Wearable Interactive Textiles for astronaut constant-wear

M2.2 PROPOSAL

JULIA VAN ZILT

“ *The best way to predict the future is to create it* ”

- ALAN KAY -

Index

Vision

"Vision is the art of seeing what is invisible to others"
– Jonathan Swift

My vision is to create communicative smart textiles that are able to provoke interactive peripheral experiences, with the purpose to reduce the current visual overload and to make more use of our physiological perception capacity. A child on average is exposed to screens more than seven hours a day (Rideout, 2010). More and more studies are show that excessive exposure to screens cause brain damage and sensory overload which often leads to a hyperaroused nervous system or a lack of restorative sleep. We seem to uncover an increasing amount of evidence pointing out the negative impacts of screens in our every day lives, yet they are inevitable and unmissable in todays developed society. I envision a future where messages, functions and other everyday interactions with our environment can be perceived through the use of our physiological senses by smart interactive surfaces. This way we would potentially be able to create a world that we can seamlessly interact with and feel more connected to. Seeing the opportunity, understanding the severance of the current situation and having a passion for design I believe it is partly my ethical duty to create, stimulate and provide people with these alternative types of interfaces. Not only to provide option, but also to improve health of the overall worldly community.

Since our screen based society makes everything easy to understand and easy to interact with, people don't seem to ask for these alternative methods. Therefore I believe that this shift towards these sensory interfaces should be market pushed, in other words to provide people with something they initially do not implicitly ask for. This belief allows me to determine where and in what sort of company I would like to carry out this future vision. I would like to work in a company that works on development projects for bigger companies so that we can inspire these companies to approach things in a certain way without initially having to focus on the financial feasibility of the ideas. Working on projects with different companies allows one to have a horizontal impact on the industry, while providing in depth solutions.

In this era of technological revolution I envision the possibility for smart materials to be dynamic interfaces that are able to adjust to the required circumstances. Another word for these smart (non- screen) interfaces could be the modern analog. Using aesthetics in a way that is not only valued by users but also justified by science. The way we design in the future is to take into consideration the science behind the motivations of certain interactions as well as what biological and neurological reactions are produced by certain motions, aesthetics and interactions. I envision a future of knowledgeable designers working closely with professionals from many different disciplines to understand and interpret this knowledge to achieve efficient, effective and pleasurable designs.

My Identity

"I'm always thinking about creating. My future starts when I wake up every morning... Every day I find something creative to do with my life."
-Miles Davis

Aesthetics and Interaction

I get inspired by different aesthetic philosophical theories such as Anthony, Earl of Shaftesbury, which I believe to be one of the firsts who would link beauty with functionality and purpose, who together with, Plato, who vouched to distinguish between replication (or interpretation) and innovation, perhaps defined what we call design today. Another source of inspiration are psychological theories that tell us the reason behind the consumer's desire towards certain products. The reason why these inspire me as a designer is that it allows me to gain a deeper understanding of the science, the motivation and the interpretation of aesthetics. Having knowledge regarding art and art history, I still try to continuously deepening and broadening my art knowledge because it allows me to learn how timeless social dilemmas can be interpreted and approached, as well as recognising the traditional and innovative sense of beauty. When all these different influences come together and are materialized within my own work, it could be defined as my aesthetical identity.

Digital and traditional craftsmanship

I like to work taking into account my passion for history and the traditional yet thriving to innovate. My interest for art and design started from an early age. I always have been actively developing artistic skills as well as acquiring knowledge regarding contextual and historical theory. Due to living in different countries throughout my life I have experienced the impact of globalization of society and with it cultures. Globalization, in my eyes, has two main impacts on the creative discipline. Firstly, it allows the unification of skills and strengths that result in innovative and highly creative art, design and solutions. Secondly, the traditional craftsmanship, which to some degree is the preservation of the tangible manifestation of cultural heritage, seems to have difficulty to survive this modern age. Appreciating both sides, I see the value of reaching out and using tradition to create, as well as to develop and create new techniques and applications. The strength lies in combining both in it appropriate proportions.

Smart Materials

My fascination for textiles started within the realm of fashion. Soft, flexible surfaces that aimed to not only make someone look stylish but also to keep someone warm, cool or somewhere in between. This gave me the inspiration to work with textiles giving them through technology and different fabrication methods different functional properties. Living abroad allowed me to develop a passion for languages. Soon I realised that aesthetics can be a type of language and that clothing and more specifically textiles could be used as a means to communicate actively with its wearer, user or any other person that would see or interact with the textile. Once I realised how many textile objects or soft, flexible surfaces surrounded us in our everyday life I envisioned a world in which I could share my passion for textiles and aesthetics by making interfaces that would allow us to seamlessly interact with our surroundings through these materials.

My previous work

Textile activation and sensors

One of the places and moments where I learned most textile skills were during my bachelor internship at the company By-wire.net. My main activities consisted of creating or executing low-fi prototypes, among which for example a sweat sensor in a t-shirt and a top activated with servomotors. During my final bachelor project I developed a product service system which aimed to motivate people to achieve their goal. People were stimulated to achieve their goals with a garment with a pattern which would become more and more visible as one would get closer to one's goal. For this project I made a prototype that used LEDs in a sweater letting the pattern slowly appear.

Figure 1. Sleeve activated by servomotors, Eindhoven 2018.

Figure 2. Digital Craftsmanship collection for Textile Academy, Eindhoven 2018.

Digital craftsmanship

During the previously mentioned internship, I was introduced to different digital fabrication methods, such as laser cutting. Later on, I attended the Textile Academy at the Waag Society in Amsterdam, where for three months each week we were introduced to new digital or chemical textile manipulation methods. During the last three months of the course, I developed a mini clothing collection using laser cutting and sublimation printing, in combination with software such as rhino and illustrator.

Textile activation and sensors

The project that I did for Mercedes-Benz is a bridging project. I incorporated the previously mentioned projects into creating an interactive leather.

Problem statement:

Based on internal research of the company, there has been determined an opportunity for new types of intuitive and non-invasive interfaces. Parallel to the latter, the development of consumers becoming more awareness and conscious values and feelings of responsibility towards environmental issues, cause an increase in demand for sustainable and animal cruelty-fee products. These two aspects together allowed me to define my project, which aims to create a leather alternative which at the same time would be interactive.

My project was eventually divided into the creation of two different samples:

The 3D printed leather alternative. This sample was created using different software, such as grasshopper, to recreate the leather texture, together with a special coating to add a leather feel post printing.
The interactive sample. This sample is a soft 3D printed sample which is laminated with conductive textiles and a thin layer of foam. One can press on the upper layer, the 3d printed sample and then light will be activated.

Figure 3. Elephantasia, a shape changing wearable collection made during my internship at by-wire.net. Utrecht 2017. retreived from by-wire.net.

Introduction

The purpose of this final master project is to create an interactive textile with embedded actuators and sensors for future interiors in the automotive industry enhancing the mobility experience. This will be a new type of textile made though traditional and digital fabrication methods. The aim is to provide a future alternative to digital based interfaces to stimulate people's wellbeing and the overall experience in future mobility vehicles.

Within this final master project I will mainly focus on the expertise areas Creativity and Aesthetics and Technology and realization. Needless to say is the other expertises will also be part of the project but to a lesser extend.

I chose the Research, Design and Development track to be able to be a specialized designer within a company that would develop products for other bigger companies to achieve a horizontal impact across different industries. Even though there won't initially be any other companies involves, I will be able to realize my project in an environment that has such business nature. Another important criteria for me to realize my final master project was that the physicality of prototypes would be valued. Since Handmade works to provide digital as well as physical prototypes, I believe that they share a similar value and appreciation towards the tangibility of design concepts.

During my final master project, FMP, I will work together with the company Handmade. Handmade is a product invention lab who work closely together with big corporations to invent, develop and prove new concepts. Handmade is starting their own Research and Development project, which I will collaborate on. My FMP will be part of their project. The scope of the project is to design an interactive textile for future mobility interiors. Together we will determine the exact user case for the final master project during the first two weeks of our collaboration. An example of a user case for this interactive textile within the future mobility concept could be an interactive control panel part in the door panel as an armrest. This textile will be fabricated in such a way that it will have sensors and actuated things integrated within. The fabrication methods will be based on traditional types of craftsmanship such as leather finishing techniques or weaving, as well as new digital fabrication methods such as 3D printing. An additional science or technique that I will use to create this interactive textile is using and manipulating the material's chemical properties to design certain material behaviours and feedback behavior.

The context of the project has been proposed by the company itself and is given as follows:

Moonwalkers

The goal is to develop a Moonwalker. Moonwalkers are long stay undergarments (also known as constant-wear) that function as a companion for astronauts - they sense and recognize human emotion, offer guidance to reduce stress levels and other negative feelings, while actively helping to increase focus and improve overall well-being.

Theoretical background

As defined by the paper Phase change materials for smart textiles, an interpretation of smart textiles is when the material shows a “clearly defined reaction as a result of a clearly defined stimulus” (Spillman, Sirkis, & Gardiner, 1996). Within my project and the field of design and electronics, we refer to the reaction as the actuator and the stimulus the sensor. Since the definition of interactive also refers to the combination of sensing and activation, “smart-” and “interactive-” will both be used in the context of textiles. A differentiation can be made between different smart textiles depending of their level of intelligence. The smart textile made for this project can be placed into the sub category called active smart textiles, which refers to the reactive capability of the material to the stimuli of an integrated sensor (Stoppa & Chiolerio, 2014).

Anything that is made from fibrous materials can be defined as textiles. This includes fabrics and any material that is constructed though knitting, braiding or other fabrication methods (Castano & Flatau, 2014). To be able to understand and construct a new type of textile it is relevant to know previous works as well as the construction of one of the most common type of textiles, fabrics. “Fabrics are hierarchically structured fibrous materials” methods (Castano & Flatau, 2014). Meaning that there are different levels of integration of these fibers. Fibers are interlaced to form thread, which are twisted to form yarn. Yarn turns into fabric when using different techniques depending on whether we are creating a woven or a non-woven. Woven materials make use of techniques such as braiding and weaving methods (Castano & Flatau, 2014), while non-woven material use techniques such as adhesive bonding, thermal bonding or the compression of yarns (Dubrovski & Cebasek, 2005). Finally when combining different fabrics we get composites. Another factor that influences the characteristics of a fabric, such as water absorption or flexibility, is the nature of the fiber used to construct it (Gioello, 2002). Which fibers we will be using in this project will be dependent on the qualities that we want to assign to it and the technologies that it has to be compatible with, which will be determined in the first stage of the project.

The making of smart wearable textiles has been in constant development since approximately 1997, starting with the exploration of a touch pad sewn onto clothing (Rekimoto, 2001) (Saponas, Harrison, & Benko, 2011). In this initial era, these electronic textiles, or e-textiles, were made out of composite materials, combining regular textiles with conventional electronics adapted to maintain the flexibility of fabrics (Buechley & Eisenberg, 2007). From this, the industry looked at creating electronic circuits on textiles to be able to add more sensors and to carry data across the textiles. An example of this is e-broidery, which uses conductive threat to embroider the circuit onto textile to then add components onto the circuit (Post, Orth, Russo, & Gershenfeld, 2000). More recently, they started to look at ways which would allow the technology to be more integrated within the textiles, using for example; conductive yarns (Langenhove, 2011), thermochromic ink, Shape memory alloys (Castano & Flatau, 2014) and coatings (Thilagavathi & Nataranjan, 2014). An example of a project which integrated conductive yarns into the fabrication of textiles to create a two dimensional grid, allowing them to track touch and different gestures, is Jacquard (Poupyrev, et al., 2016). In this case, as in many others, the main method of feedback to the users is screen based. On the other hand, wearable textile activation has been limited.

Even though the exploration of textile sensors is quite extense, in which way they will communicate effectively with the wearer is limited (actuators). An important aspect of the FMP project is giving feedback to the wearer regarding their different physiological states. Therefore, I will partly focus on how to communicate this through textile activation, aesthetically and haptically.

An interesting concept used within the field of interaction design, which at the same time aligns with my vision, is using aesthetics as a means for communication in terms of interaction (Ross & Wensveen, 2010). Rather than seeing aesthetics and interaction as two different fields, we should look at it as two co-dependent aspects of design (Petersen, Iversen, Krogh, & Ludvigsen, 2004). Aesthetics is an initiation tool, to attract the user to interact with the material in a specific way, as well as a way to provide feedback to the user. In our current world, we are overloaded with screens, which at the same time means we are overloading our visual sense. Within the field of interaction design there is an increasing interest towards the usage of haptics to communicate with the users. An example in which they study how to communicate information to users through vibrotactile messages is Tacon (Brown, Brewster, & Purchase, 2006), which studies the recognition rates of those messages. Similarly, The Inflatable Mouse communicates through increasing and decreasing its volume (Kim, Kim, Lee, Nam, & Lee, 2008). In the case of wearable smart textiles we these the most developments in the sports and medical sector, an example is the research of Luster et al., which found that vibrotactile cues can provide positive reinforcement when performance goals are met during training practice in chronic stroke (Luster, et al., 2013). Further cases can be found in the next section.

What I see is that most research either focuses on the technical construction of interactive textiles or on the visual and activated side of these textiles. My project will give a view on the co-dependency between three aspects: interaction, technique (fabrication, sensors and actuators), and aesthetics (including haptics).

Market Analysis

Below you can find some products with smart textiles.

Figure 4.OMsignal Smart Compression Shirt in 2014. Reprinted from TechCrunch.

OMsignal Smart Compression Shirt

This is a compression shirt, which uses conductive yarn and silver based thread embedded within the textile. Its goal is to improve blood circulation to increase performance levels. Furthermore, it is able to track heart rate, calories burned, reserve energy levels, breathing rate, steps and Zen Index ("OMsignal Biometric Smartshirt Technology", 2016) through a small module, which is clipped onto the shirt and can communicate with its corresponding app through Bluetooth.

Figure 5. Under Armour bioceramic technology in 2018. Reprinted from Business Insider.

Under Armour Athlete Recovery Sleepwear

Making use of the humans natural need to sleep, the sportswear brand made high-tech athlete recovery sleep wear. This garment use bio ceramic technology "that can absorb infrared wavelengths emitted by the body and reflect back far infrared wavelengths helping the body to recover faster and sleep better" (Ismael, 2018).

Figure 6. Jacquard in 2020. Reprinted from Levi.

Jacquard

Jaquard is a Levi's truckers' jacket that allows you to manage certain phone functions, such as answering calls, playing music and taking photos, by swiping or tapping your left sleeve. Conductive yarn is woven into the denim and an additional wireless device must be inserted in the sleeve to communicate with one's phone ("Jacquard by Google - Levis®")

Figure 7. Manus VR in 2020. Reprinted from Manus VR.

Manus VR

Manus VR are gloves that allow you to use your hands in the virtual world, as you would do in the real world using visual and haptic feedback. This feedback is provided in the form of vibration. For finger tracking, they use 11 sensors in each glove including a gyroscope, accelerometer, and a magnetometer ("Features & Specs").

Figure 8.3D printed hair in 2016. Reprinted from DesignAward.

Cilia 3D printed hair

Jifei Ou developed together with MIT a printable fine hair structure. This structure is completely programmable using their own software and machine. They created this technique and are now exploring the material's capabilities and possibilities (Ou, et al., 2016). In contrary to my project where I will start do design from what material properties and behavior it should have and then determining how it would be best to fabricate this.

Bacause of the comercialization of space travel there are different parties working on new type of space suits.

Figure 9. Astronaut suit in 2019. Reprinted from Virgin Galactic.

Vrigin Galactic and Under Armour

This space suit is designed for Virgin's private astronauts on the commercial space flights. The pieces are mainly designed for comfort and use the common "off the shelf" Under Armour technologies ("These are the Under Armour-designed suits for Virgin ...").

Figure 10. Astronaut suit in 2016. Reprinted from Dezeem.

Virgin Galactic and Y-3 (Adidas and Yohji Yamamoto)

This is a prototype that they are currently testing and is meant for commercial space flights. There are no technical specifics unveiled other than that it's made out of Nomex Meta Aramid, which is a synthetic material that is heat and flame resistant. It is designed for comfort when sitting and movements in the sitting position (Bain, 2016).

My FMP project will mainly be different from the previously mentioned projects in the sense that these have mainly focused on integrating sensor technology offering feedback to the user through an app. The strength of my project will be the interconnection between the sensing capabilities of the material together with the actuation of the material. Besides, most products make use of conductive threats to create the textile sensors, my aim is not to recreate a regular textile instead I will be creating a new textile construction that has the sensing and actuation qualities integrated within it.

The Project

PROJECT DESCRIPTION

The theme of the project is proposed by the company, as well as certain program goals, which are subject to change. The overall project has different aspects as can be seen in Figure 11. Since different experts will carry out the entire project, I will have a specific focus in which I will operate. I will focus on creating an interactive (wearable) textile that can be activated on demand by the wearer.

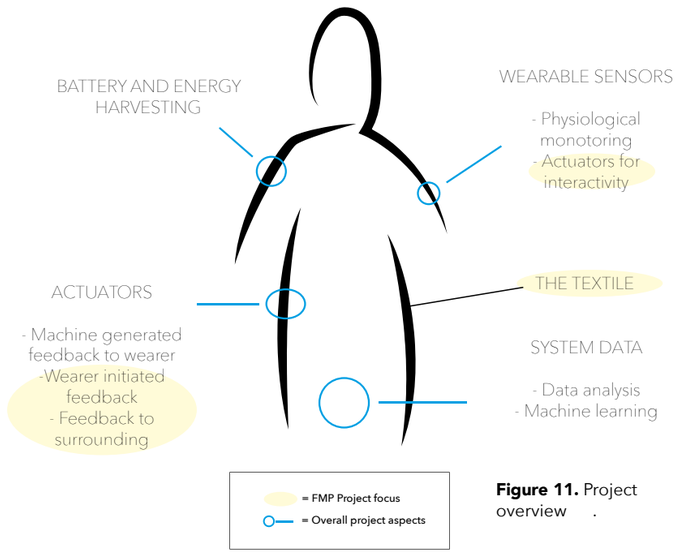

Figure 11. Project overview .

As can be seen in Figure 12, I will aim to combine the three different aspects into one textile.

The project can therefore be divided into three sections:

1. ***Sensors for feedback activation (Fabrication)***

   - How can we rethink or redesign a textile to make it all in one
   - How can we create something technically reliable (needs to survive extreme space conditions)

2. ***Feedback (Aesthetics)***

   - What should the feedback look/feel like to the wearer
   - What should the feedback look/feel like to the companion

3. ***Interaction***

   - In which way can the user interact with the suit (due to the context)
   - What ways of interaction is triggered by the aesthetics and haptics of the material

DESIGN SPACE AND CONTEXT

- ***Opportunities for the development of interactive textiles***

Moving away from an era in which we wanted to show off technology, we now move towards more seamlessly integrated technology (Wong, 2019). With technology becoming smaller and more flexible there is an opportunity for it to be bring technological functions even closer to use, to incorporate them into our garments. While it is being explored within the context of everyday life, it shows that there are success within the medical (Langenhove, 2011) and the sports field as can be seen from the new developments of sportswear companies, for it can monitor physiological functions. Since the main challenge is to design, the way users can interact with this smart constant-wear suit.

- ***Context of space (suits)***

For this project, the opportunity lays in that they are developing mostly outerwear, while little innovation can be seen on the aspect of constant wear. Which is an essential part for non-commercial space travel due to its long duration and safety. Even though I did work with wearables, and digitally fabricated garments before, I never did it in the context of space suit design. My current knowledge regarding the specific requirement of such garments is limited. Therefore, I must acquire this information during the collaboration of this project as well as individual research.

- ***Current fabrication methods of interactive textiles (mention skin factors)***

As discussed in the theoretical background, current fabrication methods of interactive textiles are extensively researched in the sensor aspect. The challenge of this project is going to be to integrate the sensors with the actuators into the same textile. The approach that this project will follow is to construct a new interactive textile from the first level of integration, not by modifying or building upon existing textiles.

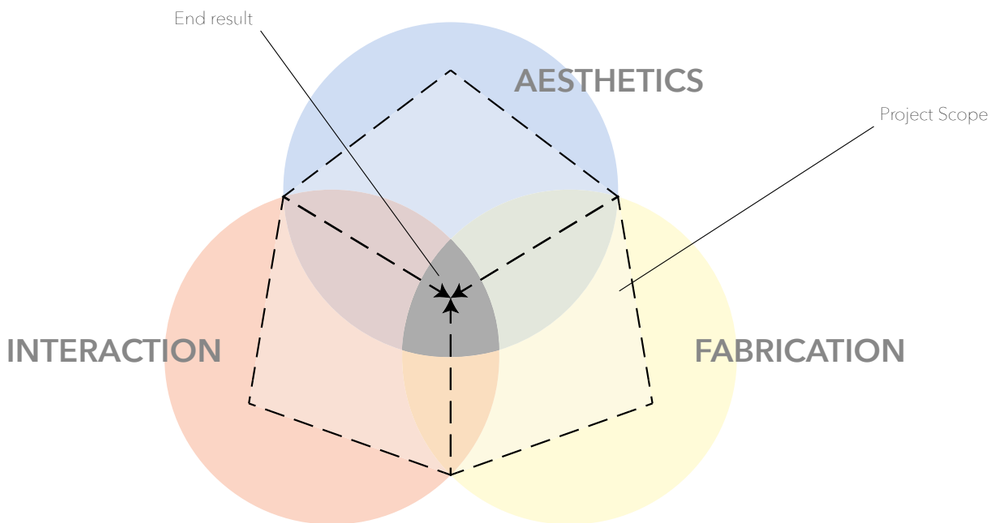

Figure 12. Project Aspects and Scope.

Goals

GOALS

For my FMP I have formulated three main goals that are based on the time and feasibility of the project.

Firstly, I would like to gain a deeper understanding of how materials can communicate to people through their different properties (sound, vision, tactility, smell). For sake of the quality of the project and feasibility due to time constraints, I will initially focus on vision and tactility. This should then show in the result of my FMP.

Secondly, I am aiming for a high degree of technological integration within the material that will be produced during this project. Using my current knowledge in combination with the expertise of those at Handmade I plan to create a new type of textiles that has technology seamlessly integrated within it. A measure of success would be the quality of the eventual material and the technological reliability.

Lastly, I would like to offer a high quality interactive textile that has both sensors and actuators integrated within it. Not merely the quality is relevant but also the usability to eventually demonstrate the co-dependency of aesthetics, interaction and fabrication. Due to time constraints, I aim to test the samples and prototype in-house but with vision on near future user testing with a more extensive and concrete test group.

PEOPLE INVOLVED

- Handmade Amsterdam
- Neurologists
- Potentially some chemists (for coating)
- Coach: Miguel Bruns

DELIVERABLES

Samples

To showcase and text the capabilities of the material faster and a more efficient production process.

Firstly, multiple samples will be produced throughout the project. They are an exploration of new interactive textiles. To be able to demonstrate intentions and functionalities throughout the project they will be made in one size to minimize the bias regarding shape, size and colour. All samples will be squares of 20x20 cm, in case this requirement cannot be met due to technical of fabrication constraints they will be realized in 10x10 cm. The colour of all samples will be white and alternatively black, to not only avoid bias but also because the human eye sees sharper defined edges and detail in white (or absence of white in the case of black.

Prototype (samples integrated in a bigger context)

A wearable (suit) that has some of the eventual functions integrated.

The final material placed and demonstrated within the user context.. I will be a prototype not a market-ready product, meaning that in some parts of the suit the eventual functions will not be fully integrated. This suit will show the seamless integration of this new textile within the context of constant wear for astronauts.

Expertise Areas

The relationship between the project and the different expertise areas

Embedded Technology

Main competency: Technology and realisation

Making a smart material, with digital fabrication techniques, in which the adequate technology is seamlessly integrated. Meaning that when using electronic circuits and components they should be designed as part of the material.

Touch and Feel

Main competency: Creativity and Aesthetics

Taking into account the science behind the perception of aesthetics to the human brain with the purpose to design the look as well as the touch (Haptics) of the material to engineer the human - technology interaction. Science will be used as well, potentially chemistry, to explore the possibilities of certain finishes and manipulations of the (3D printed) fabricated material. Lastly I will be incorporating traditional materials' look and feel as an inspiration for the design of the eventual material.

Activated Textile

Main competency: The combination of Technology & realisation and Creativity & Aesthetics

To create a dynamic material, mechanical structures or electronics should be embedded. In this way users can interact and get feedback through touching, feeling and seeing the material. The aesthetics, haptics and mechanical movements could all be factors supporting this interaction individually.

Conscious Design

Main competency: User and Society

Using scientific information regarding perception and cognitive behavior I will design purposefully for certain behaviours by at the same time being aware of the impact on the user. This topic could potentially also raise more interest regarding the alternatives to screen based interfaces introducing by promoting awareness regarding its negative impact w

Algorithmic Design

Main competency: Math, Data and computing.

By using tools such as Grasshopper I will make certain aesthetics parametric. Allowing not only to make small adjustments easily but one could potentially also predict how certain deformations due to pressure or stretch will look and take place.

Collaborations

Main competency: Business and Entrepreneurship

I will be managing this project as part of the overall research and development track of Handmade. Within this project it is extremely relevant to communicate with the company to reach a common goal. In this case for me a satisfactory final master project and for them a useful addition to their research and development topic.

Planning

Defining user case
1,5 weeks

Sample Making
3 weeks

Expert sessions
1 week

Placing the interactive textile in context
1,5 weeks

Defining Interaction and location of interface
1,5 weeks

User test/interview
2 weeks

Refining final behviour aesthetics/ habits
2 weeks

Preparation for final deliverable
3 weeks

In depth research
3 weeks

chose best fitted interface for the interaction scenario
1,5 weeks

making the material
2 weeks

References

3D Printed hair. (n.d.). photograph.

Bain, M. (2016, January 15). Photos: A high-fashion collaboration between Y-3 and Virgin to outfit space tourists. Retrieved from https://qz.com/595668/photos-a-high-fashion-collaboration-between-y-3-and-virgin-to-outfit-space-tourists/

Brown, L. M., Brewster, S. A., & Purchase, H. C. (2006). Multidimensional tactons for non-visual information presentation in mobile devices. Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 06, 231–238. doi: 10.1145/1152215.1152265

Buechley, L., & Eisenberg, M. (2007). Fabric PCBs, electronic sequins, and socket buttons: techniques for e-textile craft. Personal and Ubiquitous Computing, 13(2), 133–150. doi: 10.1007/s00779-007-0181-0

Castano, L. M., & Flatau, A. B. (2014). Smart fabric sensors and e-textile technologies: a review. Smart Materials and Structures, 23(5), 053001. doi: 10.1088/0964-1726/23/5/053001

Dubrovski, Polona & Čebašek, P.F.. (2005). Analysis of the mechanical properties of woven and nonwoven fabrics as an integral part of compound fabrics. Fibres and Textiles in Eastern Europe. 13. 50-53.

E-fashion. (n.d.). photograph. Retrieved from http://www.by-wire.net/depending-bywiren-et/

Features & Specs. (n.d.). Retrieved from https://manus-vr.com/features/

Gioello, D. A. (2002). Understanding fabrics: from fiber to finished cloth. New York: Fairchild Publications.

Ismael, A. (2018, January 22). I tried the clothes Tom Brady uses to help him sleep better and recover faster after games - and they work surprisingly well. Retrieved from https://www.businessinsider.com/under-armour-tom-brady-athlete-recovery-sleepwear-2017-10?r=DE&IR=T

Jacquard by Google - Levis®. (n.d.). Retrieved from https://atap.google.com/jacquard/collaborations/levi-trucker/

Kim, S., Kim, H., Lee, B., Nam, T.-J., & Lee, W. (2008). Inflatable mouse. Proceeding of the Twenty-Sixth Annual CHI Conference on Human Factors in Computing Systems - CHI 08, 211–214. doi: 10.1145/1357054.1357090

Langenhove, L. van. (2011). Smart textiles for medicine and healthcare: materials, systems and applications. Milton Keynes, UK: Lightning Source UK Ltd. doi: 10.1533/9781845692933

Luster, E., Mcdaniel, T., Fakhri, B., Davis, J., Goldberg, M., Bala, S., & Panchanathan, S. (2013). Vibrotactile Cueing using Wearable Computers for Overcoming Learned Non-Use in Chronic Stroke. Proceedings of the ICTs for Improving Patients Rehabilitation Research Techniques, 373–381. doi: 10.4108/icst.pervasivehealth.2013.252351

OMsignal Biometric Smartshirt Technology. (2016, December 30). Retrieved from https://urbanwearables.technology/omsignal-biometric-smartshirt-technology/

Ou, J., Dublon, G., Cheng, C.-Y., Heibeck, F., Willis, K., & Ishii, H. (2016). Cilllia. Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI 16. doi: 10.1145/2858036.2858257

Petersen, M. G., Iversen, O. S., Krogh, P. G., & Ludvigsen, M. (2004). Aesthetic interaction. Proceedings of the 2004 Conference on Designing Interactive Systems Processes, Practices, Methods, and Techniques - DIS 04. doi: 10.1145/1013115.1013153

Post, E. R., Orth, M., Russo, P. R., & Gershenfeld, N. (2000). E-broidery: Design and fabrication of textile-based computing. IBM Systems Journal, 39(3.4), 840–860. doi: 10.1147/sj.393.0840

Poupyrev, I., Gong, N.-W., Fukuhara, S., Karagozler, M. E., Schwesig, C., & Robinson, K. E. (2016). Project Jacquard. Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI 16, 4216–4227. doi: 10.1145/2858036.2858176

Rekimoto, J. (2001). GestureWrist and GesturePad: unobtr usive wearable interaction devices. Proceedings Fifth International Symposium on Wearable Computers, 21–27. doi: 10.1109/iswc.2001.962092

Rideout, V., Foehr, U., & Roberts, D. (2010). Generation M2: Media in the lives of 8 to 18-year-olds. Kaiser Family Foundation Study. http://www.kff.org/entmedia/8010.cfm

Ross, P. R., and Wensveen, S. A. G. (2010). Designing aesthetics of behavior in interaction: Using aesthetic experience as a mechanism for design. International Journal of Design, 4(2), 3-13.

Saponas, T. S., Harrison, C., & Benko, H. (2011). PocketTouch. Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology - UIST 11, 303–308. doi: 10.1145/2047196.2047235

Spillman, W. B., Sirkis, J. S., & Gardiner, P. T. (1996). Smart materials and structures: what are they? Smart Materials and Structures, 5(3), 247–254. doi: 10.1088/0964-1726/5/3/002

Stoppa, M., & Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. Sensors, 14(7), 11957–11992. doi: 10.3390/s140711957

These are the Under Armour-designed suits for Virgin ... (n.d.). Retrieved from https://techcrunch.com/2019/10/16/these-are-the-under-armour-designed-suits-for-virgin-galactics-space-tourists/

Thilagavathi, G., & Natarajan, M. (2014). Design and development of textile electrodes for EEG measurement using copper plated polyester fabrics. Journal of Textile and Apparel, Technology and Management, 8(4), 1–8.

Virgin Galactic and Y-3 Astronaut suit. (n.d.). photograph. Retrieved from https://www.dezeen.com/2016/01/14/y-3-adidas-space-suits-virgin-galactic-worlds-first-commercial-space-flights-video-movie/

Wong, W. K. (2019). Artificial Intelligence on Fashion and Textile Proceedings of The Artificial Intelligence on Fashion and Textile (Aift) Conference 2018, Hong Kong, July 3-6, 2018. Cham: Springer. doi: 10.1007/978-3-319-99695-0