EXPRESSIVE PROSTHESES

A case study through interdisciplinary collaboration

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ABSTRACT

In the field of prosthetics, the main focus is usually to bring back functionality after limb loss or congenital limb deficiency. Prosthetics can be categorized in many different ways. There are bodily powered rudimentary claws, myoelectric prostheses, and advanced bionic hands that are the most advanced prosthesis available. One of the most common types are myoelectric prostheses, with a silicone rubber glove on the outside, supposed to look like human skin. These prostheses are made to mimic the visual expression of real limbs, but still very often they have an unnatural look. The colors are not perfect, and the mechanical movements are unnatural.

The users are of all ages, from children to old people, and the prostheses are technically and physically adapted to every user's needs. But these prostheses lack possibilities for the user to express themselves through the prosthesis. Every human is unique, and we express ourselves in many ways, through clothes, hairstyle, glasses, the way we act, etc. These are all choices that reflect who we are. Glasses have evolved from being seeing aids, into fashion pieces in the wardrobe (Pullin, 2009). Can this evolution be translated to prosthetics? Our thesis takes an approach to this issue, by incorporating co-creation with users of prosthetics, orthopedic engineers and designers to create a truly unique and expressive product. Relevant literature, semi-structured interviews and other research methods were utilized to gather a foundation of insights that we used in the case study with the subject "Erik", to design a prosthesis he would want to use in his everyday life. The findings suggest that including the user in the design process with a team of designers and orthopedic engineers, could lead to higher satisfaction with the aesthetic expression. As this project will continue after the end of this project, it is important to acknowledge that more research is necessary to understand all aspects of an expressive prosthesis, as well as how it should be integrated in the process for the workshops responsible.

This thesis will explore the field of expressive prosthetics, its potential value in our society, and how it can be implemented in the orthopedic system through transdisciplinary collaboration.

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GLOSSARY

There are some field specific terms and terminology used throughout this thesis.
Refer to this glossary if needed.

Advanced hand
Myoelectric prosthetic hands that are more advanced than the typical "claw" hand. Fingers can move independently and the hand can remember more actions.

AKT26
A program created by NAV to fund people with disabilities over 26 to get access to activity aiding devices. If you are over the age of 26 in Norway, you can no longer get custom made prosthesis for your activities, unless you get funding through this program, which is a fund that gets refilled 1. January each year. Once the fund for the year is empty, you have to wait for the next year if you didn't get approved (NAV, 2023).

Congenital limb deficiency (CLD)
A condition where an arm or leg doesn't fully form in the uterus and the baby is born with the defect. The limb(s) is often shorter and or has missing limb segments.

Myoelectric
A way for prosthetic hands to be controlled by electricity generated in muscles. Muscles in the stump are contracted and sensors will pick up the small signal, amplify it, which then controls the hand.

Orthosis
Externally applied device used to modify the structural and functional characteristics of the neuromuscular and skeletal systems. A common orthosis is a device that fits around the hand to help grip items for elderly people.

Pre-preg
Pre-impregnated composite material sheets, like carbon fiber, basalt, Dyneema, fiberglass etc. Common material for making prostheses.

Prosthesis
Artificial device used to replace a partially or fully absent/deficient limb segment.

Prosthetic(s)
Prosthetics refers to the field of research and expertise in designing and building artificial limbs. Prosthetic can also be used as an adjective as well. Example: prosthetic limbs (Amputee-Coalition, 2020).

PSKK (Prosedyre for spesielt kostbare komponenter)
Procedure for especially expensive components - In Norway, to get funding for an advanced hand, or other expensive part, you have to go through a screening process. The screening tests if the hand will improve your quality of life, and to see if you are able to control this advanced hand prosthesis which is more difficult to use. This process is called PSKK (Østlie et al., 2019, 1-3).

Stump
The limb left after an amputation, or a limb that is not fully formed due to congenital limb deficiency (CLD).

Sleeve
The part of the prosthesis that fits around the stump and is in contact with the skin. It is shaped and formed around a mold of the stump.

Aesthetic prosthesis
An aesthetic prosthesis is a type of prosthesis that is a realistic visual replica of a human hand. Its sole function is to look as realistic as possible, and does not feature any moving parts, or other functionality. It is a mirrored version of the healthy hand/arm (Norsk Teknisk Ortopedi, n.d.).

Cosmetic prosthesis
A cosmetic prosthesis is a type of prosthetic that at first glance looks like a real hand, but if you look closely you will see that it is only a plastic cover with a general "skin-tone". You can also get these in a personalized color so that it matches your skin tone better. These types of prostheses are moveable and can be controlled through myo-electricity. They function like a claw and can do most basic holding tasks (Norsk Teknisk Ortopedi, n.d.).

INTRODUCTION

INTRODUCTION
Stakeholders

Norsk Teknisk Ortopedi
Our main collaboration partner during this project. NTO is an orthopedic workshop that makes prostheses only for upper limb extremities. They are the only orthopedic workshop in Norway that works exclusively with arm prostheses. Our main contacts at NTO are:
Mette Thorslund - CEO at NTO.
Anne Margrethe Gøra - Orthopedic engineer, who is responsible for Erik's prosthesis.

Anatomic Studios
Anatomic Studios is a Swedish company that specializes in making 3D-printed covers for prostheses for lower extremities. They cooperate with orthopedic engineers to create covers that work with the patient's prosthesis and will likely be the ones picking up the task of creating the final covers for our case study subject. Our main contact with Anatomic Studios is: Christian Veraeus - Orthopedic engineer and CEO of Anatomic Studios.

"Erik"
Erik is a pseudonym for our case study subject. He is a 55 year old male, born with CLD in his left arm. He has lived most of his life without a prosthesis, and has great interest in design. A lifetime without a prosthesis has left its toll on his body, and he is now starting to struggle with strain-related issues in his neck, shoulder and his healthy arm. It is now recommended for him to use a prosthesis, to mitigate further musculoskeletal issues.

INTRODUCTION

This master thesis took place from January 2023 until May 2023, and was done in collaboration with Norsk Teknisk Ortopedi (NTO), and a small part with Anatomic studios. Erik, our case study subject, did also contribute with many valuable insights and discussions. The intention of this project is to explore the field of expressive prosthetics and design a product that helps Erik express himself, increasing the likelihood of him using his prosthesis, thus reducing musculoskeletal issues from overstraining his healthy arm. We have found that there is a need for more expressiveness in the world of arm prosthetics through our preliminary research in the course "MAPD5210 Visualizing Complexity". The project had a heavy user-involved process, where Erik was an integral part in the final visual look and requirements of the prosthesis. We had frequent concept meetings and feedback sessions.

The project is based around co-creation, and having as many different viewpoints on the issue as possible. We therefore wanted to gather a diverse user panel in the beginning, and sent emails to different paralympic sports clubs, and various associations related to prosthetics. But after the interview with Erik, the project changed course, into a case study, since he had a desire to challenge how prosthesis could look. We believed that by focusing on taking things to the extreme, the project could have more impact, and help change the opinion of others.

Upper extremity prostheses are a small part of the world of prosthetics. Approximately 90% of limb prostheses are lower extremity prostheses, while the last 10% are upper limb prostheses (M. Thorslund, personal communication, 11.08.2022). NTO is the only orthopedic workshop in Norway that only focuses on prosthetic arms, and they have patients all over Norway. Even though the market for prosthetic arms is a small one, does not mean that they should be ignored. Prosthesis for upper limb extremities are naturally more exposed, and are not covered by pants or shoes. Upper limb extremities are also an extension of our minds to the physical world, and inherently personal. It's how we interact with the world, by touching, feeling and creating (F. Medola, personal communication, 07.09.2022). Losing this is a big loss for amputees, as these sensations are not yet reproducible with prosthetic devices commercially available today. We therefore believe that prostheses need to reflect who the user is, as they perceive themselves, giving them the sense of completeness and feeling whole.

The project focused on the arm prostheses and not the hands, as those are not something that NTO produces. The solution has to be something that they can manufacture/control so that it can be a part of their portfolio of services they can provide. The focus area of this thesis is primarily Norway, but the findings could be applied worldwide.

NB:
All illustrations and images not marked with "Fig #" are made by us.

Background

Preliminary project: Visualizing Complexity

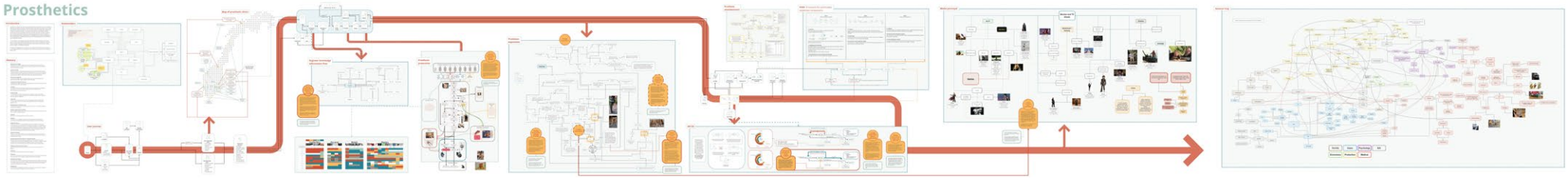


Fig 1. Gigamap from preliminary project: Visualizing Complexity, 2022, by Døviken, A. L., Opdal, E., Wallerud, J. Full PDF in Appendix B.

In the fall of 2022 we had a course (MAPD 5210) in gigamapping where we focused on exploring and visualizing the systems connected to prosthetics. Political, psychological, environmental and societal systems were analyzed and mapped. We found several intervention points in this map, where some were related to systemic change, while others were based on societal change.

In our gigamap we found 3 main intervention points where we as designers could jump in to make a change. There are two systems here where there is a definite need for change.

- AKT26 is a fund which grants money to activity prosthesis for people over 26 (NAV, 2023).
- PSKK is a procedure you have to go through to get advanced hands and other costly components (Østlie et al., 2019).

The last intervention point is related more to customization of the prosthetic, which we decided to go for. This intervention point offers a solution where the process is done in interdisciplinary teams between orthopedic engineers and fields related to aesthetics like fashion designer, industrial designers, artists etc. Through collaboration with the users the teams would create personalized and expressive prosthesis which would be a reflection of the users personality or hobbies.

According to the orthopedic engineers we have talked to there is a gray area when it comes to promoting certain products over others. They are not supposed to bring up alternatives for customization or expensive options unless the patient brings it up first. We understood that this was not a legal matter, but more of an occupational policy based in morality since NAV, i.e. the government, pays for the prostheses. There is also the issue of false advertisement. Since each patient is unique with different shaped stumps, muscle control and practice, different prostheses work better for some than others. If an orthopedic engineer recommends a certain hand or electrode pattern that works for some it won't guarantee that it will for this specific patient. A recommendation might lead to the user feeling dissatisfaction as they had high expectations of the device.

Expressive prosthetics

Expressive prosthetics are prostheses that reflect the wearer in a way they can express themselves with, similar to fashion, clothing, jewelry, makeup, hairstyle, etc. It's the rejection of conventional prostheses that try to replicate the aesthetic of "normal" arms. What the vast majority of conventional prostheses do is focus so much on the function (Kester, 2020, 5) that the aesthetics seem like an afterthought.

The mechanical look of the prosthesis gets covered in a silicone glove, which is a simplified replica of a human hand colored in one homogeneous shade of "skin color". This is supposed to camouflage it and make it seem more natural. If they achieve this with the basic glove design is arguable. Since it's not detailed enough to be a cosmetic prosthesis, and a perfect color match is hard to achieve, it quickly lands in the notorious uncanny valley.

Aesthetic prosthetic hand from NTO, 2023.

Ceramic hand, 2023.

Expressive prosthetics

The Uncanny Valley

The uncanny valley was first described by Masahiro Mori “I have noticed that, in climbing toward the goal of making robots appear human, our affinity for them increases until we come to a valley (Figure 1), which I call the uncanny valley.” in his essay The Uncanny Valley (MacDorman & Kageki, 2012). He places the aesthetic prostheses in the deep end of the uncanny valley saying “...when we realize the hand, which at first site[sic] looked real, is in fact artificial, we experience an eerie sensation.”. Cosmetic prostheses however stays out of the uncanny valley, but only as long as they are looked upon for short amounts of time. If you look for long enough or when you touch it you realize it doesn’t move like human hands and it doesn’t feel like it should, immediately giving you an eerie feeling. Thus falling into the uncanny valley again.

So expressive prosthetics seek to be noticeable and stand out from the crowd, and start a conversation about the prosthetic instead of trying to hide it. Avoiding the uncanny valley by not trying to achieve a perfect likeness to human limbs but instead having its own unique expression. We also theorized that including the user in the process would make them create a stronger attachment to their prosthesis. In her research paper “The Body as Canvas: Motivations, Meanings and Therapeutical Implications of Tattoos”, Alter-Muri found a correlation between students who partook in the design of their tattoo and the healing factor of said tattoo (Alter-Muri, 2020, 144). This could also lead to less prosthesis abandonment, which depending on where in the world you are is a big issue (F. Medola, personal communication, 07.09.2022). Medola talked about the importance of getting people to wear their prostheses, because of the strain you cause by overcompensating with the healthy arm. If the prosthesis is used more often the workload is averaged out to both limbs and prolongs the time before you risk getting musculoskeletal issues. (Chadwell et al., 2019) (F. Medola, personal communication, 07.09.20222).

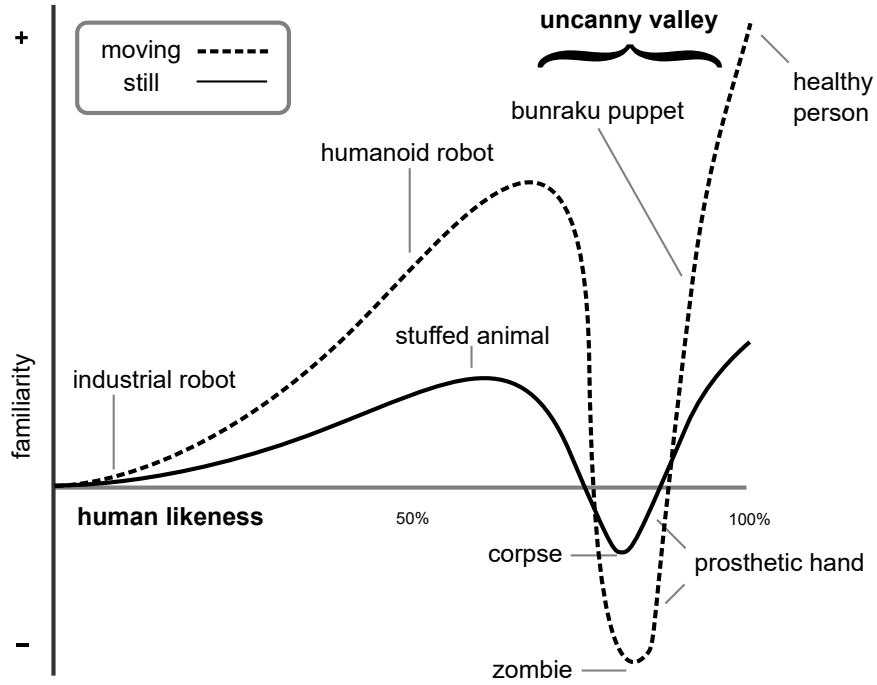


Fig 2. Mori Uncanny Valley, 1. May 2007, by Smurrayinchester. (https://en.wikipedia.org/wiki/Uncanny_valley#/media/File:Mori_Uncanny_Valley.svg). CC BY-SA 3.0

Aesthetic prosthetic hand from NTO, 2023.

Existing examples of expressive prostheses

Open Bionics - Hero Arm

Hero arm is a product line from Open Bionics where they have a standard prosthesis with changeable panels on the outside so you can customize your arm by choosing color, patterns or sometimes get a custom one made specifically for you. The arms are 3D-printed, which allows the user to customize their own prosthetic, if they have the required expertise. The Hero arm is not for everyone as the sleeve fits a large portion of amputees and people with CLD, but not all. Such is the case with Erik, as his stump is too long.

Fig 3. MagSwap™ Removable Covers, retrieved 21.05.2023, by Open Bionics. (https://openbionics.com/hero-arm-overview/).

Existing examples of expressive prostheses

Limbitless Solutions

Limbitless Solutions is a company based in Florida who makes 3D printed prosthetic arms aimed mainly for children. They have categorized their arms in different “classes”, and the children are encouraged to take an online test which will then put them in one of them. Their approach is one of co-creation, where the child can choose colors for their prosthesis, or even get a custom paint job. The different classes are “warrior”, “ethereal”, “shadow” and “serenity”. They also have collaborations with video game studios, to release arms based on different video games (Marasa, 2021).

Fig 4. Bionic arms for children, retrieved 21.05.2023, by Limbitless Solutions. (https://firebasestorage.googleapis.com/v0/b/limbitless-solutions.appspot.com/o/frontendContent%2FDec20Updates_AdultArms%2FHeader%20Creative%20Personalized%20Empowering%20Bionics%2Farms_version2.png?alt=media&token=971f44f1-5ac6-4405-920d-7b0f73854a94).

Existing examples of expressive prostheses

The Alternative Limb Project

The Alternative Limb Project is on the total opposite side of the spectrum from the aforementioned companies. Sophie de Oliveira Barata started this project where she treats prostheses like high fashion/art. She creates custom wearable sculptures specific to each person, breaking the boundaries of what prostheses are and can be. Her prostheses have been a part of several music videos and art exhibits. This approach is attention grabbing and is great for changing the public opinion, but is impractical for large scale applications.

Fig 5. Synchronised, 2017, by Sophie de Oliveira Barata & Dani Clod. Photo by Omkaar Kotedia. (https://thealternativelimbproject.com/wp-content/uploads/2020/05/1-synchronised-for-Kelly-Knox-photo-by-Omkaar-Kotedia.jpg).

Existing examples of expressive prostheses

Anatomic Studios

Anatomic Studios is a Swedish company based in Malmö. They focus on retrofitting expressive shells for leg prostheses. They have a large library of colors, patterns and designs you can choose from, and often create custom designs if the user wants something else. According to one of the co-founders, about 20-25% of their orders are custom ones (C. Veraeus, personal communication, 11.05.2023). This suggests a substantial portion has a desire for covers that more accurately represent them.

Fig 6. Prosthetic leg covers, retrieved 21.05.2023, by Anatomic Studios. (https://anatomic-studios.com/wp-content/uploads/2021/09/prosthetic-covers-2-1-1200x818.jpg).

Existing examples of expressive prostheses

Various advanced hands

There are several advanced prosthetic hands that have their own identity and look. Hands like the Covvi hand, TASKA CX and TASKA HandGen2 are three examples of hands that look more industrial and robotic. Colors are either shades of black or white, and might give a more masculine expression.

Fig 7. COVVI hand, retrieved 21.05.2023, by COVVI. (https://www.covvi.com/wp-content/uploads/2022/03/ProductOverview-NexusHand-Front.jpg).

Fig 8. Taska CX hand, retrieved 21.05.2023, by Taska. (https://fillauer.com/wp-content/uploads/2023/01/TASKA-D1FB31-U1-Back-View-QD-RT-web.png).

Research question

How can the integration of expressive features in prosthetic devices improve the perceived value and psychological well-being of individuals with limb loss, while balancing functionality and aesthetics?

The research question were formulated in the beginning of the project, and are still relevant at the end. It has been influenced by the change from user panel to case study, but at its core it is still relevant and related to the project. The change allowed us to take a deeper look into the research question.

THEORY

THEORY

Relevant articles were gathered and analyzed, which we then used to build upon. Articles and books were chosen for their relevance to the subject of aesthetics, prosthetics and disability. As an emerging field, there is a definite need for more studies related to expressive prosthetics, but we did find valuable insight from existing literature.

For instance, in the research paper "The Body as Canvas: Motivations, Meanings, and Therapeutic Implications of Tattoos" researchers explored the "relation between art therapy and tattoos by examining the motivations for obtaining them and their connection to healing"(Alter-Muri, 2020, p 139). The study found a correlation between self designed tattoos with healing and acceptance. We believe that the research's conclusions can be directly transferred to the field of prosthetics as amputations are often caused by traumatic incidents, and the road to recovery is often long and difficult. If the prosthesis itself could be used as a tool for overcoming the trauma, it might benefit the user in the long term.

In the book "Design Meets Disability" Graham Pullin argues that traditionally designing for disability has focused too much on functionality, and aesthetics and user experience have been somewhat neglected. Pullins believes that people with disabilities should have aids that are both nice looking, and well functioning (Pullin, 2009).

Remy Marasa concludes in his undergraduate thesis "Prosthetic Identity: Understanding the Relationship Between The Self, Prosthetic Design, and Society" that personal customization can foster a sense of attachment and identity (Marasa, 2021).

Both Don Norman's "Emotional Design" and Kristine Harper's "Aesthetic Sustainability" argue that emotional attachment to a product is vital for its longevity. Norman talks about the three main levels.

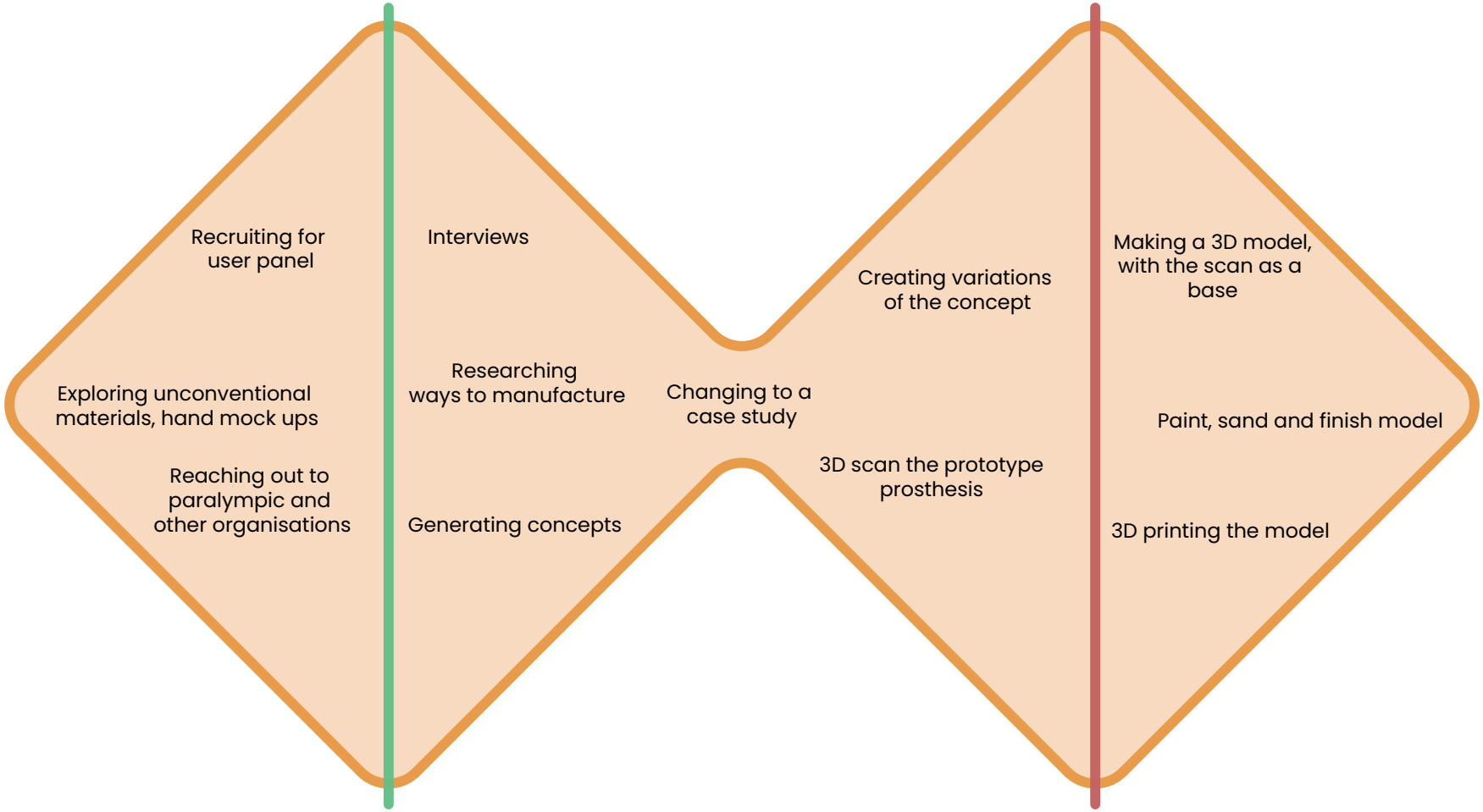
- Emotional design, being Visceral design (appearance and initial impact).
- Behavioral design (the experience of using the product).
- Reflective design (the memories attached to using the product) (Norman, 2005).

Harper, on the other hand, focuses more on aesthetics, and how aesthetics can lead to more sustainable products, through how the user relates to the object. She argues that aesthetically pleasing objects are taken more care of, and are more often repaired than aesthetically unpleasing objects (Harper, 2018, p. 26). She also delves into different kinds of aesthetics, like durable aesthetics, and flexible aesthetics, and how aesthetics can tell a story. Her chapters about the pleasure of the unfamiliar is also relevant to our work, as a body which has lost a limb is not what society deems as normal, but instead of trying to hide it, it should rather be accentuated as something unique (Harper, 2018, p. 59, 62, 75).

METHODOLOGY

METHODOLOGY
Methods
Double diamond

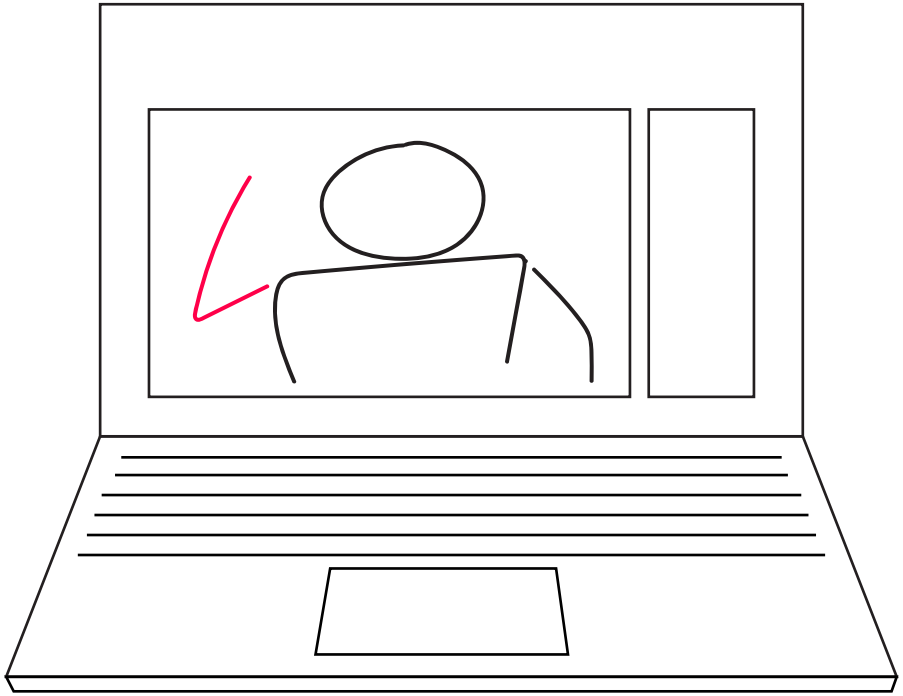
As with many design projects, we have also utilized the Double Diamond method. By using this method, more extreme ideas and directions can be explored before narrowing it down to the direction the user and we think is best. Doing this again from the starting point of the conclusion from the last phase, helps not getting tunnel vision on one idea, wasting time on refining it only to find new information making it obsolete.



Methods

Semi structured interviews

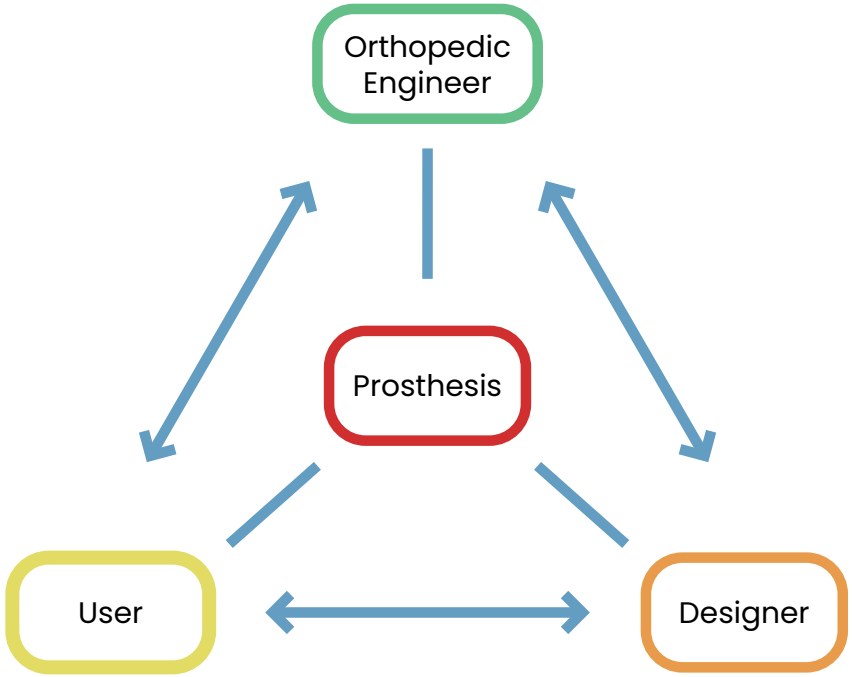
This project has largely revolved around semi-structured reviews with users, and has been our main method to gather insight during the project. We made an interview guide with general questions we wanted answered, but if the interviewee said something interesting we could ask them to elaborate further. This way we gained knowledge and interesting viewpoints we hadn't considered before. The interviews were conducted over Microsoft Teams, as the participants were spread out across Norway. A short presentation about the project was shown at the start of each interview, showing existing solutions, and our thoughts about where the project would lead. Mock-up models were also shown, so that we could try to challenge the participants on what a prosthesis could be, for example the ceramic hand. To participate the interviewee had to sign a consent-form, which told them about how their data would be handled, and that they could withdraw their consent if they wanted to. Personal data was stored according to Sikt's guidelines.



Methods

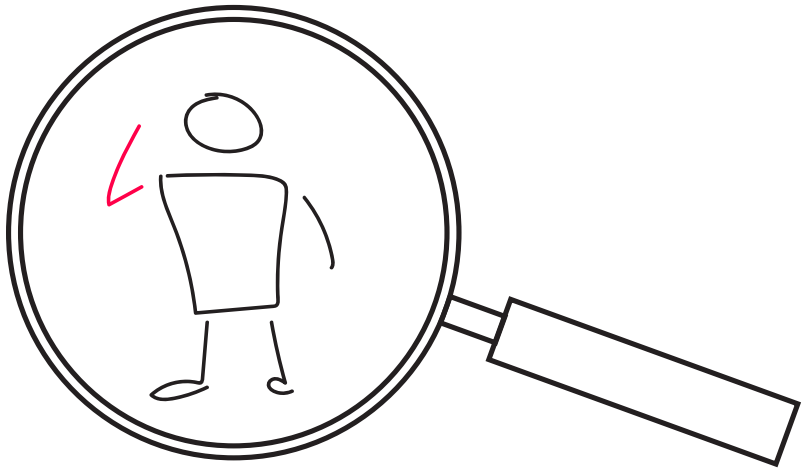
Interdisciplinary collaboration

Norsk Teknisk Ortopedi (NTO) has been our main source of professional feedback, and has been a great resource for us during the project. We have discussed possible paths for the project and they have given us valuable information about the systems around prosthetics in Norway. This method was chosen so that the project would stay grounded and relevant. Orthopedic engineers have different priorities than a designer when working with patients, but through collaboration we can bring the best parts of both disciplines to the project.



Case study

A case study is a research method where either a situation or person is examined. This method was chosen due to Eriks interest and engagement in the project, and that it would be a great opportunity to delve deeper into a specific case.



Limitations

Time

As this project had a limited time frame of only 4 ½ months, managing it was critical. Efficiency and swift decision making was important to ensure the project would stay on course. Therefore, when an opportunity opened to change the direction of the project from a userpanel and experimenting with unconventional materials into a case study of one participant, Erik we took it. He was informed that it would most likely not lead to a fully finished product due to the time left, but he was still interested and wanted us to proceed. Being adaptable and managing the remaining time efficiently to get the best possible result both for him and for us was crucial.

Data

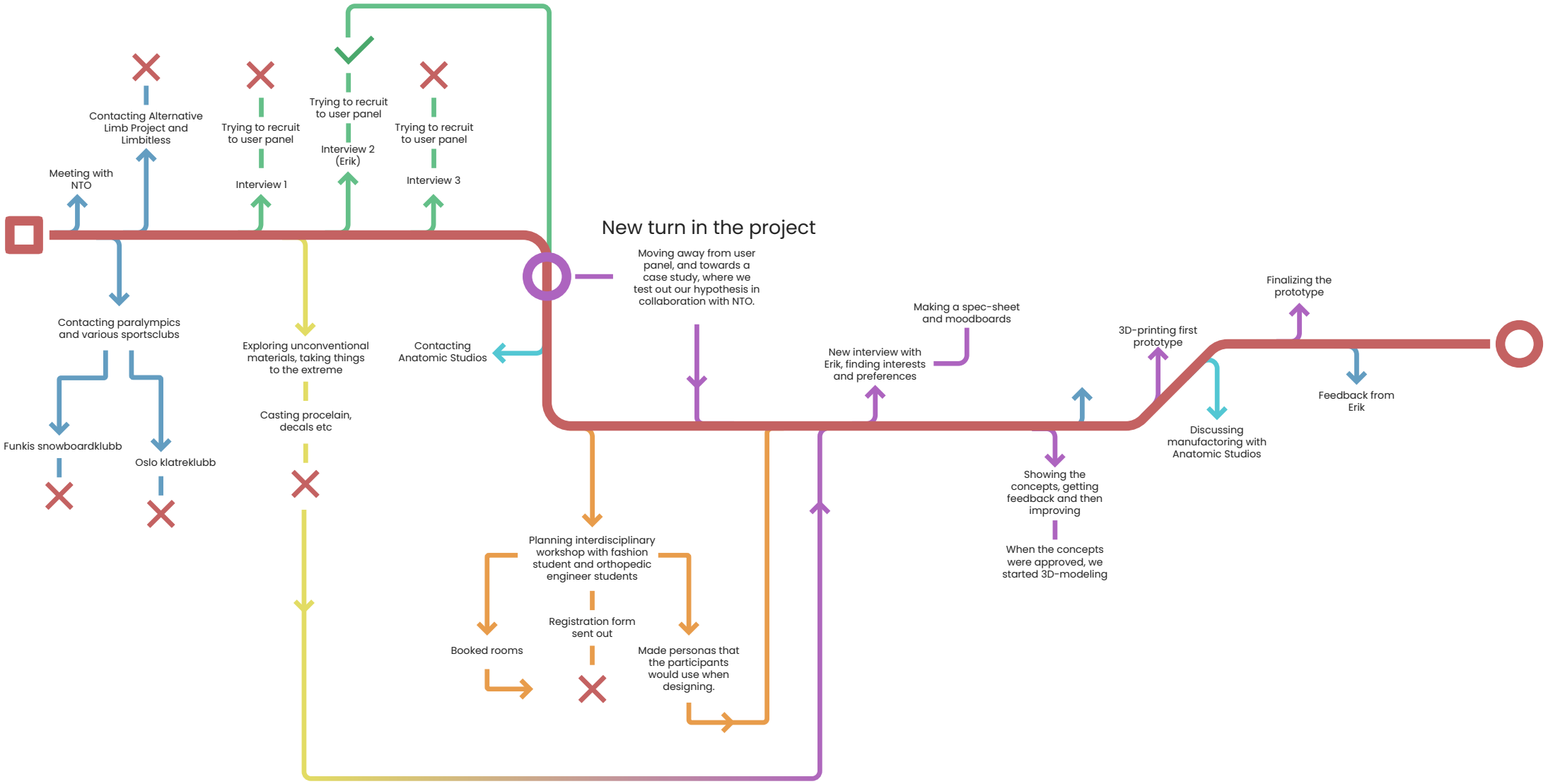
Statistics and data available to us concerning prostheses, amputees and people with CLD in Norway is limited. Finding accurate, non conflicting data proved to be more difficult than expected, so estimates from the orthopedic engineers were used instead. There are more available statistics on these themes in the US, but as they have different circumstances than in Norway we chose not to rely on these.

Participants

As previously stated, gathering participants for the user panel was difficult, as it demanded more time and effort from participants than they were comfortable with. We especially struggled with gathering female participants for our project, and as such lost the chance to gather valuable insight from them. However, Eriks interest in the project gave us an opportunity to go for a case study instead. Two of the participants were also born with CLD, which affects insights gathered, as amputations often stem from traumatic injury. The results from this study might have been different if participants with amputations had been increased.

TIMELINE

TIMELINE


Meeting with NTO
Contacting Alternative Limb Project and Limbitless
Trying to recruit to user panel
Interview 1
Trying to recruit to user panel
Interview 2 (Erik)
Trying to recruit to user panel
Interview 3
New turn in the project
Moving away from user panel, and towards a case study, where we test out our hypothesis in collaboration with NTO.
Contacting paralympics and various sportsclubs
Funkis snowboardklubb
Oslo klatreklubb
Exploring unconventional materials, taking things to the extreme
Casting procelain, decals etc
Contacting Anatomic Studios
Planning interdisciplinary workshop with fashion student and orthopedic engineer students
Booked rooms
Registration form sent out
Made personas that the participants would use when designing.
Making a spec-sheet and moodboards
New interview with Erik, finding interests and preferences
Showing the concepts, getting feedback and then improving
When the concepts were approved, we started 3D-modeling
3D-printing first prototype
Discussing manufactoring with Anatomic Studios
Finalizing the prototype
Feedback from Erik

TIMELINE

The project started broadly. Requests for interviews were sent out to relevant organizations, sports clubs and NTO, and material tests were done. We wanted to challenge the conventional aesthetic of prostheses so we chose to create hands in different styles and materials. The first experiments were done through 3D modeling and renders. This however did not turn out well enough, as the material properties were not sufficiently translated in the renders. Therefore physical mockups were made which were much more effective at translating our ideas to reality, but also considerably more time consuming. Stoneware with transparent glace was chosen, then we covered it with ceramic decals. The motif of the decals were chosen for its reverence and expensive connotations, as we wanted it to convey the feeling of a priceless artifact like Ming dynasty vases.

When the project changed course, the material experimentation aspect was abandoned, and Eriks wants and interests were the deciding factor for the material.

Ceramic hand. Glazed and fired with flower pattern decal.

RESULTS

RESULTS
Interviews

All participants have been given a pseudonym to protect their identity. These are short summaries of the interviews, for the full text, see Appendix A.

Interview 1
Peter
Male, 22 years old.
Congenital limb deficiency
Started using prosthetic arms when he was 6 months old, and used it ever since. Always learned how to live with just one hand, so it has never been an issue for him to complete most tasks, as he has adjusted to his situation.
He doesn't really mind how the prosthetic looks, as for him they are tools that need to function.

Interview 2
Erik
Male, 55 years old.
Congenital limb deficiency
Used some prosthetics when he was young, but due to not liking how they look, and since there is no sense of touch, he has gone most of his life without. Due to overstraining his right shoulder, he is now looking into getting a prosthetic arm with an advanced hand. He would really like to have a prosthetic arm that is unique and looks like nothing else you can get your hands on.

Interview 3
Frank
Male, 64 years old.
Amputee
Since he lost his hand as an adult he had to relearn how to use his left arm. He found that doing carpentry was a good way for him to learn, since there are so many different grips and tasks to perform with the prosthetic. He likes the less advanced hands, because they are sturdier and have less parts.
He doesn't really mind how they look, as for him they are tools that make him able to do what he wants, but he did say that it would be nice to have a picture of his grandkids printed on.

Reflections around the interviews

The sample of interviewees we had was relatively small, with only male participants. We're not sure why we did not get any female participants to partake in an interview, but it's unfortunate as it would be beneficial to get more diverse perspectives. It is however understandable that not everyone has the time or interest in partaking, so we worked with the ones we got access to.

Of the three interviewees, only one of them had a high interest in aesthetics, while the two others didn't really think much of it. We found it interesting that the youngest participant had few opinions on the aesthetics of his prosthetic arm. We assumed that this was something he thought about, but he had told us he accepted that the prosthetic was a part of him. He also stated that since he was born with a congenital limb deficiency that prosthetic arms had always been a part of his life. It would have been interesting to compare his situation with someone who has had an amputation, to see how much the scale of time comes into play, and if trauma affects the user's view on prostheses.

Due to the small size we can not verify that a focus on aesthetics in prostheses is useful or not on a large scale, but we do know that it can greatly affect individual cases such as our case study, Erik.

Erik, the interviewee who was particularly interested in aesthetics, wanted something that was special and unique. His arms will often be seen by others, as his job requires him to often use both hands and teach people how to use specialized equipment. He would therefore prefer something that didn't try to mimic human skin, especially the plastic unicolor "skin color" that prostheses often come in. Even though he was born with CLD, and would have benefited from using prosthesis, he still felt that it would be better to not use them, as he found them ugly. This clearly shows that in some cases, aesthetics needs to be prioritized higher when making prosthetics.

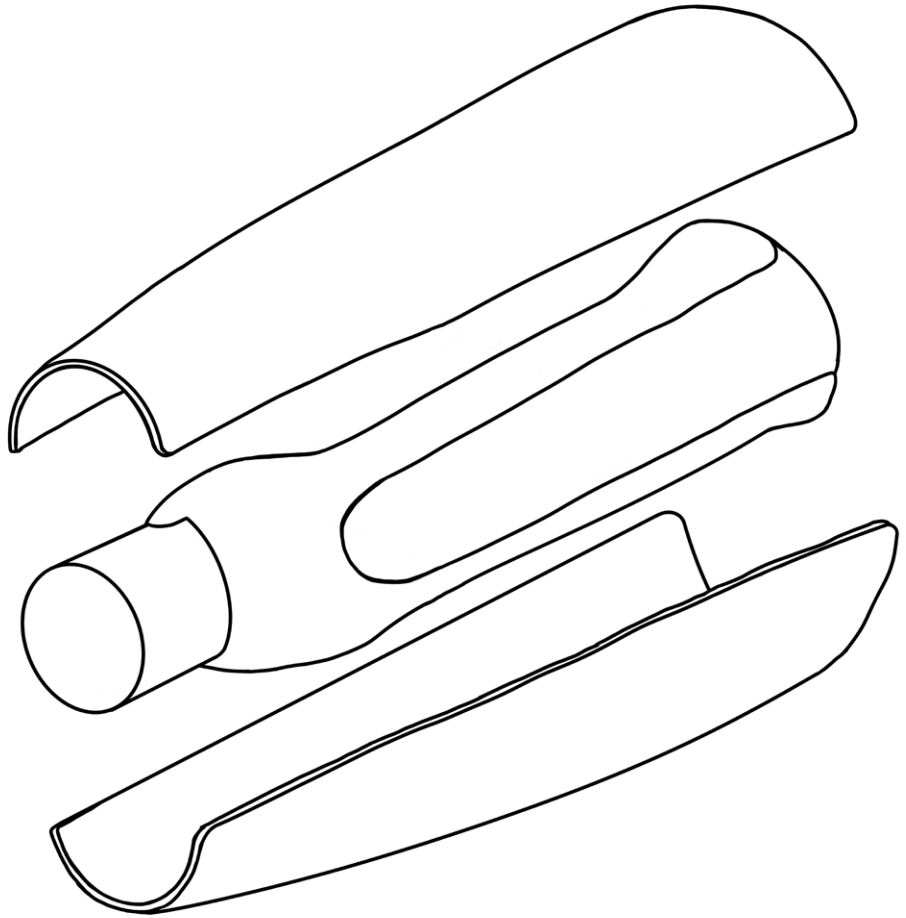
Concepts
Requirements

The finished product must be light, comfortable and easy to use. The weight of prosthetic arms is especially critical since there are less muscles in the stump and it is always in suspension from the body. This is unlike leg prosthetics where the person is supported by the prosthesis. A few extra grams can add a lot of strain and discomfort, especially if you wear the prosthesis for long extended periods of time. So the lighter the product is the less likely it is for product abandonment.

The cover should also not impede on any of the functions of the prosthesis. This includes not being in the way of the movement and not having to compromise on the critical electrical components that need space within the prosthesis. The battery especially takes up a decent amount of space and should ideally be placed on the inside of the forearm where it's naturally protected by the body. Space for the components need to be accounted for.

The user preferably needs to be able to adjust, remove and operate the product with one hand, without the need to position their hand in weird angles.

The prosthetic device also needs to express what the user wants to express. Its aesthetics needs to be flexible, as the user can change covers that suit the situation the user is in.

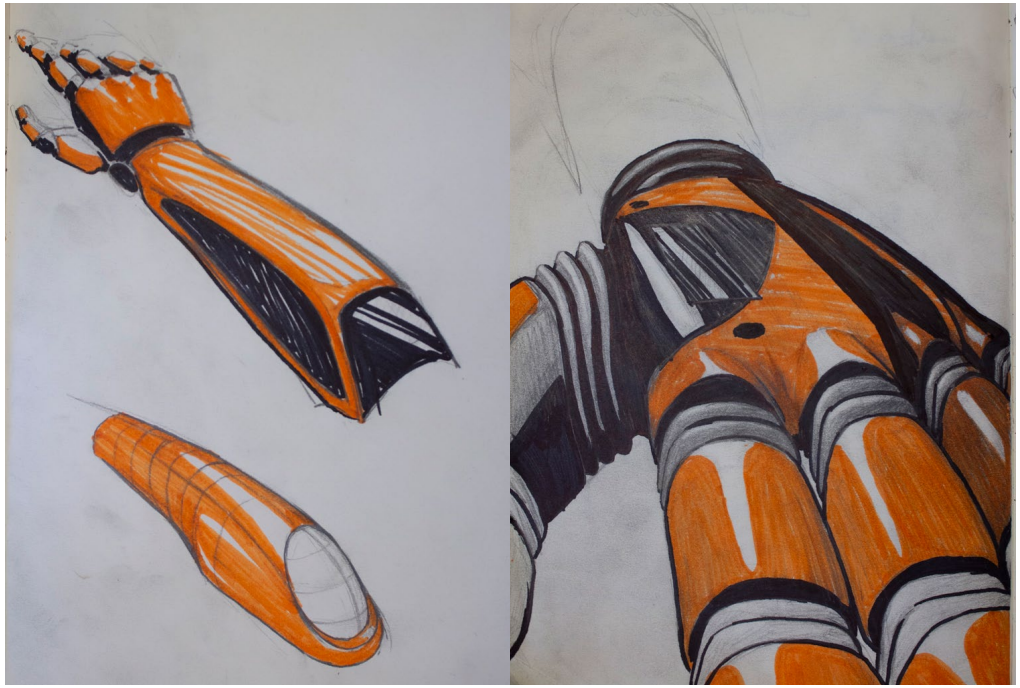


Ideation phase

In the first interview Erik talked about his hobbies and interests, and it became clear to us that he was particularly interested in cars and mechanical work. He has owned several Porsches, brings his cars to car shows and has even customized his own caravan. He also told us that he would like for the prosthesis to match his favorite car. In the photos of the cars he sent us, we could see that he had similar visual expression in many of them, by using orange as the main color, and black for accent details. We thought that this would be something he would want in his prosthesis as well, and we therefore based many of the first sketches by taking elements from the automobile design and implementing them in the ideas.

When we were ready to show him our concepts however, he found them a bit lacking in variation. He liked the color combination, but also felt we focused too much on trying to match the prosthesis with the car, and not giving it its own personality. After a bit more conversation we started mapping out what he would like and why.

Erik's Porsche.

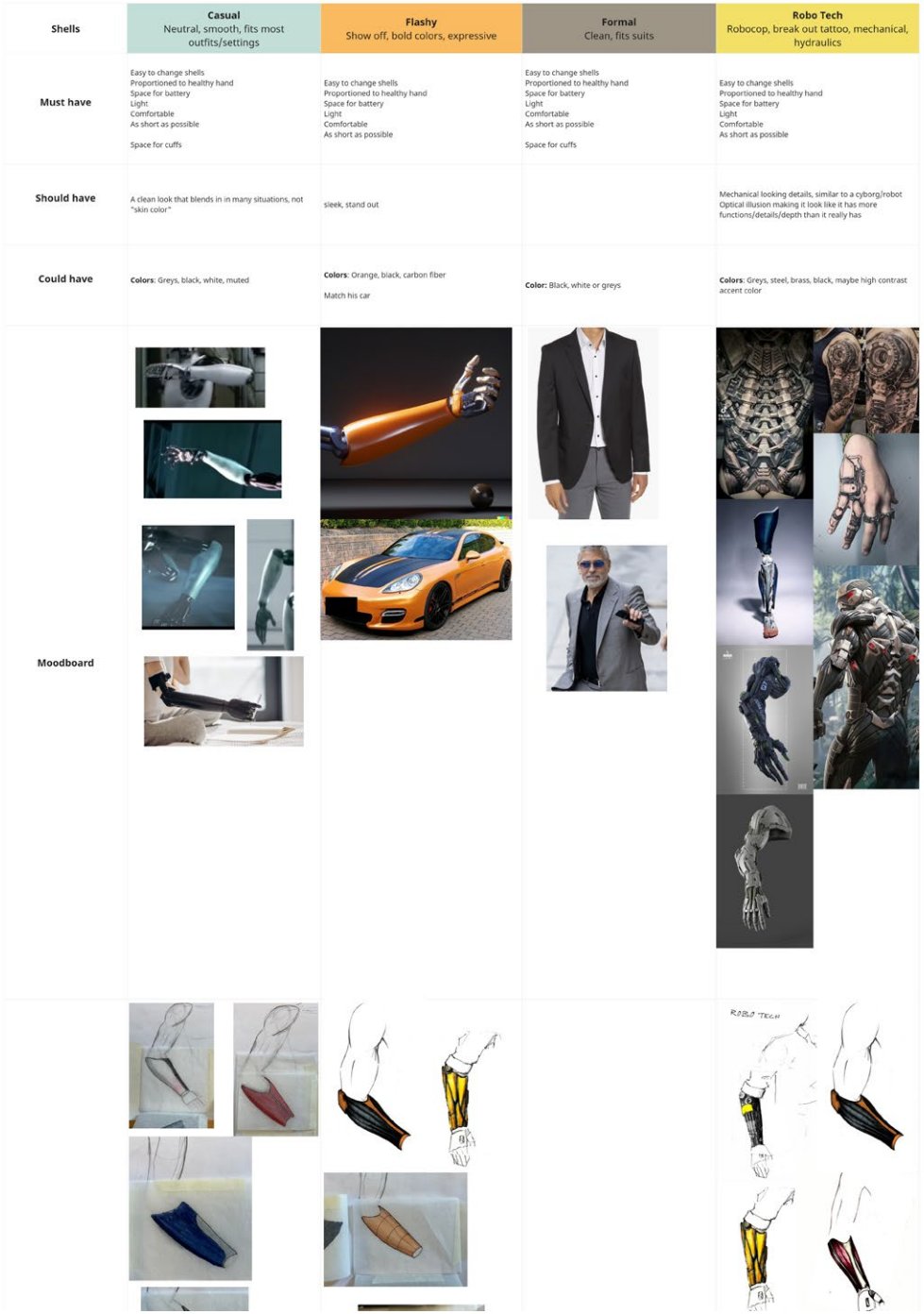


Concept sketches inspired by Erik's Porsche.

Ideation phase

After this interview with Erik we found four categories of different styles he wanted for different occasions. These were Casual, Flashy, Formal and what we called RoboTech; a direction inspired by cyborgs, robots and mechanical tattoos. We created a spec sheet with must, should and could have requirements, moodboards and a space where we could collect sketches for the different concepts.

By the second concept meeting with Erik we realized that casual and formal could be merged into one concept by keeping the same form, but change the colors by either paint or foiling, which is something Erik was excited about. Both casual and formal had to be sleek and not too attention seeking, and we realized that the main difference between the two would be the color. More muted colors for the formal, and more vibrant for the casual one.



Spec sheet of the four categories with moodboards and sketches.

Ideation phase

We drew some more refined versions of the different concepts. We utilized stock photos so that the concepts would be placed in a setting. By doing this, we could easier picture the sizes of the prostheses and how the surroundings influence them.

Fig 9. Concept art inspired by cyberpunk.

Background image: Man shopping in supermarket, 2015 by Finlay, K. (https://www.alamy.com/stock-photo-man-shopping-in-supermarket-88284923.html)

Fig 10. Concept art inspired by leatherwork and Star Wars and Terminator.

Background image: Concentrated young man preparing for exams at home,2017. Prostock. (https://www.istockphoto.com/photo/concentrated-young-man-preparing-for-exams-at-home-gm896202418-247510543)

Fig 11. Concept art inspired by Porsche, Star Wars and Terminator, and human anatomy.

Background image: Man with black protective helmet, 2018, by Apunto Group Agencia de publicidad. (https://www.pexels.com/photo/man-with-black-protective-helmet-7752839/).

Ideation phase

During the third interview, Erik said he thinks they all have their distinct personality, and that he could see himself using and liking each of them. He struggled to choose one of them, and gave us free reign to decide which cover we should focus on for the prototype.

We went for the one imitating muscles in the forearm, as we thought it was the one which would have the most impact and evoke more interesting feelings in the onlookers, and make it easier to start a conversation around the prosthetic and Erik's condition. We showed him the concepts in different colors; blue, yellow white and one flesh red. The colorful ones did not resonate as well with him as the realistic one, and therefore those concepts were abandoned for the prototype.

Fig 12. Concept art inspired by human anatomy and synthetic muscles.

Background image: Man with black protective helmet, 2018, by Apunto Group Agencia de publicidad. (https://www.pexels.com/photo/man-with-black-protective-helmet-7752839/).

Final concept/Prototype

Final prototype. 3D-printed (PLA) and painted. Basic myoelectric hand for illustrative purposes.

Final concept/Prototype
Fastening mechanism

Due to the short nature of this master thesis we were aware that we had to prioritize certain aspects over others. The fastening mechanism was less important than the aesthetic, as the visual expression is the main focus aspect for this thesis.

This does not mean that we did not think of it at all, as we have some requirements for the mechanism. It needs to be easily operated with one hand without the need for tools and strange hand movements, as the user only has one hand available. The covers also need to be securely fastened, and the mechanism needs to prohibit movement of the covers. It is vital that the user feels that they can trust that the covers are securely fastened, as we don't want the users to worry if the covers will fall off in unpractical situations.

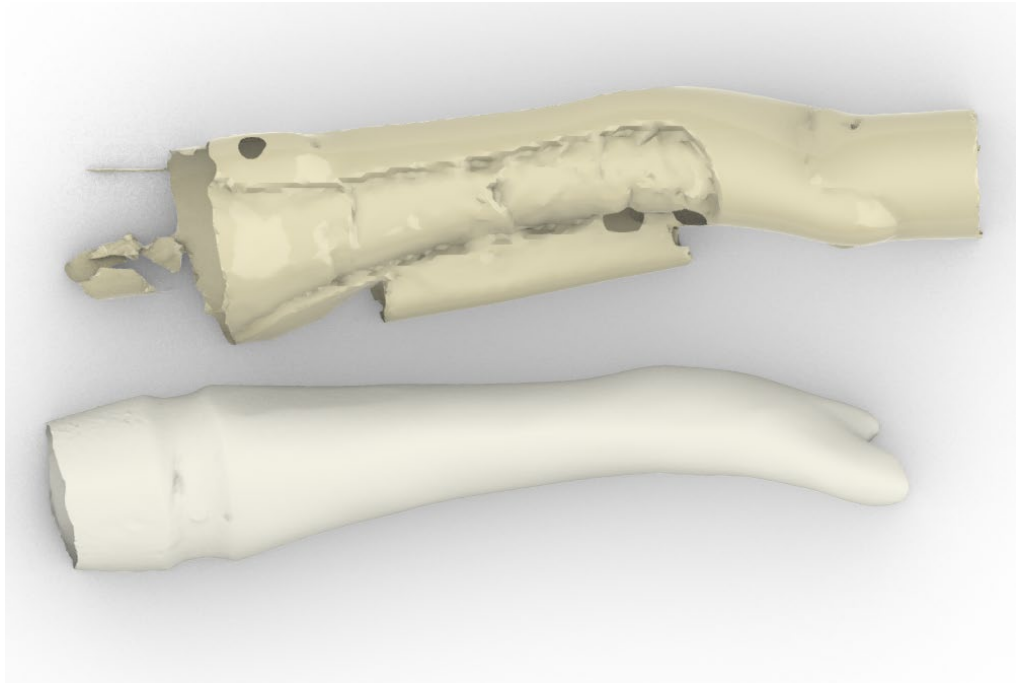
For the prototype we went for a solution that made the two covers snap together with friction, as it was the simplest solution. This however would not hold if the prosthetic was to be used, but since this is only a visual prototype, it will do fine.

Final concept/Prototype

The process of making the prototype

Before we could start modeling the covers, we had to visit NTO, so that we could 3D scan the prototype prosthesis they made, as well as scanning a plaster cast of his stump. It was important for us to have those two elements as building blocks for the covers, as there needed to be space for components and batteries under the covers. However, since this was a prototype, there are some things that would need to be changed in the final prosthesis and therefore the final covers. Mainly the angle the hand is attached to the sleeve was pointing too much inwards, and made the end of his hand protrude too much out of the center axis of the sleeve.

3D-scanning plaster cast of Erik's stump.

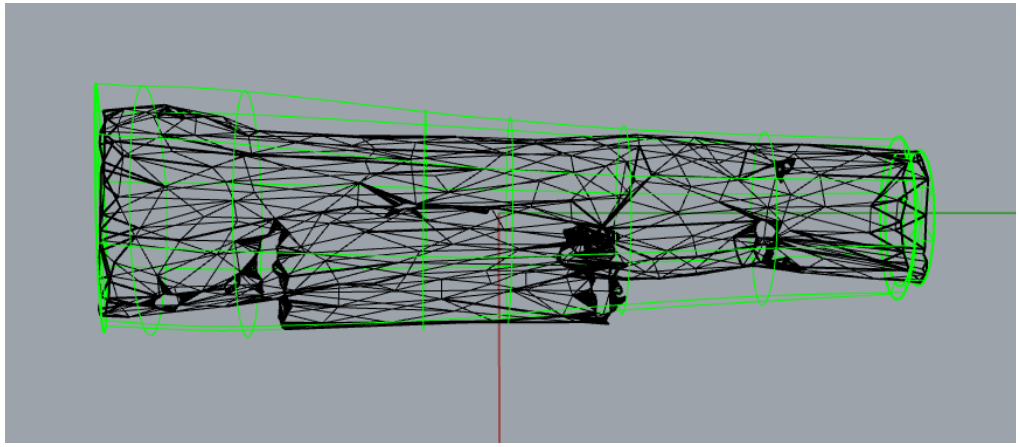


3D-models from the 3D-scanning of casting and prototype prostheseis in Rhino 7.

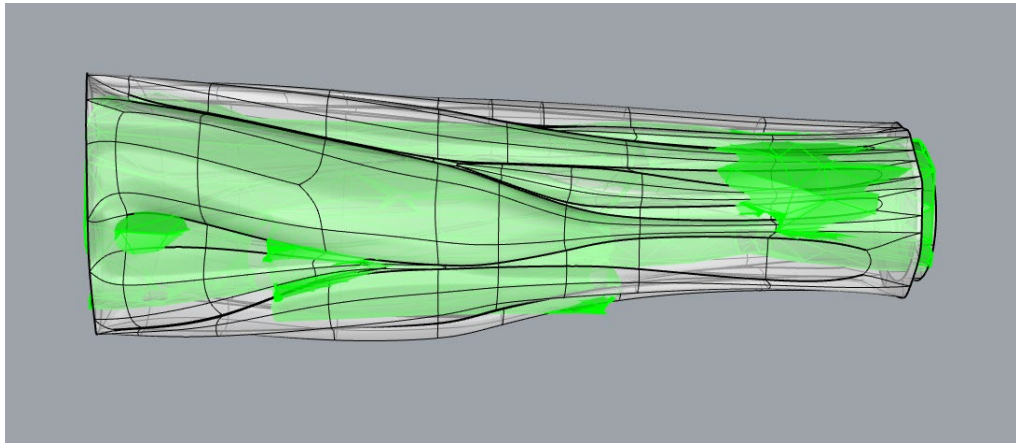
Final concept/Prototype

The process of making the prototype

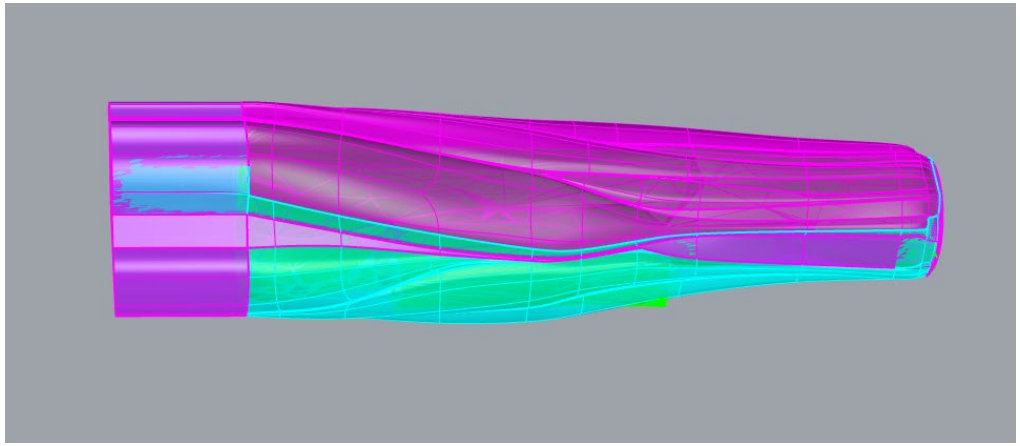
The shells were modeled in Rhino 7, a CAD software which handles organic shapes quite well as opposed to programs like Solidworks or Fusion 360. This was a new program for us to learn, but a necessity for the finalization of the project. The prototype is based on an anatomical human arm with some creative liberties, as a 100% accurate one would have features that would be in the way for important components, daily activities, and would be harder to keep clean. The size of the shells were modeled after measurements of Eriks healthy arm so that when used would have a balanced look.



Wireframe of basic shell form around proto prosthesis.



Early draft of muscle covers.

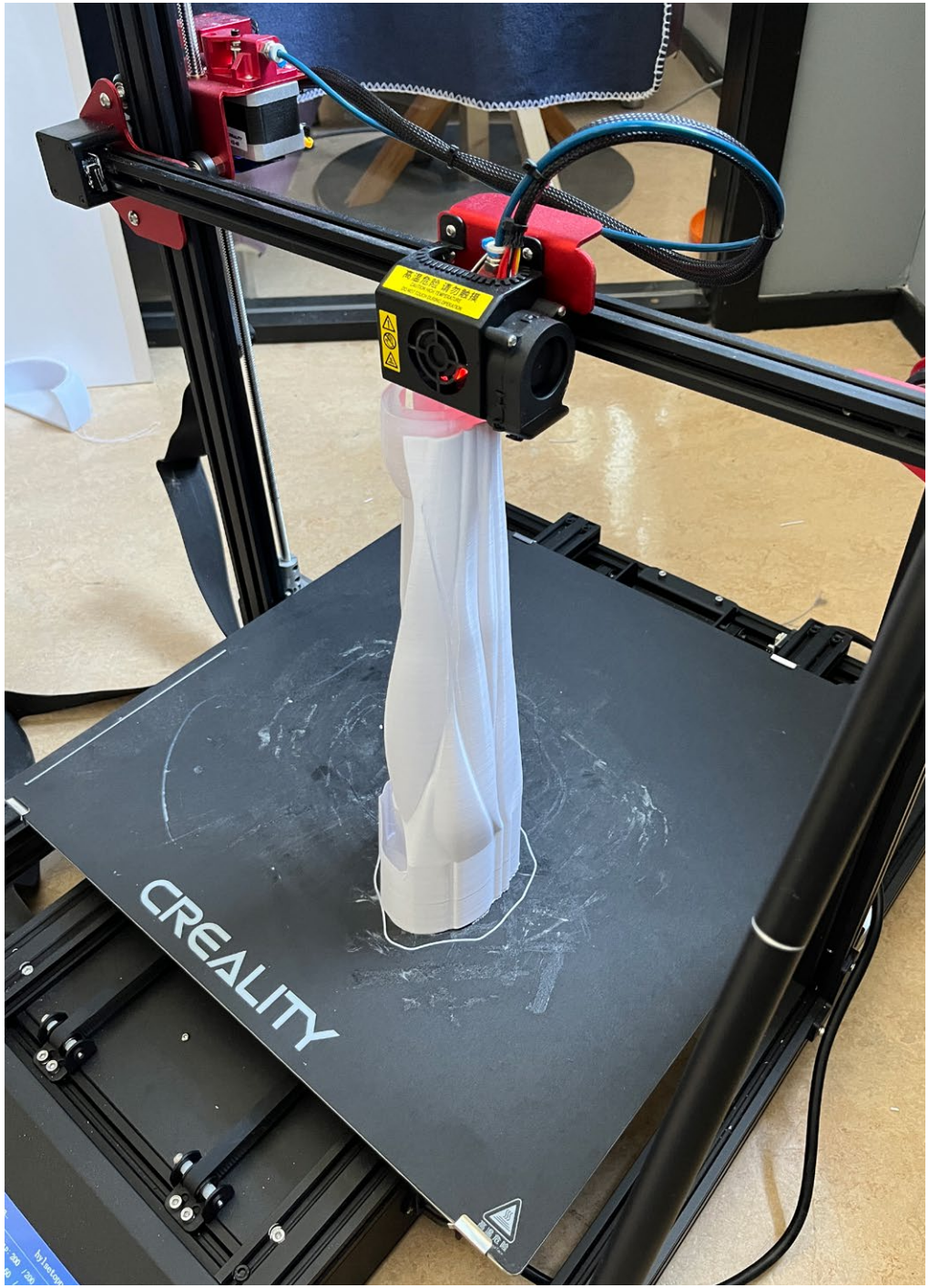


Split 3D-model of covers.

Final concept/Prototype

The process of making the prototype

The prototype was printed in PLA, and then sanded down to achieve a smooth surface. There were also structures that were added so that the print would go smoothly, that later would be removed. For this we used a dremel and files. PLA is a good material for a visual prototype, but for functional covers a different material would be chosen, as PLA can deteriorate over prolonged exposure to UV and moisture. Anatomic Studios uses 3D printed polyurethane, which could be suitable for our shells as well.



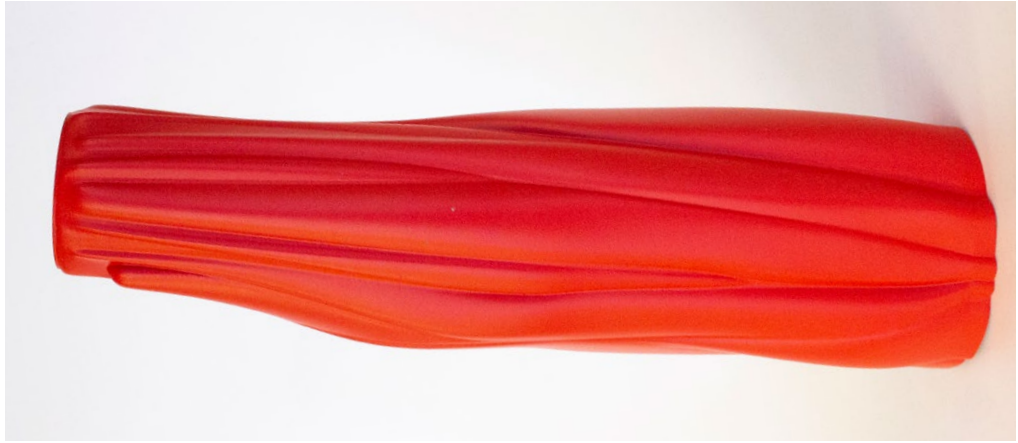
Full scale 3D print.

Final concept/Prototype

The process of making the prototype

To achieve the smooth surface, several layers of filler spray were used to fill in all layer lines, and then wet sanded with 400 grit sandpaper. This created a satin smooth finish, perfect for applying the spray paint. The color chosen was bright red which we then added details on with watered down acrylic paint, to give the object some shadows and details. The bone protruding were also given coats of white to enhance its visual presence on the model.

Sanding.



Spray painted.

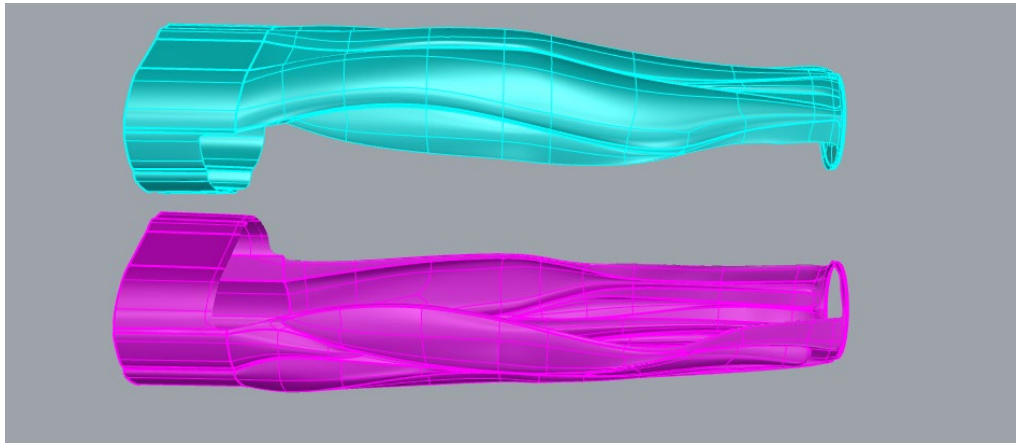
Painted by hand with acrylic paint.

Final concept/Prototype

The process of making the prototype

The split lines between the covers were placed so that they would be as hidden as possible. By following the edges of the muscles we achieved a uniform and natural look. For the covers in the sleek-line however, we see that the split line could be a visual feature to bring more interest in the design, while keeping its minimalistic expression. However adjustments need to be done to the model so that the prosthesis fits better. Currently the fitment is tight and the covers bulge more than we would like. This makes the covers in their current form unsuitable for daily use, as they would simply just fall off. There needs to be some way of retaining them in multiple axes, which we have not yet developed. We will get back to this in the discussion section of this paper.

Proto prosthesis in one cover illustrating position and fitting.



The two halves in Rhino 7. Note extra geometry to help SubD keep shape.

Printed, sanded and spray painted prototype.

Final concept/Prototype

The process of making the prototype

The prototype is true to its concept art, and Erik was pleased with the result so far. He is aware that this is a first prototype, and there will have to be more renditions before a final product is ready for him. He brought up some points needing refinement, the fastening mechanism for the covers, and how the end of the covers have to be rounded over so shirts and clothing don't snag on them.

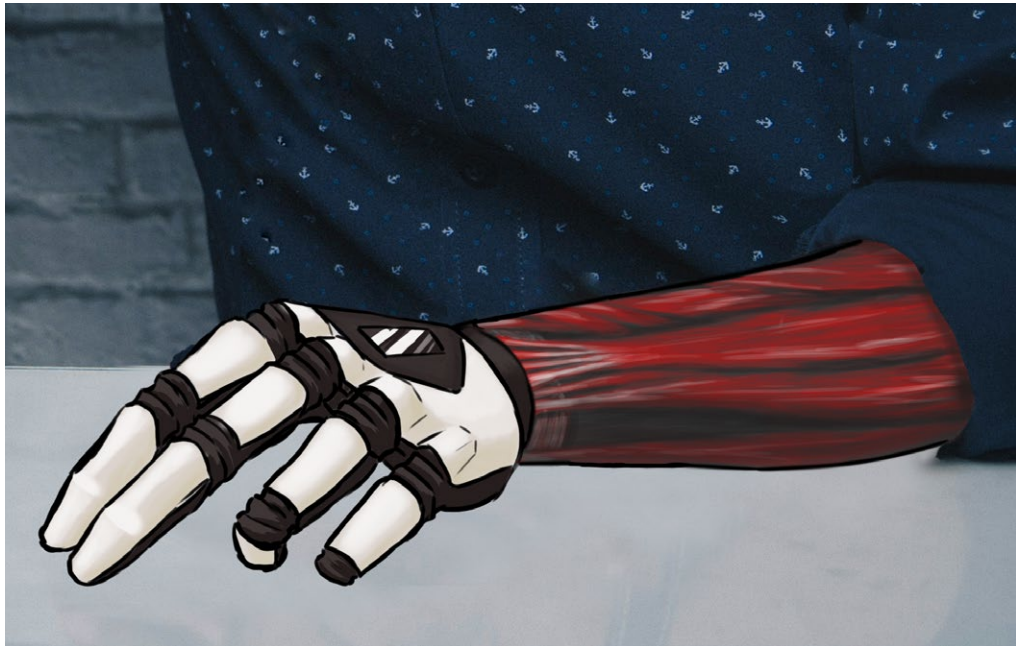


Fig 13. Background image: Man with black protective helmet, 2018, by Apunto Group Agencia de publicidad. (https://www.pexels.com/photo/man-with-black-protective-helmet-7752839/)

Finished covers.

Finished prototype.

Finished prototype.

DISCUSSION

DISCUSSION

We would argue that there is a need for expressive prostheses in the world, but we do not have a definite answer to how it should be solved. We see from our research a number of different approaches to this problem, each with a different set of pros and cons. The way we got to our result is one that needs refinement and adjustment.

We went for a heavily user-involved process, where the user was involved in every big decision. For commercial actors this might not work as more work hours are needed. The user might also have been involved a bit too much, as they were involved in many big and small decisions. This might have led to decision-fatigue. We should have been more aware in our role as designers and aestheticists to make the choices that would have an impact on the final result.

DISCUSSION

As we have stated earlier in our thesis we had a very small sample of participants, but for further development of this method a larger sample size would be preferable.

Aesthetics and self expression is deeply personal and subjective and what one person finds pleasant another might find appaling. With a larger sample size one can find more insights into how a preferable interdisciplinary development of expressive prosthetics should be conducted. But what we have covered in this text should still be considered as relevant.

The fact that expressive prosthetics is an emerging field, means that there are many people who share the same thoughts about its value. Many of these companies started with a focus on children's prosthesis, but are now expanding out to adults as well. Changing focus over to adults might challenge many users' views about what a prosthesis could be.

The two people we interviewed that expressed they didn't think about the aesthetics, might not have been challenged with this concept before, and just accepted that the prosthesis will have the visual expression that prosthesis have. The value that the prosthesis brings them is functionality, and they feel that they don't need anything more than that. This might be the case for some, but we have a suspicion that they would care to some degree if they knew they had more choices. It's important to understand that expressive prosthesis does not necessarily mean bright colors and wild shapes. It could just as easily mean minimalistic, muted colors or conventionalism. If the user prefers to blend in and not stand out in the crowd then that is their way of expressing themselves. Finding the right aesthetic for them to achieve this goal is just as important as giving our case study, Erik, a conversation piece.

By giving the prosthesis changeable covers, its expression can change quickly. If Erik wants a conversational piece he can use the Flashy covers, or if he wants less attention to his prosthetic he can use the Sleek covers. This allows Erik to adapt to his changing needs, and creates a more customized and reflective experience of expression. This acknowledges that we as humans change and adapt over time, allowing the prosthesis to adapt to these changes. We believe this kind of flexible (Harper, 2018, p. 102) aesthetics will create a strong bond between the user and their device. The device accommodates the needs of the user, and in a way works as a multifunctional device. As in Erik's line of work he wants to have something special when showing how to use specialized tools, but on other occasions he would have something different and more subtle to the situation.

DISCUSSION

Christian said during our conversation that several female patients had complained about the inherent masculinity in the parts that make prosthetic legs, and their wish to cover them up with a more feminine expression. The masculinity makes it difficult for them to attach/accept the leg as their own, as they do not feel that it expresses who they are as a person. As we did not have any women participate in our study we can't confirm that this is the case from our data. However we do agree that prosthetic devices have a visual expression that is heavily focused on function and material properties, which might conflict with what society deems as feminine. Words like mechanical and machined often come to mind when looking at the structural parts of a leg prosthesis, which are not words we associate with feminine.

DISCUSSION

When the direction from the user panel to case study happened we had to reconsider our approach. Materials were chosen for their relevance to the case study instead of exploration of new materials. We find it interesting that our preliminary experiments and our final prototype both can be categorized as expressive prosthetics, but on completely different ends of the spectrum. One could fit in well at a wedding while the other might be unpleasant or distracting. Or in other words one could fit well in a mechanics workshop, while the other would be out of place. By saying this we imagine you already know which one belongs where. The ceramic hand would typically be categorized as pure and clean, fitting for situations that require reverence, while the muscles are anatomic and grotesque, and represents a more laid back but still ominous presence. The purpose of the muscles was to initiate conversation by having a great visual impact. By giving it the visual expression it would peak the curiosity of the onlookers, and make it easier for them to ask about the prosthetic, as it conveys that there is no attempt at hiding it, but rather capturing the eyes of the people watching, subconsciously telling them that it is ok to ask about it.

The visuals of the muscle covers could have been translated in different ways. It could be an abstract interpretation of the muscles, a simplified one where all edges would be smoothed out, or a sci-fi route with dark colors and mechanical components attached. This however softens the impact of the prosthesis by conveying to the onlookers that this is not a real arm. We chose to keep the covers as anatomically correct as possible so that we could utilize its shock factor.

DISCUSSION
Social sustainability

We would argue that increasing the time a prosthesis is worn is beneficial to their wellbeing, as overreliance of one limb can lead to musculoskeletal issues (World Health Organization, 2022). These issues can lead to the degradation of users quality of life, or making them unable to work, making them feel useless or depressed. If expressive prosthesis could help increase the time the device was worn, then it could prolong users' activity, keep them healthy and as active members of society. This is a benefit for both the individual, but also society at large. Early retirement, doctor appointments, extra physical therapy etc. which is supplemented by the government can be expensive. Our theory is that by decreasing the risk of musculoskeletal issues caused by overstraining the healthy arm, we reduce the need for these extra costs, hopefully weighing up for the increased cost of investing in expressive prostheses.

An expressive prosthesis might also lead to higher self esteem among users. Maslow's hierarchy of needs places self-esteem high on the pyramid, which current prostheses can fail to achieve. Prostheses today cover the basic needs, but often overlook the individual expressive needs of the user. The current method of producing prostheses is utility focused, limiting the ability of the user to apply themselves onto the prosthesis which causes the risk of prosthesis abandonment, which defeats the purpose of the prosthesis in itself.

It is of our opinion, based on our research, that accounting for self expression is necessary for some to bond the individual with the product. Creating solutions that allow for self expression and modification is therefore a necessity for establishing an emotional bond with the product. The prosthesis is already a personal product as they are custom fitted and adjusted to the individual user from the start, creating solutions that also take aesthetics into account should therefore be feasible to implement in the existing system.

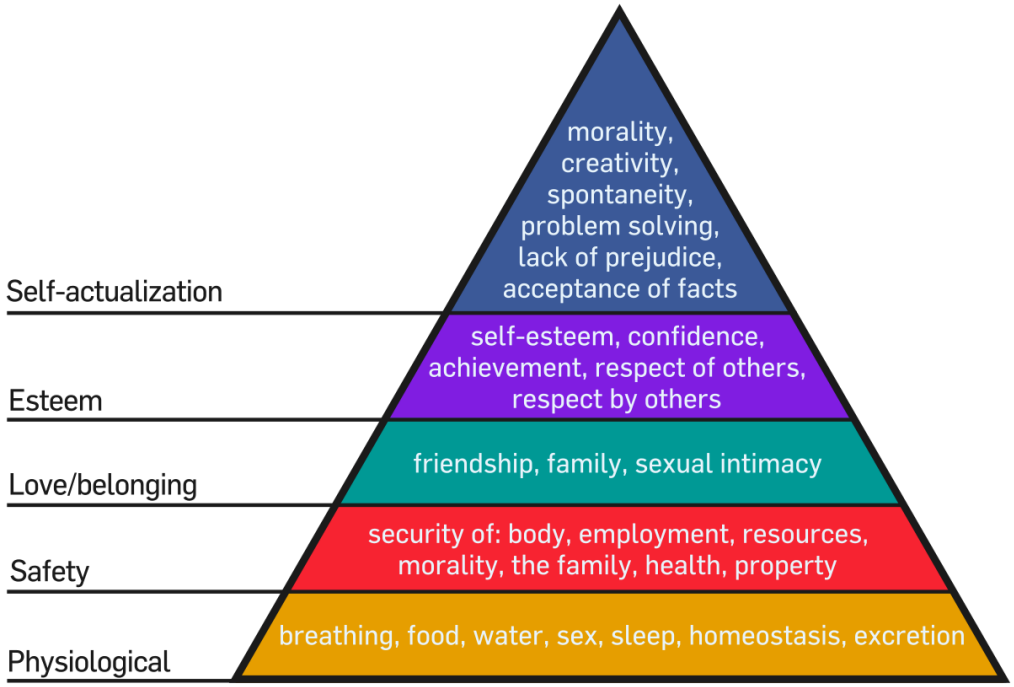


Fig 14. Maslow's Hierarchy of Needs Pyramid, N.D., by Saul McLeod. (https://creativecommons.org/licenses/by-sa/4.0/?ref=openverse). CC BY-SA 4.0.

FURTHER DEVELOPMENT

FURTHER DEVELOPMENT

Even though we had decided to move onwards with the muscle covers, Erik was interested in the possibility of buying or manufacturing the other concepts himself or get a company like Anatomic studios to pick up the project after us.

Since our intention with this project was to explore expressive prosthetics we had to prioritize our time. We therefore focused our work on the shell and decided that some aspects would have to be considered later. The way the covers would be attached to the sleeve is one of the main things that needs to be developed, which we did not look deeply into. We did however find several requirements for the mechanism, as they are important aspects of how the covers will be used.

The covers should ideally be partially standardized to streamline the work so they don't need to be designed and built completely from scratch for each patient. Certain parts like the locking/fastening mechanism, wrist and general shape could be standard and then adjusted and modified for each case. Since each prosthesis is unique and can differ quite a lot from person to person, fully standardizing is impossible. Some prostheses are going to be longer, wider or have different components than others, which will affect how the covers can be fastened. Since these covers will be tailored to each individual prosthesis and every prosthesis is unique, there needs to be some common ground where the mechanism can be attached.

This project will be brought further by NTO and Anatomic Studios. The market share for prosthetic arms is smaller than that of prosthetic legs, but as Christian said during our talk, he thinks there might be a higher need for custom covers that express your identity. Getting into this market is something they have thought about, and this project could be a good pilot-project for them, to see what challenges lie in the field of arm prosthetics.

FURTHER DEVELOPMENT
Fastening mechanism

Open Bionics' Hero Arm has interchangeable covers, and their solution works only for their "ecosystem". They have only one model of prosthetic arms, the Hero Arm, that comes in two versions, the 3-motor version with 3 different grips, and the 4-motor version that has 6 different grips. The 4-motor version requires more power, and therefore looks a bit different from the 3-motor one. Since they have designed their arm with interchangeable covers in mind, they have had a unique opportunity to integrate a fastening mechanism directly into the prosthesis. Their solution is using magnets and registration marks, in a standardized pattern, which makes the covers snap in easily and in the same position each time.

Anatomic Studios on the other hand does not make or design prosthetic legs, but retrofit their covers to fit prosthetic legs. Most prosthetic legs feature the same structure, a prosthetic foot, then a metal tube, and lastly the sleeve. Their solution is firstly a modular fastening mechanism for the tubes, which is the main point of securing the shells to the prosthesis, then the secondary being both shells attach to each other. The mechanism for the tube can be adjusted in several different axes, and since the shells attach to each other you are left with a streamlined look.

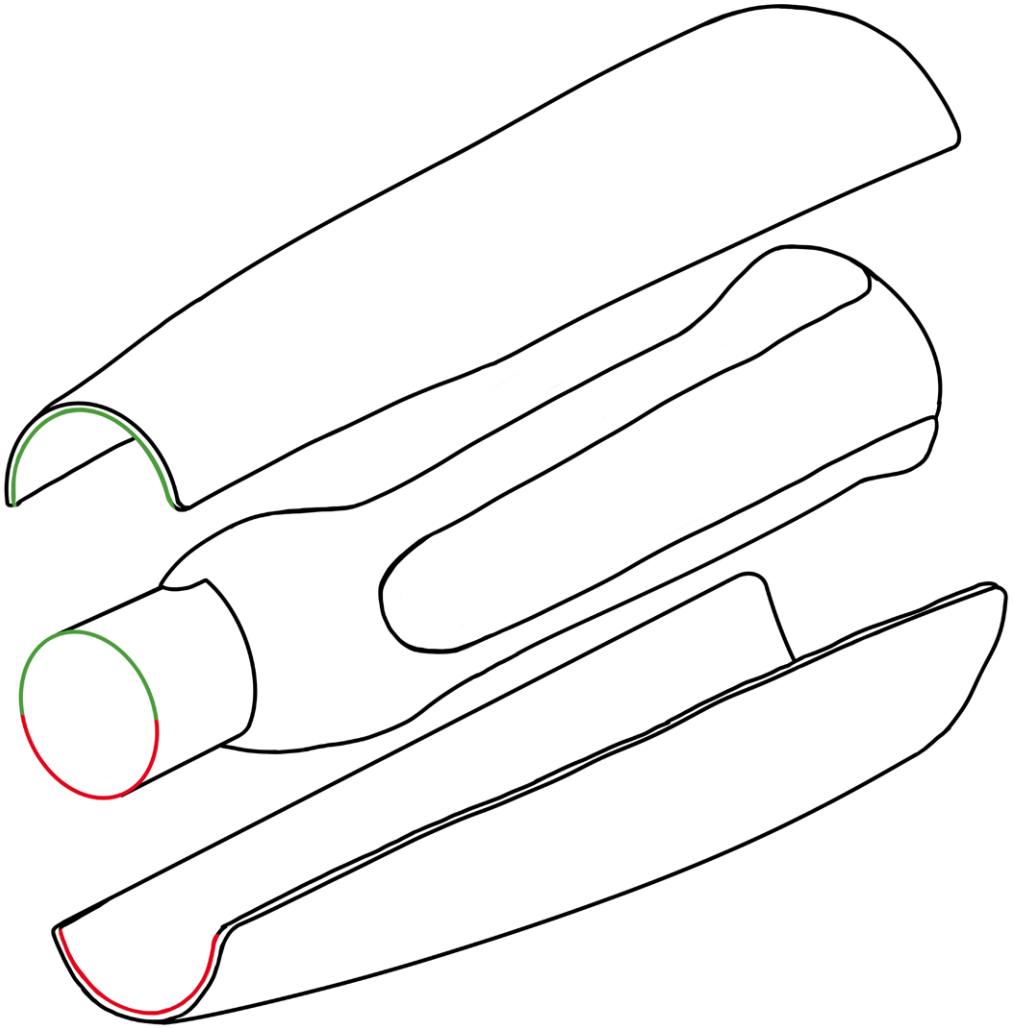
FURTHER DEVELOPMENT
Fastening mechanism

There are aspects of both these ways of securing the covers which we could take inspiration from for our covers. However, both of these solutions rely on standardized parts, which there are few of in the world of arm prosthetics. As most prostheses are made custom to the individual user, the size, shape and length varies greatly.

There are of course standardized parts in an arm prosthesis, like batteries, sensors and the like, but few structural and exposed parts. However, we have found that the attachment point for the hands is a good candidate for the “main” point of fastening. The quick-connect systems for the hands are categorized into different sizes, which means this is a stable and predictable size for several different prosthetics. By utilizing this point, it will therefore be easier to make a fastening system that can be used on several prosthetic arms. This solution would also need secondary attachment points located higher up on the prosthesis, and preferably be casted into the prosthesis.

We believe that a mechanical fastening mechanism would be preferable, compared to either using magnets, or cloth straps.

We discussed this issue when talking with Christian from Anatomic studios, and shared our viewpoints of the different solutions we had discussed. He agreed with us that a cloth strap might not be the best idea, and he pressed the importance of simplicity in both design and use. The more complicated the solution is, the more expensive it gets and there are higher chances of failure. Adding the possibility to adjust the fastening mechanism is also important, at least for the covers that Anatomic Studios make. Adding some adjustment to the mechanism for the arms could also help the covers to sit in a way that makes both the healthy arm and the prosthesis have somewhat the same size and shape.



SUMMARY

During this project we have come to the conclusion that by letting the user of the prosthetic device be a part of the design process they will feel a stronger attachment to it. Our findings in this thesis supports that by the feedback we have gathered during the process. There is still a need for further research in this field as the long term effects have not yet been documented. The case study used in depth interviews with the subject, discussions with orthopedic engineers, prototyping and feedback from the user. By giving them the possibility to change covers you also end up having a flexible device that works in different settings. This is valuable for both the user but also orthopedic workshops, as the covers are easier and less costly to produce than making several prostheses.

The covers we have made are still in the early phase, but we believe that we have made a good foundation for further work with Anatomic Studios and Norsk Teknisk Ortopedi. We hope that our findings will be taken into consideration for how prosthesis will be made in the near future.

Our process has been goal driven and effective, and we believe we have made a good foundation for further work with Anatomic Studios and Norsk Teknisk Ortopedi. We hope to see this project continue on, and make a good change in the world.

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