (shell dimensions) were already being considered in Phase 1. In essence, this meant the project did not only contain traditional design iterations, but also went through some of those iterations in reverse to get to the best starting point for the next iteration. While a change in the amount and configuration of modules or any change to the design for that matter is certainly a possibility, the nature of this project makes it difficult to implement large changes without having to fundamentally change the entire design in order to keep the benefits in assembly it offers. The fully integrated design as presented here may be optimized for its starting conditions, but it might not be fit for the direction SenseGlove wants to take it in by the end.

Additionally, this project has been developed in collaboration with SenseGlove, but eventually due to time and scope constraints it was decided to develop this project and the 'true' final version of Nova separately. This means that some of the proposals in this report are already superseded, but not without their principles being applied in the new design.

Recommendations

Throughout the project, multiple recommendations have been formed for SenseGlove to successfully continue the development of Nova 2.0. Some of these have already been communicated throughout the design process and are even already being considered for the final version of Nova, but for the sake of clarity have been repeated in this Section. In addition, some new recommendations have been formulated based on the results of the aesthetics and assembly evaluation, as well as other findings, and have been categorized below.

Main recommendation:

It is essential to maintain the assembly principles presented in this report when further developing Nova. Implementing changes without enough consideration of their effect on assembly can cause issues down the line that will need to be resolved in Nova 3.0, repeating some problems that were occurring with Nova 1.0.

a. Keep the number of components and assembly steps minimal.
b. Maintain a logical, vertical structure that requires minimal mental and physical effort to assemble.
c. Keep dependencies between components minimal to prevent the need for complicated or destructive disassembly during repairs.

Aesthetics

1. Investigate ways to obscure or completely hide the force feedback cables on the glove, as they currently interfere with the otherwise refined design direction according to outside observers.
2. Improving the form language of the cable guides can help bring the aesthetics closer to the refinement and modernity that SenseGlove desires and can contribute to the previous recommendation.
3. Explore different colors for the softglove to be more in line with the aesthetic direction without compromising computer vision performance.

Assembly

1. Further develop the proposed assembly jig for better accessibility to the cables and increase its weight to prevent it from tipping over. Horizontally tensioned cables are expected to provide better access than the current configuration.
2. Find a way to secure the shell in place during assembly to make rotating it easier.
3. Investigate optimal ways to connect the module wires to the main PCB. Wire management can cause a bottleneck in assembly time when improperly implemented.
4. Add iconography to the main insert to make it immediately clear where each component goes.
5. Though the variety in screw types has been lowered in the 2.0 design, it can likely be minimized further. This is worth pursuing for additional ease of assembly and possibly reduce cost.

Manufacturing

1. Adjust the proposed shell design to be fully injection moldable and increase stiffness by placing ribs.
2. Conduct further testing to evaluate whether the placement of the screws results in a strong construction that is in line with the durability goals SenseGlove has for Nova.
3. Improve the design of the main insert for injection molding or optimize it for in-house FDM 3D printing.
4. Maximize the amount of cable guides that are made with a single mold to reduce cost. The reduction in type variety should allow this.
5. Investigate different types of cables to allow for more routing versatility and increase durability.

Ergonomics

1. While the current design contains all the requirements for ergonomics within the scope of this project, further research is needed to make sure Nova 2.0 fits most hands and is comfortable for all users. Specifically, the curvature of the bottom and the raised front over the knuckles need additional validation.

Sales and Marketing

1. Do additional research into the final cost price for Nova 2.0 and try to keep it as low as possible to make it attractive to more clients and possibly affordable for consumers, in line with the long-term goals for SenseGlove. Consider as well that the addition of the active strap feature might warrant a higher price, and that a similar price with increased value is also considered an improvement.
2. Though the new Nova design might not fit the original packaging, take this opportunity to refresh it and reinforce the idea that Nova 2.0 is something new and attractive.

Conclusion

Looking back at the original project brief, the Program of Requirements and the three focus points in Section *Requirements*, this project has resulted in a design that balances a number of disciplines to deliver an integrated concept with test results and prototypes to back up its validity, meeting all requirements to some extent with most requirements being fully met. Some additional research is required to fully determine if specific requirements are feasible, but initial findings show promise. Though not every wish was relevant to the project in the end (Like wishes 14.1 and 18.1), those that were have been mostly successfully implemented. Some wishes relating to detailed testing and standards have not been met as they can only be evaluated when Nova is brought to a near-final level. Overall, the three focus points mentioned in Section *Requirements* were the leading driver behind the design process, with the program of requirements being used to describe the most essential goals that were needed to deliver an acceptable design.

The proposal presented in this report fulfills its purpose as a first version of Nova 2.0, but requires further development to become ready for production and sale. Based on initial evaluation, the assembly time for Nova 2.0 can be reduced to around 53% of the original, with the most time gained by optimizing the Hub and cable guides for assembly, resulting in several assembly stations being eliminated completely. Due to scope and time constraints, the design could not address the internal modules, which are the most important components when it comes to Nova's function, but also have the greatest effect on cost and assembly time.

In addition, the proposal shows an integrated aesthetic direction that is appreciated by outside observers, though not loved, and visually fits in very well with other equipment in the industry. The main factor that influences people's opinion on Nova 2.0 is the exposed force feedback cables which compromise the otherwise refined look.

Cost-wise, Nova 2.0 is expected to be more expensive than Nova 1.0 because of the addition of the active strap feature. The shell and internal modules are not expected to change significantly in cost and the thimbles and cable guides will become significantly more affordable, but the increased complexity of the PCBs and the addition of the active strap will likely raise the total by a large margin. A definitive cost price could not be determined as the active strap development was not in the scope of this project and is expected to significantly influence the total.

Reflection

Working on this project has been a great experience. SenseGlove has been extremely helpful when it came to providing information, advice and resources needed to work on my goals and was actively supportive during the development of the Nova 2.0 concept. I had indicated at the start of the project that I would like to use this graduation as an opportunity to gain more work experience and that I would like to be involved with the design meetings and discussions as much as possible. The people from SenseGlove made sure this happened and not only allowed me to observe but also participate in the meetings as a proper designer. This made the project feel important and motivated me greatly to do my best and deliver the best possible result. This enthusiasm was mostly helpful but also caused a pitfall during the project: the complexity of the product I was working on was quite high, and this required two extensions of deadlines as I was not happy with the results yet and required more time to refine the design. This had no major consequences for the project or SenseGlove, as they were working on Nova 2.0 simultaneously though were not dependent on my results, but it did cause some stressful moments and a little bit of embarrassment when having to announce the extension of the deadline twice. I do truly believe this was necessary and has brought the project to a level that I am happy with and is in line with my original vision, though it showed that I had underestimated the complexity of the project.

Though I worked outside of the Scrum planning that SenseGlove utilizes, I was informed of developments frequently and had weekly meetings with Bryan to evaluate the progress so far and set goals for the next week. This happened during a scheduled hour to which I brought a form stating what went well, what went bad, some notes on the progress and updates on my learning goals. This was very helpful during the first half of the project and helped me gain a better understanding of the way to handle its complexity. As SenseGlove was developing Nova ever further and my contribution was nearing completion, we mutually agreed to treat the graduation project as a separate entity from now on. This did bring an end to the weekly form, but by that point it was no longer required.

The aforementioned split between SenseGlove's development and my own was a necessary decision that did in the end help me finish the project. As is expected with a startup that is still improving and finding ways to deliver better products, indecision was an issue that started to interfere with the momentum. There was a feature freeze quite early in the project that would decide what direction Nova would go in, but the temptation of new findings and experimental features undid the clarity the feature freeze brought. Eventually, the feature freeze for the actual Nova 2.0 was moved way back, but to keep my project manageable I decided (in discussion with Bryan) to isolate my own work and continue from the original feature freeze. Though I understand the changing of the feature freeze was an acceptable decision, as a single person balancing input from different departments it was a little frustrating to be unable to finalize aspects of my design and optimize them. When I communicated this to SenseGlove, they were understanding, and we found a better approach together.

Personal learning objectives

At the start of the project, I formulated several personal learning objectives. These can be found in the project brief and have been repeated here, along with a short reflection.

Assembly design/design for repair
As the design of Nova 2.0 revolved around design for assembly, I got in touch with this subject a lot. I learned about the principles of Poka Yoke and Boothroyd & Dewhurst's DFA. I also got to find out some DFA principles myself from prototyping and testing. Critically looking at my work and discussing a lot with people from the assembly office has taught me a great deal about this subject.

Integrated function design
Integrating different functions into a single component has always fascinated me, and designing for assembly inherently contains some of this. Though there are not any specific methods or literature I came into contact with during the project, trying to integrate multiple functions into a single part with CAD and prototyping gave me a good understanding of the benefits and limitations of this approach. It also taught me that you do not need to integrate functions into a single part if they have problematic dependencies. For example, the main insert integrates several constraining functions, but combining it with the regular strap would make them dependent on each other; if the strap breaks, the main insert would also need to be replaced. Finding a balance between isolating potential problems and integrating functions was a fun challenge.

Injection molding design for production
From the start of the project, I kept rules of thumb for injection molding in mind that I read in literature and was taught during the Bachelor. Looking at the existing shell parts for Nova and finding both the clever solutions and flaws in them was very educational and gave me an increased appreciation for this type of product. Looking at products outside of SenseGlove's portfolio also gave me new insights and directly inspired some solutions to subproblems (the integration of the power port hole was inspired by a disassembled computer mouse). Near the end, speaking with the CTO about manufacturability also

allowed me to reflect on my own work and recognize where I could still improve my design and understanding of injection molding.

VR hardware design challenges
Even before the start of the graduation project, I have had a fascination with VR hardware. To me it seems remarkably difficult to make a simulation feel as real as possible with limited hardware and clever tricks. SenseGlove's Nova would show me one method of achieving this and I was curious to see what considerations were needed before a product was ready for VR. Most of the factors that determined a pleasant VR experience were ergonomics and reliability, and I got to experience some of the ups and downs of this during several physical demos where I got to use Nova myself. I understand now that there are a lot of challenges that come into play, especially with a product that is trying to achieve a lot in a small package. VR hardware like Nova will probably never be perfectly immersive, but with good design it can come very close to making the user forget they are using it.

Product certifications and standards
This was a more general learning goal, in which I wanted to learn more about standards for consumer electronics and what kind of legal hoops companies must jump through to get their products to market. I initially thought I could apply some of this knowledge to my own design (it was even mentioned in the PoR), but after a talk with Chun, who handled this for Nova 1.0, I understood that it was way above the scope of my project and was practically impossible to fully understand as a mere student. I did have a nice talk with Chun about these processes and the certifications a company can get for their product, but it also showed me that it was not relevant or feasible for the project.

Acknowledgements

I would like to offer thanks to the people at SenseGlove, who have been amazingly supportive throughout this effort and who went out of their way to make sure I was able to fully commit to this project and do the best I can. Working at the headquarters has been one of the most pleasant experiences I've had during my studies, and I hope we can continue working together in the future.

Special thanks to Bryan Zaaijer, who has been a great help throughout the project and was always open to suggestions, questions, and random conversation. The design sessions were so much fun, and I could not have asked for a better mentor throughout the process. Now go tell everyone I said that. I know you want to.

Additional thanks:
Floris – for our productive discussions and permanently lending me company property.
Johannes – for the laughs, weird prototypes, and genuinely helpful expertise.
Anne – for hosting the design meetings and listening to my ramblings therein.
Rania – for always responding to my nagging about the internship compensation.
The D&D crew – for the fun evenings and the pizza.

And of course, Sander and Erik for their guidance during the coaching sessions.

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Appendices

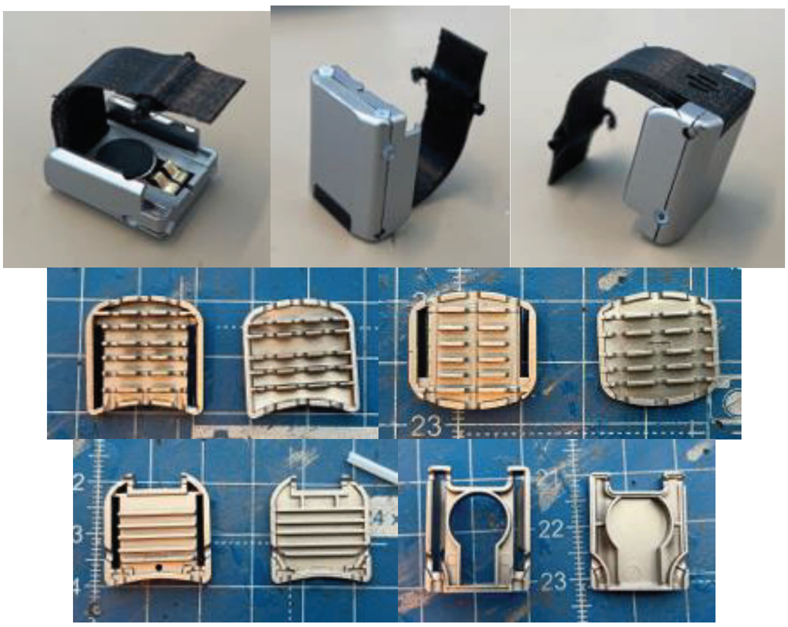
Assembly Office Visit Notes

From a first tour of the assembly lab, some topics came to light as being high-priority in this project:

- The removal of glue from the process
- The simplification of the thimble assembly
- Streamlining the assembly steps of the Hub

Thimbles

Assembly for the Nova happens in many steps at different stations. One which needs a lot of steps for relatively small parts are the thimbles. These need to be glued together with Teflon tubes in-between, and then cut to length to sit flush with the part. A pin is also inserted to keep the TPU end of the thimble in place an in the case of the thimbles with force feedback, a FF module is inserted and glued in place. Problems can arise during assembly of the thimbles:



I tried assembling some of the thimbles myself, and these are my impressions:

- The placing of the tubes is intuitive and easy, as they sort of fit into place and stay there.
- Special rigs are required to assemble the thimbles, which are not optimal because they are 3D printed in PLA (I think) and are likely not durable or consistent. However, the rigs are quite helpful in aligning and pressing the parts.
- Gluing the thimbles requires some knowledge about how they are supposed to look in the end. For example, if you do not glue the corners or some small parts at the edge of the parts, the thimbles get quite big gaps between the two halves.

- While waiting for some thimbles to dry, you can work on others. This makes the work sort of parallel, but doesn't result in faster build times.
- The PTFE tubes need to be squeezed to keep from slipping. This however means that they need to be compressed quite hard, resulting in gaps between the halves if not done correctly.
- The ribs keeping the PTFE tubes in place also function as glue points, with them coming into contact with each other when combining the halves.
- Replacing broken thimbles would have to involve cutting the strings, as the knots inside them are sealed with a flame.
- Attachment of the TPU thimble flaps is done with a metal pin which has to be inserted after gluing the thimbles. This means the effectiveness of the pin is also dependent on the quality of gluing.
- There are a lot of factors which can make a thimble 'scrap'. The glue can be too weak, the glue can leave marks, the gaps between the halves can be too large, the tubes can be cut wrongly, the process of cutting the tubes can leave marks, etc.
- A lot of tubing is wasted by cutting it off, but this may not be relevant when the tubes are made obsolete.
- Gluing the thimbles leaves a lot of internal stresses, as great force is required to keep the halves in place.

Components associated with thimbles:

- Top half
- Mid half
- PTFE tubes
- Glue
- (TPU flap)
- (Metal pin)
- (Vibro motor)

Current Thimble assembly

The thimbles are mounted on snap fits located on top of the smart glove. These snap fits are glued in place or knitted into the glove during production. Because they should keep the thimbles in place during use but still remain detachable for cleaning and maintenance, the snap fits are modeled to allow one-way attachment and detachment while still remaining in place under force. This has the consequence of the thimbles containing features which are challenging to injection mould while keeping costs low, namely undercuts and holes. For the sake of durability, the strings that run through the thimbles are routed through PTFE tubes that are mounted into the holes.

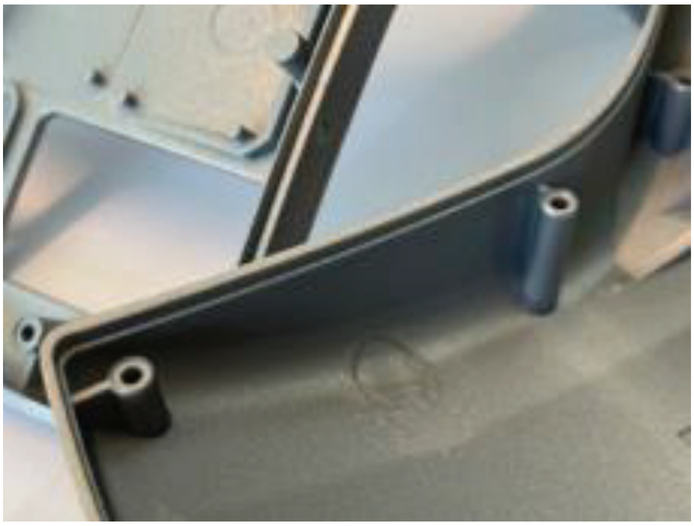
Hub
Besides the thimbles, the enclosure (hub) on the back of the hands also has some assembly challenges:

- Some parts need to be glued in place in order for the enclosure to properly close, as there is excess volume from the cables on the inside.
- The design of the enclosure was rushed, so a 3D printed insert is needed to add stability and make sure the enclosure does not warp when force is applied.
- Screw holes need to be drilled manually, as the mold does not contain them out of the factory.
- Attachment points are needed for the controller adapters

Components associated with the Hub
- PCB
- Braker module*
- Cable pot*
- Thimble vibrator
- Thumper
- Battery
- FF cables
- Cable guides
- Temperature sensor
- Reset button adapter
- USB cover
- Cables

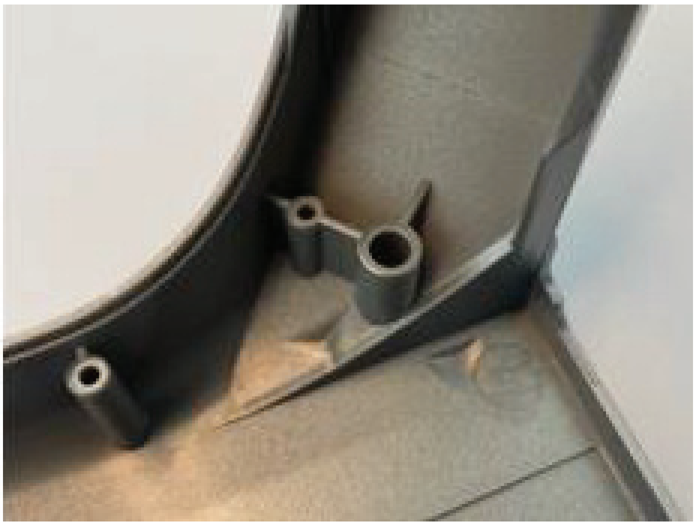
*Subassembly

Current Hub features
The design of the current Hub was done quickly and with little room for iterative design. Though it is not yet up to the standard SenseGlove holds for their own product, the current hub contains some features which are interesting to analyse for this project. These are listed below.



Feature 1: Ridges

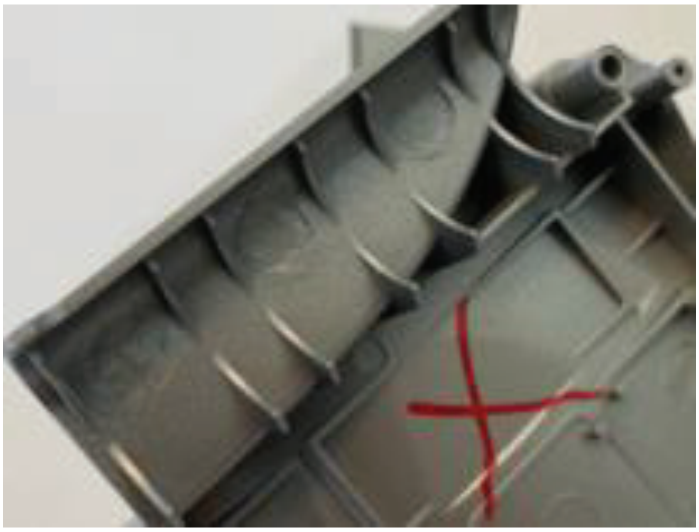
The ridges on the sides of the Hub prevent the halves from shifting around and helps with alignment during assembly. They can also function as additional points of determination when using fasteners like screws; one vertical screw and two horizontal axes with ridges can make the two halves fully constrained. This is something to keep in mind when reducing the fastener count in version 2.0.



Feature 2: Bosses

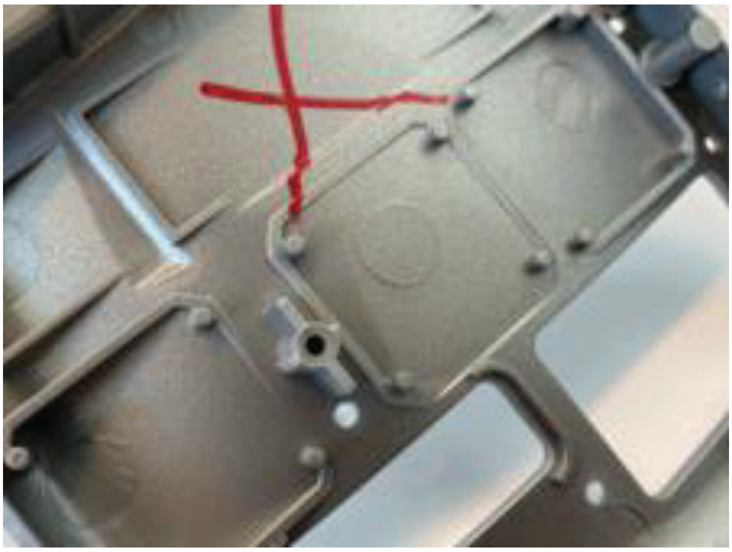
In order to mount the screws in their proper position and to provide support for the shell, bosses are added in specific locations. These are sometimes connected to the main walls or each other using ribs that add stiffness to the construction. Two of these bosses contain inserts for the attachment of controller mounts.

NOTE: The placement of the inserts for the controller mounts determines whether they need a redesign as well. If the mounts are supposed to remain the same, that may greatly influence the design freedom in this project.



Feature 3: ribs

Ribs are placed in various locations to support or align internal components and can also function to increase the overall stiffness of the shell. Using these effectively can reduce the need for screws and/or glue, as the components can be kept in place using these features. Adding holes or cavities to the ribs could also provide opportunity for cable guides to be integrated.



Feature 4: pegs

Small round protrusions are used to keep components in place. These align with screw holes present on the components, and when no screw is present or it is recessed deep into the hole, the pegs fit inside. These can function similarly to a screw, but without the axial constraint.

Preliminary points of focus

From my first impressions of the assembly process, I have formulated a few points to focus on during this project. Based on new insights these may be subject to change.

- Eliminating the need for glue in the entire enclosure assembly (including thimbles)
- Eliminating the need for string guides in the entire enclosure assembly (including thimbles)
- Eliminating the need for drilling in the entire enclosure assembly (excluding internal components)
- Improving the hub geometry to better accommodate the electronics (with minimal gained volume)
- Improving the hub geometry to reduce the width of split lines
- Improving the hub geometry to reduce the amount of fasteners needed
- Optimizing mold line placement for minimal aesthetic impact

Standardize fasteners in the enclosure assembly to a single type (excluding internal components)

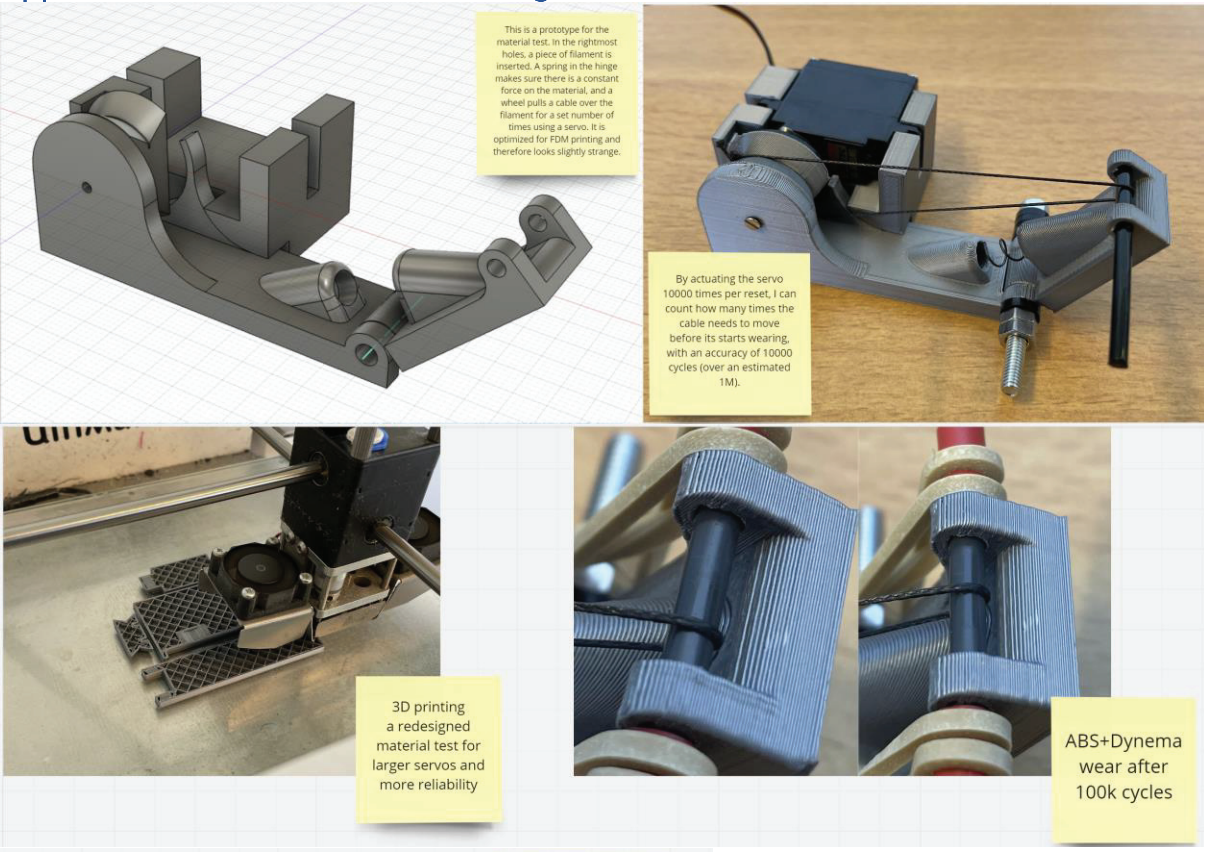
Appendix B – List of Requirements and Wishes

Program of Requirements and Wishes- Hub

	Requirement ID	Requirement Category	Description	Associated Wish	Requirement met?	Wish met?	Elaboration
1. Performance							
	1-1	1. Performance		Assembly of the Hub should take as little fasteners as possible			
	1-2	1. Performance		Assembly of the Hub should take as little different fasteners as possible			
	1-3	1. Performance		When fully assembled, the hub should not generate any noise from non-dynamic component rattle			
	1-4	1. Performance	The placement of the thumb cable exit holes should retain the same dimensional relations as with Nova 1.0				
	1-5	1. Performance	The placement of the finger cable exit holes should retain the same dimensional relation as with Nova 1.0				
	1-6	1. Performance	The Hub should accommodate room for one serial number sticker				
	1-7	1. Performance	The Hub should accommodate a glove connector				Space for a glove connector was reserved, but the connector itself was not implemented to maintain a manageable scope of the project.
	1-8	1. Performance	The Hub should accommodate 4 FFMs				
	1-9	1. Performance	The Hub should accommodate 5 Stringpots				
	1-10	1. Performance	The Hub should accommodate a processor and power management				
	1-11	1. Performance	The Hub should accommodate a power button				
	12-23	1. Performance	The Hub should accommodate a power/data port				
	1-13	1. Performance	The Hub should facilitate wire routing during assembly				
	1-14	1. Performance	The Hub should be detachable and attachable on the soft glove				
10. Size and Weight							
	10-1	10. Size and Weight		The Hub's total mass should be as low as possible			No efforts were made to reduce the weight of the product overall, but the reduction of component count has helped reduce weight in some areas.
	10-2	10. Size and Weight		The Hub's volume should be as low as possible			
11. Aesthetics, appearance and finish							
	11-1	11. Aesthetics, Appearance and Finish	The Hub should have aesthetic features implemented as determined from the aesthetics development	The Hub should be aesthetically pleasing			This wish has been marked as met because the design was liked by test participants, but there are still improvements to be made to the aesthetics and raise its score.
	11-2	11. Aesthetics, Appearance and Finish	Split lines should not widen as a result of forces occuring during normal use	Split lines in the enclosure should be as small as possible			
	11-3	11. Aesthetics, Appearance and Finish		The Hub should facilitate a flush connection with the active strap			
14. Standards, Rules and Regulations							
	14-1	14. Standards, Rules and Regulations		The redesigned hub should be ready for FCC testing			FCC testing was not yet relevant during this project and has been omitted as a goal.
	14-2	14. Standards, Rules and Regulations		The redesigned hub should be ready for CE certification			CE certification was not yet relevant during this project and has been omitted as a goal.
15. Ergonomics							
	15-1	15. Ergonomics		The Hub's center of mass should be as far back on the hand of the user as possible			
	15-2	15. Ergonomics	The Hub should be curved at the bottom to allow comfortable use	The curvature of the bottom of the Hub should remain identical to the original			
	15-3	15. Ergonomics	The Hub should contain no sharp edges on the bottom				
	15-4	15. Ergonomics	The Hub's straps should be positioned in the same spots as with Nova 1.0	The Hub's straps should be as or more comfortable than Nova 1.0's			The Hub's redesigned straps were perceived as comfortable by some, but no test has been done to quantitatively or qualitatively prove it for a larger population.
18. Testing							

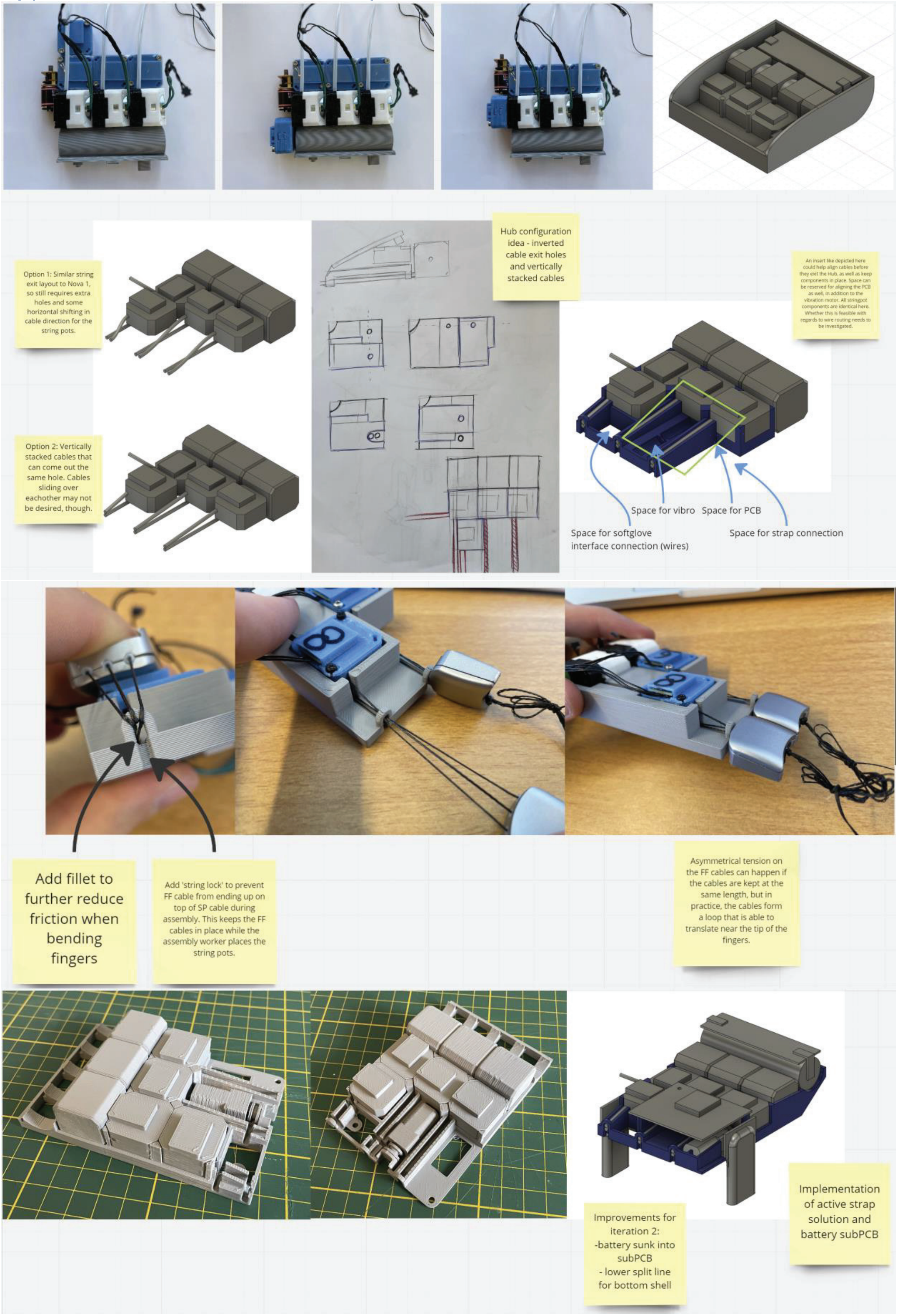
	18-1	18. Testing		The redesigned Hub should remain functional after a drop from 1.5m	No testing has been done in this area.
	18-2	18. Testing		The Hub should have equal or better moisture resistance than the original	No testing has been done in this area.
	18-3	18. Testing		The Hub should have equal or better dust resistance than the original	No testing has been done in this area.
23. Installation and initiation of use					
	23-1	23. Installation and Initiation of Use	Assembling the Hub with all internal components for one Nova 2.0 unit should take less time than with the Nova 1.0 version	Assembly should take 60% of the current assembly time	
	23-2	23. Installation and Initiation of Use	Hub assembly should not require permanent fastening methods		
	23-3	23. Installation and Initiation of Use		Assembly should be as intuitive as possible, with markers and text on the parts themselves helping with identifying and placing parts	Care has been taken into ensuring components are easily distinguisable and are considered an improvement over Nova 1.0, but the assembly time test proved that additional distinguishing features were required to make assembly more intuitive.
	23-4	23. Installation and Initiation of Use	Part rejection rate for the Hub should be lower than 5%	Rejection rate of Hub enclosure parts should be as low as possible	Though no data has been gathered in this area, the elimination of the postprocessing station and omission of processes that may damage the shell, Hub part rejection rates are expected to be lower with Nova 2.0.
3. Life in Service					
	3-1	3. Life in Service	The Hub's enclosure should be resistent to wear from the strings where they meet for at least 1M cycles		
	3-2	3. Life in Service	Any snap fit connections in the design should be resistant to wear from at least 3 cycles.		This has not been tested, but with a proper implementation of the design proposal (materials, dimensions, principles) it is expected to be possible.
4. Maintenance					
	4-1	4. Maintenance	Assembly of the Hub should be nonpermanent and reversible, with disassembly being possible non-destructively		
	4-2	4. Maintenance	All components and subassemblies should be individually replaceable		
	4-3	4. Maintenance	Disassembly of the Hub should be possible faster than with Nova 1.0	Disassembly of the Hub should take as little time as possible	
5. Target product costs					
	5-1	5. Target Product Costs		Manufacture of one full Nova 2.0 unit should be less costly than with the Nova 1.0 version	The addition of the active strap and the increased complexity of the PCB configuration lead to the estimation that the costs for Nova 2.0 will be higher than the original. The increase is slightly reduced by savings in other areas, but still has to be considered when determining a sales price, especially since Nova 2.0 offers an additional feature over Nova 1.0.
	5-2	5. Target Product Costs		The Hub's enclosure redesign should require the least amount of mould parts possible to save costs	
	5-3	5. Target Product Costs		The Hub's manufacturing cost should be as low as possible	
9. Production Facilities					
	9-1	9. Production Facilities	The Hub should be manufactured and ready to assemble without post processing		
		9. Production Facilities	The Hub's shell should be injection moldable	The Hub's components should be mostly mass producible	
	9-2	9. Production Facilities	Production of the Hub enclosure's injection moulded parts should be possible with the same producer that SenseGlove already uses		
7. Packaging					
	7-1	7. Packaging		Shipping should be possible in the same packaging as before	Due to the Hub's slightly increased dimensions in some areas and the different shape from the original, it is not expected that the new Nova will fit the original packaging. A new package might also be desired to indicate the novelty of Nova 2.0 to clients.
8. Quantity					
	8-1	8. Quantity	The redesigned assembly process should allow a production rate of 50 Novas per month		

Appendix C – Cable Friction Testing

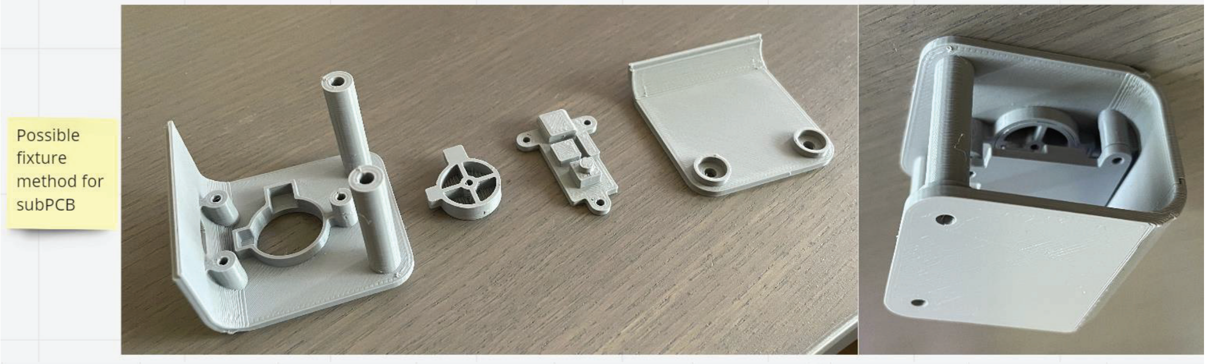


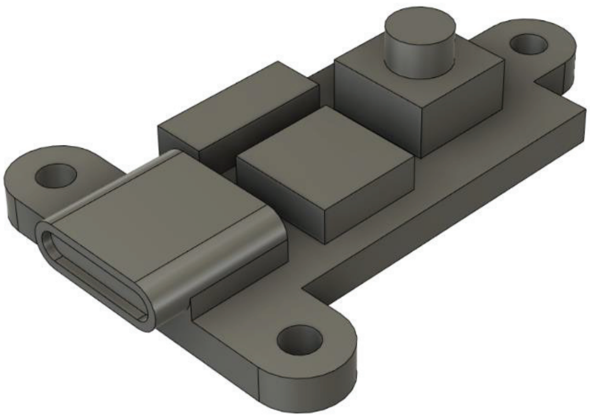
Using a simple test setup, a cable of Dyneema (SenseGlove's cable material of choice) was pulled across a piece of ABS filament for 400 thousand cycles. The material and cable showed no wear at all, which indicated that the friction between the two was low enough to allow the cables to run across the shell without PTFE tubes, in the cable guides and Hub. It should be noted, however, that the diameter of the filament helped in reducing the friction, instead of what for example a rectangular sample would have. This is why when implementing a cable-less solution into the Hub and cable guides, proper attention should be given to filleting the exit holes for the cables. The texture of the shell in those places should also be kept as smooth as possible.

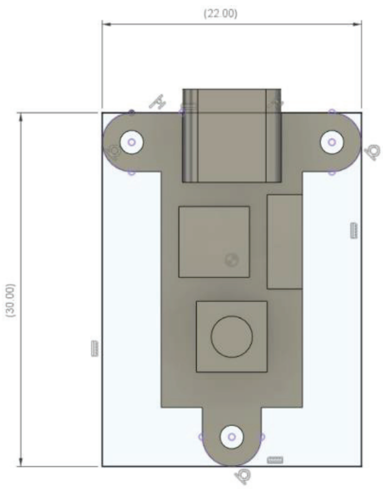
Appendix D – Main Insert Development



Appendix E – Power Port Development



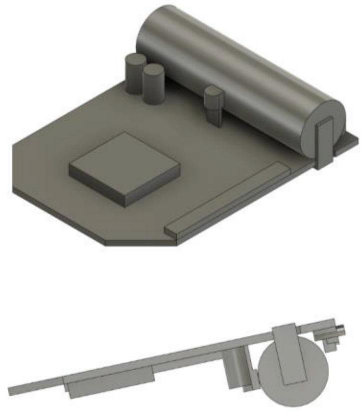




Some ideation took place in which the power port would be placed on a separate PCB along with the power button. This showed some promise, but because the battery assembly needed a redesign as well, this was later assimilated into the idea of an all-in-one power PCB that contained all non-computing related electronics, including the power port. The power button was moved to the main PCB to facilitate easy pressing using the beauty shell.

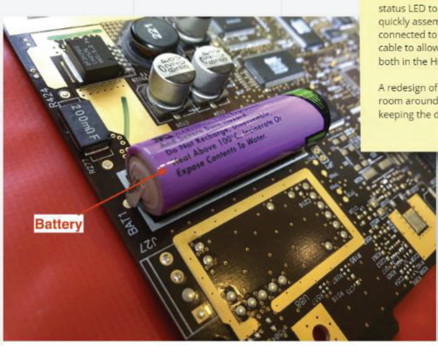
An iteration on the idea of a battery/button/power subPCB. This version allows for easy symmetry between gloves. The mounting point of the temperature sensor is undetermined here, but if a surface mounted sensor exists, it can be placed below the battery.

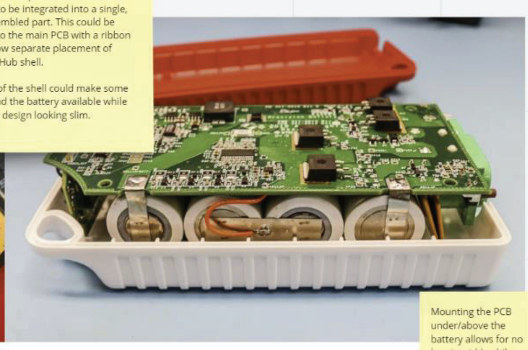
Placing the power port on a (nearly) vertical surface is challenging from a draft angle perspective. In order to mold the hole for the port, the outer edge of the top of the hole needs to end where the inner part of the bottom starts. Reducing the wall thickness locally allows for a more vertical angle in the wall. When a less steep angle is used (right), the wall thickness still needs to be small so the power plug can enter the port fully. An example of this in the wild can be seen in the mouse above.



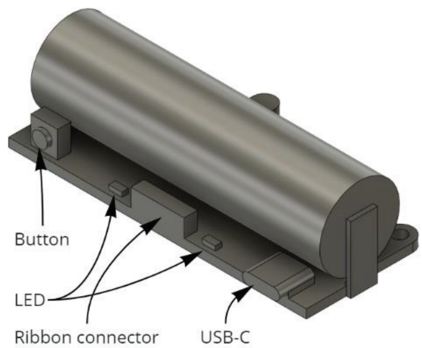
Possibility: Make a large subPCB that holds the battery and contains the button and charging port. This also allows for the temperature sensor and status LED to be integrated into a single, quickly assembled part. This could be connected to the main PCB with a ribbon cable to allow separate placement of both in the Hub shell.

A redesign of the shell could make some room around the battery available while keeping the design looking slim.

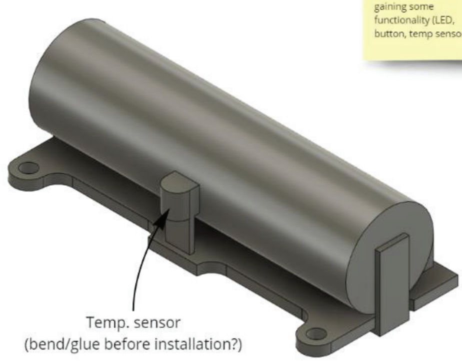




Mounting the PCB under/above the battery allows for no loss in width while gaining some functionality (LED, button, temp sensor)

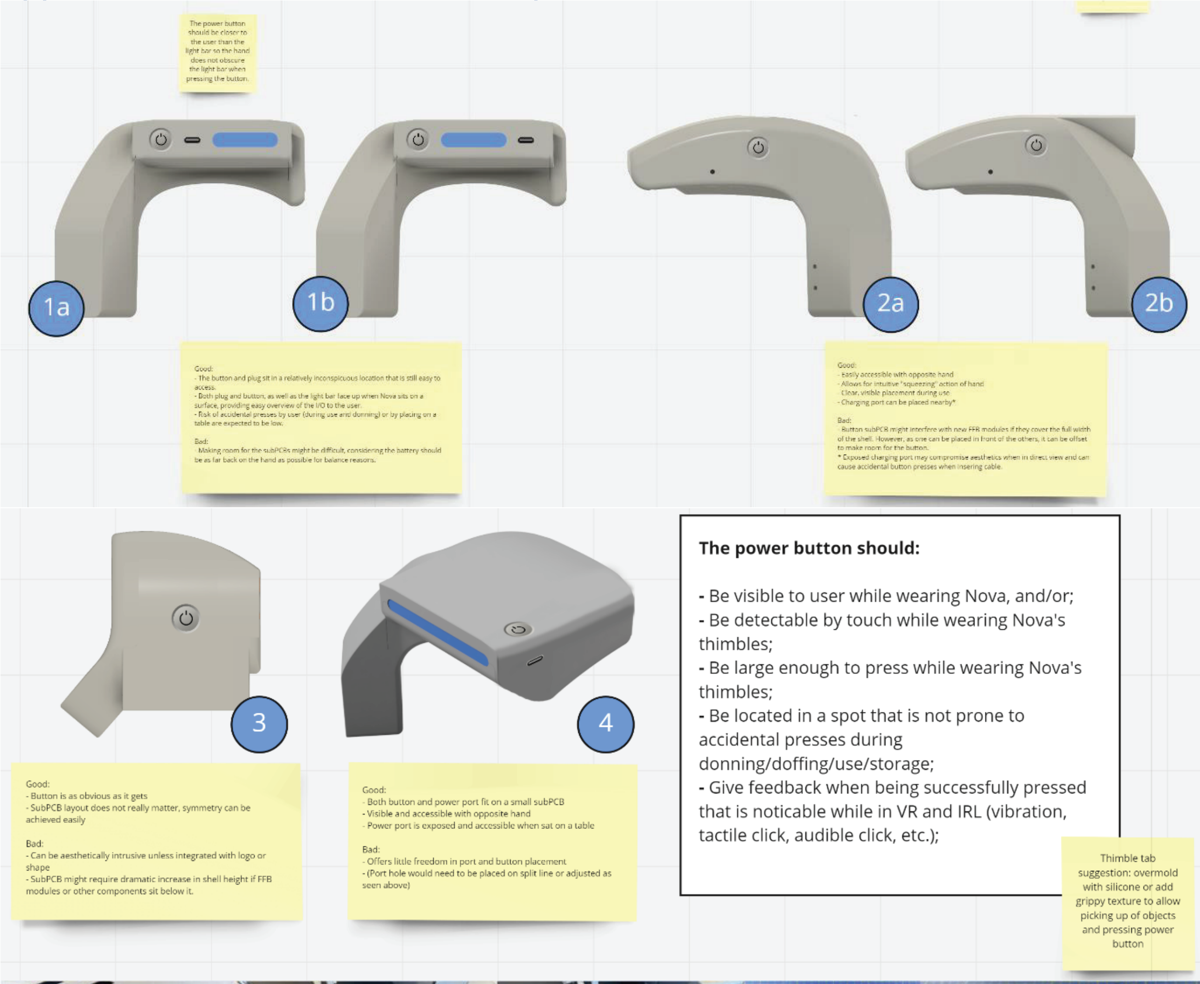


Backside of Nova.
The ribbon cable could be curved over the top of the battery towards the main PCB.

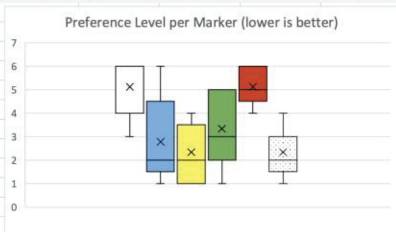


Attaching the temperature sensor to the battery might still require some glue or a precise bending of the feet of the sensor.

Appendix F - Power Button Development

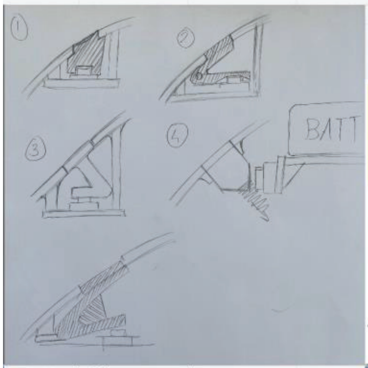


White	Blue	Yellow	Green	Red	Cross
4	2	1	5	6	3
6	2	3	1	5	4
3	1	4	5	6	2
6	2	4	3	5	1
4	2	3	5	6	1
6	5	1	3	4	2
6	4	1	3	5	2
6	1	2	4	5	3
5	6	2	1	4	3
5,11	2,78	2,33	3,33	5,11	2,33



With a cardboard prototype and a user test, people were asked to rate their favorite locations for the button and whether they would like to see it in another place than the suggested ones. A button mounted on the thumb facing the user had preference overall, but it was later determined that it would be more practical to have the trainee press the top of Nova to activate it, as that was easy to do even with the thimbles on. The thumb power button would also be difficult to integrate, both for design and assembly, while the 'mouse click' solution allowed the button to sit directly on the main PCB below the beauty shell.

Thumb mounted power button ideas

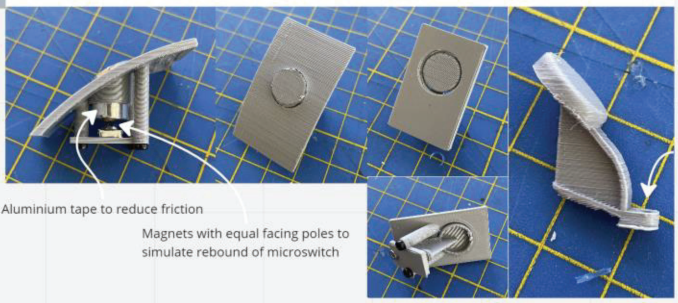


1 - Vertical linear actuation
2- Tilting actuation with lever
3 - Semilinear actuation with sliding press
4 - Linear diagonal actuation with perpendicular switch

Linear button press on curved surface. Forces are not ideally oriented to depress the button, but the solution is simple and easily assembled.

Tilting button press on diagonal (or curved) surface. Force translation means the micro switch is depressed optimally, while the button press direction is intuitive to the user.

Still needs optimalization in terms of draft angles



Aluminium tape to reduce friction

Magnets with equal facing poles to simulate rebound of microswitch

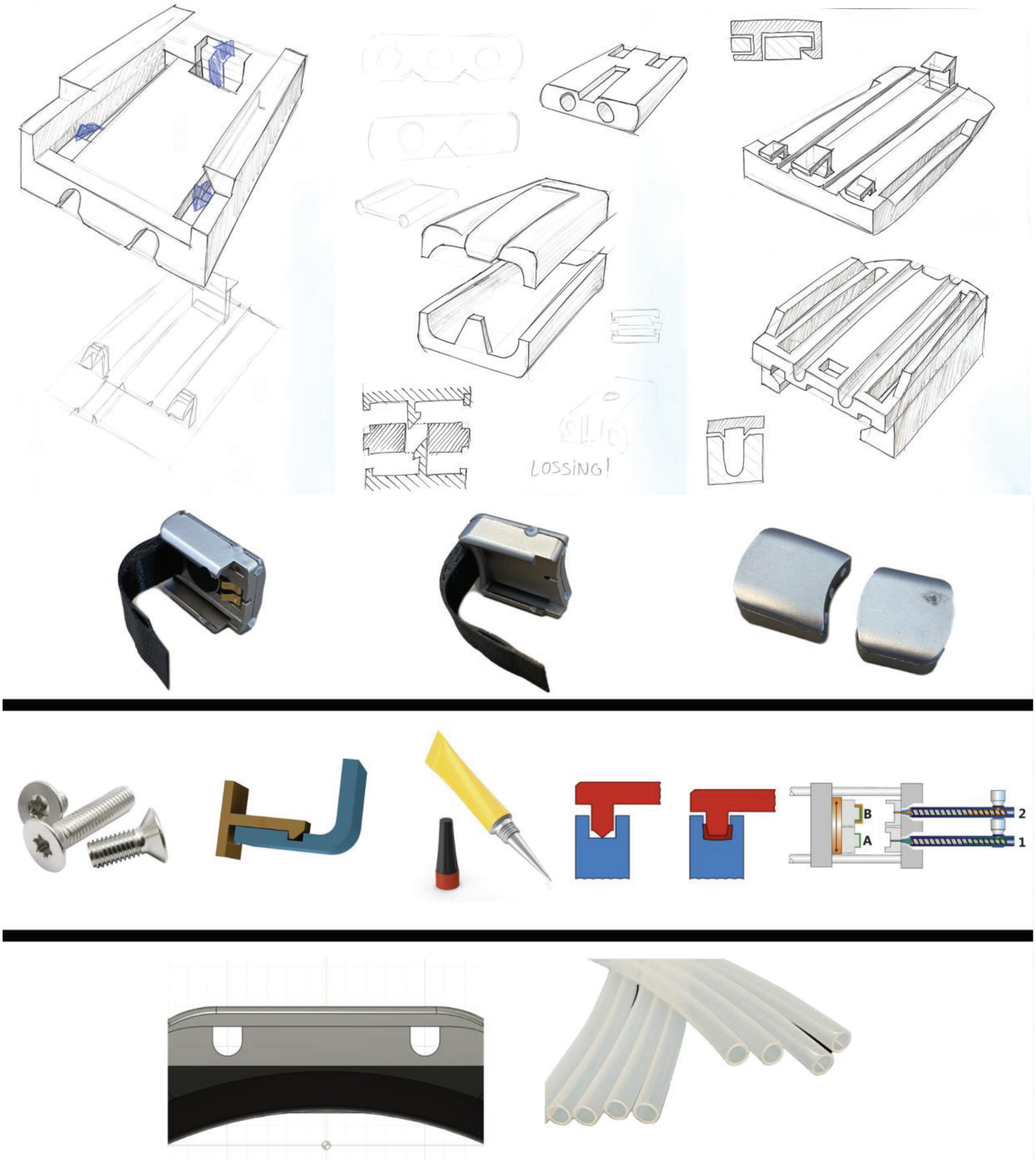
While the idea of the tilting button shows the most promise, features need to be added to prevent the button from rotating around its screw attachment point. Otherwise, it will shift to one side of the button hole over time and introduce friction.

Design direction: Bryan's "Pico" sketch with rounded bottom and clickable top surface

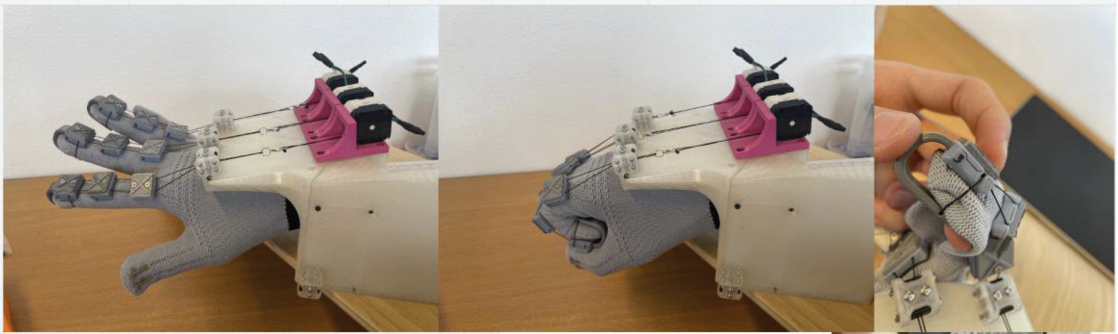
Power button will be replaced by multifunctional 'mouse click' button located underneath the top shell, similar to a computer mouse

This allows for easier pressing when the user is wearing the gloves, and does not require the user to 'feel out' where the button is located

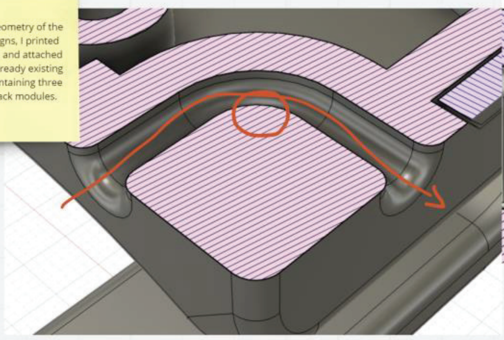
Appendix G – Thimbles and Cable Guides Development

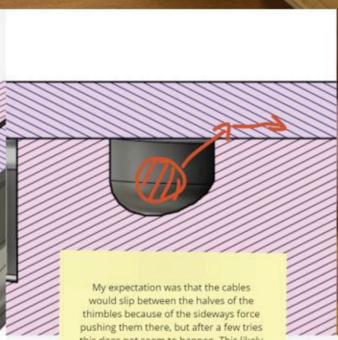


Cable guide ideation started with some early sketches to explore different approaches to reducing the amount of components in them. Later, a morphological chart was made to see if there were other approaches, but it was quickly determined that snap fits were the optimal choice, as they did not require additional manufacturing processes and were expected to take the least amount of assembly time compared to the other fastening methods. More ideation and prototyping was then done for this direction.

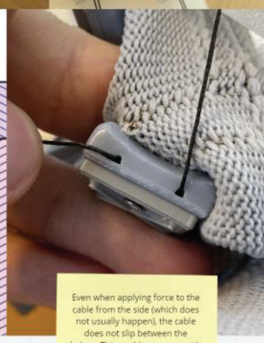


To test the geometry of the thimble designs, I printed them in resin and attached them to an already existing test setup containing three force feedback modules.





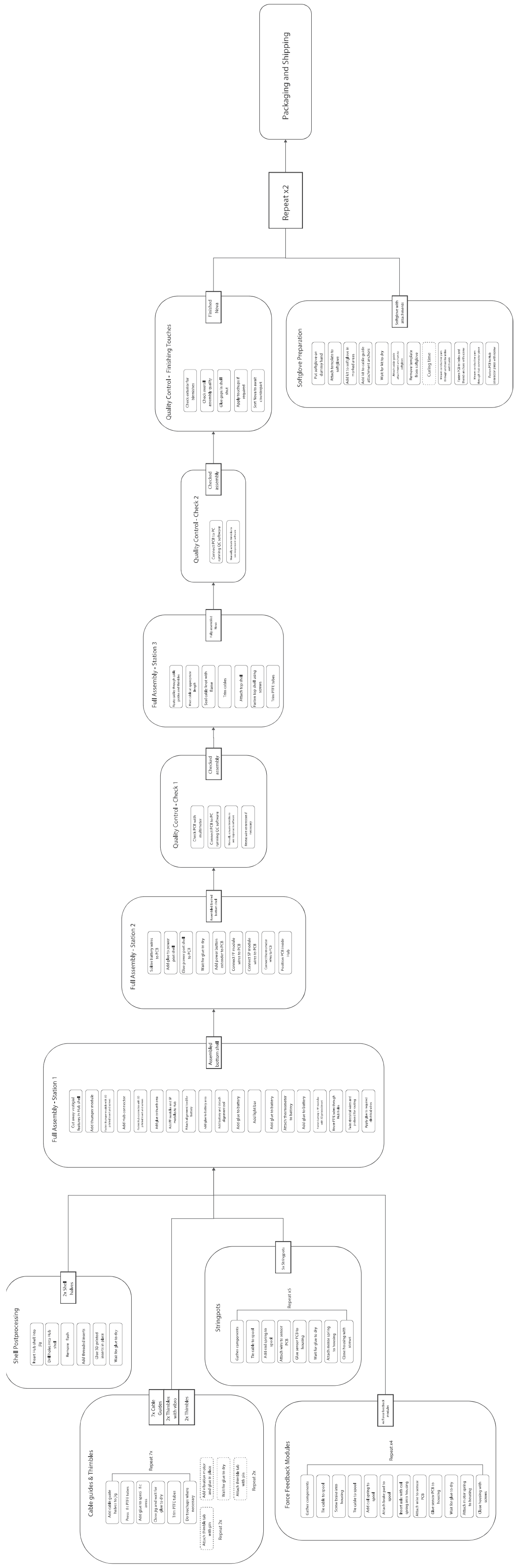
My expectation was that the cables would slip between the halves of the thimbles because of the sideways force pushing them there, but after a few tries this does not seem to happen. This likely has to do with the cable diameter, split line width, amount of force applied, split line position, and cable channel angle. With the current resin prints it seems the current approach for all three versions is okay, but these prototypes are not fully representative of the final product.



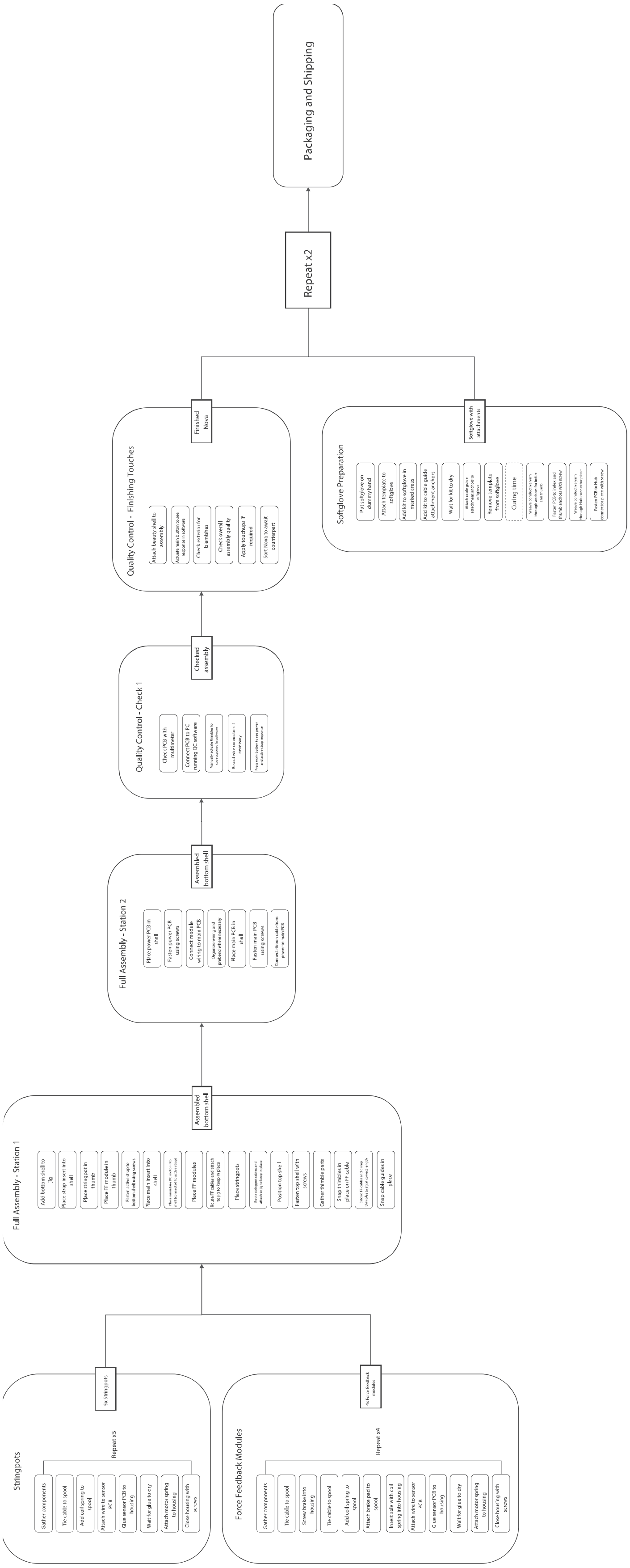
Even when applying force to the cable from the side (which does not usually happen), the cable does not slip between the halves. This could get worse with wear, though. Also, the stabiliser panels now add a uniform clamping force to the halves, instead of the three points that are present with the snap fits.

The thimbles and cable guides were developed as proof of concept and were therefore not embodied to the level that they could be implemented directly. In parallel to the developments made in this project, SenseGlove themselves were also creating a new type of thimble and cable guide, which justified the level of embodiment made here, as further refining would likely result in diminishing returns in terms of usefulness for the overall Nova 2.0 design. That being said, the 2.0 thimbles and cable guides concepts showed great promise to save assembly time and combined with the new assembly process, it is likely that these components are the biggest time savers when properly finalized and manufactured.

Appendix H – Assembly Process: Nova 1.0

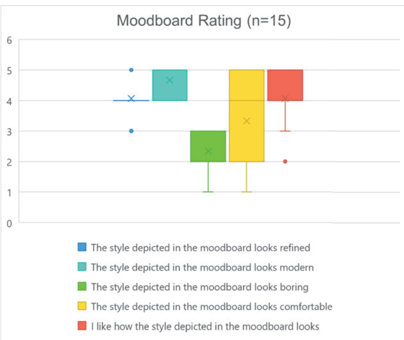


Appendix I – Assembly Process: Nova 2.0

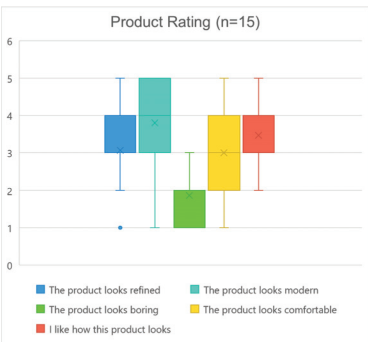


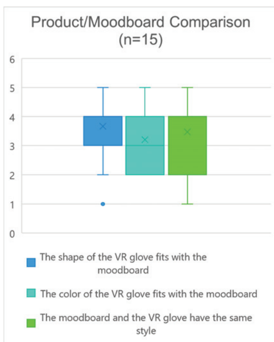
Appendix J – Aesthetics Questionnaire Results

Timestamp	I understand that my answers to this questionnaire will be processed anonymously and will not be used for any other purpose than this research.	I identify as:	My current age is:	The style depicted in the moodboard looks refined	The style depicted in the moodboard looks modern	The style depicted in the moodboard looks boring	The style depicted in the moodboard looks comfortable	I like how the style depicted in the moodboard looks	Do you have any additional comments or remarks to elaborate on your opinion?
2023/01/24 9:57:46 PM GMT+1	I understand and wish to participate.	Male	21	4	5	2	5	5	
2023/01/24 10:04:20 PM GMT+1	I understand and wish to participate.	Male	28	4	4	2	4	4	
2023/01/24 10:24:06 PM GMT+1	I understand and wish to participate.	Female	55	4	5	2	5	5	
2023/01/24 10:34:05 PM GMT+1	I understand and wish to participate.	Male	26	5	5	1	4	5	What I really like about this style is the mix of minimalism with texturized elements, and enhacement of details and shapes with the use of sharp edges. These elements make the designs pop up even though they seem to use simple shapes
2023/01/24 10:47:55 PM GMT+1	I understand and wish to participate.	Male	25	5	4	2	2	5	
2023/01/24 11:32:52 PM GMT+1	I understand and wish to participate.	Male	23	4	5	3	4	4	
2023/01/25 8:35:40 AM GMT+1	I understand and wish to participate.	Male	24	4	5	3	1	3	
2023/01/25 9:13:26 AM GMT+1	I understand and wish to participate.	Male	24	4	5	2	4	4	
2023/01/25 9:29:06 AM GMT+1	I understand and wish to participate.	Male	24	4	4	3	3	4	It looks like a set of products with very modern, design, but where not always the care is taken to look at practical ergonomics.
2023/01/25 10:00:28 AM GMT+1	I understand and wish to participate.	Female	24	3	5	3	1	2	Please keep in mind Im not too familiar with VR and its design, so this is a layman's opinion. The mood board does seem like it's in line with other VR designs (does give the same vibe and feel as Oculus), but it's design seems terribly plastic-y. Is there an idea of what kind of inner lining the glove will have? Knowing a few VR users they can use these devices for a long amount of time with little breaks, so comfort should be taken into account as well. I don't see this reflected in the mood board. The color of the mood board is nice, although using light shades of grey or white might not be as practical for a glove (depending on what you do with it of course). Signs of usage are more visible on white. I'd recommend a shade of grey that is visible on the upper left image shown in the mood board, as it will still fit with the design you have in mind but that's also a bit more user friendly. I like the dotted ribbing on the buttons that's seen in the bottom left image and feel like it will add style and practicality into the design. Being able to feel where buttons would be with your headset still on feels like an advantage. The style of the button displayed in the upper middle image is also nice aesthetically. Overall a great mood board that can be the foundation for a great product. Good luck!
2023/01/25 11:53:14 AM GMT+1	I understand and wish to participate.	Male	23	4	4	2	5	4	
2023/01/25 12:16:46 PM GMT+1	I understand and wish to participate.	Male	23	5	5	3	2	4	The style looks very sleek and modern, but does makes me feel like aesthetics were prefered over some functional behaviours (i.e. form over function instead of form from function, whatever those functions may be for these products I don't know).
2023/01/25 3:58:15 PM GMT+1	I understand and wish to participate.	Male	23	3	4	2	2	3	I have always felt that VR equipment looks and feels uncomfortable. The size and hard surfaces do not speak to me. This moodboard contains some smaller size equipment and softer materials which are more attractive to me. Color does not matter for me, even though I tend to own either gray or black electronics (mostly because they are made only in that color). Ergonomic design does seem more attractive to me than bulky design with hard edges.
2023/01/25 5:56:42 PM GMT+1	I understand and wish to participate.	Male	58	4	5	2	3	4	
2023/01/26 10:25:56 AM GMT+1	I understand and wish to participate.	Male	22	4	5	3	5	5	The soft textures give a comfortable impression and the lack of major variation makes it look whole and modern, but introduces a little boringness. It is very much in theme with currently widely used styles in gadgets/tech. The expression of the items are soft in feeling and character. Using a more bold/wider colour palette and more strong visual accents can improve character in the moodboard.
Averages			28.20	4.07	4.67	2.33	3.33	4.07	

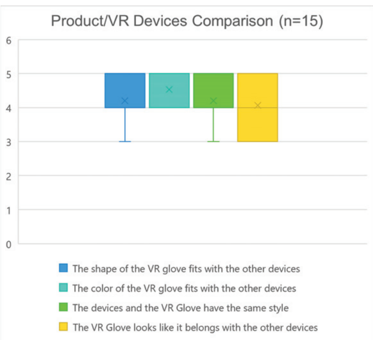


The product looks refined	The product looks modern	The product looks boring	The product looks comfortable	I like how this product looks	Do you have any additional comments or remarks to elaborate on your opinion?	The shape of the VR glove fits with the moodboard	The color of the VR glove fits with the moodboard	The moodboard and the VR glove have the same style	What influenced your opinion in the previous answer?
3	5	2	4	4	Though the general shape of the solid structures are very sleek and refined. The black wires clash slightly with the clean aesthetic	5	5	4	
3	5	2	3	4		4	2	4	
4	5	1	5	5		5	4	5	
5	5	2	4	5	Although I like the aesthetics quite a lot, i feel like the black part of the casing coud have extra slight features to make it look more interesting. These could be different textures or elements engraved/highlighted (like a logo)	5	5	5	Simplicity of shapes, predominant curves, the use of discontinuities and sharper edges to enhance the shape and change of parts, use of neutral colours, and same type of material
3	4	2	1	3		4	2	2	All devices in the moodboard seem wireless, the glove design has a lot of them. Also none of the products in the moodboard are black
3	3	2	2	3		4	3	3	
1	1	1	1	2		2	2	1	
4	5	3	4	3		4	2	4	
2	3	3	4	2	The proposed design looks it bit bulky. This might interfere with the wrist.	3	5	2	The glove looks more bulky compared to the mood board. The white tips of the fingers do not look like they flow seamlessly over the hand.
3	3	1	3	3	This concept image looks really interesting! I have a few questions/ comments: The thing that immediately stands out to me is the fact that that there is no resistance mechanism for the pinky finger. Is there a reason why this is omitted? I can think of a few instances where the pinky is useful (Playing Spiderman, a virtual rock concert). The design for the resistance mechanism on the other fingers looks sleek, but the exposed wires give the impression that they can be snagged easily when they're out in the open. Maybe add a second layer of fabric on top of them to make sure they're not exposed? The fabric of the glove looks sleek and comfortable, so disregard my earlier questions about the fabric. In that regard I cannot say with full confidence that the whole glove looks comfortable, as I can't eye what the feel of the upper housing (black leather object with white lining) will be. It looks heavy and clunky. The thing that docks the most points for me is the housing of the machinery on top of the glove. As I said it looks heave to me, and the different materials and colors make it stand out a lot. Its clunky design also diminishes the modern feel you are going for, putting it more into the retro-modern feel a la Terminator. The placing of the upper housing is logical as there no other place it could go on the hand, but it might be an idea to look further up the arm and place it between the wrist and elbow. If the housing is heavy it can place strain on the wrist with it's current placement and that might be a disincentive for an older demographic or those with wrist problems (carpal tunnel, etc). Placing it further up the arm will give you more room for whatever tech you have in there and keep the glove itself sleek.	1	4	5	The shapes shown in the mood board all have a sleek, minimalist style to them. The concept art of the glove shows a big, overarching upper housing that takes up most of the view and looks quite clunky, which strongly separates the shapes shown in the mood board and the ones visible in the concept art. Most of the colours shown in the mood board are similar to the color of the glove part of the concept art. Once again the pitch black upper housing stands out and doesn't compare to tints shown in the mood board. When looking at the general design of the glove and the elements highlighted in the mood board they are highly similar. It gives off a modern feel with a design that's as sleek as possible.
3	3	2	4	3		4	2	3	
4	3	2	2	3	At a first glance it looks like a very functional interface, but not comfortable to use (which I can only know when trying)	4	2	4	The style is mostly in line between the mood board and the glove design, however the colouring of the moodboard contains more saturated and muted types of gray compared to the stark contrast of the black/gray and white of the glove.
1	3	1	2	3	The exposed wiring and bulky housing make it look somewhat unrefined. I would be afraid of the weight seeing the large housing on the back of the hand.	2	4	2	I feel the design of the glove is not as optimized and refined as the tech on the moodboard
4	4	2	3	5		4	3	4	
3	5	2	3	4	Refinement is lost a little due to the visible strings and separate finger elements. It's the continuous flowing shapes that really emphasised refinement. Shape and colour of the whole help counteract this, but not completely.	4	3	4	The size and shape balance of the glove is different from the moodboard, but looking at the elements more individually, the shapes are the same style. The strong use of black is something that I see in the glove, but not the moodboard.
3.07	3.80	1.87	3.00	3.47		3.67	3.20	3.47	

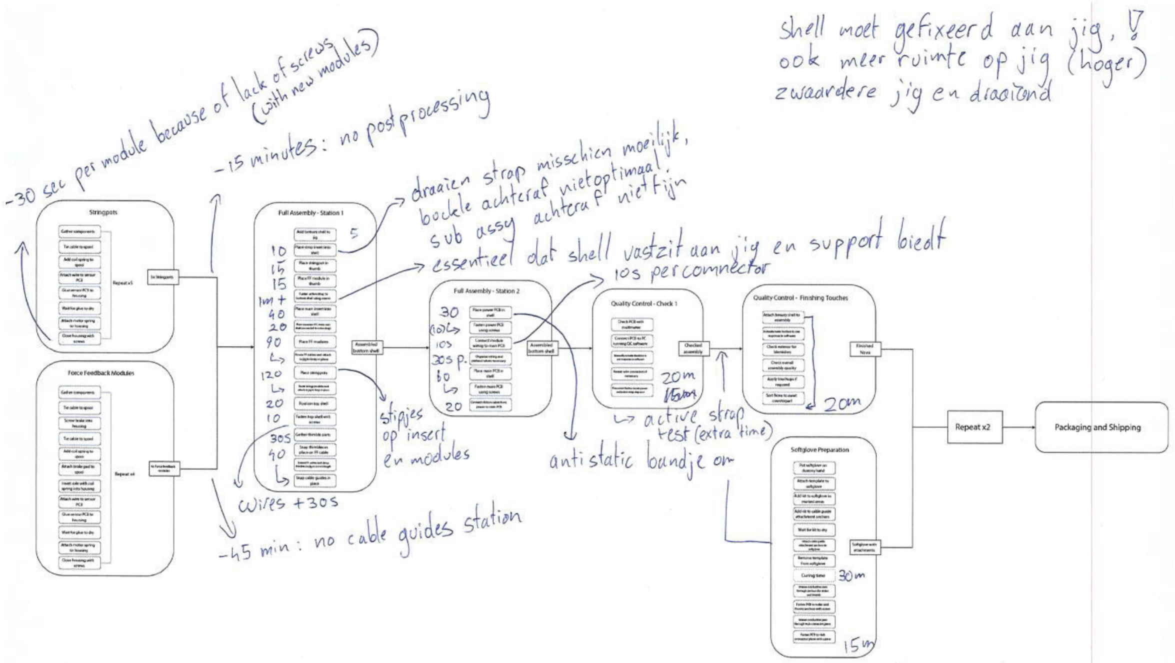




The shape of the VR glove fits with the other devices	The color of the VR glove fits with the other devices	The devices and the VR Glove have the same style	The VR Glove looks like it belongs with the other devices	What influenced your opinion in the previous answer?	If you could change anything about this product to make it look better, what would you change?
5	5	5	5		Black wires look a bit do-it-yourself like. Maybe a way to hide them?
4	4	4	4		Perhaps give the black shape some more definition. Play with linework to create identifiable shapes?
5	5	5	5		Maybe a white glove
5	5	5	5	Same syle of shapes (rounded, avoiding sharp corners), colours and materials	I would add small details. As this is a product that is worn on the hands, it is likely to receive some sort of impact/scratching during it's lifetime. I would add some dotted extruded texture on those areas where it is more likely to receive impacts as a medium of protection. I would also try and include an engraving of the name of the product/company somewhere in the black area. In small size should already be enough. Also, some lights that indicate the basic status of the product could be a great idea for ease of use and clarification for the users
3	4	3	5	They all have sci-fi characteristics	Turn the black into light grey, it would create a better uniform whole. The black is too strong
4	4	3	4		Minder dik
4	5	4	3		
4	4	4	4		The design, while modern, still look very bulky. To make it more efficient and easier to handle the design could be more slim.
5	4	5	5		I would reduce the size of the device on the back of the hand, it looks heavy. I would also try to integrate the white sensors of the fingers more into the glove. Additionally, the wires on the glove stand out to much against the grey glove, I would add some sort of pattern to the glove, to blend it in better.
4	5	4	3	Once again the big upper housing stands out as the shape that doesn't jive with the rest of the images shown. All headsets are sleek and have that matte plastic look, while the upper housing on the glove with it's shiny leather really stick out. The color scheme of the glove makes much more sense with a dark VR headset in mind, as it now fits both a white as well as a black headset. I am of the opinion that, especially with color, one should not try to cater to both markets at the same time as it lessens the core design of the glove itself. Sure, it makes sense when paired with a VR headset, but on it's own the color scheme feels jarring. If you want to cater to both markets while keeping your design more cohesive it might be an idea to release your glove in two colours: one light grey, the other dark grey. I understand for such a small team that impossible as you can make only one, so your current design choice is understandable. As I mentioned in an earlier comment the style of the current design for the glove gives off a more retro-modern style that feels like a Nintendo Powerglove or other 80s-style modern design, while the VR headsets are current day modern design. they're definitely in the same sphere, but it feels like the glove was released in 1999 and the headset in 2019. Especially because the glove is juxtaposed against headsets, a fundamentally different product, it's hard to say like it belongs because it's the odd one out. It does feel like it could belong in the	It's best to consult my previous notes as they are more detailed, but here are some highlights from the top of my head: - cover the exposed wiring to prevent snagging (possibly by an extra layer of fabric) - Possibly find a different placement for the upper housing as it looks like it's heavy, obstructs the wrist movements, and takes away from the sleek design of the glove (possibly move it further up the arm to keep freedom of movement and distribute weight better to make it possible to use the glove for a longer period of time) - rethink the color scheme of the glove to fit one aesthetic instead of trying to fit two to make your design more cohesive.
4	4	4	3		Cover the fabric glove and perhaps the cords above
4	5	4	3	I feel very strongly that the glove fits the design of the top right headset	Assuming the black part is made of hard plastic, it looks like it would be uncomfortable to flex your knuckles against the plastic. Regarding looks I think it looks very much in line with the headsets shown in the previous question and would go realy well with a headset of a similar aesthetic. As a personal preference I would maybe mute the contrast between the black and white a bit. And it
5	5	5	4	The glove has similar dimensions, design elements and colors as the headsets. I would say it fits best with the top right headset with the color combo	The somewhat large housing seems unattractive to me (in the same way early models of VR headsets do). The exposed wires seem vulnerable for getting caught in something. If possible I would make the housing smaller (by possibly extending it over the wrists). The wiring could be protected in some way to avoid tangling. In my opinion the casing extending at the base of the thumb seems somewhat uncomfortable but when using a headset this might not matter.
4	4	4	4		Black color
3	5	4	4	Colour and shape wise it feels like the design suits the headsets, but the headsets feel more carved out of a single shape. The glove, as stated before, feels more separate.	Flow of the shape w.r.t. the form of the hand and arm. Colour blocking of the black and white, I feel would be better suited inverted. A more connected feel between fingers and back of the hand and more texture blocks, perhaps using fake split-lines to separate these blocks.
4.20	4.53	4.20	4.07		



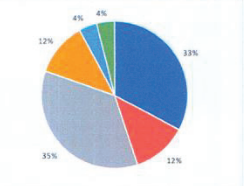
Appendix K – Assembly Time Test Notes



onbekenden:
- hoe klaar is active strap?
- misschien aparte button pcb in final v2?
-

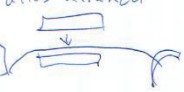
marges: geen factory speeds
\+ 10 minuten "waste" time
totaal = 80% efficiency, dus +20% tijd voor niet-fixed stappen

	Assembly Station/Step	Time per Nova (mins)
Modules	Force feedback modules	60
	Stringpot modules	65
Cable guides	Cable guides type AB	16
	Cable guides type BC	12
	Thimbles	8
	Thimbles with vibration	10
Hub Assembly	Full Assembly - Station 1	45
	Full Assembly - Station 2	45
	Full Assembly - Station 3	45
Quality control	Quality control - Check 1	15
	Quality control - Check 2	15
	Quality control - Finishing Touches	15
Postprocessing	Shell postprocessing	15
Softglove preparation	Softglove preparation (excluding curing time)	15



Total assembly time (1 Nova):
381 minutes or 6,35 hours

- gleuven active strap niet genoeg om te fixeren
- aparte tool per schroef, dus dezelfde schroeven is beter
- main issue micro DC: kabels aan strap
- terugschieten modules is een risico als overshoot
- eis: strings moeten uitsteken
- nova 2: achteraf stroomkabels is beter
- stringpot & FF kabels kunnen klemmen tussen CGs
  ↳ kabels ver horizontaal uitrekken en dan alles klikken
    ↳ nu awkward door jig grootte
- inder extra CG in 2.0: andere cable guides hub



- \+ 1 m batterij op PCB solderen
- \+ tijd voor assembleren strap lock in-house (10-20 sec) => niet non-destructive

- stroomdraad ins-van voor betere cable guidance
  - ↳ kabels hebben extra lengte nodig voor assembly → lusje per kabel voor clearance
    - ↳ wordt nog steeds spaghetti
- fixeer PCB vóór aansluiten
- magneet in Hub is extra werk, dus klik voor beauty shell
- openen beauty met schroevendraaier kan

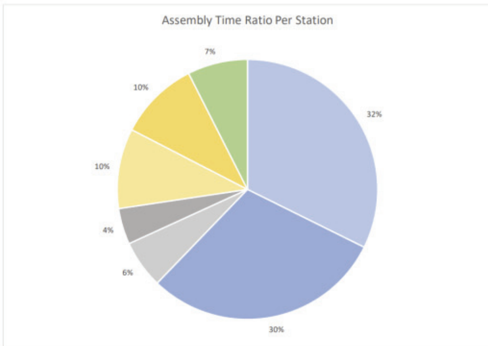
Voordelen naast tijd:

meer logica
minder fouten
fastening goed geregeld
schade en reparatie meegerekend
kleine aanpassingen, groot voordeel
pijnpunten

Appendix L – Assembly Time Test Calculations

Station:	Stringpots		Force Feedback modules		Full Assembly - Station 1		Full Assembly - Station 2		Quality Control - Check 1		Quality Control - Finishing Touches		Softglove preparation (excluding curing time)	
Activity and estimated duration (seconds):	Stringpots assembly	3900	Force Feedback modules assembly	3600	Adding bottom shell to jig	5	Placing and fastening powerPCB in shell	30	Regular checking	900	Regular checking	900	Gluing and assembling softglove	900
					Placing strap assembly into shell	10	Connecting wires for modules to main PC	50	Active strap checking	300	Active strap checking	300		
					Placing stringpot in thumb	15	Organising and managing wires for all mo	270						
					Placing FF module in thumb	15	Placing and fastening main PCB	60						
					Placing and fastening active strap	60	Connecting ribbon cable between PCBs	20						
					Placing main insert into shell	40								
					Placing micro DC motor	20								
					Placing and routing cables for FF modules	90								
					Placing and routing cables for stringpots	120								
					Adding top shell	20								
					Fastening top shell	10								
					Gathering cable guide parts	30								
					Snapping cable guide parts in place	60								
					Additional time:		Additional time:						Additional time (not counted):	
					Managing wires while fastening top shell	30	Putting on antistatic bracelet	5					Curing glue	1800
					Inserting and fastening glove connector	30								
Total time per station (seconds):		3900		3600		555		435		1200		1200		900
Has efficiency factored in:	Yes, is at 80% efficiency		Yes, is at 80% efficiency		No, needs adjustment		No, needs adjustment		Yes, is at 80% efficiency		Yes, is at 80% efficiency		Yes, is at 80% efficiency	
Time in minutes (100% efficiency):		65		60		9.25		7.25		20		20		15
Realistic time in minutes (80% efficiency, rounded):		**65**		**60**		**12**		**9**		**20**		**20**		**15**
Percentage of total:		32%		30%		6%		4%		10%		10%		7%

Assembly time at realistic efficiency (seconds):	12060
Assembly time at realistic efficiency (minutes):	201
Assembly time at realistic efficiency (hours):	3.35



Appendix M – Manufacturability Analysis Session Transcript

Do you foresee any issues that come to mind immediately when looking at this design?

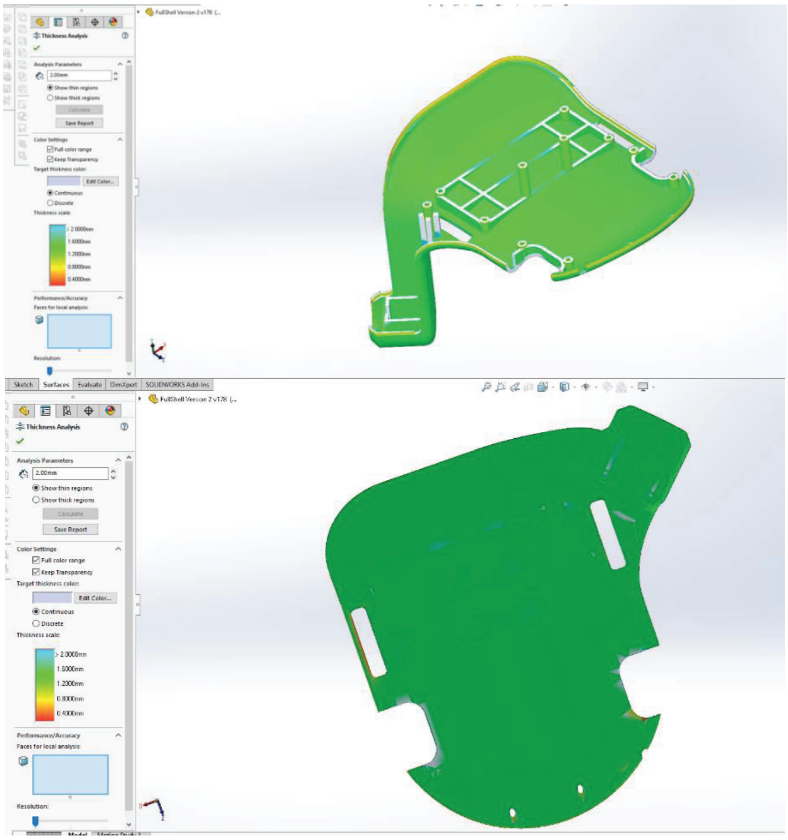
- Er komen niet direct grote problemen naar voren.

Do you foresee any issues regarding material flow in this design that might cause knit lines or other artifacts?

- Op de kleine ribben in de topshell zouden extra aanspuitpunten handig zijn omdat materiaal daar goed moet vloeien. Een alternatief zou zijn om er een extra onderdeel van te maken, maar dat is misschien niet goed voor het design.
- De overgang van dik naar dun in die ribben is niet optimaal, wandjes zullen ongelijk stollen en dan ontstaan er interne spanningen.
- De wand die de USB poort inklemt is ook te dik; 1mm zou acceptabeler zijn.
- 2mm is dik voor ABS. Als je stijfheid in je onderdeel wilt behouden zou je een holle wand kunnen maken, dus met een offset vanaf de rand en met opstaande wandjes.

Do you foresee any issues regarding cooling in this design which might cause sink marks or similar problems? And: Where do you expect warping to happen in this design and why?

- Sommige wandjes zijn te dik en lopen niet geleidelijk in elkaar over, dus daar krijg je warping. Bijvoorbeeld bij de boss voor de schroef bij de duim zijn de ribben te dik.
- De active strap verbindingswanden zijn ook te dik en zullen dus gaan warpen bij het afkoelen.
- Ook de regular strap ribben zijn eigenlijk te dik, maar die zouden makkelijk dunner gemaakt kunnen worden. Dat zou het probleem al moeten oplossen.
- Algemeen advies vooral voor de bottom shell: maak alle ribben iets dunner, die geven nu problemen voor koeling en material flow.

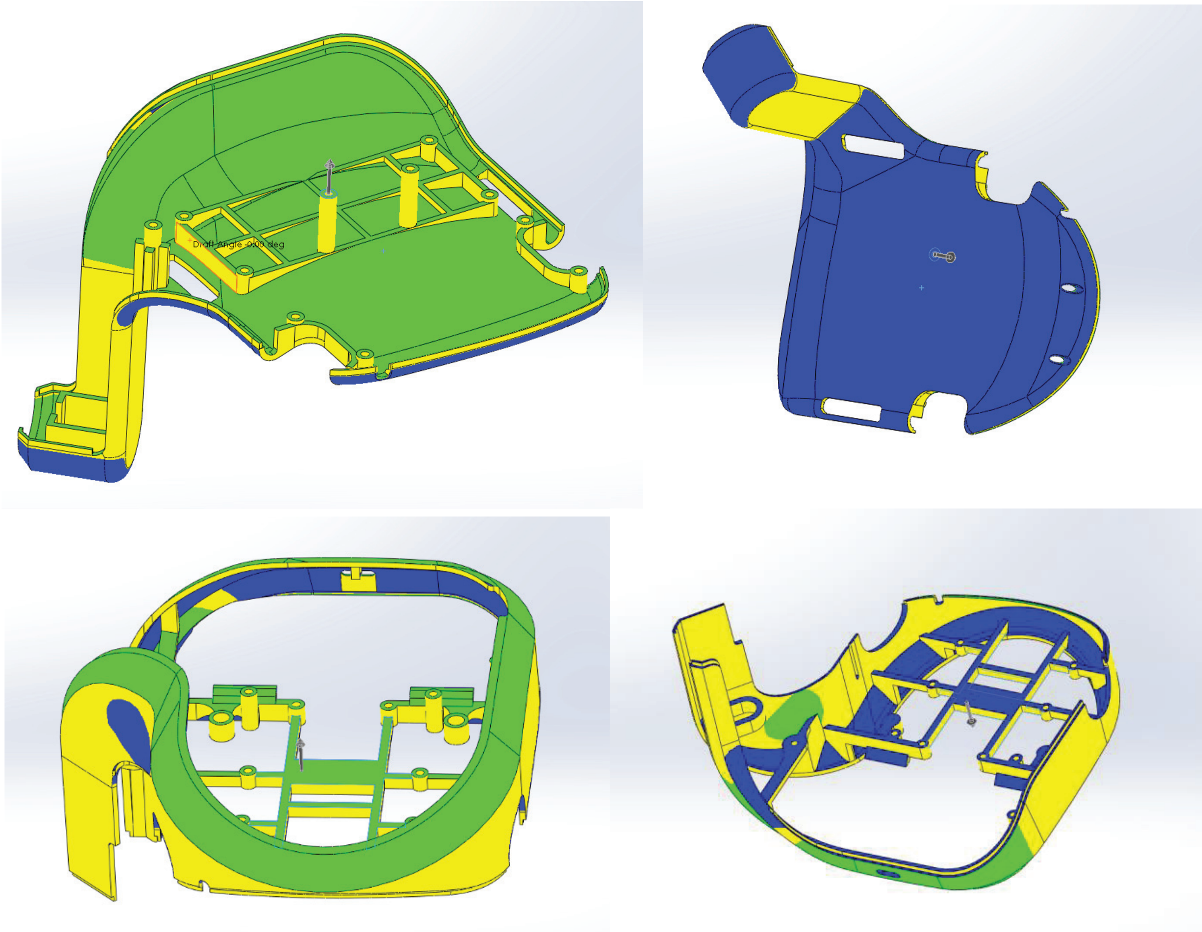


Green: constant wall thickness within acceptable limits; White: (too) high wall thickness

This design does not contain draft angles yet, but should be free of undercuts. Do you expect the design to be draftable with minor adjustments? In the case it is not, why is this the case?

- Aan de achterkant van de bottom shell lijkt een kleine undercut te zitten die opgelost moet worden.
- Verder is het toevoegen van draft angles goed genoeg om de bottom shell produceerbaar te maken (met vorig advies verwerkt).
- De top shell heeft een probleem met vormovergang bij de duim, die heeft een omgekeerde lossingshoek. De achterkant van de duim heeft ook een blauwe plek in de analyse, die duidt een omgekeerde lossingshoek aan.
- Het lange deel van de duim zal een hele dikke wanddikte krijgen aan de bovenkant en een heel dunne aan de onderkant als je simpelweg lossingshoeken toevoegt, dus je zou die wanden in het ontwerp een beetje schuin moeten laten lopen om dat probleem te voorkomen.

- Advies over lossingshoeken: Met de SolidWorks Feature Xpert kun je sommige kleine problemen oplossen, maar je moet het model zo goed mogelijk aanleveren, dus zonder fundamentele fouten.



Green: positive draft; Yellow: needs draft; Blue: negative draft.

What is your (rough) estimate of the price for manufacturing these parts? What could increase or decrease this price?

- De prijs zal ongeveer hetzelfde of goedkoper zijn dan de huidige Hub, omdat er geen schuiven in de mal meer zullen zitten, maar wel een extra onderdeel gemaakt moet worden. Nu zijn de schuiven handwerk vanwege de lage productieaantallen. Als de Hub in grotere aantallen gemaakt zou worden zouden schuiven goedkoper kunnen zijn.
- De Hub van Nova 1 kost 3 euro en 3 cent per shelldeel. De malkosten zullen rond de 6000 liggen met de huidige producent. Die zijn nu van normaal staal en dat is prima voor de productieaantallen, maar een gehard stalen mal voor bijvoorbeel een miljoen cycli zal al snel de prijs verdubbelen.

If you could change this design to be easier to manufacture, what would you change?

- Vanwege het frezen van de mal is het verstandig een minimumradius van 0.2mm aan te houden bij scherpe randen. Dat is hoe klein de malmaker minimaal kan frezen. Voor de andere features kiest de malmaker zelf de beste maat, dus daar hoef je niet veel rekening mee te houden.

The envisioned material for this design is ABS. Do you have any recommendations or suggestions for a (more) suitable material for this kind of geometry, considering its function as an enclosure for a device?

- PC aan het ABS toevoegen zou de stijfheid kunnen verbeteren. Vanwege de extra kosten en de eisen voor het product is dat echter niet nodig.
- De bottom shell heeft een relatief lage deellijn/wand die de stijfheid kan beïnvloeden. Dit kun je beter oplossen met ribben op het onderdeel of een hogere rand, maar je hoeft daarvoor niet naar een ander materiaal te kijken.

What are the tolerances that can be achieved? How does the design's geometry affect this?

- Die worden niet meegerekend met het onderdeel dat door het bedrijf wordt aangeleverd, dat lost de spuitgieter zelf op. Voor de lip & groove op de deellijn heb ik 0.1mm aangehouden bij Nova 1, maar de spuitgieter zorgt dat de toleranties in je ontwerp worden gehaald.

Where would you recommend the runners and ejector pins be placed (generally)?

- Als je bij de malmaker aangeeft wat de zichtvlakken van je onderdeel zijn, dan komen daar in ieder geval geen aanspuitpunten en ejector pins. De spuitgieter bekijkt dan wat het beste alternatief is.
- Je wilt een goed verdeelde druk van de ejector pins, dus grote oppervlakken zijn fijn om ze op te kunnen plaatsen. Bij de top shell is dat misschien een probleem vanwege de dunne structuur. Een uitsnijbaar onderdeel toevoegen voor ejection zou handig zijn. Anders kun je misschien die ribben laten uitlopen over het gehele onderdeel zodat de kracht verdeeld is. Met zo'n uitsnijbaar onderdeel zouden de wanden iets dunner zijn waar je wilt afsnijden, net zoals bij een modelbouwset.

Do you have any additional comments about the design?

- Voordat je het onderdeel aanlevert moet je bepalen wat de zichtvlakken zijn. Dan komen daar geen aanspuitpunten en ejector pins, maar dan kan de spuitgieter ook zorgen dat daar geen zichtbare markeringen achterblijven bij het spuitgieten.
- De ribben van de topshell zou ik zelf misschien proberen toe te voegen aan de main insert zodat ik de beauty shell in een inham in de top shell zou kunnen leggen. Dan is de stijfheid van de top shell ook beter omdat het echt een gesloten onderdeel is, wat goed is voor de plaatsing van je ejector pins.
- De insert zou ik zeker 3D printen in plaats van spuitgieten. Vanwege wanddikte maar misschien ook om mogelijke productiefouten te corrigeren. Dat kan niet makkelijk met spuitgegoten onderdelen, maar wel als je snel in-house nieuwe onderdelen kunt maken. Hij zou ook uit twee delen kunnen bestaan als het nodig is.

Appendix N – Personal Project Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: de Vries
initials: A.J. given name: Joris
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD / DfI / SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Sander Minnoye — dept. / section: Materializing Futures
** mentor: Erik Thomassen — dept. / section: Materializing Futures
2nd mentor: Bryan Zaaijer
organisation: Senseglove
city: Delft — country: Netherlands

comments (optional): The subject of my project leans heavily towards embodiment design and manufacturing, which is were my interests lie. For this reason, having two mentors from the MF department seems best for everyone involved.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair ______________ date 25 - 08 - 2022 signature ______________

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 33 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name C. van der Bunt date 26 - 08 - 2022 signature ______________

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED ○ NOT APPROVED

Procedure: ★ APPROVED ○ NOT APPROVED

comments

name Monique von Morgen date 06 - 09 - 2022 signature ______________

Initials & Name A.J. de Vries Student number ______________

Title of Project Optimizing a VR glove's enclosure for assembly and production

Optimizing a VR glove's enclosure for assembly and production

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 01 - 08 - 2022

23 - 12 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The goal of this project is to develop a redesigned enclosure for Senseglove's Nova VR haptic glove, focusing on optimizing its assembly and production, and improving build quality. Any adjustments to the enclosure's design should have minimal or a positive effect on the rest of the product. By developing this solution, Senseglove benefits on financial and competitive grounds: Improved assembly time and consistency saves on labor costs per product, which in turn lowers its retail price. This lowers the barrier of entry for individuals or companies looking to adopt the technology, while still keeping a profitable margin for Senseglove and improving the product's quality. Additionally, this allows for upscaling of Senseglove's production line, resulting in the manufacture and assembly of more Novas per year, reaching more clients.

Project stakeholders:
- Senseglove desires to create a functional and attractive product to achieve their vision and strengthen their competitive market position. They also seeks to improve Nova's assembly time in order to scale up production while increasing profits.
- The Senseglove Assembly Team desires an easy-to-assemble product that requires a minimal amount of time and/or steps to complete. They want to be able to deliver more assembled products in the same time frame while maintaining employees' wellbeing and ergonomics.
- Senseglove's clients seek to implement VR haptics into their business with minimal financial and intellectual investment. They want good quality and longevity from their purchase.

Opportunities and Limitations:
In a developing, experimental VR market, there is a need for accessible, good quality hardware. With an improved production and assembly process, Nova can be shipped to clients in greater numbers and with a better build quality. Implementing optimized fastening features instead of glue can improve Nova's assembly time while increasing its durability and consistency, and lower the rejection rate of parts during the process. Design for intuitive assembly can make assembly worker's tasks easier to understand and execute, lowering the risk of human error in the process.

Ergonomic aspects like the size and weight of Nova can make radical changes to the current design challenging to implement. Special care has to be taken to keep the current experience intact (or improved), while also implementing meaningful design choices that improve assembly.
Due to Senseglove's desire to scale up production while keeping manufacturing costs as low as possible, only traditional manufacturing methods like injection molding are likely feasible, limiting design freedom in a way because parts need to be designed with compatible features in mind.
The degree in which production can be scaled up is dependent on the assembly time saved with the redesign, but it is difficult to determine how much that can be before starting the project. Also, investment costs associated with implementing redesigns should not outweigh the benefit that they offer, keeping in mind that an increase in part price should be justified with optimization in other areas.

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introduction (continued): space for images

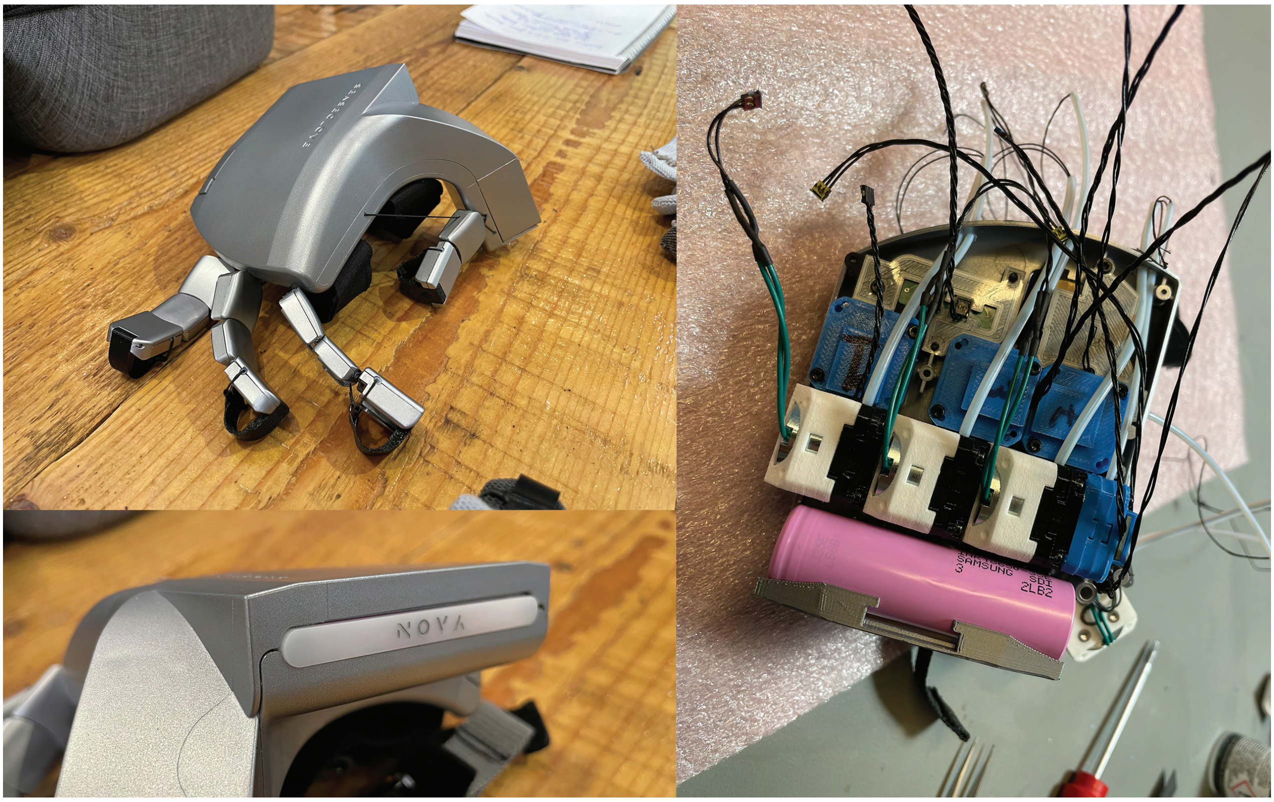


image / figure 1: Senseglove Nova enclosure with internals (current design).

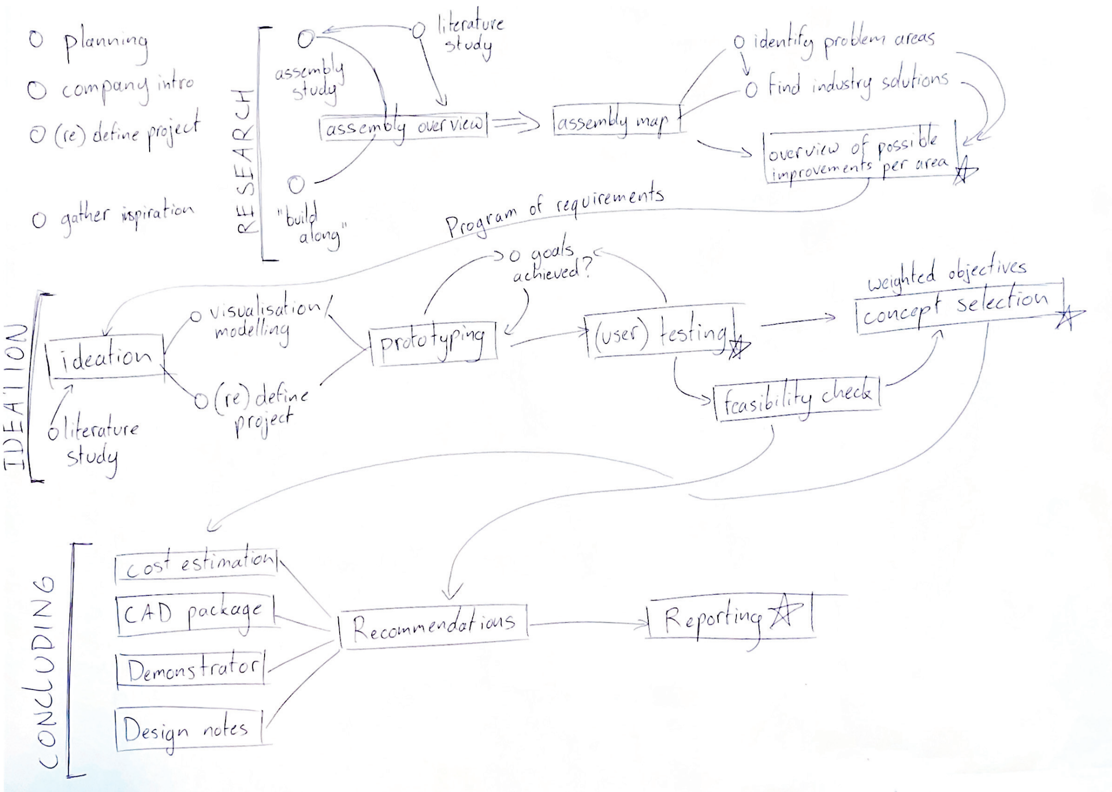


image / figure 2: Design process overview.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Senseglove's current Nova VR haptic glove is not yet up to the standard the company has for its vision of the product, but is functional and already being applied in multiple use cases. The current design of the enclosure for the components sitting atop the glove can be improved from a production perspective. The goal of this project is to develop a redesigned enclosure, focusing on optimizing the assembly time and consistency, which enables larger-scale production and better build quality, while using non-permanent fastening solutions to allow for repair and replacement of individual parts.

By identifying points of improvement through analysis of the Nova's assembly process and current enclosure, effective changes can be applied to its parts using CAD, prototyping and (user) testing in the assembly line. Desires from stakeholders and limitations in materials/production methods need to be balanced to deliver a viable redesign.

The scope of the project will be limited to the embodiment of the enclosure of the Nova (hand mounted case and thimbles). No adjustments will be made to the current functioning of the internal components, as these will remain mostly identical for the next version of Nova, but the layout and physical interaction between components and the enclosure may change depending on critical points identified during analysis. While the project is ongoing, Senseglove will continue their design work in parallel and share findings and insights that might be relevant for the redesign, but the scope of this project is limited to the enclosure itself and potentially some components affected by it. Therefore, any major changes in other parts of Nova are considered 'black boxes' to keep the project manageable within 100 working days and to make sure design choices in this project can be made independently of developments within Senseglove which are out of scope.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

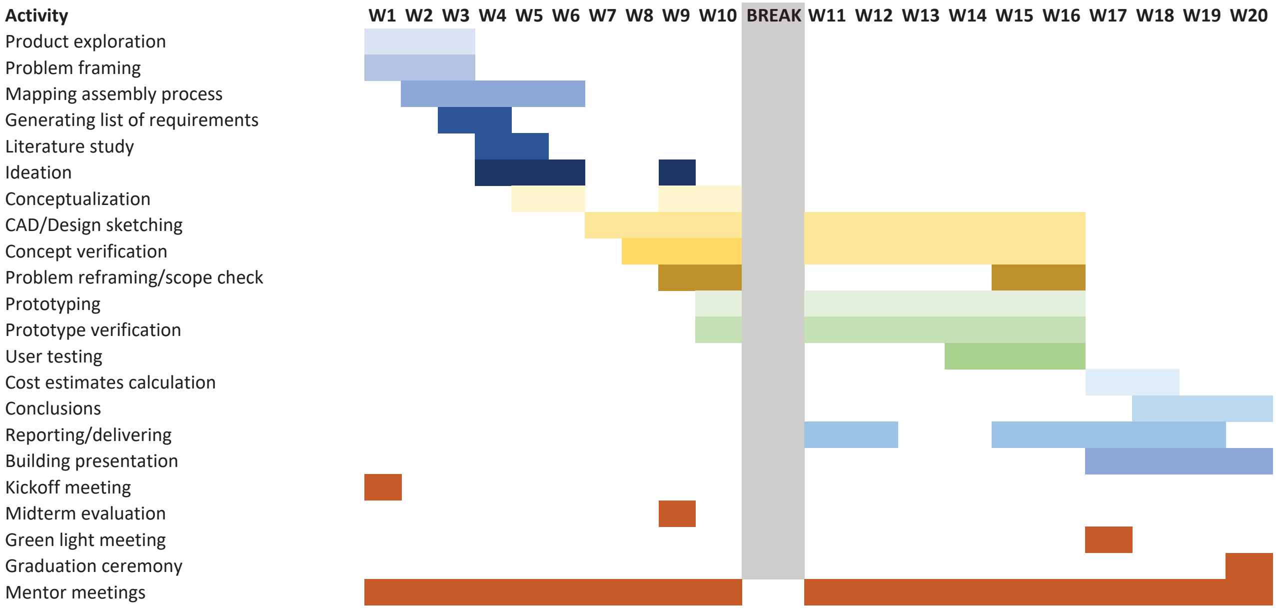
Redesigning Senseglove's Nova enclosure for larger-scale production, improved assembly time and better build quality through analysis of the current design and assembly process. With a redesigned enclosure, Senseglove can produce, assemble and sell more Novas to potential clients for a larger market share and increased profits.

The envisioned deliverable for the project is a (functional and fully assembled) physical prototype ready for testing and demonstration, plus an extensive CAD package containing new part dimensions, materials and geometries. Additionally, the final deliverable will contain detailed notes on the new design and possibilities for future development. The goal of the deliverable is to provide Senseglove with an updated version of the enclosure which is ready to be implemented alongside other design changes to the Nova, which will become apparent during the project. At the end of the graduation project, Senseglove should be able to integrate the redesign into their Nova V2 with minimal additional development required.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 1 - 8 - 2022 23 - 12 - 2022 end date



My planning starts on August 1 and ends the 23rd of December. This totals to 105 working days, 5 of which I have reserved for a possible break. In my previous experience with full-time work/projects, I have found that time spent on personal projects greatly improves motivation and inspiration. The date of this break is flexible, but it is currently planned to occur after week 10, shortly after the midterm evaluation.

To take into account a possible extension of four weeks after the green light meeting, I will discuss contract and workspace possibilities with Senseglove. I do not expect to need an extension, but as a safety net it might be wise to take this into account.

The graduation ceremony would preferably take place late December, but depending on the schedule of all stakeholders it might be moved to after New Year, as the Christmas period can be difficult to plan around.

The majority of the project is prototyping and evaluating designs with the Senseglove assembly team, but this requires proper analysis of all aspects involved with the production line. I want to therefore use the first few weeks of the project to get to know Senseglove and the Nova, as well as reserve time to go through the full process of assembling a unit. This way, I get a better understanding of the process of how Nova is manufactured and also where to identify points of improvement. In the second half of the project, I intend to gradually build up a report and a demonstrator for Senseglove. Mentor meetings would ideally take place every week to keep all parties updated and to discuss progress.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The reason for setting up this project is that I want to graduate on a topic which fits my personal interest. Virtual Reality is a technology which I have always found fascinating, and I believe there are many possibilities to implement it meaningfully in consumer or professional markets. As I have always had a passion for physical prototyping and figuring out how things are made, I wanted to combine these topics into a project. Senseglove provided the opportunity to work on a new version of their product, with results actually affecting the course of its development and possibly going to market.

I seek to improve my prototyping and CAD skills further, applying them in a corporate setting with higher stakes and more advanced tools at my disposal. Graduating at an external company has been a conscious choice, as I want to get more experience 'in the field' and come in contact with industry professionals, learning from them and possibly forging relationships which last into my own career. A startup like Senseglove operates on a scale which is attractive to me, where there is enough staff with varying expertise that the company can operate independently, but the size of the company does not cause delays which affect the versatility and flexibility of design work.

I would like to acquire more knowledge in the fields of:

- Assembly design/design for repair
- Integrated function design
- Injection molding design for production
- VR hardware design challenges
- Product certifications and standards

Hopefully, this projects functions as a stepping stone into the manufacturing/prototyping industry. I have always been fascinated with making things and want to find a career in which I can work with physical products as much as possible. Computer peripherals (input devices) have always been an interesting topic for me because they combine electronics and physical interaction, and I wanted to work on a product in this field. Senseglove's Nova is the perfect product to work on where I can work with and learn about all these aspects.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.