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Aquaborg

From mythological hybrids to assistive techno fashion

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-Maria-

ABSTRACT

Aqua-borg presents a socio-technical strategy for designing female prosthetics by valuing the users' desire for expressiveness, affects and emotion equally with their physical needs. It is assumed that engaging female, prosthetic users in exploratory research and co-creative sessions will lead to speculative wearables that empower their users and help them re-imagine their embodiment, identity and attractiveness in non-normative ways.

I present the methods and results of my iterative collaboration with a female prosthetic user, a journey full of frustration and ambiguity for both of us, which challenged me to alternate roles between a critical listener, an empathetic researcher, a technological designer and a woman. I describe my user's disability journey, pain points and oppressed desires, as well as how feminine attractiveness and body-image can be reconstructed through the lens of techno-hybridity. Together we ideated scenarios of morphing prosthetics and explored how those ludic wearables potentially satisfy the user's physical, expressive and emotional needs on the beach. Finally, I crafted those prosthetic concepts into virtual models and mapped them on the human body through an Augmented Reality app so that prosthetic users can evaluate the emotional and experiential affects of emerging prosthetics.

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1. INTRODUCTION

Being a woman with an artificial limb is a complicated and complex experience. Apart from facing social discrimination as disabled humans, female prosthetic users are often stigmatized as unattractive, masculine or even genderless beings (Grant 2015). And this situation escalates during summer time, on the beach and by the pool, when physical difference is fully exposed. Consequently, women with disabilities easily doubt their physical beauty and femininity.

This thesis intends to empower disabled women by proposing to couple them with technological designers. Together they can delve into the user's disability story and design artefacts that explore the user's needs for expressiveness, social affects and aesthetics. So far, attractiveness and self-representation haven't been considered as design factors in prosthesis design, as a medical view of disability used to prioritize prosthetics either as tools to perform physical activities, or as humanlike concealers of physical difference. Though, this thesis adopts a social model of disability that rejects the view of prosthetics as simple medical replacements. By discussing findings from Disability Studies, and by drawing upon studies in Psychology, Sociology and Human-Computer Interaction, I describe the value of prosthetics as transitional, evocative and social objects. This way, I develop a view of prosthetics as key elements in their one's identity building and emotional empowerment against social stigma.

Recently, great design efforts started in the domain of assistive tech that aim at empowering disabled humans to fight for their right to be included in the design procedures that shape their lives, as well as to oppose to their body's discrimination. As precedents, I discuss open-source design communities, prosthesis co-design and expressive prosthetics as a type of activism through appearance. As a designer myself, I take my place in this chain of efforts, prototyping this thesis as an act of activism by design.

To demonstrate that both the process and the results of speculative co-design may eventually improve a disabled woman's self-perception, I discuss the context, methods, and results of a case study: speculating about underwater prosthetics with a female, prosthetic user. The first part of the study revolved around an ethnographically informed workshop. That enabled me to delve into the user's disability journey, understanding her personality and developing empathy for her experiences and desires. It also allowed both of us to reflect on

prosthetics as dress, opening a dialogue about how feminine attractiveness can be reconstructed through the lens of techno-hybridity. Finally, I developed an understanding of the user's physical and social needs focusing on aquatic environments and swimming-specific prosthetics. I analyzed the data through affinity diagrams and synthesized the findings according to cultural studies about technology, body and feminism, presenting a rich qualitative study about disability, prosthetics and social stigma around women wearing them.

The second part of the study documents 1) how the exploratory research inspired scenarios of prosthetics, 2) a speculative co-design between me - a technological designer - and F - a disabled woman-, 3) our different roles and starting points, 4) the contradictions and frictions that arose and the way I solved them through iterative clarifications and design efforts. To contextualize the participatory design sessions, I employed the technically plausible concept of 'morphing prosthetics', in other words, wearables with embedded, material interactivity that are capable to self-transform. Within this context, the user and I produced scenarios of prosthetics that morph under different spatial circumstances to enable the user to operate both on land and underwater and self-represent through expressive material transformations. Those speculative wearables provoke reflection about what prosthetics could do within or beyond the human spectrum.

During the last design iteration, I demonstrate how to prototype try-on experiences for prosthetics by developing an AR app for iPhones. The latter one maps speculative prosthetics on the human body, allowing users to explore the wearable's emotional and experiential affects, updating the design process.

Aqua-borg shows a meaningful way to employ speculative co-design and mixed reality technologies in order to induce a fresh energy around non-normative, female attractiveness and representation. The case study turns into a self-reflective and confessional experience for both me and the prosthetic user that reveals hidden truths about disability and prosthetics, offering lessons to designers, and helping prosthetic users to embrace their uniqueness. Therefore, Aqua-borg delivers an inclusive design thinking and strategy for designing prosthetics and assistive technologies, as well as ways to use design and technology to start healing a prosthetic user's traumatized body-image.

2. DISABILITY AND PROSTHETICS

2.1 A SOCIAL MODEL OF DISABILITY

Even though prosthetics play a crucial role in their users' life, a strictly medical view of disability has limited a prosthesis' multidimensional role to the restoration of physical abilities and social appearance according to the standards of fully abled bodies (Hall and Orzada 2013). So far, most prosthetics have been built to serve either functional or/and cosmetic needs (Figure 1), as from a medical perspective, a person is considered as disabled when they are physically impaired (Frauenberger 2015). Indeed, many disabled humans learn to accept prosthetics either as tools or as humanlike costumes (Murray 2004). In the first case, robotic wearables allow amputees to return to their physical routines or try new hobbies, while in the second case, natural limb reproductions conceal body difference and normalize appearance according to the socially accepted body image (Hall and Orzada 2013).

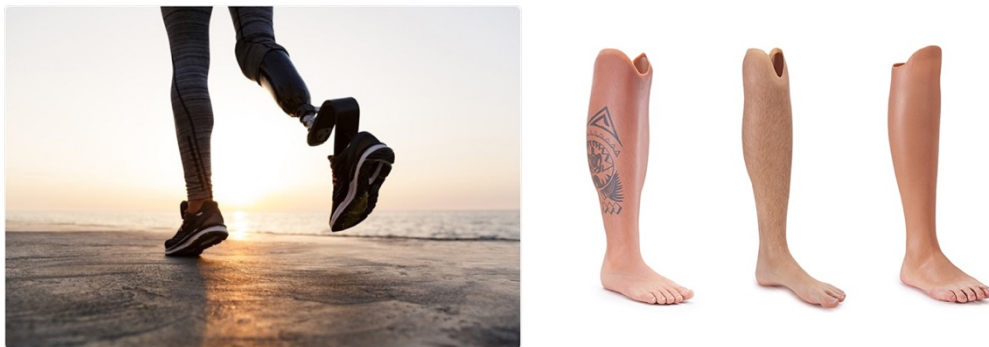


Figure 1. (Left) Example of functional prosthesis that allows the user to better walk and run, Source: <https://www.news-medical.net/news/20191003/New-prosthesis-feels-and-acts-like-original-limb.aspx> (Right) Example of a cosmesis that allows the user to hide physical difference, without restoring physical movement though, Source: <https://www.dorset-ortho.com/en/patient-services/silicone/lower-limb/>

However, such purely medical views come with certain dangers. First, Frauenberger (2015) presents the study by Shinohara and Wobbrock (2011), who found that the medical model of disability generates (a) the misconception that assistive technologies (AT) can eliminate one's disability by restoring their physical abilities and (b) the expectation that disabled humans may become functionally equivalent to people without disabilities. As neither is the case, the users, eventually, experience feelings of comparison, disappointment, and inferiority.

Second, presenting the work by Shinohara (2012), Frauenberger (2015: 5) argues that this medical model “ignores key social factors that contribute to the disabled experience in relation to technology”. In disability multiple elements interact with each other, such as one’s nature of impairment, their personality and attitude toward disability, the others’ perceptions about body, the available support systems, as well as the user’s socio-financial state (Frauenberger, 2015). Therefore, even if at first disabled humans may accept their physical uniqueness, this “complex interaction among individual and structural factors” (Shakespeare, 2014, as cited in Frauenberger 2015: 3) may later in life negatively impact their self-esteem and the acceptance of any assistive technology.

Hall and Orzada (2013) shed light on a social model of disability by looking into Disability Studies literature. Their article highlights the previous work by Reeve (2002), Sousa (2009), Swan and French (2000), according to which disability is an artificial and socially produced label, separated from the concept of physical impairment. This label is being informed by the views held around the normative body and as those norms do not correlate bodily deformity with attractiveness (Hall and Orzada 2013), a traumatized body gets visually stigmatized either with or without assistive technologies. On these grounds, it is time for prosthesis experts to realize that “one may be biologically impaired”, but it is the way society stigmatizes an impaired body and traditional prosthetics that “make one feel and be viewed as disabled” (Sousa et al. 2009, as cited in Hall and Orzada 2013: 21). For the aforementioned reasons, designing for disability should be more than just coupling one’s physical needs with technological aids.

This social view of disability delivers assistive technologies that articulate body impairment as a socio-medical problem. In particular, Sansoni et al. (2016: 75) argue that experts should start viewing “the prosthetic form as a creative design and not just as a medical support”. Furthermore, Pullin (2009) emphasizes the necessity of social and artistic expressiveness in assistive technologies, by comparing the solution-based design strategies adopted by engineers to the more exploratory approaches taken by designers. By being creative and exploratory, specialists can turn assistive wearables like prosthetics into a powerful medium that allows their users to celebrate their physical uniqueness, fight against their body’s discrimination and shake the society’s perception about what is perceived as abled, disabled or even super-abled.

On these grounds, prosthetics are more than simple replacements, as they claim the power to implant an embracing attitude toward body variation in both their users and the society. On the one hand, prosthetics become sites of creative exploration calling their users to reflect on what their body could look like and do (Bennett et al. 2016; Sansoni et al. 2016; Blom and French 2018). Through this creative practice, users may start to recover emotionally by gradually re-constructing their body image. On the other hand, Hall and Orzada (2013: 20-21) use Aimee Mullin's statements to explain how artistic prosthetics as "embodied markers of difference purposefully draw attention to disability, highlighting embodied differences as a form of social criticism and activism". Taking that into consideration, prosthesis experts hold the power to spread strong, social messages about disability through the prosthesis's form and function.

The aforementioned account reveals the reasons why technological designers should care about the production of socio-technical prosthetics, instead of purely medical ones. Though, creative aspects in prosthesis design have been seriously overlooked as research variables. For this reason, the next chapter brings together studies from Psychology, Sociology, Prosthetics and Human-Computer Interaction, in order to communicate the importance of a more inclusive design strategy for prosthetic technologies.

2.2 PROSTHETICS AS EVOCATIVE, EXPRESSIVE AND SOCIAL OBJECTS

To expand the design thinking around prosthetics and enrich the research variables in their design process, I re-construct the importance of prosthetics through their roles as transitional, evocative and social technologies.

Prosthetics are transitional technologies, as they mediate the user's relationships in the world. According to Winnicott (2018) infants become attached to a particular object, which they attribute a special value to. This object mediates the infants' relationships with the rest of the objects and subjects. In a similar way, we should think about prosthetics. Prosthetics are given a special value, as they filter and transits their users' relationships with the environment and the external observers. Becoming part of one's body image, prosthetics mediate how users think and feel about themselves and how they present themselves to others (Murray 2004;

Bennett et al. 2016; Sansoni et al. 2016; Hall and Orzada 2013).

Prosthetics are evocative, as they boost the users' intellectual and emotional mechanisms. Turkle (2011) describes how objects evoke emotion and provoke reflection. Applying Turkle's theory on assistive technologies, prosthetics become emotional and intellectual companions during a journey full of ambiguity and frustration. They help the user mourning for a lost self and desiring a new identity. They empower the user to adopt a different way of living and perceiving, as well as to survive under the social status of being a minority. Therefore, Sansoni's (2016) argument that as designers we possess the power to turn prosthetics either intentionally or unintentionally into evocative artefacts, should be emphasized. Reflecting on the visual form and function of prosthetics, designers can enact positive emotions around disability for different audiences: uniqueness, self-satisfaction and empowerment for the user, as well as empathy and sympathy toward body difference for the observers.

Furthermore, prosthetics become sites of self-exploration, self-expression and identity production. According to Sayeki (2015), we all dispatch imaginary selves into objects and through this distributed self, we identify with those objects, feel through them and adopt our imaginary behaviors. Many prosthetic users share this experience with their assistive wearables. Bennet et al. (2016) offers examples where individuals used their prosthesis to distribute and physicalize imaginary identities or behaviors. They turned prostheses or limb loss into socio-technical outlooks, portraying pirates with prosthetic hooks or courageous surfers with prosthetic, shark-bitten boards. And this practice helped the users to start a dialogue about disability and prosthetics, reconstructing gradually their self-worth as humans. Sharing your story and feelings allows others to know the real you, beyond physical and social differences. And this is empowering and humane in its own nature.

Within this context of self-representation, prosthetics gain even stronger social value for female users. Grant (2015) presents findings of multiple studies, according to which the reconstruction of a feminine body image constitutes a priority for physically disabled women. Grant (2015: 4) explains that this happens because "in patriarchal cultures women are being judged more by their bodies than men are", and this thesis reinforces this view. The first common issue that handicapped women face, is that they have to reconfigure their embodied,

feminine self through prosthetic technologies that are culturally associated with masculinity. The second difficulty is a journey of self-acceptance, through which disabled women should re-imagine their attractiveness outside the normative box. Thus, as the factors influencing the recovery and empowerment of female, prosthetic users are mainly social (Grant 2015), and the society continues to judge those women based on their outlook, prosthetics as expressive and exploratory wearables can address new trends in fashion, shaking the social models around female attractiveness. They can generate instances of female techno-hybridity that are admirable, seducing and influential to challenge the conservative models of beauty.

2.3 DESIGN EFFORTS THAT EMPOWER PROSTHETIC USERS

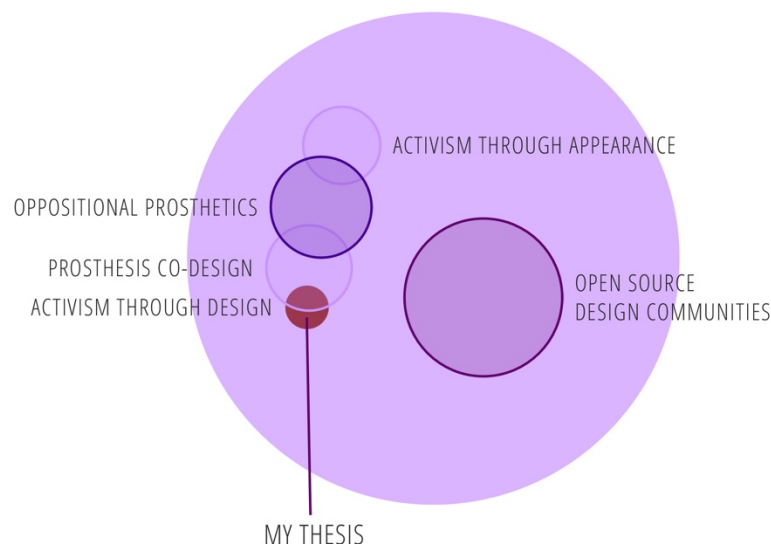


Diagram 1. My thesis among other efforts that empower disabled humans

It is imperative to allow prosthetic users' evocative and expressive needs to inform the experts' design thinking and practice. 'Nothing about us, without us' (Charlton 2000). People with disabilities use these words to demand their inclusion in the design procedures that shape their lives, environments and bodies. Therefore, co-designing with disabled users, offers the opportunity to prosthetic users to share their story and reconfigure their identity along design technologists.

Co-design workshops, allows designers to couple with real users to include their perspective,

knowledge and daily expertise when using a technology. On one side, co-design with disabled users respects the persons' right to be involved in the imagination and transformation of their life. On the other side, co-design teaches technologists the skill of empathy, prompting them to perceive a medicalized design procedure as a creative exploration of materials and forms that meet expressive and social requirements along functional ones. For example, co-design is a favorite research method within the UX community, as it sheds light on the interests and opinions of multiple stakeholders, as well as on the experiences and perceptions of real users. Especially in the case of healthcare design, the information, ideas and artifacts from co-creative workshops influence design decisions and carve new directions.

However, up to now, limited research exists that explores expressiveness or co-design in the domain of prosthetics. As appeared in the work of Hall and Orzada (2013), most of the literature either reports engineering and manufacturing innovations or explores psychological and emotional aspects of limb loss, factors of fit-comfort-function that impact the acceptance, rejection and evaluation of prosthetics. Only Blom and French (2018) provides evidence of the value of co-design in the aesthetic expressiveness of prosthetics. The study describes how prosthesis co-design creates an environment of mutual respect for users and makers. By understanding what it means to feel disabled, users and makers design together personalized artefacts that feel meaningful and socially empowering. Apart from the aforementioned study, a few more consider aesthetics and visual form as a research variable in prosthesis design. One example is Donovan et al. (2002 as cited in Hall and Orzada 2013), who studied the positive influence of naturalistic prosthetics on user's social interactions and self-esteem. Another example is Sansoni et al. (2016), who analyzed the importance of visually appealing designs in medical engineering.

Apart from prosthesis-oriented literature, there is a rising body of Human-Computer Interaction studies that demonstrates the contribution of open-source design communities to the empowerment of disabled individuals (Bennett et al. 2016; Hurst and Tobias 2011). Assistive technologies are not easy to afford, are limited in variety, and individuals present diverse needs across time in terms of how they desire to look, act and relate to others (Murray 2009; Bennett et al. 2016). Therefore, experts from various disciplines are willing to donate design ideas online, motivating audience to customize them. By suggesting affordable

materials and manufacturing techniques, those resourceful communities offer the opportunity to disabled people to build personalized assistive items. Their goal is not to produce fancy and high tech artefacts, but to create the sense of a community, where users get involved, express and physicalize their desires.

Last but not least, industrial companies and designers such as Simple Limb Initiative, Alternative Limb Project etc. collaborate closely with disabled users to produce provocative prosthetics (Vlachaki 2020) that make positive social statements about disability and body difference (Figure 2). Hall and Orzana (2013: 25-26) explain that “this type of activism through appearance is described in fashion studies literature as oppositional dress (Holland 2004; Kaiser and Looyzen 2010)”. Within the context of disability, designing prosthetics as dress becomes a social activism by design against body discrimination. Designers making prosthetics like those and users wearing them oppose to the social stigma of disability, promoting a new sense of self through fashionable artefacts. In their articles, Anna Vlachaki (2020), Sansoni et al. (2016), Hall and Orzada (2013) offer examples of users, who made positive social statements about disability by wearing oppositional prosthetics.

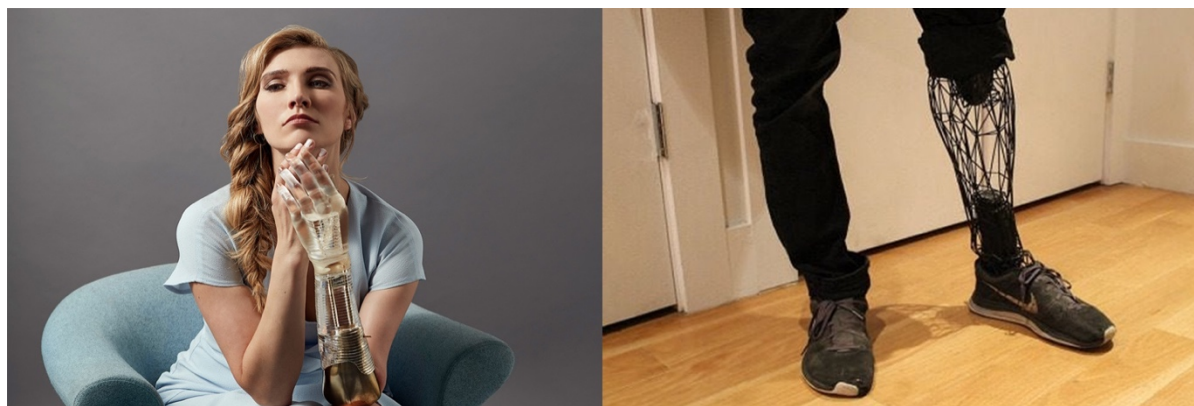


Figure 2, Examples of expressive prosthetics that make positive social statements about disability, Source: (Left) <https://thealternativelimbproject.com>, (Right) <https://www.wired.com/2015/01/3-d-printed-prosthetics-look-fit-sci-fi-warrior/>

3. PROTOTYPING A THESIS AROUND AN EVOCATIVE PROSTHESIS DESIGN

3.1 CONTEXT

3.1.1 UNDERWATER PROSTHETICS

The previous chapter presents examples of prosthesis co-design, as well as ways that expressive and social factors have been addressed in prosthesis design. However, none of those examples explores co-design or expressive design for swimming-specific prosthetics. So far, the majority of studies about swimming specific prosthetics have been medically driven, investigating factors like water resistance, propulsion and buoyancy performance or limb symmetry (Dyer and Deans 2017). Some of these artefacts resemble prosthetic ankles alternating between plantar and dorsiflexed positions (Nakashima et al. 2013), while others take the form of fins or flippers (Bragaru et al. 2012). Despite their engineering oriented focus, the aforementioned studies agree that “... exclusivity, self-identity, social identity and negative affectivity are all of relevance to limb absent swimmers” (Dyer and Deans 2017: 7).

Possible reasons that clarify why social factors in underwater prosthesis design haven't been articulated yet, may be the following: First, as people with limb absence are able to float and swim easily without the need for prosthetic items, a further design exploration may not be perceived as necessary. Second, the strict evidence-based case of prescribing swimming prostheses and the fact that availability is not a reason for offering them to everybody (Dyer and Deans 2017; Hanspal and Nieveen 2002), may be another possible scenario. For the aforementioned reasons, if underwater prosthetics are not easily prescribed and regularly worn, it may not be a priority for experts to explore other factors beyond performance and clinical rehabilitation.

However, within the scope of the current thesis, the lack of a more inclusive design strategy for swimming-specific prosthetics feels surprising for the following reason: It is either on the beach or by the swimming pool, where physical difference is fully exposed, and especially handicapped women experience the most intense social discrimination. And apart from that, a unique need emerges within those hybrid environments: that of using one single prosthesis

that is expressive enough to navigate social staring positively, while allowing one's to operate both underwater and on land.

From my perspective, two interesting design challenges arise. The first one challenges designers to collaborate with female prosthetic users in order to produce aquatic prosthetics that empower female users during their most vulnerable moment: being semi-naked on the beach. The second one challenges experts to develop new design strategies that focus on the design of a single prosthesis that adapts to multiple needs, both on land and underwater by changing material and visual properties.

To offer a design direction for future prosthetics that can be both expressive and adapt to changing needs, I contextualize participatory design for underwater assistive wearables through the technically plausible concept of 'morphing prosthetics'. I thought of this term in order to describe prosthetic wearables made partially or entirely out of materials with embedded material interactivity. As introduced by Lining Yao, director of Morphing Matter Lab, those materials are preprogrammed to morph, changing shape or other material properties, as a response to external stimuli such as temperature, humidity, darkness and so on. Therefore, I propose to take advantage of the spatial dipoles (humid|dry, cold|warm etc.) encountered in environments where land and sea intersect, in order to induce multiple morphing effects into a single prosthesis that satisfies the user's various needs.

3.1.2 UX DESIGN THROUGH MORPHING MATERIALS

My personal interest in morphing materials, prompted me to engage in two research activities that offered me a valuable take-away: Aside technical functionality and innovative accessibility, morphing materials offer user experiences that deliver certain delight and social affects. I further elaborate on those contributions by presenting two different material strategies for user interfaces in the domain of healthcare.

The first project refers to second skin actuators that turn a painful and unpleasant activity such as physical rehabilitation into a ludic play among users and soft, morphable machines (Figure 3). It is well known that patients experiencing physical traumas participate in

rehabilitation sessions. Unfortunately, outside the clinical setting, a lot of them are bored to execute the painful exercises for muscle strengthening. *ExoSkin*, an intuitive interface, encourages the on-demand and at-home rehabilitation, rendering physical recovery into an interactive and exploratory experience, that engages the user both physically and intellectually. Two soft, morphing and portable actuators, are placed along the finger, forcing the muscle to bend and unbend under the user's control through capacitive touch. One's curiosity to learn how the interface works and how it morphs, motivates the rehabilitation process. Finally, through the lens of transspecies symbiosis, the user boosts the fingers' physical strength and flexibility.

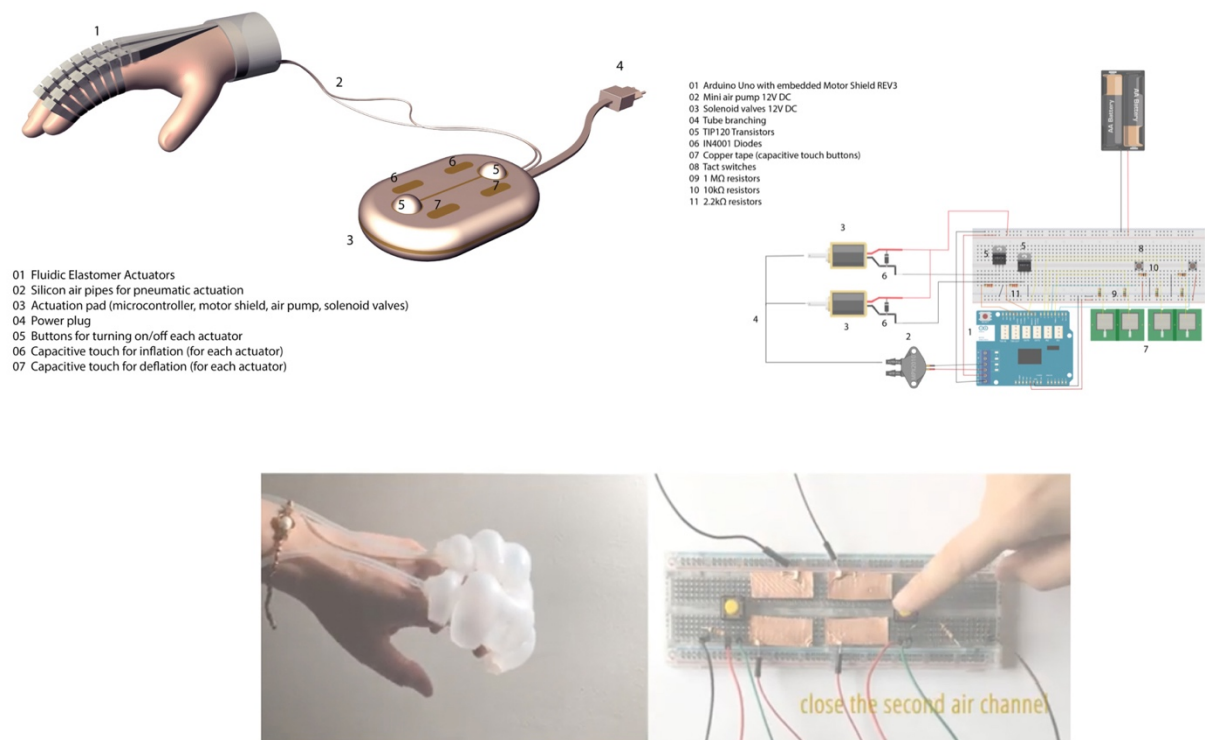


Figure 3, ExoSkin. (top-left) Overview of the system. (top-right) Circuit of Actuation system. (bottom-left) Actuated fingers. (bottom-right) User Interface, Source: <https://www.evocativeinteractions.com/work/exoskin>

Second, as a member of the Morphing Matter Lab, I participated in the projects *ExoForm* where our interdisciplinary team of engineers and designers developed a self-morphing and self-fusing composite to address functional, expressive and evocative factors in the design of orthotics and medical masks for Covid-19.



Figure 4, ExoForm wearables

Both *ExoForm* and *FaceMorph* (Figures 4-6) meet important functional requirements, as they are lightweight, customizable, self-assistant, and re-adjustable over time. Initially, the wearables are printed flat, allowing for easy storage or transfer and then, they morph on demand around the topological curvatures of the human body and face. Their morphing effect is reversible, so they can be re-flattened to get cleaned and reused in the future. The composites also present an integrated sensing system that notifies the user when it needs to be re-adjusted and further customized through massagable gestures. Second, the prototypes are expressive, as they integrate visually appealing designs that employ free-form curves, symmetrical patterns, proportions and colorful materials. The goal was for the wearables to remind more of social signatures than medical support.

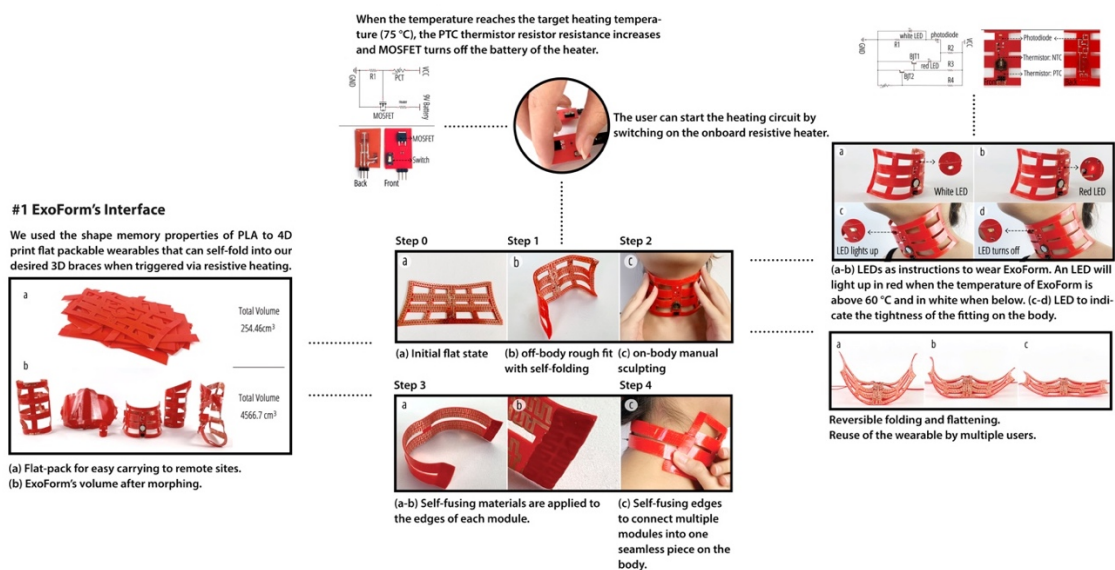


Figure 5, ExoForm's Interface, Source: <https://dl.acm.org/doi/10.1145/3411763.3451818>.

Finally, the user's interplay with the self-sensing, transformable orthotics and the self-assembling facial origamis, evokes emotions of exploration, playfulness and creativity. On the one hand, Exoform users feel empowered, as the concept of cast as a techno-fashion piece overshadows the unpleasant perception of cast as rehabilitation aid. Therefore, ExoForm augments the user's social identity: Instead of being the person with the broken arm, the user becomes the owner of the self-morphing cast. On the other hand, the facial origamis engage the user into an interactive, construction activity that produces delightful masks that totally seal the face, while integrating visual aesthetics compatible with social norms.

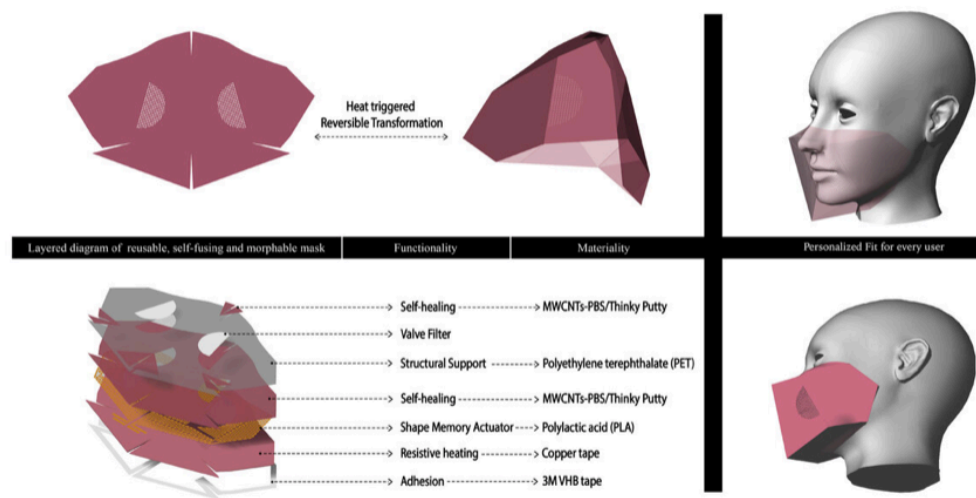


Figure 6. FaceMorph Interface. Source: <https://www.evocativeinteractions.com/work/facial-origamis>

My involvement in those two projects taught me that shape-changing interfaces offer playful interactions that stimulate amusement through exploration, an encouraging condition to deal with disability. Morphing wearables may have the power to evoke ludic play for the domain of prosthetics, by bringing the user closer to a “disembodied” artificial limb through the exploration of transformative properties. Finally, a wearable with integrated interactivity and morphing behavior may enrich the user's expressivity and identity, by becoming the social signature for a techno-fashion hybrid. To conclude, my experience with morphing materials, renders them as a promising design medium for plausible prosthetics.

3.2 HYPOTHESIS

My thesis assumes that ethnographic research in collaboration with participatory design and speculative design inspired by morphing materials could bring a positive change in the domain of prosthetics. First, it will make technological designers emphasize with the emotional needs of prosthetic users, so that they start considering factors such as aesthetics, playfulness and affects when designing prosthetics. Second, giving the opportunity to prosthetic users to be heard and share their ideas, will empower them as both social and creative beings. And third, scenarios of programmable prosthetics will emerge that satisfy physical, evocative, and social needs of disabled swimmers.

Physical needs refer to the user's dependence on technological aids that allow her to physically operate. In this particular case, the environmental changes observed in swimming specific spaces (from dry to wet, light to dark, cold to warm) could become stimuli that force a prosthesis to change properties, so that the user better operates both on land and underwater. To give an example, the prosthesis could present a varying stiffness or fluorescence that allows the user to have a rigid limb on land, a more flexible one underwater, and a glowing one in dark waters.

Evocative needs refer to a person's desire for uplifting emotions and experiences. As the user participates in the design decisions about a new prosthesis, coupling her needs with material transformations she would potentially enjoy, positive feeling are being evoked. On the one hand, the user feels engaged and productive. On the other hand, she adopts a ludic attitude that prompts her to re-imagine her embodiment through techno-hybridity.

Social needs refer to the user's desire for self-expression and social statements. As the user reclaims her right to self-represent, she co-designs programmable, techno-fashion pieces, which allow her to express her identity, femininity and attractiveness in non-normative ways. This self-reflective process empowers the user to gradually reconstruct her self-confidence and body image, while making a positive statement about the social labels of ability, disability and super-ability.

To better demonstrate this social goal, I would like to place it within a real, potential context. If you could help handicapped, little girls feel powerful, through prosthetic limbs that change colors or glow in the dark, how would that impact their body-image and the society's norms? Wouldn't those girls start to show off their unique limbs to their friends, instead of using them as concealers of their physical difference? Wouldn't the society secretly wonder if similar boots and gloves exist for non-disabled children, instead of focusing on the violation of the social norms?

Employing innovative, technical concepts alongside computational and human-centered design in order to address disability in an empowering way, is the change this thesis aims to bring to the domain of prosthesis design: To inspire technical and at the same time evocative prosthetic concepts that become symbols for both their users and the society.

3.3 STRATEGIZING USING DIFFERENT METHODS

3.3.1 METHOD A: CASE STUDY

The thesis' goal is to deliver new design thinking about feminine prosthetics. Through a case study that integrates a real user into-the-design-loop of speculative prosthetics, I prototype an inclusive strategy that through exploratory research and co-creative sessions indicates how to design for and with handicapped women. Case study, as a research method, allows an in-depth study of a specific instance of a situated phenomenon (Lazar et al. 2017). In this particular case, the phenomenon is the disabled experience for female, prosthetics users and by studying a selected user, interesting insights may emerge that can produce general principles to better understand how other women with disabilities live and feel.

Design researchers conduct case studies of various forms in an effort to understand problems or novel situations related to design. As a case study provides feedback, designers better understand the context of their design and think of possible solutions to update their concepts (Forlizzi and McCormack 2000; Wiethoff and Gehring 2012). Through my case study, I explore the experiences, perceptions and values of a female prosthetic user, and through a rich qualitative analysis, I inform my initial design goals and aspirations. The case study ends

with me a) gaining an understanding of how disability-specific experiences influence a female user's perception about her body and prosthetics, b) empathizing with the user's needs and c) co-designing speculative wearables that align with those needs.

Case studies are usually used to develop models that indicate how emerging technologies can be beneficial to a particular category of users. In the case of disability, studying multiple users to produce one artefact would be challenging, as each disabled individual relates differently to assistive technologies, hence, builds diverse interconnections between different needs (function, expression etc.). Therefore, whenever it is difficult to reach a unified design concept for multiple users, a single case study (one user) with multiple units of exploration is being used (Lazar et al. 2017). In this embedded case study, the prosthetic user participated and evaluated the design efforts according to three units of analysis: functionality, expressiveness, and emotional empowerment.

Moreover, collaborating with a handicapped woman is both intrinsic and instrumental (Lazar et al. 2017). On the one hand, being a female, congenital amputee is not a common case and that makes the study particularly worthy in its own right. On the other hand, augmenting the social identity of a female, prosthetic user may affect other disabled women as well, who share similar concerns regarding self-representation in swimming specific environments.

Finally, according to Lazar et al. (2017), describing a new system may have an interesting impact. And this thesis describes a methodological system that combines qualitative research and analysis along with computational methods and advanced engineering concepts that challenged me to reconfigure my ethical stands throughout different procedures of the thesis. Using different 'hats', I alternated roles between a critical listener, an empathetic researcher, a technological designer and a woman during two different stages: The Ethnographic Workshop and the Participatory Speculative Design.

3.3.2 METHOD B: DESIGN ETHNOGRAPHY

Designers often employ a wide range of ethnographically informed methods to gain insights about 'situated' phenomena in the present (Lindley et. al. 2014) and turn them into design

concepts for new technological products (Helgason and Smyth 2020; Wiethoff and Gehring 2012). Therefore, ethnographic research can be really beneficial for understanding the context or the user that one is designing for (Millen 2000). In this thesis, designing for a woman with limb absence became all about learning and understanding the user's experiences related to disability and prosthetics, and how those shaped her self-perception, self-representation and personal battle against social stigmatization.

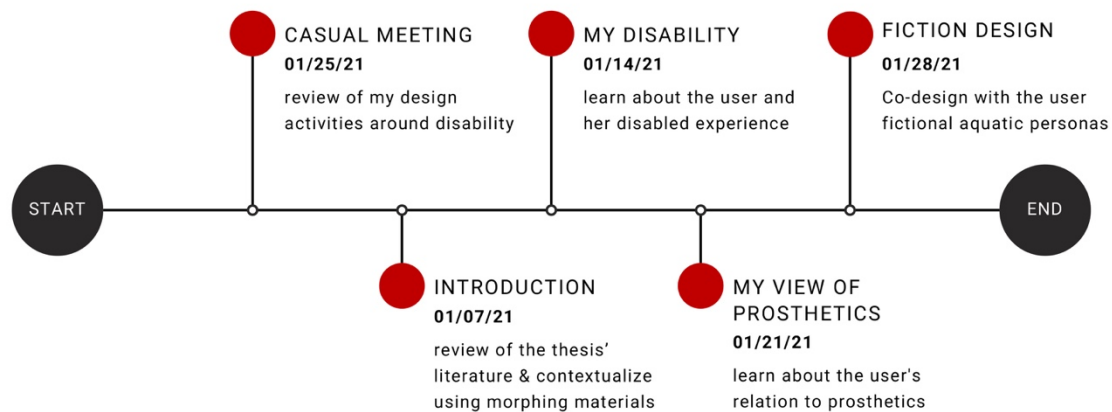


Diagram 2. Meeting Protocol of Ethnographic Workshop

Through a casual meeting, an introductory meeting and three rigorous cycles of semi-structured conversations (Diagram 2), I collected information with the intent of answering the following questions:

- What does disability mean to my user?
- When does she feel disabled?
- How did disability influence her social/personal life?
- How does she fight against her body's discrimination?
- How does she think of prosthetics?
- What kind of prosthetics would boost her body-image and self-confidence?
- What technical and expressive properties should the perfect aquatic prosthesis have?

The motivation of workshops like this (Blom and French 2018) is to set up an understanding and a collaborative relationship between users and designers through a mutual exchange of knowledge and experience. On the one side, as a designer I captured the user's personality in

order to update my original design reasoning. On the other side, the workshops fostered self-awareness, broadening the user's perspective and informing her about a whole community of disabled people, researchers and designers, who collaborate with each other. It was anticipated that this procedure would be intellectually and emotionally empowering for the user, making her feel released from the social oppression related to body norms, so that she reveals well-hidden desires. Additionally, different designs of prosthetic limbs were demonstrated to the user, in an effort to reconstruct a meaningful relation to prosthetics.

The final goal of the workshop was to articulate the user's needs in swimming specific contexts. The first two cycles of the workshop collected the prosthetic user's perceptions and emotions by investigating real experiences from her past and presence. However, the third and final cycle applied the ethnographically informed method of fiction design (Helgason and Smyth 2020), to reveal emotions and oppressed desires through the production of creative personas that represent fictional, aquatic hybrids. The user was told to think creatively in order to reconstruct herself through a fictional persona, who belongs to an imaginary, aquatic world. Apart from identity details, such as gender, body appearance and physical abilities, most of the details of this fictional world and life were constructed during a semi-structured interview process. It was anticipated that this fictional persona would force the user's critical reflection on her real life and problems inducing creative inspiration to deal with negative feelings and memories.

The workshop's data were collected through field notes, video recordings and a prosthesis-oriented survey. During the latter one, different types of prosthetics were presented to the user, during which she had to rate them, choose her favorites ones and justify her choice. To analyze the data, I started looking for codes related to disability, prosthetics and underwater experiences. As my notes were in an electronic form, it was easy to highlight the different codes using different font colors. Later, I started working with affinity maps, where I organized my notes into clusters of different themes like 'moments that F felt disabled', 'negative feelings on the beach', 'staring but not asking' etc. I organized those clusters into other clusters, resulting in four high level categories that offered lessons about: disability and impairment, disability and social stigma, prosthetics-gender-identity and being disabled on the beach.

Finally, in order to synthesize my findings, I analyzed the data according to theories around feminism and technology, disability and fashion and distilled them into pain points, needs, design lessons and principles related to disability. Upon them, I founded the participatory design sessions, where the user and I ideated speculative versions of assistive, underwater wearables.

3.3.3 METHOD C: SPECULATIVE CO-DESIGN

In order to produce new and personalized concepts of prosthetics, I integrated the user into the design loop by interweaving Speculative Design (SD) with Participatory Design (PD).

Speculative Design is being used by an increasing number of designers, who wish to reflect on current technologies and evolve those by designing futuristic versions of them. According to Dunne and Raby (2013), SD is a powerful tool to imagine possible futures by producing new ideas and perceptions about how things could be. In this particular case study, SD is employed in an effort to attribute new properties and aesthetics to prosthetics that render them into social signatures and emotional supports. My aspiration was to carve new ways of thinking of what assistive technologies could look like and do, so that they boost the self-confidence of women with physical disabilities, who feel exposed and being stared on the beach or at swimming pool. Finally, these futuristic wearables could also foster new ideas about morphing wearables and clothes for non-prosthetic users, who wish to transform their body either underwater or on land, expressing a hybrid identity and gender enabled by technology.

Participatory Design is often used as both a generative and an evaluative method, so that new technological concepts or design processes are being generated or informed during the stage of development (Kusunoki and Sarcevic 2012, Forlizzi and McCormack 2000). PD integrates the human actor directly into the design loop by applying different rules of engagement for the user. The form of participatory design I chose for this case study is that of consultative design by Mumford (1981). Here, the user produces inputs for the technological designer. I opted for that, because the user lacks interdisciplinary knowledge and skills that are necessary to obtain a more active role in the design and prototyping procedures.

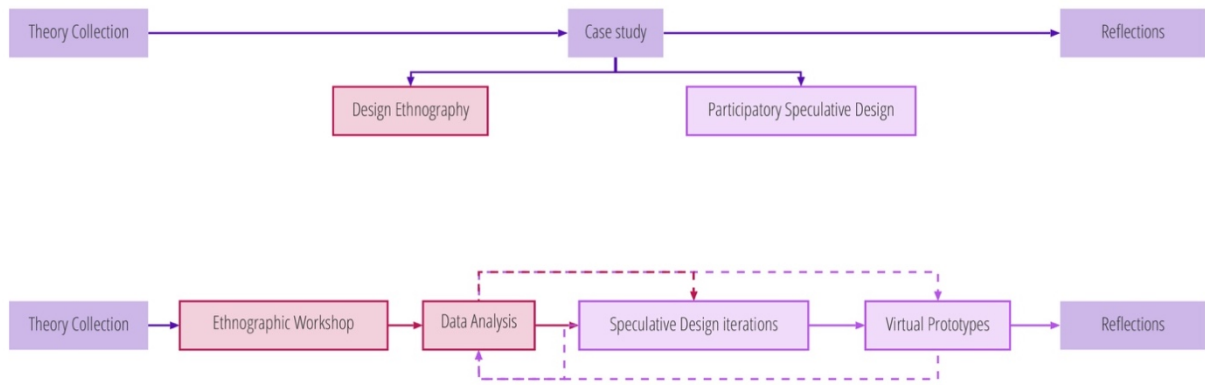


Diagram 3. Methodological Protocol

The thesis documents the process and the results of three iterations of speculative co-design. Each iteration describes different ways of collaboration between me and the user. During the first iteration, I interpreted the ethnographic data into provocative concepts of morphing wearables without the user's further involvement. I crafted those concepts into visual models and evaluated them with the user, articulating frictions and take-aways. Then, I reflected on the user's inputs, so that I update my design reasoning.

During the second iteration, the user and I brainstormed together, discussing morphing properties that could produce speculative wearables that feel truly practical, expressive and evocative to the user. I demonstrated how those properties work through a fictional storyboard. During the last iteration, I prototyped virtual prosthetics by animating their morphing properties in Unity. I developed an AR application that maps the prosthesis on the user's body, so that a sense of an augmented self is constructed. It was expected that the user would try-on the virtual prosthetics, offering back embodied inputs that could update the process in the future. Unfortunately, due to geographical distance, technical limitations related to iPhone hardware and the user's summertime vacation, this evaluation never took place within the thesis' timeline.

4. AN ETHNOGRAPHIC WORKSHOP WITH F

4.1 WHO IS F?

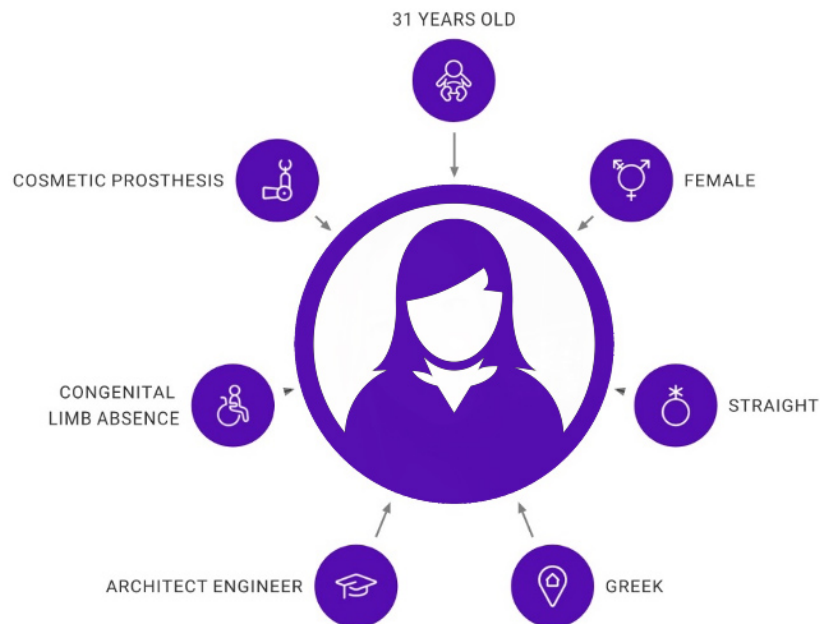


Diagram 4. Demographic data about F

F is a Greek, 31 years-old, woman with congenital limb absence. She was born with her right foot shorter in length, missing a fully developed heel and the responsible bone for the ankle's flexion and extension. F often self-deprecates, claiming that she feels like an inborn dancer, as her foot's permanent extension reminds of a ballerina standing on pointe. She learnt to bolster her whole body on the toes of this foot, enduring the pain and arguing: *"Try to find a prosthetic user in this life, who is not in pain!"*. F encloses her foot into a limb-shoe that enhances its appearance and protects it from gestures and movements that could hurt the rest of her underdeveloped bones.

I met F during my graduate studies in Design Research. What brought us together was my graduate master thesis, where I was studying the role of body in spatial perception and I was looking for insights from people with motor disabilities. Even though back then my research was quite different, it was my conversations with F, who inspired the idea of programmable prosthetics. Hearing her complaining about her solid, non-waterproof and non-flexible

prosthesis that doesn't allow her to enjoy the underwater experience, I thought of speculative prosthetics that could change properties like form and stiffness, adapting at different spatial mediums and allowing the user to act both on land and underwater.

4.2 LEARNING ABOUT F's EXPERIENCE OF DISABILITY

4.2.1 APPROACHING F AND INTRODUCING THE IDEA OF EVOCATIVE TECHNOLOGIES

One and a half year after the aforementioned discussion, I asked F to become my case study in the current thesis. I told her that the goal was to co-design speculative prosthetics that have the power to morph and turn a disabled woman into an aquatic cyborg: an aqua-borg. Initially, F couldn't comprehend what I was meaning by that and how she could contribute. As a prosthetic user for over thirty years, F was used to collaborate with prosthetic makers only for physical and functional issues, like the anatomy of the prosthetic sock and the comfort it offers. She has never been asked before to explore the expressiveness of her prosthesis, let alone in non-normative ways.

In order for F to better understand my design aspirations, sensitivity and goals, we set up a casual meeting for 'virtual coffee' over zoom, as for the time being, the geographical distance between us (Europe-USA) and COVID-19 rendered travelling and physical encountering impossible. For almost two hours, we were discussing about the concept of 'expressive' and 'evocative' assistive technologies: technologies that assist a disabled user in an empowering way, by invoking positive, thoughtful emotions through their form, function and interaction with the user. To demonstrate this concept in practice, I described to F the four following applications of mine: *ExoForm*, *ExoSkin*, *kidSpy* and *Water Pilly*.

ExoForm and *ExoSkin* are the orthotic and rehabilitation systems I mentioned in the previous chapter. *kidSpy* is a smart phone application for hearing impaired parents who wish to monitor their children's health. As a sensory substitution device, *kidSpy* translates the intensity, duration and frequency of auditory illness symptoms like coughing and sneezing into visual drawings that the parent needs to decipher artistically. My goal here is to turn the unpleasant

sound of illness into a pleasing vision that doesn't terrify the users, but delivers bad news through happy visual cues. Finally, *Water Pilly* constitutes a mechanical flower that flourishes to notify the user when they need to take their pills for environmental asthma. A closed sensing system, computes the relative humidity and temperature in relation to the user's tolerance and opens the petals to offer access to the pills. My goal in this project is to couple the danger of suffocation with a positive signal of regeneration, so that the view of an evocative blossom enacts positive feelings relating to one's breathing disability.

During my projects' description, I focused carefully on F's comments and voice tone. Seeing her smile and having fun with the applications, was my green light that I was on the right track. *"This is how we should think",* I told her. *"Through your example, we will imagine a new future for female prosthetic users, by designing underwater wearables that help them embody feelings of attractiveness, dominance, freedom and hybridity. We will turn them into aquaborgs".*

As early as this meeting, I felt that I am about to open a total new world for F that comes with both hope and disappointment: Hope, because co-designing speculative wearables that imagine a new social presence for disabled swimmers would boost her self-worth and self-confidence. Disappointment, because the study would not lead to an actual product in the foreseeable future. In order to be transparent, I explained directly to F that this thesis only proposes a new inclusive strategy for prosthesis design and if actually applied, it would take years and different experts to produce the resulted wearables.

One week later, F and I updated our meeting in order to introduce her to the theoretical background of my thesis as presented in the *DISABILITY AND PROSTHETICS* chapter. I prepared slides in order to describe different natures of prosthetics, and explain the diverse models of disability that underly their development. Our discussion took place as usual over zoom. Sharing screens and keeping our video cameras on, we showed each other slides, articles, YouTube videos, as well contextualized F's current prosthetic boot. We ended up, discussing the meaning of prosthetics as transitional, evocative, and social objects. Finally, I cited examples of morphing applications for various use cases in order for her to understand the technological innovation, on which we were about to base our speculative co-design.

From the first moment, F doubted the prosthesis' powers to induce positive feelings toward one's body or the world. She claimed that *"it is the intangible things, like my mind's tricks, my life experiences and others' stereotypes that defined how I feel and felt about myself now and in the past. It isn't the prosthesis"*. I started reflecting on F's disclosure and I shared with her my ideas concerning the role of a prosthesis in mediating some of those experiences: *"It may not be about the prosthesis itself, but about how well your prosthesis reflects who you are and how satisfied you feel with what you present or represent to others" ... "Of course, our mind sets up traps for us. But since we were young, toys and clothes helped us to discover who we were about to become by reflecting through them on ourselves. And this is what your prosthesis is: a companion that mediates your experiences and a dress that evokes feelings to you and the others."*

F delved into a thoughtful silence. After a while she shared with me that it was her prosthesis' reconstructions that made her become the inventive person she is today. Looking for ways to improve technically her prosthesis, she gained hands-on experience to assemble and restore other constructions in her house. Moreover, she added: *"A dress... you are right about that. Improving my limb's anatomical characteristics and making it look more female, was a boost to my self-confidence as a woman"*.

F also mentioned that she recently opened her mind to prosthetics that achieve more than being cosmetic reproductions. After her move to Netherlands, she met with prosthetic makers that informed her about the new trends in prosthesis design. According to them, Dutch prosthetic users prefer wearables that highlight their physical difference through vivid colors and decorative patterns instead of concealing it. I stepped on F's reference, in order to discuss the role of expressive prosthetics in their users' identity and socialization. Finally, I brought up the example of a prosthetic monofin that allows a little girl underwater to feel and self-represent as a mermaid, alluring other children to play with her.

It wasn't the mermaid monofin in its own nature, but the concept of a prosthesis as play and conversation starter that made F think: *"A fancy prosthesis may achieve that: triggering others to approach prosthetic users and ask questions about the wearable itself and eventually about the user's disability"*. However, she argued that the problem with prosthetics like this, is

that one may dream and talk about them, but that doesn't mean that one will ever have the capacity to afford them.

F explained, *"of course, my self-confidence as both a human and a woman would be boosted, if I had the money to buy sophisticated prosthetics like that" ... "But, how can people like me participate in an activism through appearance, if we never had access to technologies that express who we are and what we want to achieve?"* F also argued how prosthetics like those leave from the category of the 'functional necessity' and go to the category of the 'social desire'. And so far, self-expression did not constitute a pre-condition for prosthesis prescription according to her health insurance.

Finally, it seemed that F aligns with the idea of morphing wearables, arguing that *"it makes sense, because technology's goal is to mimic the nature"*. However, she looked pretty suspicious with the idea of wearing anything fully autonomous either on land or underwater. She warned me about the dangers of competence that such an interaction would entail and the feeling of confusion in terms of movement co-ordination such an endeavor may result in. Her reasonable argument pointed out a new design factor for me: the user's control over the morphing wearable.

4.2.2 DERIVING LESSONS ABOUT DISABILITY AND PROSTHETICS

The two introductory meetings put both F and me on the same page. F gained a complete picture of what my thesis was about and I had the opportunity to examine overlaps and contradictions between F's experiences and my theory, so that I design and organize the ethnographic workshop accordingly.

The ethnographic workshop took place in three sessions, each of which lasted around three hours and organized as a semi-structured interview over zoom. The first two sessions collected and analyzed information about F's life, experiences and needs in relation to disability, social stigma and prosthetics. The way I organized each semi-structured interview is the following: I reflected on the things I would like to learn about F and then I thought of both direct and

indirect questions to trigger a conversation (Diagrams 4-5). Direct questions resulted in descriptive answers about real facts. Examples of direct questions were:

- *Can you share some bad and good experiences that resulted from your physical difference?*
- *How did others treat you and make you feel?*
- *Describe the times your prosthesis made you feel exposed.*
- *Describe the ideal prosthesis for you!*

On the other side, indirect questions generated answers that needed interpretation and had to be analytically encoded into oppressed desires and needs. Paradigms of indirect questions were:

- *Which was your favorite fictional heroine when you were a child?*
- *How would you sketch yourself?*
- *What is the gender of your prosthesis?*
- *If others called you 'Terminator', how would you feel like?*
- *Among those prosthetics, which ones would you use and which not? Explain your selections*

My intention was to let the interviews flow handily, in the form of two friends chatting, and not 'attacking' F with questions. Therefore, I put myself into this loop of asking and answering. In the disability session, I employed my identity as a disabled person to connect with F. As a person suffering from severe food allergies, I am not able to consume a great range of foods. Therefore, I started to talk about my own disabled experiences, whenever I schedule dinner with others. "Every time that I meet new people, they are surprised about my food allergies. They can't believe that I have never tried chocolate or ice-cream and that makes me feel somehow unique. However, when I start asking about the ingredients in this and that, I feel like a weirdo. I am pretty sure that you had similar moments. Please, tell me about them! "

During the prosthetics session, I was trying out a different ‘hat’: I used my female identity to talk to F as one woman to another woman. We started discussing like two girlfriends, who compared and graded outlooks according to the accessories used. The only difference was that in this case, the accessorize was the prosthesis.

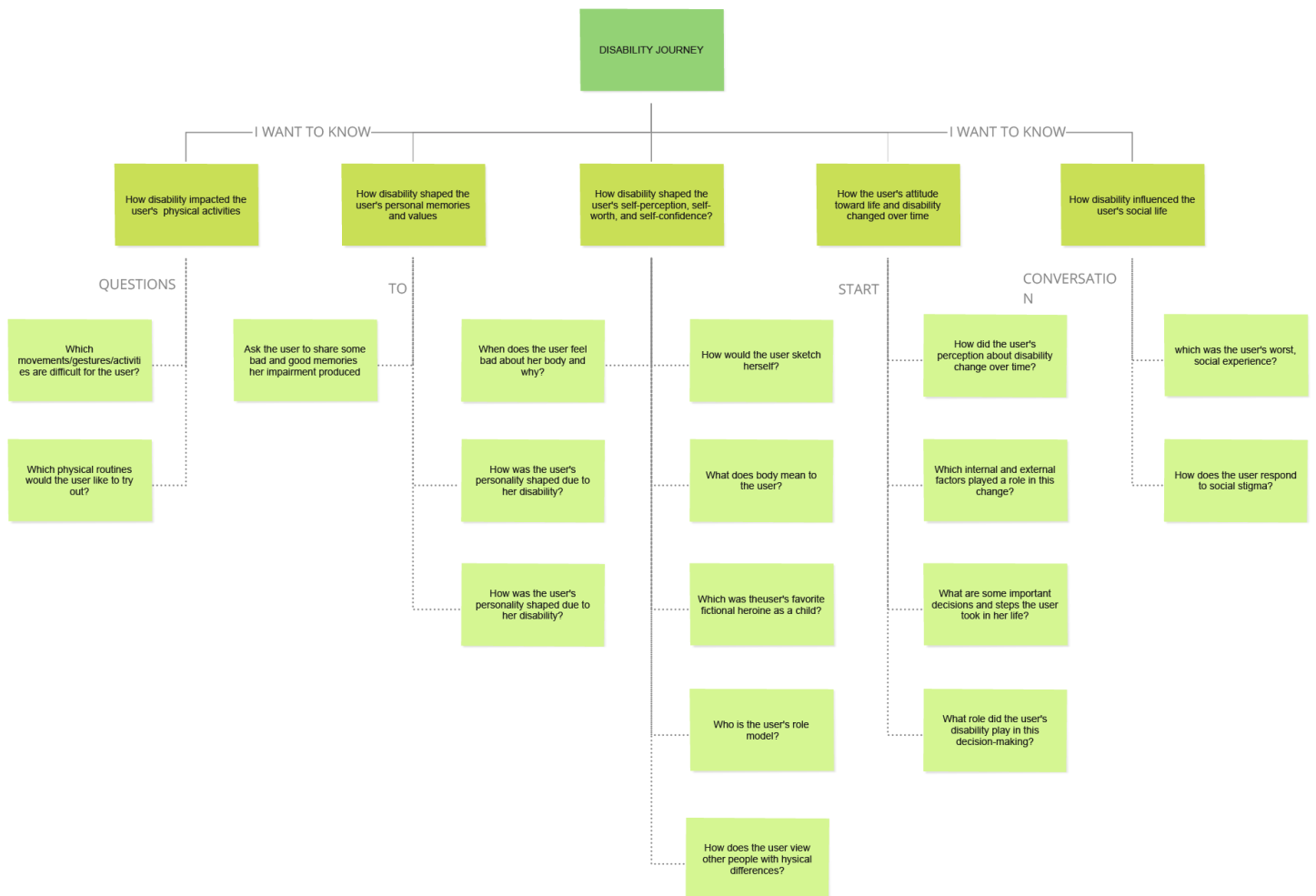


Diagram 5. Semi-structured interview diagram with the theme *DISABILITY*

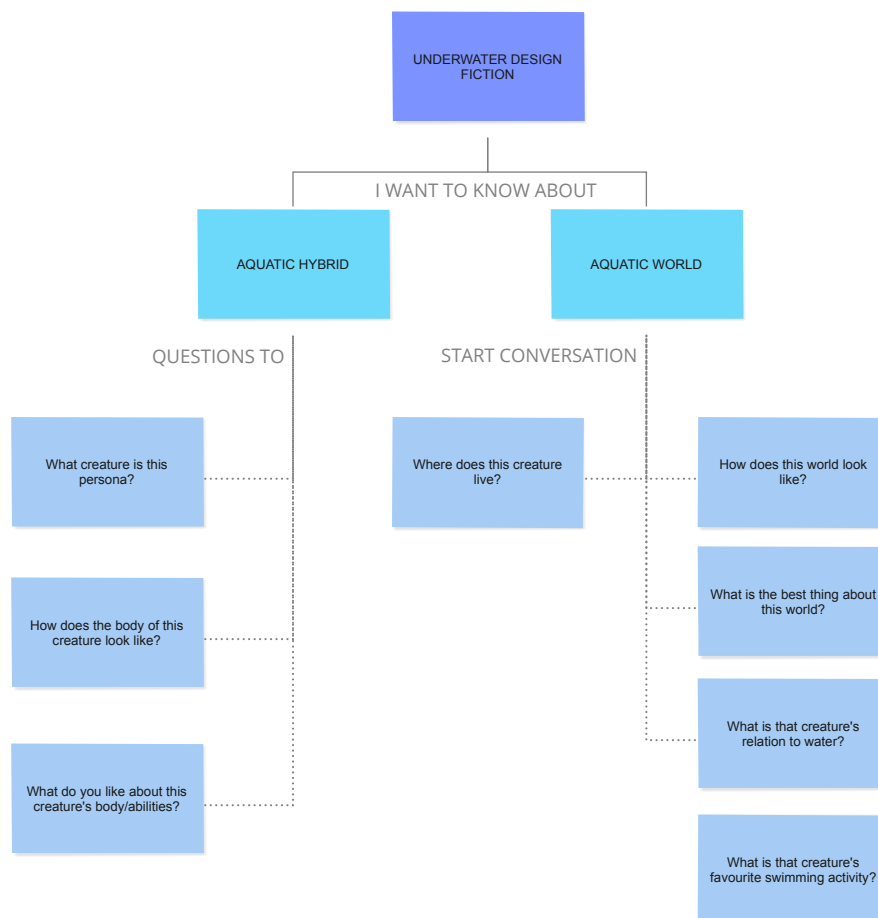


Diagram 7. Semi-structured interview diagram with the theme *UNDERWATER DESIGN FICTION*

The data collected were synthesized through affinity diagrams (Diagram 6). On the one hand, the stories gathered throughout the disability section reinforced the thesis' view that disability has always been a social phenomenon. On the other hand, the information extracted from the prosthetics session showed that prosthetics, indeed play an essential role in F's life, much greater than she initially believes.

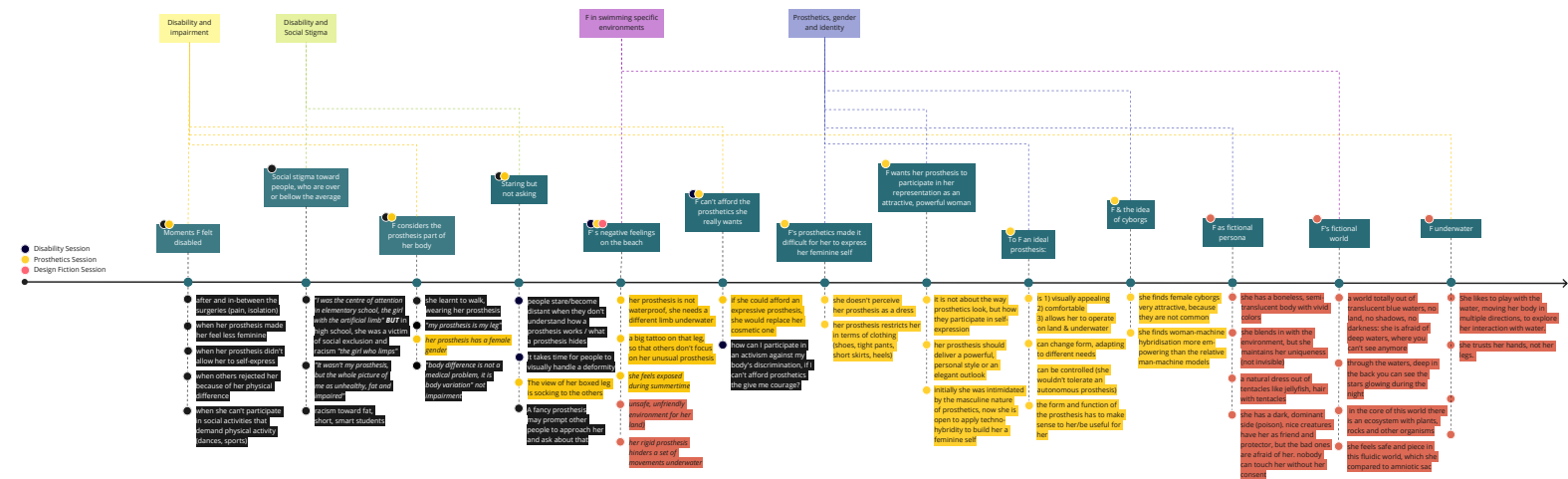


Diagram 8. Analysis through affinity diagrams

To F, who grew up with congenital limb deformity, body difference doesn't feel like an impairment or a medical condition that needs to be fixed. Her limb absence and prosthetics have always been part of herself. *"I walked for first time at an expected age like other kids did. The only difference was that I had to use a special shoe. This shoe became my real leg and I gave to my deformed limb the nickname 'little foot'."*

When I asked F, which movements she wished to better perform with her prosthesis, she couldn't think of any. My assumption was that this was down to the fact her disability is congenital, hence, not performing properly certain movements was indifferent to F. According to her, she has been missing the cognitive connection to a set of embodied actions and perceptions that people with two natural legs develop gradually and tacitly. I believe, that the

fact that she never experienced any phantom sensation¹ or neural mirroring², has been preventing F from feeling the emotional loss of activities and gestures she can't execute. The only cases, F felt the curiosity to try out new physical activities were social. Usually, it derived from her desire to participate or blend in with other people her age in socially engaging activities, such as sports or dance. In other words, as any other person, either male or female, F cared about her social life and has always been looking for ways to boost her social identity.

F's life story confirmed the view that one may be born physically impaired, but it is the society through different instances of people and behaviors that forces prosthetic users to feel disabled and abnormal. To begin with, it was the fear of social stigma for wearing a prosthesis which *"emotionally forced F's parent to look for medical solutions all over the world"*. In an effort to restore her limb, F endured experimental surgeries that resulted in long and painful recovery periods that costed her health, socialization and play activities as a kid. If F could decide for herself back then, she would never turn her body's difference into a medical problem. *"It is ok to be physically different. Body variation is not a problem."* She would prefer for her parents to have invested their effort and money in designing the perfect prosthesis that would make F happy, instead of trying to change her in order to look like the way society dictates.

According to F's accounts, I realized that the only times F felt disabled and viewed her physical difference as a problem, was when others hurt her attractiveness by targeting directly or indirectly her impairment. The first case took place during high school, where F became a victim of both social ableism and exclusion. The social label of 'the girl who limps' or 'the girl with the short limb' used to make her sad. However, the times F felt even more vulnerable were when boys rejected her, because they were too scared to become 'the guys who date the deformed girl'. Growing up, F started to realize that it wasn't her prosthesis in its own right that caused her social bullying; It was the school's little society that didn't tolerate anyone who

¹ A phantom limb is the sensation that a missing limb is still attached.

² The sensation where you're watching someone do something -perform a movement - and you can just *feel* exactly what they must be feeling, as if you were in their shoes.

looked different or was a minority. Being short or too tall, being smart and a woman, fat, poor or unhealthy, all those constitute reasons for stigmatizing a person.

Another case that hurts F's self-confidence, takes the form of social staring. Staring constitutes a natural response to someone, who is different and may happen for many reasons: out of admiration, shock, curiosity and fear. F supported that *"people usually stare at me in an effort to process and understand my physical problem and the seams between my natural and artificial limb. It takes time to accept a body that deviates from what is considered normal... To some extent, I learnt to forgive that weakness of others, because I may get it; this is something we all do. We all judge based on personal aesthetics, including me"*.

However, despite her apprehension and strength of character, there is a single thing F never understood or tolerated. Apart from silent assumptions, judgmental whispers, fearful and/or pitiful gazes, nobody ever took the initiative to ask her openly about her physical condition. F reflected on the emotional support she would feel if others approached her to ask about her prosthesis with the same directness and spontaneity people approach each other to discuss about clothes. Recalling our previous conversations, F started seriously to consider the idea of an extraordinary prosthesis as a solution to this problem. She argued that by evoking admiration and positive curiosity, a elaborated prosthesis may invite external observers to overcome their taboos and make this big move.

As a female prosthetic user being born and raised in a typical patriarchal culture, F felt oppressed by social norms about femininity and beauty. According to Grant (2015), girls and women in such societies experience a lot of anxiety about maintaining their feminine status, because they are judged more by their bodies than men do. Based on the conventional, social expectations about female appearance, women with disabilities are usually considered unattractive, masculine or gender-less.

As a disabled woman herself, F often worried about her ability to embody and perform sexiness either with or without her prosthesis. Therefore, her self-confidence and body-image was depending on her prosthesis' ability to integrate stylistic attitudes linked to feminine identity, like wearing tight pants, short skirts, boots and high-heels. F viewed her prosthesis as

an embedded part of her feminine identity. This is why, she has always been prioritizing appearance over comfort and function, caring about how a prosthesis made her look like rather than what it allowed her to do.

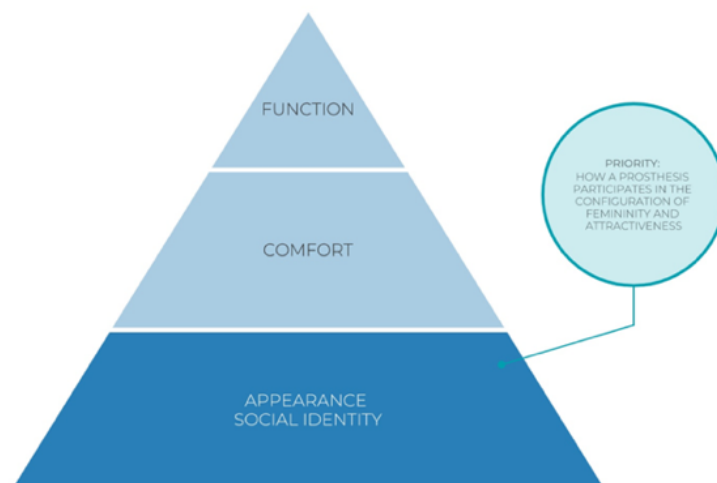


Diagram 9. F's pyramid of needs in terms of prosthetics

The theme of female sexiness and attractiveness was repeated throughout the whole workshop. Sometimes it was related to F's social discrimination, while other times it derived from F's desire to wear prosthetics that allow her to feel beautiful without others focusing on her disability. Eventually, F's story won me over, because as a woman myself I emphasized with all those concerns that every female, either abled or disabled, deals with. And that had a great impact on me: First, I realized that my initial design concepts about what can be expressive, empowering, attractive and healing for disabled humans were related to my personality, perspective and feelings as an external observer. Second, I started to look for studies that present how other women embraced techno-hybridity and how the concept of female cyborgization has been empowering in its own nature for disabled women. I brought up those concepts to F starting an interesting conversation about prosthetics, gender and physical attractiveness.

During the session about prosthetics, F showed a strong preference for expressive limbs that through their stimulating and provocative appearance, empowered female users to re-imagine femininity far beyond the standards of typical beauty. F reflected on those prosthetics more as

dress and less as limbs, arguing that their users performed sexiness through their courage to oppose to social taboos by using their prosthesis to develop sophisticated and elegant, personal styles. F declared that if she had to choose between the femininity embodied through expressive prosthesis and that performed through the perfect cosmesis, she would undeniably represent herself in the first way. I assumed that F's attitude changed, because she was influenced by the self-confidence that the disabled models in those pictures reflected. And she wanted to feel like that herself.

This powerful representation of femininity, made F reconsider the cultural associations of industrial prosthetics with masculinity and the resulting stigma around women wearing them. While the society is used to representations of man-machine hybrids, like Iron Man and Terminator, it is less familiar with the idea of female cyborgs. Indeed, in elementary school, F remembered other kids calling her "RoboCop". She also recalled how unique she felt, as she was the girl with the artificial limb, a kind of sci-fi persona to the eyes of her peers, who weren't "fully socialized into the hetero-patriarchal gender norms" (Grant 2015: 9) and could imagine worlds beyond dichotomies, focusing on the hybrid identity her artificial limb produced. Even though the representation of F as a male cyborg sounded the same intimidating to her, as it used to sound back then, she found the idea of her as a female RoboCop both intriguing and empowering. F considered the feminine instances of techno-hybridity in science fiction movies and animations, as more admirable, seducing, and influential than the common male ones.

4.2.3 EXPLORING HIDDEN TRUTHS THROUGH ETHNOGRAPHIC FICTIONS

In the last session of the ethnographic workshop, F and I designed a fictional, hybrid persona inspired by F's relation to the aquatic world. At the beginning, F's imagination and creativity were both blocked, and she didn't know how to start and what was important to say. In order to show her the way, I took the lead in producing an aquatic fictional character inspired by my childhood memories and experiences with the sea:

If I were to be an aquatic creature, I would be Airam; An adolescent mermaid with a bluish tail that likes textured stones and collects rare shells from the bottom of the sea. Airam is fearless and enjoys the deep and cold waters of the ocean. She loves her flexible tail and the

bending movement it induces to the rest of the body. Airam spends a lot time by herself, enjoying the freedom and speed of her body's locomotion. Every day, she approaches the beachfront, hiding in between of rocky formations and eroded chesses in order to observe the lives of human beings. She doesn't want to speak to them, only learning their deepest thoughts, as everybody reveals their secrets to the sea.

While describing this persona to F, I was explaining at the same time how this fictional hybrid was related to my personality and real memories as a child:

My family used to have a little cottage house on a coastal area close to Athens, where we used to spend our summers. As an only child, I learnt to spend a lot of time by myself, so my mom was worried and pushed me to socialize with other kids on the beach. As a response to her pressure, I used to take my long fins and disappear in the deepest waters of the sea. Attaching my legs together and placing my arms parallel to my body, I pretended I was an escaping mermaid enjoying the freedom and the speed of my body. And after I returned close to the beachfront, I used to silently approach other people and learn about them by observing their lives. As the shy kid I was, that was my own way of connecting to others.

F carefully heard my story and replied: *"I could never imagine that someone that sociable like you, would ever have been that introvert as a kid"*. And I responded back: *"This is why, I want you to design with me your creative persona: to reveal through that deeper emotions and secret desires. Nobody knows what other people actually hide in their hearts, until they wear a mask that sets them free to tell you"*. After this personal sharing, F felt ready to start weaving her story. From times to times, I popped in with direct questions in order to help her add more details to her fiction: *How does your body look like? What do you like the most about this self? Where do you live and how is this world?* Eventually, based on her descriptions, I reconstructed F's storytelling:

Oilif is a hybrid creature sharing physical properties from both a human being and a jellyfish. She possesses a boneless, semi-translucent body that glows in the dark, changing spectacular colors, when she performs different functions or if her organs malfunction. Oilif has no legs, so flowing tentacles arising from her hair and body like a natural dress, navigate her in the fluidic

space. Even though she is semi-transparent, she is not invisible. In contrast, she has a dominant presence all over the place, because of her dangerous poison. With her poison she both hurts and protects, so that she maintains the balance in the marine ecosystem. Oilif's world is made entirely out of water and has no seabed. It is a continuous, see-through space, with clear, blue waters that do not become darker the deeper you go. Instead in the deep core, you can see clearly rocky structures containing plants and other forms of organisms. This fluidic world feels safe, like being in an amniotic sac.

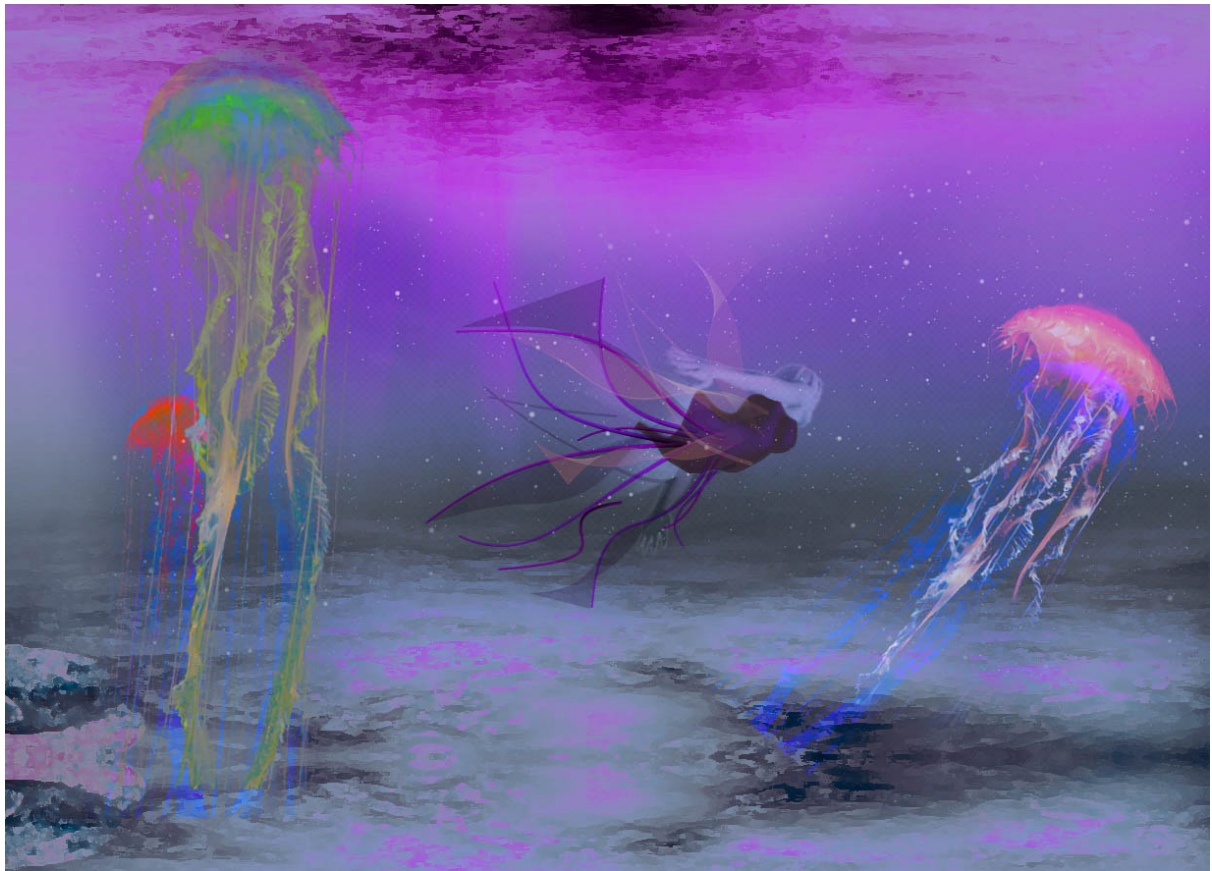


Figure 7. Oilif - F's creative aquative persona

F's alter ego was also inspired by childhood memories and described her special connection to the sea. *"My dad had a little boat and he used to take me with him for fishing. Even though, the gooey sense of aquatic creatures makes me sick, I remember this one time I felt awe instead of disgust. We had found a transparent, colorful Medusa, the most captivating jellyfish I have ever seen."* When I asked F about the special effect this creature had on her, she responded: *"Jellyfishes are distant but at the same time dominant all over the space. They are*

simultaneously beautiful and dangerous, and even though they navigate leisurely and innocently, humans are afraid to touch them”.

F used this creative persona in order to visualize herself as a powerful and seductive creature, which possesses both bright and dark sides. This creature felt the need to be admired and noticed, as well as to induce fear and awe to others around it, reclaiming the control of who can or can't enter its personal space. Oilif had a unique relation to her tentacles, the same way that F had with her hands underwater. She trusted her hands and liked to observe their movements, as they are the ones that define her locomotion. In contrast, F was afraid to depend on her legs, because her bulky and floating prosthesis has always been preventing her from performing a wide range of gestures and movements.

Finally, F described an imaginary world that is the opposite of reality: Safe, pleasant and 'transparent'. On the beach, F felt exposed, as her unusual prosthesis and physical difference were totally revealed. She also explained that in an effort to move away the unfriendly gazes from her prosthesis, F hit a colorful tattoo on her residual limb. She did that in order to articulate her physical difference in a more artistic way within the general context of body variation.

4.2.4 THE MEDUSA HYBRID: TURNING PATRIARCHIC NORMS INTO STONE

F's creative fiction was inspired by her childhood affinity for jellyfish and by the Greek mythical creature 'Medusa'. In Greek, the word Medusa names either the jellyfish or the Greek mythical hybrid, who was half woman, half animal and had the power to turn men into stone by a single gaze. As F reconstructed her aquatic alter ego based on concepts of female dominance and captivation, I decided to further investigate the symbolism behind Medusa's reference. In particular, I had the curiosity to figure out how hybridity culturally relates to femininity and women's self-expression in patriarchic societies.

A quick search in cultural and feminism articles showed that ancient myths of hybridity become contemporary platforms to reflect on 'women's power in the face of threatened male authority' (Donohue 2020). According to Schwark (2019), most people remember Medusa as

a lonely, angry and monstrous Gorgon, whose story was based on punishment and revenge. This depiction remained the main sexist product of the myth for many people. The problem with focusing on this one-dimensional aspect is that people may miss the opportunity to examine the right of a woman, who looked and thought differently to be extraordinary. Medusa became the subject of feminist and psychoanalytic studies that turned this mythical character into an avatar of female rage against the patriarchic norms, as well as into a metaphor for gender ambiguity.

My assumption was that F referred to this mythical creature, because Medusa unconsciously evoked the fascination or the feeling of being both unordinary and desirable. F expressed the social pressure that women of different appearance or abilities often face in male dominant societies, professions or even relationships. She described how her disability made her strong, enduring, intuitive in hands-on crafts, a fighter and a survivor, as well as how those qualities often terrified the men she encountered in her life.

In his article, Donohue (2020) presents women like Medusa, as persons unable to 'conform and submit to the enforced codes and structures of a patriarchal society'. Medusa was both feminine and monstrous and while she was better known for her horror, her beauty remained the same dangerous. In ancient Greece, the male-centered society used to demonize femme fatales, women, who presented a "conflicting view of femininity; one that is alluring but with a threatening or sinister underside" (Karoglou 2018 as cited in Cain 2018). The femme fatale archetype was latent in F's storytelling and confirmed her deepest desire as a female prosthetic user: to embody a human oxymoron of being good and bad, elegant and redundant, beautiful and fearsome, something that is not normative at all.

5. SPECULATING ABOUT ASSISTIVE WEARABLES

5.1 ITERATION 1

5.1.1 FROM MYTHOLOGICAL HYBRIDS TO ASSISTIVE TECHNO FASHION

The days that followed, found me distilling F's needs and fictional persona into a six-element board that summarized 1) F's imperative need to feel beautiful and captivating in a non-normative way, 2) her desire to reclaim back her power in social space, 3) the important role of dress in her self-expression and self-representation, 4) the idea of elegant and fancy wearables that become game-changers and conversation starters, 5) the vulnerability and playfulness she feels when entering an aquatic environment, and finally 6) her awe for glowing, semi-translucent and color changing elements.

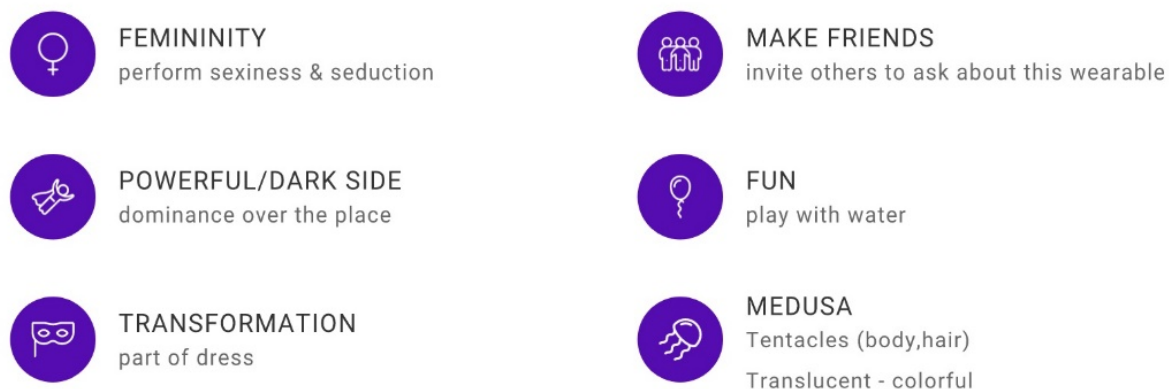


Diagram 10. Distilling F's needs and fictional persona

As travelling restrictions started to loosen up, I found an opportunity to travel back to Greece. There, I reunited with good friends of mine, all coming from the field of design and willing to hear about my ethnographic analysis. As our conversations took place at the intersection of disability, technology and female couture, we ideated about the contemporary dimensionality of female hybrids like Medusa and Mermaid, and how their powerful qualities could be captured and embodied through techno-hybridity.

The discussion inspired me to start working on concepts of assistive techno-fashion that portrayed handicapped women as modern sirens through non-representational soft robotic swimsuits and matching lower limb prosthetics.

My first design effort illustrated a whole body, robotic swimsuit with computational power and material interactivity (Figure 8). On the one hand, fibers coming out of the swimwear in the form of gradient tentacles, would be preprogrammed to bend in the three-dimensional space, when different parts of that would be inflated and deflated continuously. As a result the semi-translucent, silicone fabrics attached to them would start to deform according to the forces induced by each pair of tentacles. The two pairs of morphing fabrics at the back and around the belly would produce hydrodynamic power on-demand, whenever the user decides to activate them in water. According to the body's movement, different modes of hydrodynamic movement would be automatically activated to either help the user to twist her torso or propel in different directions. On the other hand, the translucent silicone would present fluorescent properties and as a result in deep, dark waters, the fabric would glow.

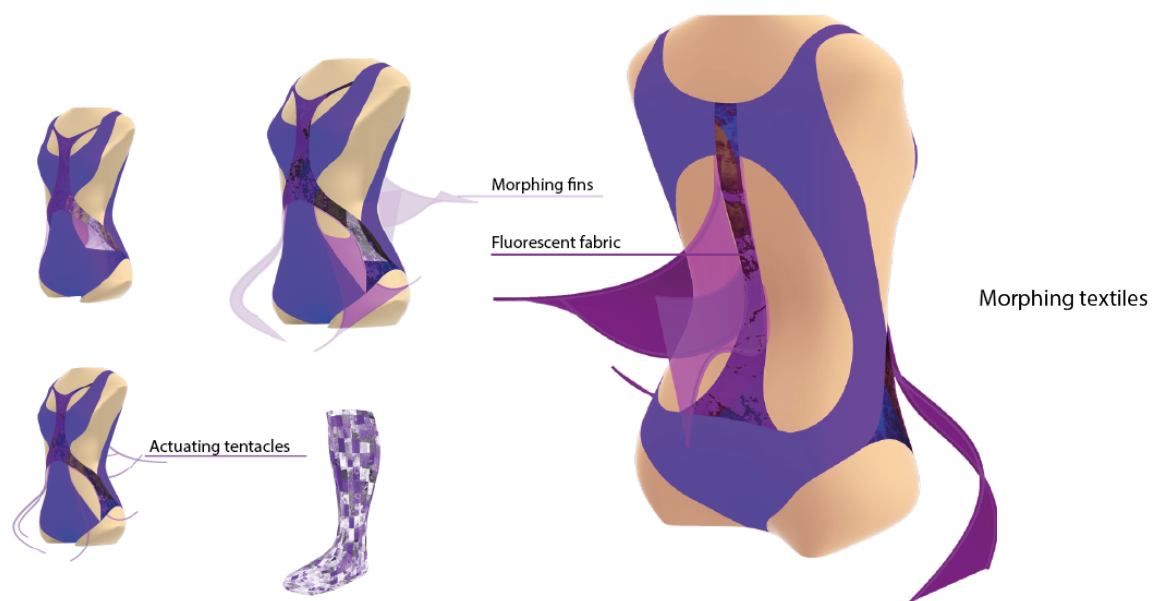


Figure 8. A cybernetic Medusa set: programmable swimsuit and prosthesis

Out of the water, the user could choose to deactivate the wearable so that the active textiles become passive. Then, they could either hang from the body or be folded manually back on the swimwear. The prosthetic limb proposed to complete this outlook would take the form of

a soft and waterproof limb socket made out of semi-translucent silicones, with matching colors to the swimwear. The color purple would create a feeling of mystery and supernatural powers, while the visual design of the swimsuit would reflect the female dominance of a modern, cybernetic Medusa.

This speculative wearable was based on the technical concept of fluidic, elastomer actuators that are made out of silicon prepolymer and fluorescent ink. The tentacle fibers would be made of those. Such actuators (Figure 9) deform under fluidic pressure due to the expansion of the pneumatic networks within them. In existing literature (Ramses et al. 2012), a method to induce 2D or 3D bending, is by embedding multiple pneumatic channels into a single body. By pressurizing the fluid entrapped in channels, stress is induced within the elastic material producing localized strain. This strain in combination with the depressurized channels induces bending in three different directions. When more than one channel is actuated, the bending directions multiply.



Figure 9. FEA prototype with three distributed air channers

My second design effort illustrated a whole-body swimsuit with embedded inflatable modules that would be pneumatically driven and temperature reactive (Figure 10). This particular design would be made out of colored polyester and translucent silicon. The actuating modules would be distributed in two clusters, fabricated upon the silicon part and offering texture in the form of geometric polygons. The user would have the option to either actuate both clusters simultaneously or in different times and speeds. In the first case, the inflated modules would help with floating by increasing body's total buoyancy. In the second case, the alternating actuated modules would induce fluctuating buoyancy into different body areas, causing the soft free form locomotion of the body's torso. Lastly, the modules would present the property to change color when exposed to different temperatures. Containing

temperature sensitive compounds, they would present different colors when dry and wet. The color transformation would follow the drying of the human skin due to the sun after the bath.

Out of the water, the user would deactivate the wearable so that the modules dry, change color and adapt visually at the swimsuit. The prosthetic limb proposed to complete this outlook would follow a similar design approach like the previous one. The design and colors of the current outlook would be less provocative and highlight the beauty of the female body. The modules were inspired by the fish's scales that participate in the underwater locomotion. Outside the water, the user would remind of an elusive Mermaid that approached the beachfront in order to rest and enjoy the sun.

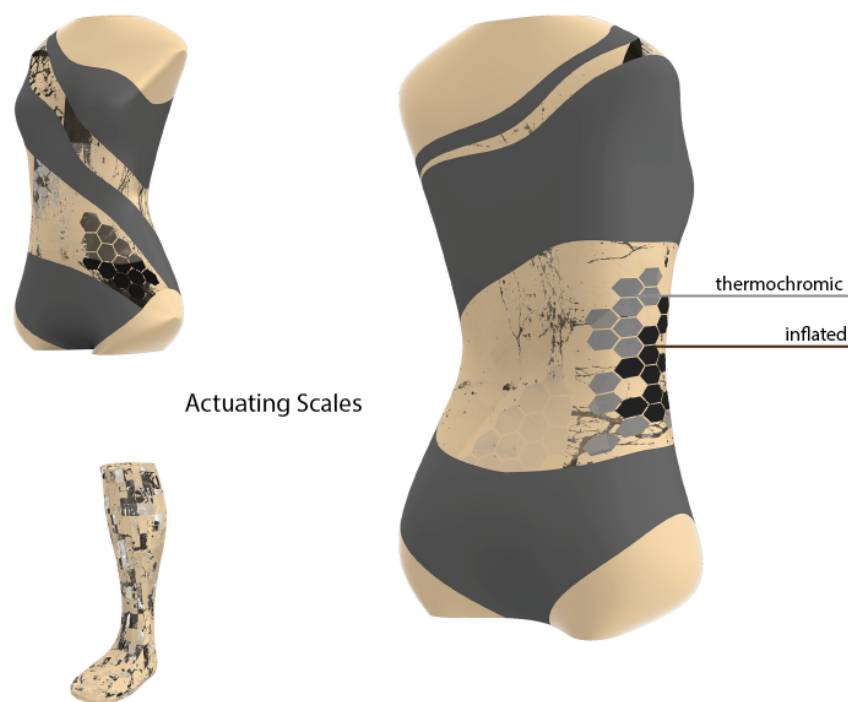


Figure 10. An elusive Mermaid set: programmable swimsuit and prosthesis

The actuated scales would also constitute fluidic elastomer actuators that are made out of silicon prepolymers and thermochromic ink. Such actuators would be assembled out of two parts of silicones that present different stiffness. Silicones with greater shore hardness have a limited range of deformation and that would make them suitable for fabricating the rigid area of the scale that can bend but not expand. In the middle of the assembly, there would be a circular pneumatic channel. When pressurized, this channel would expand in the half area that

is most compliant, meaning the one that was made out of the material with the lowest stiffness.

5.1.2 THE FIRST FRICTION

After I crafted my ideas through visual models, F and I scheduled to meet over zoom so that she gives me feedback to update my design perspective. Even though, I tried to express through my designs elements that were important to F, I soon realized that none of the designs could satisfy her needs or were compliant with her perspective of functionality, expressiveness and social affects.

F expressed the following concerns as both a prosthetic user and a designer herself. First, even though her first impressions were positive and she comprehended my intention to represent a modern, powerful woman (Figures 8 & 10) through my design concepts, she was afraid that the message behind such an endeavor would be misinterpreted by people who do not have a relative background: *“You and I are designers, so it is our job to make connections and dream of innovative things. But that doesn’t mean that others will have the same creativity or sensitivity to emphasize or identify, so that they embrace such radical outfits for disabled humans like me”*.

Second, she argued that such robotic swimsuits would make her standing out in an unfamiliar way, a feeling intimidating according to her. She explained that *“people are weird, when they see something completely new and fancy, either in the form of simple shoes or dress and especially on the beach. And this behavior of society toward something totally unfamiliar, will continue placing me in the center of attention. An attention that I will keep perceiving as negative according to the way my personality was shaped based on my past experiences”*. She discussed that society, especially the Greek one, can only handle baby steps when it comes to new social models. Based on that, she would prefer to shake the social perception about the normative body through wearable representations that either feel somehow familiar to society or augment existing references.

When I asked F to offer an example of a provocative reference that would celebrate physical difference on the beach, she responded: *"I was so tired of everybody looking at my different prosthesis, so that I decided to hit a symbolic tattoo on my residual limb"*. This way, F moved away the negative attention from her prosthesis, by turning her natural limb into an artistic canvas. The colorful tattoo illustrated a composition of two roses and the spiral of the golden number phi. The roses symbolized pure beauty, while the spiral was referring to the proportional patterns observed in nature and human body. F liked the oxymoron that this tattoo produced, as she was fighting for her right to feel beautiful, even though she was born with two non-proportional limbs.

Through this example, F made several points. First, she explained that either permanent or temporal body painting is something that others have seen before, probably already applied on their own bodies. For this reason, according to her, tattoos constitute a good reference in order to augment a disabled limb and make it look expressive. Second, F reflected on how her self-confidence and emotional mood positively changed, after she showed up on the beach with her new outlook. She stopped thinking about others focusing on her prosthesis and she started to enjoy people's gaze at her expressive limb. She felt that this curiosity was different, more light-hearted and thoughtful. Third, drawing inspiration from our previous conversations about expressive prosthetics, F popped the idea of applying body painting upon her prosthesis, unifying, this way, the seams between her natural and artificial limbs through colorful drawings.

F used the concept of 'natural intervention' to demonstrate how the second swimwear (Figure 11) looked indeed provocative, but somehow 'down to earth'. The whole conversation made me emphasize with her sayings. I realized that the actuated scales augment the already familiar concept of inflatable life jackets and this is why it may be perceived as a natural intervention by external observers.

F also emphasized that her opinion was just one woman's perspective. Looking more carefully at my designs, she credited to them the potential to be functional and ludic for other disabled users. *"Maybe for people who miss both legs or both arms and they experience serious difficulty to balance, float and move. Or for disabled children, who would perceive the shape and color morphing as super-abilities or as play starters with other children."* F said that if she had

such a playful outlook as a child, she would feel unique wearing it and she would enjoy showing it off to others. Finally, F claimed that it is easier to sculpt the society's perception about disability through children wearing such provocative technologies. On the one hand, little girls would build playful memories that would empower them through their adult life. On the other hand, non-disabled kids and their parents would become easier familiar with such wearables. And this embracing attitude might motivate older, disabled users to wear provocative, assistive tech in public.

However, neither of the proposals would augment F's body in any way that feels useful, expressive or evocative to her. She explained that she already enjoys swimming, especially diving without any assistive device. The only problems holding back this experience was her fear for dark waters and her non flexible, floating prosthesis that pulled her back to the surface of the sea. But how else would she walk into the sea if she left her prosthesis behind? Lastly, she mentioned that if an assistive device was to get disactivated outside water, and get turned into a typical swimsuit, that would neither augment her functionality or her identity as a prosthetic user on land. So the problem somehow remained.

5.2 ITERATION 2

5.2.1 FACING THE FRICTION

The second co-design iteration started with me facing this friction. After my meeting with F, I fell into a thoughtful silence for several weeks. While feeling totally blocked off, I was trying to digest the fact that my design strategy needed a big change. I felt like I had either misinterpreted F's words in all the ethnographic sessions or underestimated the complexity of F's experience as a disabled woman. In my mind, I replayed highlights of all our previous dialogues that presented certain contradictions:

- *"My prosthesis is my leg"*
- *"When others reject me, I usually blame my prosthesis"*

- *"If I had the financial recourses, of course, I would replace my cosmesis with a more expressive limb. That would be a great thing"*
- *"I don't believe a prosthesis or a dress can change the way I experience things"*
- *"After I begun to customize high boots for my prosthetic limb, my self-confidence as a woman was boosted"*
- *"Check this video with this teenage girl. She also supports that once she replaced her cosmetic arms with robotic ones, she felt empowered and better represented as a kid-cyborg".*

The above statements made me doubt the objectivity of my analysis: Did I turn a blind eye every time F shared insights that didn't align with my research aspirations? Did I somehow force F to adopt opinions that eventually didn't express her? Was I the one, who misinterpreted F's words into extravagant designs or was there a slight possibility that F has actually been experiencing contradictory emotions and sharing different perspectives? To solve this mystery, I called F to share with kindness and transparency my aforementioned concerns and the conversation that followed was the most enlightening one in the whole thesis.

F expressed in the most beautiful and original way that between the state of desiring an eye-catching prosthesis and the state of actually wearing it, there are multiple factors that keep her staying in between. First, she claimed that growing up with a dysfunctional limb is quite different than losing your limb later in life, because one's life experiences and personality have been shaped hand in hand to their relation to their limb. And indeed F is still experiencing contradictory feelings in her relation with her artificial limb. Even though she considers her prosthesis her real leg, there were multiple times in the past, when she got angry with it, either because she couldn't walk properly or due to its physical appearance.

Second, F explained that she constitutes a special case of prosthetic user, because she wasn't born with her limb fully missing or fully amputated later in life. Either of those two cases would have offered her access to a greater range of prosthetic solutions to try on various physical activities. For example, she never had the opportunity to wear athletic prosthetics that allow amputees to perform physical activities such as running. By contrast, her half, deformed limb demanded customized prosthetic boots to enclose it. In addition, the fragile nature of her little

leg didn't allow her to participate in sports or ride bicycle. *"As a kid, I was never able to try activities that I wanted and that hurt. It still hurts"*. Finally, F still recaptures the fear of social judgement and isolation that she experienced in high school. *"All those factors hold me back to dare adopting outlooks that make me differentiate from others"*.

Dealing with this friction offered me an invaluable insight about designing for prosthetic users. What it may feel assistive in terms of functional, practical, expressive or evocative to a designer or a non-prosthetic user may not be assistive at all to a prosthetic user. And this varies from disabled human to disabled human. Even though in theory, I integrated F into the design loop asking for her input, in practice, I continued perceiving things from my perspective and this was where it led me: guessing about what would be good for F without directly speculating with her.

For the second iteration, I decided to re-evaluate both my design strategy and the co-design dynamics. I drew inspiration from F's indication for innovative but natural, material interventions: *"Maria, I really liked what ExoForm does, using smart materials that reconfigure their shape, allowing the user to re-adjust the wearable to achieve better comfort or serve a particular style. Even though simple, such material transformations would have a huge impact on my daily life. I also liked the concept of a self-tanning prosthesis. Those are all interesting ideas"*. F's suggestions situated my design strategy, while motivating me to give her more space to express her thoughts during the creative process.

5.2.1 LET'S SPECULATE TOGETHER

This time, as both F and I were in Greece, we grasped the opportunity to meet in person. Together, we speculated about material concepts of transformative prosthetics that felt more natural, playful and personalized around F's physical and expressive needs. Diagram 11 illustrates our final speculative morphing behaviors, the stimuli triggering them and the needs they satisfy.

The first problems that F and I speculatively solved were purely functional. The first one was about F's non-flexible, floating prosthesis that hinders her swimming. I proposed a prosthetic

limb made out of elastomers of different shore hardness. Hard elastomer would build the main support of the boot, while soft silicon would embrace internally her natural limb like a glove. All the prepolymers would be mixed with bubble glass, so that the boot's density would increase underwater, simulating the buoyancy of the human body.

	Function	Emotion	Expression	Social identity	Stimulus
stiffness morphing	rigid on land flexible underwater	-	-	-	temperature
color morphing	-	childhood memories	mystery, supernatural	-	temperature
fluorescent glowing	fear of dark sea bottom	safety	sci-fi sense	-	brightness
translucency morphing - camouflage	camouflage her deformity through different translucent degrees	personal affinity	-	-	humidity
density morphing	decrease/increase buoyancy	-	-	-	water
body - prosthesis skin painting	-	personal symbols of empowerment	artistic exploration	body difference as artistic canvas	-

Diagram 11. Board with speculative material properties

Second, the prosthesis' hard elastomer would be temperature reactive. It would change stiffness while entering the sea (temperature drop), turning into a soft, bendable fin that would facilitate propulsion. Once F would come out of water and temperature would increase, she would lock her prosthesis on a flexion gesture, until the material would harden on this position and would support her walking on land (Figure 11).

As I aforementioned, F has a colorful tattoo on her residual limb that makes her disabled leg more expressive. She came up with the idea to turn her whole limb, both natural and prosthetic into an artistic canvas by extending a permanent body painting upon her prosthesis. F ideated a composition out of jellyfish tentacles, in colors of purple, blue and pink like the ones she recalled from the jellyfish in her childhood memories. I augmented her concept with

thermochromic properties, so that the colors of the tentacles would change while her skin would be drying under the sun after swimming (Figure 12).



Figure 11. Variable prosthesis stiffness. (right) Hard in warm/neutral environments so that the user locks the prosthesis on a comfortable gesture that allows her to walk on land. (left) flexible in cold environments so that the prosthesis turns into a flexible ‘fin’ that allows the user to better swim underwater



Figure 12. Thermochromic painting. The prosthesis patterns change colors according to temperature.

Furthermore, F proposed to add responsive, semi-transparent properties to her prosthesis. Whenever she enters water or any humid spatial medium, the prosthesis would become see-through, while in dry environments, the prosthesis would be remaining semi-transparent. When I asked her, if she was sure about that, meaning that her natural limb would be visible, let alone it would appear 'boxed' within an external limb, she replied that the body painting would camouflage it. She presented that like an artistic composition out of materials, drawings, colors and human flesh (Figure 13).



Figure 13. Variable prosthesis transparency. The prosthesis becomes more transparent when the user enters water (humid environment)

Finally, inspired by F's fictional persona and motivated by her fear of black see bottom, I enhanced the concept of translucency through fluorescent properties. If F found herself in dark waters, her prosthesis would start glowing, illuminating the surroundings and building a sense of safety (Figure 14).



Figure 14. The prosthesis glows when the user swims in dark waters.



Figure 15. Prosthesis' variable material stiffness and fluorescent properties

5.3 ITERATION 3: AR FOR PROSTHETIC USERS

The third design iteration found me in front of a big concern: So far, F and I have been looking for designs, materials and interactive features that felt useful, expressive and appealing to F. To explore them, we have been evaluating speculative prosthetics based on virtual models, gifs and storyboards. As finally F and I were on the same page, something changed: all those hypothetical questions about expressivity, aesthetics and affects felt like lacking trustfulness, as we all tend to idealize ideas or products before trying them out in real life. Especially when it comes to physical appearance and female representation, moments of frustration usually accompany the fitting process of any wearable: clothes, accessories, even prosthetics. For this reason, I started asking myself how artefacts of speculative design could be evaluated in a more experiential and embodied way.

In cases of hypothetical questions like *“How would you use this speculative prosthesis ”* or *“How would this speculative prosthesis make you feel”*, two evaluation approaches came to my mind. The first one was to understand the experience of those speculative prosthetics through a comparison with similar wearables that the user has already tried. However, as F had never worn expressive prosthetics or any kind of interactive wearables, this approach became pointless. The second and more suitable method was to immerse F in a new reality, so that she better reflects on the experiential affects of those speculative prosthetics through an augmented, kinesthetic experience.

This method draws inspiration from a recent trend that fashion, jewelry and cosmetic companies started to follow in an effort to enhance try-on experiences and retail: They begun to craft AR magical mirrors or apps for physical stores and smartphones, which allowed users to explore the embodied and emotional affects of clothes on them. Even though, the goal in cases like those, was to increase the conversion rates of the company by expanding the access of the products and by boosting consuming without requiring the associated infrastructure and staff, AR for fashion constituted an effective way to measure the users' reactions, feelings and self-perception related to particular wearables.

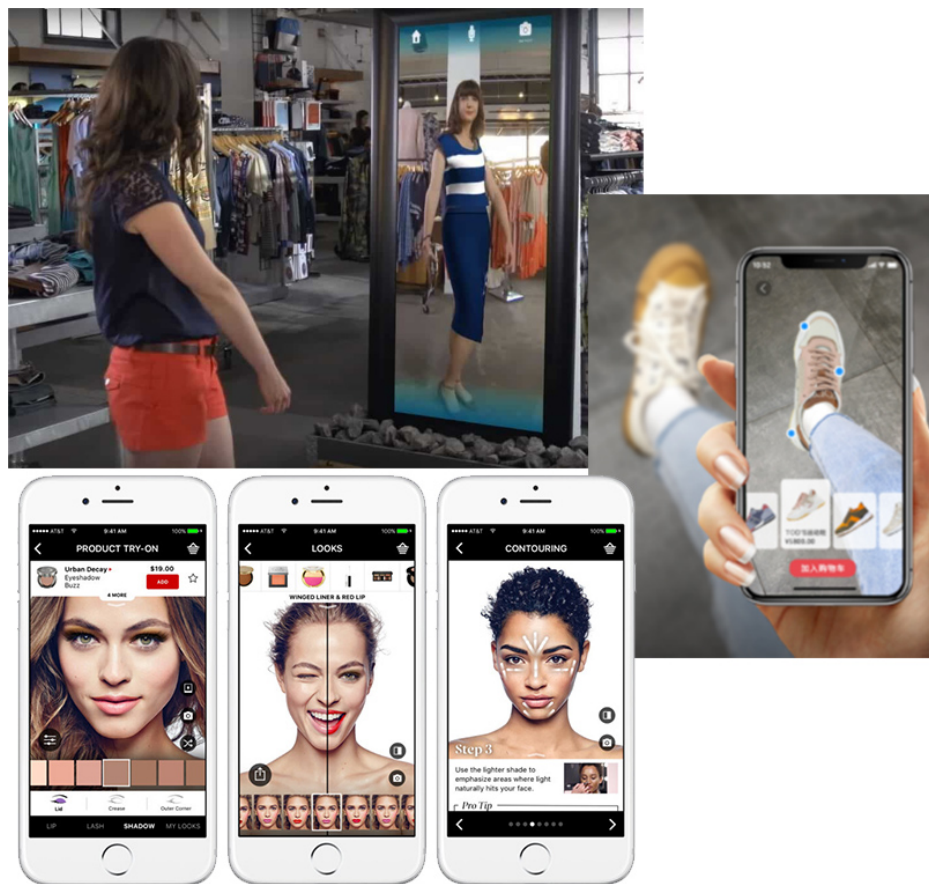


Figure 16. Different AR applications that enhance the try-on experiences for clothes, shoes and make-up
 (Top-left) AR Magical mirror, Source: <https://smartglasseshub.com/augmented-reality-clothes-fitting/>
 (Bottom-left) Sephora's virtual artist app, Source: <https://www.indigo9digital.com/blog/how-six-leading-retailers-use-augmented-reality-apps-to-disrupt-the-shopping-experience>, (Right) Body scanning and shoe fitting, Source: <https://jdcorporateblog.com/jd-com-explores-ar-foot-measurement-tool-for-online-consumers/>

As this thesis considers prosthetics as dress, as well as an integral constituent for the user's identity building, I decided to build an AR application for iPhones that would allow female

prosthetic users to map on their body speculative prosthetics, customize their visual properties and reflect on the affects of their morphing behavior.

To develop this application within the thesis' timeline, I had to make several design and technical conventions from the beginning. First, this app should constitute just a tool that helps with the evaluation of different prosthesis designs and not a tool for creating science fiction experiences. For this reason, the goal wasn't to develop a fully working prototype that measures the environment's spatial conditions (brightness, temperature, humidity etc.) and activates a corresponding morphing effect in the virtual prosthesis. It is an interface that allows users to choose different types of prosthetics, map them on the human body, customize parameters like albedo/emission colors, fluorescence's tensivity/radius, transparency or iridescence level and cause manually effects like color morphing, glowing, refraction and reflection. This way, users gain an understanding of how the prosthesis would visually transform.

Second, for simplification purposes, the tool prototypes morphing behaviors that are visual in nature and not haptic like changes in material stiffness and density. Unfortunately, on these grounds, the user doesn't experience visually how a rigid prosthesis becomes more flexible underwater or how the prosthesis' buoyancy drops underwater. Finally, when it came to the prosthesis' mapping on the human body, I decided to use as less hardware as possible. For this reason, I opted for the technical opportunities that the ARFoundation framework in Unity offers through the package of Airkitt for iOS devices. Avoiding hardware installations like Kinect, made it easier to use the app in different places and on different users for calibration and testing purposes. At the same time, it gave me the freedom to distribute the app to people living either in the US or Europe, who possess an up-to-date iPhone with a bionic microchip A12.

After defining these conventions and simplifications, I decided to work upon the open-source file 'arfoundation-samples' offered by Tim Mowrer on Github³. This particular file

³ <https://github.com/Unity-Technologies/arfoundation-samples>

gathers all the AR possibilities offered by ARFoundation in Unity. Its original UI menu contained buttons, each of which led to a different AR setting allowing the user to interact with various types of augmentations such as face tracking, image tracking, virtual objects in physical space and so on. I decided to hack and augment this original menu, by adding a button named after ‘Aquaborg’ that branched into three different AR scenes (Figure 17). Each scene contained settings for tracking the human body, applying a different prosthesis on the body, rendering the prosthesis through Universal Rendering Pipeline and allowing the user to activate a hidden UI for controlling the prosthesis’ properties through buttons, sliders and color pickers.



Figure 17. The app, the menu and the AR prosthesis scenes

The scene ‘Medusa 3D Tracking’ maps on the human body the prosthesis that F and I co-created in our last session: a prosthesis covered by jellyfish patterns out of thermochromic inks that would glow in the dark and increase its translucency underwater. By checking a little box on the upper left corner, a control menu appears that allows the operator to change the prosthesis’ color, emission and transparency level, fluorescent color and the patterns’ hue as shown in the figures 18-20.



Figure 18. Trying out different prosthesis colors

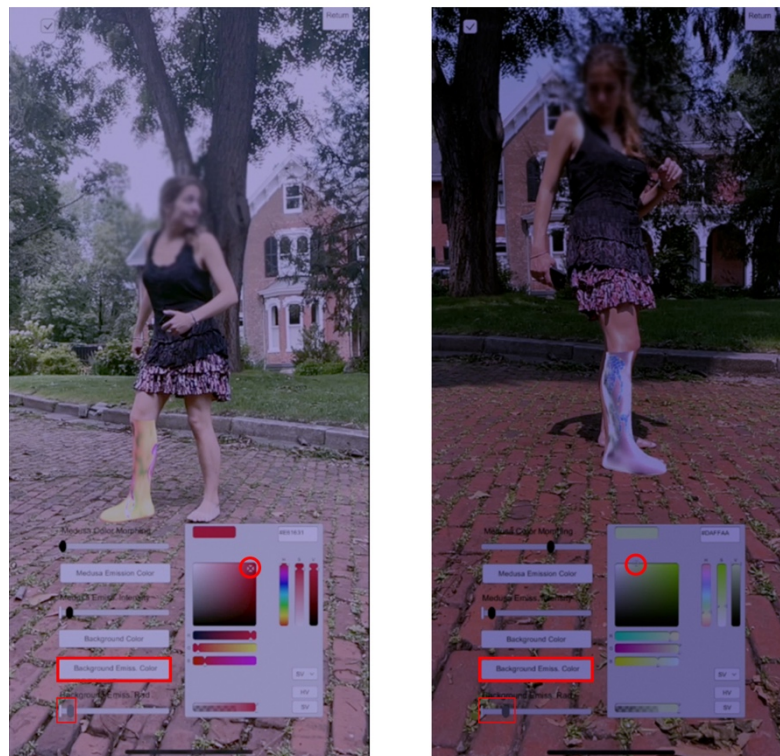


Figure 19. Changing the prosthesis' fluorescent color and transparency degree.



Figure 20. Understand how the thermochromic jellyfish patterns behave while temperature is changing

Additionally, I created the scene 'Sci-Fi 3D Tracking' to experiment with a new futuristic type of prosthesis. The scene presents the same morphing principles, as well as a similar control menu (color morphing, fluorescent and translucency properties). The only difference is the thermochromic patterns that are more abstract, reminding of science-fiction suits (Figures 21-24). Creating more scenes, I aimed at offering to F more wearable variations to explore, like she would do in a fitting room for clothes and accessories.



Figure 21. Changing the translucency of the non-colored parts of the prosthesis



Figure 22. Changing the fluorescent intensity of the non-colored parts of the prosthesis



Figure 23. Observing how the pattern colors morph according to temperature



Figure 24. Woman in purple. Choosing a color that matches the user's favorite outfit

Finally, I created a simpler scene under the name 'Emission 3D Tracking. The word 'Emission' may be a bit misleading in this case, as this particular prosthesis presents iridescent/reflective and refractive properties instead of fluorescent ones (Figure 25). Those get activated by the natural light rays and differentiate according to the angle the light rays hit the wearable. I inspired this prosthesis from F's admiration for plexiglass.



Figure 25. Iridescent prosthesis that adopts different colorations according to the body movement in space.

6. FUTURE STEPS

The development of the AR application found both F and I in different continents again. As a result, I couldn't use the app in my iPhone on F's body. Moreover, I couldn't transfer the app to F's Android phone and she couldn't find access to any up-to-date iPhone through her friends and family. Therefore, my initial plan to have F experientially evaluate the prosthetics within the thesis' timeline, failed.

The next step of this thesis is to go back to Greece, so that F and I experiment together with the application in my iPhone. She will be asked to evaluate the speculative prosthetics, as well as to reflect on her augmented body and its hybrid identity. Based on her feedback, I will redesign the app, adding new features, updating the prosthetic designs or even uploading more scenes with new designs inspired by her reflections.

Another future step is to improve the user experience of the app. So far, the app demands two people to operate it. An operator who holds the iPhone, choosing the scenes and controlling the transformations, while the prosthetic user changes poses. This way, the prosthetic users cannot control the transformations themselves and are able to see the prosthesis on their body only through screen recordings. With the help of multiple engineers, I wish to turn this app into an AR mirror for MacBook users, so that prosthetic users during the co-design period will be able to control, experience and reflect in real time on the expressivity and social affects of their new prosthetics, before ordering them.

7. CONTRIBUTIONS AND REFLECTIONS

The thesis prototypes a research methodology so that a more inclusive design strategy for prosthetics arises. Blending foundational and generative research with speculative and computational design methods, my methodology motivates technological designers and disabled users to explore together well-hidden truths about disability, as well as produce innovative concepts of assistive techno fashion that feel personalized and empowering to their users.

Even though the findings and the produced wearable scenarios are personalized to a particular disabled woman, the thesis offers interesting insights into the disabled experience from a first person perspective, as well as revealing a social need that many people, abled or disabled, experience every day: to feel and look beautiful, desired and accepted. If this design strategy would be applied in a more massive way, engaging multiple technological experts and prosthetic users, then we could explore statistically this oppressed need, as well the importance of expressivity and social affects as design factors. The findings and design results would offer us enough data to oppose pressure to health insurances to recognize aesthetics and expressiveness as a necessity for the well-being of disabled humans.

Among its contributions, the thesis offers valuable lessons for technology experts. As a designer myself, I fell into a typical trap that many technologists do: I overestimated my ideas, believing that I knew better than F what was best for her. Even though F's disability story won me over, there were moments I found it difficult to leave my technical aspirations aside and decide with her by thinking through her. I began this thesis with the initial goal to change the world of disability, but eventually this world changed me. And that was the moment I realized that this thesis was not about me anymore, but about them: disabled humans like F and my mother who experience a life long journey of frustration and ambiguity.

Finally, as the thesis started in late January 2021 and the greatest part of it was completed around May, its greatest contribution was F's empowerment during the summertime of 2021. Giving her the opportunity to share her story and her ideas, as well as to discuss with me disability theories, prosthetic trends and instances of female hybridization, were therapeutic

to her. She felt unique again, starting to reconstruct her body-image and self-esteem: *“Dear Maria, you gave me back my strength, as our conversations over the past months helped me to reclaim my self-confidence in this world. I don’t hide anymore my prosthesis, like I used to do for so many years. And I don’t care about others anymore, let them stare. I am unique!”*.

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