THE POSSIBLE APPLICATIONS OF SELF-HEALING FIBRES IN THE APPAREL INDUSTRY
A Sustainable Strategy to Reduce the Production of Clothing?

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1. INTRODUCTION

1.1 Rationale

According to the Cambridge Dictionary, sustainability is defined as; “The idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment” (Anonymous, 2016). Although, the meaning of the term sustainability is more detailed than this explanation. Sustainability strives in society to create innovative solutions for the damaged and seriously affected environment caused by ignorance in the past. Currently, the awareness of these conditions have a great influence on everyday lives, which results in the need for sustainable innovations. The needs of the future generations have a significant influence on these developments, as they should not result in compromising the quality of life for generations either now or in the future.

Sustainable development is based on three pillars, which were defined by the World Summit on Social Development in 2005 (Adams, 2006).

Firstly the economic development pillar. This pillar focuses on taking control over consumerism without compromising on the quality of life or on compromising on the needs of the consumer.

Secondly the social development pillar. This pillar focuses on the quality of life by protecting the health of people from harmful activities.

The third and last pillar is environmental protection. This pillar is probably the biggest drive for innovation, as it focuses on understanding the nature that is surrounding us at present and for our future generations.

Unfortunately, the apparel industry contributes to the pollution of the environment and over the past decade its impact has only increased. Since the beginning of the fast-fashion trend in 2004, clothing consumption has increased, caused by the shortened trend cycle (Snoeren, 2005). Nowadays, consumers are more likely to buy ‘throw-away-clothes’, that due to poor quality have a short lifecycle. Since production rates have increased, the annual carbon, water and waste footprints has reached a significant level. Research by a UK government funded program named WRAP Organization, shows that in the UK in 2013, the global footprint per household was 1.5 tonnes of CO₂e emissions, more than 200,000 liters of water and 70 kg of waste (Cooper et al., 2013). This research suggests that extending the life of garments by even a few months could have a major impact on the volume of resources consumed and the waste generated. The relationship between the amount of garments being produced and the pollution depends on the user durability. The longer clothes are used, meaning that there is not the need for replacement, the smaller the production volume and therefore less harm caused by the production. It is assumed that by extending the life of a garment, the production of a substitute garment, would be delayed.

How to extend the user durability of clothing? Previous research has indicated that the user durability of clothing is closely related to the quality of the garment (Jang et al, 2012). Using a different material might not be sufficient to upgrade the quality of a garment, but it could prevent the garment from wearing out as quickly as before. A sustainable strategy should focus on an innovative solution, for when a garment is already in the process of abrasion, instead of preventing
the damage. For innovative solutions one may search for processes and solutions which already exist and mold them in a new way. For example, research executed by Delft University of Technology Faculty Aerospace Engineering, approached the healing of a wound in a scientific way - to use it as an inspiration for self-healing materials. According to Zwaag, “If one’s skin is cut, blood will temporarily be able to leave the veins and to flow into the cut. Once in direct contact with air, the blood will rapidly cross-link and the liquid blood becomes a flexible (non-flowing) gel which over a number of successive chemical reactions turns into new skin” (2015). The self-healing process is a possible solution in order to extend the user durability of clothing if it is applied at the core of a garment, the fibres.

To which articles of apparel would self-healing garments be beneficial? Consumers must be willing to preserve their garments for a longer period of time, then they do now. In a trend focused era, ‘throw-away garments’ are produced in a loop providing new collections every week. It may not be easy to convince consumers to pay more for fewer items of not trend related clothing. Research by WRAP Organization, a UK government funded program, reveals that even though the fast-fashion industry produces relatively cheap clothing, consumer spending on fashion has not decreased (Cooper et al., 2013). Fast fashion garments are easily thrown away due to wear and tear, resulting in buying more frequently, for example; caused by cheap fabrics. Eventually, the turnover speed of fast-fashion is higher, compared with qualitative products. In the end, consumer spending—on fast fashion is the same as spending on quality products which can be used for a longer period of time. In comparison, fast fashion garments are disposed of after a short use period. Is the consumer willing to give up the trends and replace them for high-qualitative garments? Or are self-healing fibres more applicable in an apparel sector which is already focusing on durable garments?

Eventually clothing production should be decreased enormously to protect the environment without compromising the needs of the consumer. By inserting self-healing fibres into garments the user durability will be extended, which may lead to lower levels of clothing production.

The possible applications of self-healing fibres in the apparel industry - a sustainable strategy to reduce the production of clothing?

1.2 Aim

The aim of this research is to define how to make self-healing fibres relevant for the apparel industry. This implies research on the application of self-healing fibres into garments and into which apparel sector self-healing technology would be beneficial. Eventually, the research will be used for an article for the Fibre2Fashion magazine, to encourage the apparel industry to invest in self-healing technology and its research. The Fibre2Fashion magazine provides information for businesses on the latest developments in the worldwide textiles and apparel industry. It provides effective business solutions and textile based information; for instance, through informative articles. The article based on the research report will inform the readers about the various possibilities of self-healing technology in the apparel industry. Also more in depth information about the application of self-healing fibres in garments will be provided and give advice for whom self-healing fibres could be beneficial.

1.3 Questions

In order to achieve the aim several subjects need to be examined;

Firstly, the self-healing technology requires examination to define how self-healing fibres could be applicable for the apparel industry. Several proposals have been suggested and discussed, to clarify
the best option of how to implement self-healing fibres in garments. Self-made self-healing fibres will be produced under guidance of PhD researcher W. Post at the laboratory of Delft University of Technology. These fibres will be woven into small prototypes at the atelier of S. Roos.

Secondly, the need for self-healing technology in the apparel industry will be measured by comparing opinions on self-healing garments. The core values of various product groups will be studied, to determine if and how self-healing technology would be suitable.

Thirdly, the future recommendations for self-healing garments needs to be defined. These recommendations are based both on previous research and the research that is described in this report. Various applications of the self-healing technology will be discussed and various ways of self-healing technology in the apparel industry will be examined.

The four sub questions to achieve the aim are as followed;
- How are self-healing fibres produced to make them applicable for the apparel industry?
- How to incorporate self-healing fibres in garments?
- What are the possibilities of implementing self-healing garments in the apparel industry?
- What are the future recommendations for the apparel industry, concerning self-healing technology?

1.4 Methodology

- How are self-healing fibres produced to make them applicable for the apparel industry?
  Technical research: Currently, Delft University of Technology is in the process of developing self-healing fibres (Mookhoek et al, 2015). Together with PhD researcher W. Post, self-healing fibres will be produced in the laboratory at Delft University of Technology. The self-healing fibres should be as optimized as possible, allowing the fibres to be applicable for the apparel industry. Besides results from the laboratory, other possible technical solutions of self-healing technology will be discussed for further research.

- How to incorporate self-healing fibres into garments?
  Technical research: To find out how to implement self-healing fibres into garments, various research set ups will be examined with the knowledge of Delft University of Technology and the atelier of S. Roos. To indicate if the set ups are applicable, the self-healing fibres will be woven into small prototypes at the atelier of S. Roos.

- What are the possibilities of self-healing garments in the apparel industry?
  Interviews: Clothing repair shops will be interviewed to define where garments show abrasion and which product group is brought in for repair the most. The clothing repair shops should indicate why customers repair their garments, instead of disposing of a garment which shows abrasion. A consumer survey will provide in depth information on consumer behavior towards disposal and preserving of garments. Various product groups will be determined which require further investigation by the results of the consumer survey and clothing repair shops interviews. A possible business opportunity might occur when comparing these results.

- What are the future recommendations for the apparel industry, concerning self-healing technology?
  Field and technical research: To define future possibilities, field research and technical research will be combined. Various ways of applying self-healing technology in or on garments will be discussed, as well how the self-healing technology could be applied in the apparel industry for several product groups.
2 SELF-HEALING TECHNOLOGY

As mentioned in section 1.1, self-healing technology is a possible solution to extend the user durability of clothing. According to the Cambridge Dictionary, the term self-healing stands for; “A piece of equipment or system that had the ability to discover and correct faults without needing outside help” (Anonymous, 2016). Previous research indicates that the self-healing approach is more advantageous than the damage prevention approach (Brinkman, 2013). The damage prevention approach has been the main approach for thousands of years. Even though the damage prevention approach has been useful, the materials have never been strong enough to exclude defects entirely. Another downside of the damage prevention approach is that when the damage has been determined, it will never completely disappear.

Self-healing technology is making its way into society, even though the damage prevention approach still dominates. Since 2011, people are able to drive on self-healing asphalt and walk on self-healing concrete (Brinkman, 2013). Currently, the fashion industry has also been triggered by the self-healing advantages. As Fibre2Fashion mentions; “The ability of a material to heal automatically is the most promising functionality in smart textiles currently in the whole industry” (2016). The main benefit, as mentioned by Fibre2Fashion, is to create long lasting products which results in the use of fewer resources. This is exactly the aim of this research- focusing on the application of self-healing fibres in the apparel industry.

Section 2.1 compares the production method of regular fibres with the production method of self-healing fibres. The production of self-healing fibres is examined at the Delft University of Technology under guidance of PhD researcher W. Post. To indicate how self-healing fibres could be optimized, results and future research is discussed.

Section 2.2 illustrates a draft of how the self-healing technology and fibres could be applied in a garment. At the atelier of S. Roos future possibilities of incorporating self-healing fibres into a garment are discussed by experimenting with weaving.

Section 2.3 presents the challenges of self-healing technology in the apparel industry and potential solutions. The challenges are divided into the production of self-healing fibres and garments, and the use and care of a self-healing garment.

Section 2.4 contains the conclusion on the research of self-healing technology.

2.1 Self-healing fibres

Fibres determine the characteristics of a cloth. This includes the look, the feel and the drape. Textile fibres can be set apart in two main groups, namely natural fibres and man-made fibres (Eberle, 2008). As explained by the Natural Fibre Specialist from Switzerland; “Natural fibers can be defined as substances produced by plants and animals that can be spun into filament, thread or rope” (Boinay et al., 2016). Man-made fibres have the ability to meet the characteristics that are demanded, as well as self-healing fibres. A figure is included in section 7.1 showing the currently used fibres.

Current research by Mookhoek indicates that a self-healing fibre is comparable to a man-made fibre spun by the wet spinning method (2015). The wet spinning method withholds that the polymer solution is extruded into a chemical bath, which neutralizes the solvent and coagulates the filaments. After the extrusion and solidification, the fibres are drawn out between rollers. The final
fibre diameter is determined by the spinneret size, plus spinning and drawing conditions (Eberle et al., 2008).

The difference between self-healing fibres and regular man-made fibres depends on the spinning emulsion. The spinning emulsion of a self-healing fibre include capsules containing a healing agent. After the extrusion of the polymer solution including the capsules, the chemical bath neutralizes the solvent and coagulates the fibres. After drying the fibres, water is evaporated and the capsules become visible. A self-healing fibre, is a hollow fibre with capsules containing a healing agent which will be released when the fibre is damaged. The healing agent restores the default when the liquid healing agent sets hard. Ultimately the healing agent is strong enough to bond the fibres back together.

The self-healing technology is situated in small capsules which, in the case of self-healing fibres, are applicable in the spinning emulsion. Currently, Delft University of Technology is in the process of developing self-healing fibres using alginate as the base material for the spinning emulsion. Other base materials could be man-made fibres which are produced by the wet spinning technique. Nylon, polyester, acrylic and polyolefin are the four synthetic fibres which are responsible for 98% of the global synthetic fibre production. Polyester alone is responsible for 80% of the global market share of man-made fibres (Anne, 2010). These four synthetic fibres could be a base material for the self-healing fibres to make them more applicable for the apparel industry, than alginate.

2.1.1 Results laboratory

Together with PhD researcher W. Post, two healing agents were tested in the existing set up at Delft University of Technology, figure 2. Textile glue and acrylate were used as healing agents in an alginate solution. To encapsulate the healing agents, they were solved in the alginate solution. Since the acrylate reacted with the alginate solution, this healing agent is not suitable as healing agent. The textile glue encapsulates into small beads in the alginate solution, workable enough to create fibres. To create a possible better spinning emulsion, the textile glue was also dissolved in olive oil.

Figure 2 (a) Schematic of the wet-spinning line and (b) design of the spinneret. Source: Mookhoek, S. et al (2015), “Compartmented fibres: a local and multiple healing events approach for self-healing fibre reinforced composites”, Eindhoven: TNO Science and Industry

<table>
<thead>
<tr>
<th>Emulsion 1</th>
<th>Textile glue (1.68gr.)</th>
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<tbody>
<tr>
<td></td>
<td>Alginate solution (38.26gr.)</td>
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<tr>
<td>Emulsion 2</td>
<td>Textile glue mixed with olive oil (1.65gr.)</td>
</tr>
<tr>
<td></td>
<td>Alginate solution (38.28gr.)</td>
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After extrusion and solidification, small capsules become visible. Emulsion 1 resulted in a stronger fibre than emulsion 2. When testing the healing ability of the capsules, it failed on both fibres. The healing agent textile glue, was already hardened within the fibres. Further research will be discussed in section 2.3.

2.2 Self-healing garments

As Fibre2Fashion has mentioned, the ability of material to heal itself is the most promising function in the fashion industry (2016). In 2011, Scandinavian researchers from SINTEF started developing a textile coating which heals tears on the surface of waterproof workwear (Zimmer, 2011). To create a self-healing coating, microcapsules with a glue-like solvent were applied within the coating. As proven by the research of SINTEF, the application of self-healing technology in the apparel industry is not new, but it reveals the interest and perhaps the need for self-healing technology in the apparel industry.

The factors strength, diameter and the suppleness of the fibre require consideration for an optimal application of self-healing fibres in a garment. The spinneret, as mentioned in section 2.1.1, only consist of one hole. This self-healing fibre can be named a monofilament yarn. A monofilament yarn consists of only a single continuous filament (Eberle et al., 2008).

The tension on the yarns will be high while weaving or knitting a cloth or a garment. Therefore the self-healing yarns need to be as strong as possible, to prevent breaking during production. Previous research indicates that when twisting monofilaments yarns together, a stronger yarn will be produced (Eberle et al., 2008).

After a cloth or garment is woven or knitted, the healing agent should still be able to heal tear and abrasion.

2.2.1 Results atelier

The self-made self-healing fibres, should have been woven into a small cloth at the atelier of S. Roos. Unfortunately these self-healing fibres, also known as self-healing monofilaments, are not strong enough. The self-healing monofilaments break with the smallest tension on the thread, possibly because of the base material of the fibre.

Together with S. Roos we thought of possible solutions to improve the alginate monofilament, also applicable in case a different kind self-healing monofilament is not strong enough. To strengthen the self-healing filaments, they can be twisted into a thicker and stronger yarn.

This research focuses on the production and advantages of a core spun yarn. A core spun yarn, is a yarn which the core yarn is completely wrapped by a cover yarn. According to Heddels, a core spun yarn is 40% to 50% stronger than regular spun yarn of the same weight (2016). Usually a synthetic filament core is used, to provide the yarn with high strength and durability. The cover yarn protects the core yarn from hazards during sewing and/or weaving. To implement the self-healing monofilament in a core spun yarn could be a possible solution to strengthen the yarn for production. Figure 3, is a schematic draft of the core spun yarn, with a self-healing monofilament core.

Figure 3 (a) Schematic core yarn, self-healing monofilament (b) Schematic cover yarn. Source: Islam, Z. (2013), “Effect of core draft on the properties of core spun yarn”, Bangladesh: Bangladesh University of Textiles.
2.3 Challenges

Self-healing fibres are still under development to become applicable for the apparel industry. The results, as mentioned in sections 2.1.1 and 2.2.1, pinpoint the difficulties which require further development.

Section 2.3.1 focuses on optimizing the production of the self-healing fibres which would eventually be used in garments. Section 2.3.2 focuses on optimizing the self-healing fibres to prevent pitfalls during the use and care of self-healing garments.

2.3.1 Production of self-healing garments

According to the results from Delft University of Technology and at the atelier of S. Roos, self-healing fibres require optimization in the following areas:

- The base material for the spinning emulsion requires further examination, which was an alginate solution in this experiment. Research indicates that alginate fibres are rather unstable, since they dissolve in soapy water (Eberle, 2008). Acrylics and viscose could be a good follow up to research, since these fibres are made with the wet spinning technique and often used in the apparel industry;
- The glue-like solution needs to ultimately capsulize within the base material. The glue-like solution withholds the healing agent and should preserve its characteristics after capsulizing. The base material should not react with the glue-like solution. The capsules with the glue-like solution should be strong enough to not break during weaving and/or knitting, but still break when abrasion or tearing occurs;
- The glue-like solution requires to be liquid when the spinning emulsion is extracted through the spinneret and dried. Otherwise the solution would not be able to heal a default. Results have shown that using a textile glue is not suitable as a healing agent. The textile glue is not liquid after drying;
- The capsules with the glue-like solution should be equally divided in the self-healing fibre, this provides a wide span of the fibre to heal when abrasion occurs;
- The self-healing filaments, as they leave the spinneret, should be as supple as a regular filament. The self-healing filament should not limit the movements of the self-healing garment wearer. Suppleness will prevent the self-healing filaments from breaking during production. The alginate filament from the experiment is not suitable for production, the filaments break with the smallest tension;
- The self-healing filaments should have a workable diameter, or been twisted into a thicker yarn, for example; core spun yarn. This provides the self-healing filament of breaking during the production of a garment.

2.3.2 Use and care of self-healing garments

According to the results from Delft University of Technology and at the atelier of Sytze Roos, self-healing fibres at least require to be optimized on the following subjects:

- The self-healing capsules should only break when the tension on the yarn is high enough. Meaning the tension is at the level it causes abrasion or tear in a garment. Capsules should not break during movements;
- The self-healing capsules should be able to heal in a short amount of time while garment is worn;
- The self-healing capsules should not cause an allergic reaction with the human skin or other garments. Always mention the possible allergic reaction with the healing agent on the carelabel;
- Self-healing garment should have same characteristics after the self-healing capsules have burst. Otherwise the garment is not the same as before, then the healing process would be useless;
- Self-healing garment should be able to protect the human body the same as regular garments against natural events;
- Self-healing garments should be at least suitable for washing, drying and ironing. According to Roos et al., the washing, drying and ironing contribute to tear and abrasion (2015), which means the processes are harmful and damaging for the garment. The capsules should not break during these processes, unless fibres are breaking after multiple times of washing, drying and ironing, causing tear and abrasion.

2.4 Conclusion

Based on experiments at Delft University of Technology and the atelier of S. Roos, the self-healing fibres require further development before being applied in the apparel industry. Previous research indicates the possible application of self-healing capsules in a waterproof coating (Zimmer, 2011). The application of self-healing technology in the apparel industry is not new, but it also reveals the interest and possibly the need of self-healing technology in the apparel industry.

A self-healing fibre should have the same requirements and characteristics as the base material of a man-made fibre. Results have shown that textile glue does not ultimately capsulize in the alginate solution. The textile glue is not able to heal after breaking the capsules. The textile glue has already hardened within the capsules. The alginate fibre itself is very fragile, it breaks with the smallest tension and thus not suitable to make a garment of. Since polyester is the most used man-made fibre in the apparel industry, the suitability of polyester as the base material for self-healing fibres should be researched. The following requirements should at least be taken into account, when self-healing fibres will be produced for the apparel industry;

- The self-healing fibre should be a strong filament or yarn, including equally divided capsules with a glue-like solution. Preventing the fibre from breaking in a too early stage;
- The capsules with the glue-like solution should still be able to heal after garment production. Unlike the textile glue which already hardens when being capsulized;
- The capsules with the glue-like solution should not break, while wearing, before tear and/or abrasion occurs;
- The glue-like solution should not be harmful for the wearer or other garments, since the capsules should be able to release the glue-like solution and set hard while wearing, in a short amount of time;
- A self-healing garment should be at least suitable for washing, drying and ironing. Meaning the capsules should not break during the process of washing, drying and ironing, but only when showing tear and abrasion.
3 POSSIBLE APPLICATIONS IN GARMENTS

According to Eberle, protection, decoration and identification are the basic functions of garments (2008). Garments protect the human body against cold, warmth, rain etcetera. Fashion is driven by aesthetic change, social preferences and cultural conditions- focusing on the aesthetical decoration function (Fletcher, 2012). The main functions for workwear and uniforms are identification and protection. The basic functions of clothing are important to understand the advantages and applications of self-healing garments for various product groups.

Opinions on garment perseverance and disposal are required to determine the applicability of self-healing fibres in the apparel industry. These opinions are collected throughout survey, interviews and literature research from consumers and the apparel industry. Results will be compared to each other, to determine the applicability per product group.

Section 3.1 focuses on the findings of the clothing repair shops- if self-healing garments are adapted by consumers, their jobs might not be needed anymore. Ten interviews were held with clothing repair shops to determine which product group requires the most repair. Possibly the tear and abrasion occur in specific parts of the garment and it might be textile related. The ten interviews will also be a test of consumer behavior, by questioning if the consumers bring in their garments for repair for particular reasons.

Section 3.2 provides in depth information on consumer behavior towards the disposal and preserving of garments. The information is collected through a survey, which is explained in section 3.2.1. Section 3.2.1.1 illustrates the disposal of garments. Section 3.2.1.2 illustrates the preservation of garments. The results from the survey form the grounds of in depth research on several product groups.

Section 3.3 focuses on workwear and uniforms. Workwear and uniforms are designed to meet their functions; protection and identification. Durability already being key for these sectors, besides easy handling. The need for innovation on durability is researched, to determine the applicability of self-healing technology in the workwear and uniform sector. An interview with Van Puijenbroek Textiel was conducted to collect more in depth information about the current material usage.

Section 3.4 contains the conclusion on the possible applications in garments.

3.1 Clothing repair shops

Clothing repair is needed for various reasons; for instance, poor workmanship or construction, tear and abrasion (Baker, 2007). How does one decide whether to repair a garment or not? Answers to this question could form an idea on how self-healing garments could anticipate the consumer needs. Throughout ten interviews with clothing repair shops, a rough outline will be setup. To check if supply and demand meet, the responses from the clothing repair shops will be compared with the responses from the consumer survey.

The ten interviewed clothing repair shops- repair all kinds of garments. Toverschaar is a clothing repair shops that is specialized in repairing costumes. Bubble & Stitch responded that the repairs are not product group related, but rather related to the kinds of repair; for instance, jacket zippers.

When the clothing repair shops have to pinpoint a garment, which is brought in for repair the most, it would be the trousers. Jeans and pantaloons are more likely to show abrasion in the crotch, as de Keet mentioned; “The abrasion usually occurs in the crotch, due to bike rides. The costumers think it
is a shame to dispose the garments, so they let me repair them”. Damage in the fabric is the most common repair. Zippers, elbows, collars, buttons and ripped seems, are repairs which occur every once in a while. The consumer survey will provide an in depth overview on which repair is requested most frequently.

Most clothing repair shops do not notice if the tear and abrasion is textile related. Only clothing repair shop Begga noticed that the cheaper fabrics are brought in more often; “The touch and feel shows that these fabrics are cheaper”. Clothing repair shop De Pijp guessed that denim and cotton would be taken in for repair the most. The majority of the clothing repair shops do not notice if a textile is brought in for repair more often than other textiles.

Customers seem to take their garments to clothing repair shops for various reasons. What all responses have in common is their relation with emotional or economic value. Logically, it is often cheaper to repair the garment, then to buy a new one. When customers are emotionally attached to a garment, they are even willing to bring in the garment for repair multiple times. Clothing repair shop Oner even had a costumer who comes back every six months with the same jacket.

Almost all of the ten clothing repair shops, which were interviewed for this research, are located in and around Amsterdam. According to the yellow pages, there are 85 clothing repair shops in Amsterdam. This indicates the need for clothing repair. The clothing repair shops responded they not only repair the garments anymore. Garments are also brought for adjustments, due to change of the body or change of fashion.

Garments such as underwear and socks are not likely to be taken to a clothing repair shop. These garments could be applicable for self-healing fibres, as it would not harm the clothing repair shops by taking over their jobs. The disposal of garments, which are not taken to a clothing repair shop, will also be examined in the consumer survey.

Trousers are taken to clothing repair shops due to the tear and abrasion of the fabric in the crotch. While jackets are likely to be brought in due to failing zippers or torn out pockets. These results show that the tear and abrasion varies per garment and its usage. When wanting to apply the self-healing fibres in the apparel industry, it is important to divide the product groups. Every product group could have a different place of application and different type of application.

Throughout the consumer survey, the research will be more specific and in depth on business opportunities for self-healing garments in the apparel industry. Ultimately, the consumer survey show a demand for repair, which the clothing repair shops do not supply.

3.2 Consumer

A Nielsen study, found that in 60 countries, “more than half of online consumers, are willing to pay more for products and services from companies that are committed to positive social and environmental impact” (Chua, 2016). Since the majority of the online consumers are willing to pay more for products which are determined to be “good”, self-healing garments do have an opportunity to become a success. Self-healing garments undergo a more technical and chemical procedure than a regular garment. The process of the self-healing fibres alone, would in all probability, cost more time and money compared to other man-made fibres. A possible solution to limit the production costs as much as possible, is to apply self-healing fibres only in the parts which require extra abrasion resistance. Therefore these parts need to be determined.
Fashion, with the function to decorate the human body, is one of the biggest assets within the apparel industry. Research by Annamma indicates, fast fashion being the main reason why production level are at its highest (2012). Is there a possibility that consumers are willing to give up trends to protect the environment? Or is there a possible way around trends and create a new way of design and production? The following survey will answer these questions, to find out if self-healing garments could meet the demands of consumers.

3.2.1 Survey

A survey was held in the Netherlands to understand the consumers behavior towards the disposal and preservation of garments. Responses on the survey should indicate if self-healing garments could be a sustainable solution to reduce the production of garments. By implementing self-healing fibres in a product group which is thrown out the most, the production of this product group could be increase. Section 3.2.1.1 displays if self-healing garments could be beneficial, concerning the grounds of garment disposal. Section 3.2.1.2 indicates if self-healing garments could meet the possible needs of the consumers to preserve the garments for a longer period of time.

In a group of hundred respondents, 80% were women, 20% were men. More than half of the respondents were aged under 25 (52%), 24% was between the age of 25 and 50, and 24% was older than 50.

3.2.1.1 Disposal of garments

Previous research does not show current information on the main reason to dispose garments. Therefore this survey was set up for in depth information on the disposal of garments. More than half of the respondents (55%) indicated tear and abrasion, as the main reason to dispose garments. Followed up by 41% whom dispose garments because they no longer fit. 27% of the respondents, dispose garments when they are out of fashion or rather have something new. Applying self-healing fibres into garments, should prevent the garments from showing tear and abrasion. Self-healing fibres cannot prevent a garment of being out of fashion, but changing the trend design into a basic and timeless design could be a way to make self-healing fibres applicable. Self-healing fibres could be applied in garments which do not have to deal with the probability of not fitting anymore; for instance, socks.

Fast fashion sells garments that are expected to be used less than ten times (Birtwistle, 2007). Since fast fashion garments are made of poor quality, they could show abrasion quickly besides becoming out of fashion. When wanting to tackle these two problems which cause disposal, two possible solutions need to cooperate. The quality of a garment could be upgraded by implementing self-healing fibres. When applying the self-healing fibres in a basic and timeless designs, the garments should not be disposed caused by the trend cycle.

Results of the survey formed the following list, showing which product group and placement tears and abrades the most.

1. Socks - Toe/Heel
2. Trousers - Crotch/Knee
3. Underwear - Hip
4. Tops - Armpit/Belt area/Elbow
5. Outerwear - Pockets
6. Sportswear
In general - Seams/Zipper/Buttons
According to the following outcomes, socks are most frequently torn or show abrasion. Since the clothing repair shops do not mention socks at all as a product group which is brought in (the most), it is likely to assume socks are disposed when showing tear and abrasion. This makes socks an interesting product group for further research on possible applications of self-healing fibres. Section 3.2.2 shows in depth information on the possible application of self-healing fibres in socks.

Trousers are mentioned as second when it comes to showing tear and abrasion. The crotch and the knee are the placements which show tear and abrasion. Trousers are the product group which is taken to clothing repair shops the most and therefore it is not a sustainable solution. It could cause economic damage to the clothing repair shops, meaning damage to the economical pillar of sustainability.

Underwear tears between the fabric and the elastic band. Underwear is, as well as socks, not mentioned in the interviews with the clothing repair shops. Therefore this could be a product group which is disposed as soon as it tears and shows abrasion. A suitable product group for the self-healing fibres.

Tops tears in the armpit, belt area and elbow. These three sections of tear and abrasion are far apart from each other and probably resulting in creating a completing garment in self-healing fibres. Possibly the creation of self-healing fibres will cost a lot more than regular fibres, causing the garment to become too expensive to sell.

Section 3.2.3 focuses on outerwear, as the self-healing technology has already been applied in waterproof raincoats, other possible applications will be discussed.

Sportswear is mentioned as the product group, which shows the least tear and abrasion. Perhaps sportswear is already made of durable fabrics, section 3.2.4 shows in depth research on the durability of sportswear. Seams are mentioned as a part of the garments with tear regularly, a possible solution could be by producing a self-healing sewing yarn for the seams.

In general seams, zippers and buttons are likely to break. Seams could be made of self-healing sewing yarns, varying on the product and its use. Zippers and buttons are design parts within product groups and do not occur in every garment. Further research is required to examine the possible application of self-healing technology in zippers and buttons.

3.2.1.2 Preservation of garments

After focusing on the reasons why to dispose garments, the focus will now be on why preserving the garment. The majority of the consumers seem to dispose their garments when it shows tear and abrasion. This problem could be solved by applying self-healing fibres in garments, but what if the consumers do not think it is necessary to preserve garments for a longer period of time? Research by WRAP Organization has shown that by extending the life of garments by an extra nine months of active use would reduce carbon, waste and water footprints by around 20-30% each and cut resource costs by around 20% (Cooper et al., 2013). The willingness of preserving garments for a longer period is questioned in the following subjects, to indicate if the long lasting self-healing garments could have a beneficial outcome.

According to Birtwistle, consumers do not have a specific idea about how long they would keep their garments (2007). Usually garments were kept for as long as they were wearable. Sometimes the garments were donated when they were too expensive to be thrown away. Cheap clothing would quickly become unwearable and disposed, also known as ‘throw-away garments’.
Results of the survey on the question; “how old is the oldest garment?”, formed the following list. Possibly the garments are still wearable, too expensive to throw away or have emotional value.

- 1-10 years: 65%
- 11-20 years: 18%
- 21-30 years: 9%
- > 30 years: 5%
- Secondhand: 1%
- No idea: 2%

The reason why the respondents have kept this specific garment longer than most garments, is a matter on which self-healing garments could anticipate. Respondents have various reasons of the preservation. More than one-quarter answered; “because it still fits”. 24% of the respondents answered; “due to emotional value”. For instance, garments which are kept for over more than thirty years are often inherited or wedding costumes. Other reasons vary from favorite items which are still worn, till timeless good quality garments. How to anticipate on the two most common answers is difficult. A garment which still fits after several years would not necessarily be production or design related. Of course an oversized garment could work, but such designs are usually in fashion for a period of time. A garment cannot be made to have emotional value. The third most important reason to preserve a garment is because it is timeless. 14% of the respondents have kept their garments for several year because of its timeless design. The design of a garment which could be worn for a long period of time, is extremely important. 27% of the respondents dispose garments for being out of fashion. While 14% of the respondents preserve their timeless garments. Applying self-healing fibres in a garment which is timeless or basic, should be a suitable solution in order to prevent disposal.

64% of the respondents thought if it was useful to extend the user durability of clothing. Their main reasons were; to save money, because they would buy less. 24% of the respondents were aware it would be better for the environment. According to Birtwistle, consumers agreed there was a general lack of knowledge of how and where clothing was disposed of, or even how it was made (2007). Consumers also stated that they might modify their clothing consumption and disposal behavior if they were more aware of the social and environmental consequences. The only downsides that the respondents indicate is that the garments would possibly not be trend related and it might have a bad influence on the economy. 27% of the respondents earlier responded that being out of style was the main reason to throw away garments in the first place. Research by Birtwistle, showed that fast fashion products have lost intrinsic value, encouraging consumers to replace and dispose products before their real life cycle had ended (2007). This indicates that the self-healing fibres should not be applied in any trend related garment. Self-healing fibres should be applied in timeless garments and make the consumer aware of the great sustainable solution this withholds.

The awareness of the consumer on the added value for a longer user durability, combined with the willingness to pay more for a positive social and environmental produced garment, demonstrate the possibilities of introducing self-healing garments in the apparel industry. There is a small chance a consumer could become emotionally attached to a self-healing garment, but other applications form better future perspectives. Designing timeless garments, instead of fast fashion, could be one of them.

3.2.2 Socks

38% of the respondents voted socks as their number one garment which tears and shows abrasion the most. Socks are protective knitwear garments, which are most vulnerable at the toe and heel parts. Socks are worn by men and women of all ages. Research indicates that feet normally do not
get fatter or thinner, only bigger till approximately the age of 15 (Gehwol, 2016). While 41% of the respondents told they dispose garments when they do not fit anymore, socks do not have to deal with this kind of problem as much as other garments.

Bridgedale Outdoor Ltd; “the global market leader in the manufacture of technical socks for: Walking/Hiking, Mountaineering, Running, Skiing, and Everyday (Bridgedale, 2016). Bridgedale uses their own Fusion Technology, which combines natural fibres with technical fibres. To produce the most comfortable socks, Bridgedale uses the latest machinery and progressive designs. Bridgedale is continually innovating their designs and fibres to create excellent quality for their customers.

Bridgedale Outdoor Ltd, also focuses on the durability of the socks. All styles which contain wool, are guaranteed for three years and all styles without wool are guaranteed for one year. To ensure the quality of the socks meet the demands of the customers, Bridgedale socks are made in parts. The toe and heel part could have the self-healing fibres, to upgrade their quality level and thus extend the durability of the socks.

Bridgedale Outdoor Ltd, is just one of many companies specialized in socks. When a market would rapidly change, others will follow and adapt the innovations. To apply self-healing fibres in socks is definitely a possibility. The socks will not have to be thrown away, not only because they will not tear or show abrasion in the toe and heal, but also because the sock will always fit and is a basic product. A company like Bridgedale Outdoor Ltd, could even pursue their durability guarantee more. Another plus side is, the self-healing socks would probably not replace the task of a clothing repair shop.

3.2.3 Outerwear

Outerwear in general has priority to keep the human body warm in all kind of weather conditions. As mentioned in the consumer survey, outerwear, is likely to show abrasion and tear in the pockets. In the general comments of the same survey, ripped seams and broken zippers were also indicated, which from own experience are applicable for outerwear. In 2011, SINTEF started research on a self-healing coating to be applied on waterproof raincoats (Zimmer, 2011). Perhaps for future notice, self-healing technology could be applicable for all kinds of outerwear.

Fjällräven is a performance outdoor brand, which provides durable products and does not follow the main trends (Fjällräven, 2016). Still, the brand has become a hype as it is worn for outdoor activities and worn as casualwear. Forums as Reddit are discussing if Fjällräven is just a hype, or that the qualitative products are really worth their money (Reddit, 2015). Fjällräven profiles itself as; “the best outdoor fabric on the market” (2016). Since this statement sounds so convincing, the fabric is worth researching.

The Fjällräven G-1000® fabric is made from 65% polyester and 35% cotton, and is waxed with Greenland wax. Polyester containing excellent properties for the outdoors. The Greenland wax makes the product wind and water resistant and increases the durability of the G-1000® fabric. The wax is an environmental friendly product, consisting of paraffin and beeswax, which makes the product not dangerous to use. The G-1000® HeavyDuty fabric is an even stronger fabric, used in garments which require extra durability.

Fjällräven, which has a broad consumer audience and a high-sustainability awareness, currently concentrates on product recycling. Implementing self-healing fibres in the G-1000® fabric, could be an addition to their sustainability program, probably under the condition self-healing fibres are recyclable. Another possible application, inspired by SINTEF research, is implementing self-healing
capsules in the Greenland wax, creating a self-healing coating which could be applied at home (Zimmer, 2011). Concerning the abrasion and tear areas, as mentioned in the consumer survey, a self-healing sewing yarn would be better applicable. Considering a brand as Fjällraven, the self-healing technology would be applicable, but since the brand is already known for its durability, the application would not be necessity but an addition to their own durability program.

3.2.4 Sportswear

According to Cooper et al., sportswear includes garments used for physical activity from low impact (jogging, yoga, golf) to high impact (tennis, running, football) (2013). Sportswear is usually bought for a specific sport or activity, but is also worn as casualwear. Research by WRAP Organization found that over a third of people in the UK wears sportswear, without taking part in a sports activity (Cooper et al., 2013). Which makes it important for sportswear brands to preserve the technical performance, as well as the fashion ability of the product. In the consumer survey, sportswear came forward as the best durable product group. The following research focuses on the durability of performance garments and possible applications of the self-healing fibres in sportswear.

The fabric choices differ depending on the physical activity impact. Fabrics used in sportswear are mostly wool and synthetic fibres. Synthetic fibres are well suited for performance sportswear, as it is a strong, durable and abrasion resistant material. Nylon and elastane are used for the elasticity and stretch recovery in the garments. The performance requirements for the fabrics include abrasion resistance, elasticity, elastic recovery and flexibility.

According to MBA Skool, Nike is the world’s number one innovator in sportswear (MBA Skool, 2015). For this reason, their sustainability performance is researched. The sustainable business performance summary of Nike offers insight into their sustainability strategy, performance and progress against the targets and commitments from the past (NIKE Inc., 2013). Together with NASA, US Agency for International Developments and the US Department of State, Nike works on uncovering sustainable materials. Nike mentions; “Reducing materials-related impacts is among the strongest levers we have for improving our overall environmental performance” (2013). Disposed garments make up 59% of the total waste in the value chain of Nike (2013). Their solution lays in decreasing waste during the manufacturing.

Concluding from the sustainable business performance summary, Nike seems to be aware of the enormous impact as an apparel company rather than a sportswear company. Therefor Nike could be an example, not only for the sportswear industry, but for the apparel industry in total. Applying self-healing fibres for a sportswear company as Nike would be beneficial, since the company itself is searching for new ideas of reducing waste and becoming more sustainable through material usage.

3.3 Workwear and Uniforms

The basic functions of workwear and uniforms are identification and protection. Depending on the work occupation, the identification or protection function has the upper hand. Durability is an important requirement for workwear and uniforms. To find out if self-healing fibres could be an innovative addition for the workwear and uniform sector, an interview with Van Puijenbroek Textiel was held with purchaser Kees Timmermans and commercial director Anna van Puijenbroek. Van Puijenbroek Textiel, located in Goirle, is a family company which is specialized in professional industrial and safety clothing. Van Puijenbroek Textiel claims to use innovative high-quality textile fibres for the protective workwear and to meet the corporate identity of customers (Van Puijenbroek Textiel, 2016).
Currently used fabrics and applications were discussed to understand if self-healing fibres have a business potential for Van Puijenbroek Textiel. CORDURA® is now partly used in the garments, parts which require more protection. For instance, the workwear trousers have CORDURA® knee patches. The knee patches are plain woven, so the sturdy material does not hinder the knee movements. The knee area requires the extra abrasion resistance and in this manner it remains durable throughout wearing. CORDURA® is a brand name for a durable, versatile and reliable textile used in the apparel industry; for example, outdoor wear, military wear and workwear (Investa, 2016). Rockywoods even describes the durability of CORDURA® as; “CORDURA® fabrics are ten times more durable than cotton duck fabric, two times more durable than standard nylon and three times more durable than standard polyester fabric” (Rockywoods, 2016). Van Puijenbroek Textiel admitted they have not been actively searching for a new innovative textiles to replace CORDURA®, since Van Puijenbroek Textiel has been using the textile for over more than 10 years. When the market of durable textiles changes, they admitted that they cannot stay behind and will adapt.

Having discussed self-healing fibres with a workwear and uniform company, gave insight to their way of thinking. Prices need to be low as possible and the textiles should be at least suitable to wash and tumble-dry. Most important are all the additional requirements, that are especially applicable for protective workwear. Fire resistant garments should not melt, ignite and continue to burn when exposed to flame or estimated energy, according to The National Safety Council of the USA (Baker, 2015). The weight, texture, weave and color of material are factors which could vary the protection level of a garment. In this early research stage of developing self-healing fibres, it is not guaranteed, the self-healing fibres would meet all the requirements for protective workwear and uniforms. Although, the durability requirement, which is key to workwear, will be improved.

Even though the self-healing fibres might not be possible to apply in the workwear and uniform sector, due to strict protection requirements and the underdevelopment of self-healing fibres, it did arise new ideas. For instance, to use the self-healing capsules in a coating. This insures the capsules not to break in a too early stage and to apply the self-healing capsules only on the parts that require extra abrasion resistance. As already mentioned, self-healing coatings for waterproof workwear, think fishermen for example, are already under development. This means that the application for self-healing technology has potential in the workwear and uniform sector. Another possible application of the self-healing technology might be, to implement the self-healing capsules in the sewing yarns. Since the seams and stitching often get possible risks of breaking; for instance, caused by welding sparks. Creating a sewing yarn with self-healing capsules, requires new experimental and literature research. To begin with; the sewing yarn must be able to go through a sewing machine, without breaking any self-healing capsules. Research on creating self-healing sewing yarns does have potential, since not only Van Puijenbroek Textiel mentions the abrasion of stitches and seams, but also in the consumer survey it has been mentioned.

3.4 Conclusion

The possible application of self-healing fibres in various apparel sector are diverse, depending on the end-use of the products. The self-healing fibres could be embraced by consumers, since 64% of the survey respondents recognize the added value of garments with an extended user durability. As more than half of the survey respondents answered that tear and abrasion was the main reason to throw away their garments, the correct apparel sector needs to be determined.

Socks show the most tear and abrasion, in the heel and toe parts. The possibility that a garment would not fit anymore and should be thrown away, is not applicable to socks. Socks are timeless protective garments for women and men of all ages. Bridgedale Outdoor Ltd. produces their socks in parts, which could contain self-healing fibres, to increase their quality. If the self-healing fibres
would be applied in the sock industry, it also withholds the advantage of not taking over the jobs of the clothing repair shops.

Outerwear did not outstand in the consumer survey, but as SINTEF researchers have started experimenting with self-healing capsules in the coating for waterproof raincoats, it indicates the possible necessity for outerwear to become self-healing (Zimmer, 2011). Fjällraven describes their fabric as the best in the outdoor market, aiming on the durability of the fabrics (Fjällraven, 2016). The fabrics are specially made for the brand and the brand also withholds their own wax, Greenland wax. For this company, self-healing fibres could be applied in the garments, or in the sewing yarn, to extend the durability of the garments. Perhaps, the self-healing capsules could be implemented in the Greenland wax, inspired by the research of SINTEF.

In the consumer survey, sportswear scored as being the best durable product. Sportswear is worn during sport activities, but also worn as casualwear. Making it important for a sports brand to be considerable about trends and performance requirements. As Nike is the number one sportswear brand in the world, their sustainability program was researched. 59% of Nike’s waste, exists of disposed garments and self-healing garments could reduce this waste level (2013).

The workwear and uniform sector, stands for functionality and durability for a specific time and place. Van Puijenbroek Textiel is a workwear and uniform company, which uses CORDURA® in their garments to make them durable. As well as other apparel sectors, for the workwear and uniform sector it is important to keep the manufacturing costs at a minimum. Meaning the durable fabrics could be applied in parts which require extra abrasion resistance; for instance, the knees or seams. Self-healing fibres could be applied in workwear and uniforms, on the condition the additional requirements for protective workwear can be achieved.

Throughout the research on the possible applications, the following ideas came forward;

- Creating a self-healing sewing yarn. Results from research interviews and survey indicated that every product group has to deal with breaking seams. By creating a self-healing sewing yarn, the seams should be able to repair themselves and prevent the disposal of garments.
- SINTEF research has shown the self-healing application in a waterproof coating for workwear (2011). Perhaps the self-healing coating could be applicable for various coatings in the apparel industry.
- Since self-healing fibres require more time and proceedings than any kind of man-made fibre, it is likely to assume that self-healing fibres will cost more. The production costs could be minimalized by only applying self-healing fibres in the parts which require extra abrasion resistance.
- Consumers indicate to dispose garments when being out of fashion. To prevent the disposal of a garment, the self-healing fibres could be applied only in basic timeless garments.
- To make the self-healing fibres in the apparel industry truly beneficial, the consumers need to be made aware of the advantages of extending the durability of the garments.
4 FUTURE RECOMMENDATIONS

The most promising function for smart textiles is the ability to heal automatically, according to Fibre2Fashion (2016). This research points out several pitfalls which require further examination to make self-healing fibres applicable for the apparel industry. The lifecycle of a garment would extend when applying self-healing fibres. This would result in a sustainable solution to reduce the production of clothing.

The future recommendations are based on the reviewed literature and test results combined with outcomes on the survey and interviews.

Section 4.1 discusses the recommendations which should assist further research to improve results on the self-healing fibres.

Section 4.2 is an overview on several applications of the self-healing fibres and technology, which could be applicable for the apparel industry.

Section 4.3 indicates which apparel sector should implement the self-healing fibres in their sustainability program to reduce the production of clothing.

Section 4.4 contains a conclusion on the future recommendations.

4.1 Possible future research

Currently, self-healing fibres are not sufficiently developed to be applied in the apparel industry. Test results from the Delft University of Technology laboratory and the atelier of S. Roos point out the following parts which require further research.

- Research on various base materials for the spinning emulsion, which was an alginate solution for research at Delft University of Technology. Research indicates that alginate fibres are rather unstable, since they dissolve in soapy water (Eberle, 2008). Test results have shown that alginate fibres break with the smallest tension. Alginate fibres are not suitable for weaving or knitting. Acrylics and viscose could be a good follow up to research, since these fibres are made with the wet spinning technique and often used in the apparel industry;

- Research on the optimal self-healing capsules for the fibre. The glue-like solution in the capsules withholds the healing agent and should preserve its characteristic after capsulizing. The base material should not react with the glue-like solution. The capsules with the glue-like solution should be strong enough to not break during weaving and/or knitting. The glue-like solution within the capsules requires to be liquid when the spinning emulsion is extracted through the spinneret and dried. Otherwise the solution would not be able to heal a default. Results have shown that using a textile glue is not suitable as a healing agent, possibly due to complete spinning emulsion. The textile glue is not liquid after drying. The healing agent within the capsule should not cause an allergic reaction to the wearer. The capsules with the glue-like solution should be equally divided in the self-healing fibre for ultimate repair;

- Research on the production of self-healing filaments. Self-healing filaments should have the characteristics as the base material characteristics. This includes that the suppleness of the filament should not limit the movements of the self-healing garment wearer. Suppleness will prevent the self-healing filaments from breaking during production and wearing without abrasion. The self-healing filaments should have a workable diameter, or been twisted into a
thicker yarn. A suitable yarn structure is a core spun yarn, it provides the self-healing filament of breaking during the production of a garment;

- Research on the care and use suitability of a self-healing garment. The self-healing capsules should only break when the tension on the yarn causes tear and abrasion, and not break during regular movements. The self-healing capsules should be able to heal, while garment is worn, in a short amount of time. The self-healing capsules should not cause a(n) (allergic) reaction with the human skin, or other garments. Self-healing garment should be able to protect the human body against warmth, cold, rain etcetera. Self-healing garments should be at least suitable for washing, drying and ironing. According to Roos et al., the washing, drying and ironing contribute to tear and abrasion, which means the processes are harmful and damaging for the garment (2015). The capsules should not break during these processes, unless fibres are breaking after multiple times of washing, drying and ironing, which causes tear and abrasion.

4.2 Possible future applications

Throughout the research, other possible applications are discussed which require further development;

- Research by SINTEF pointed out the possibility to create a self-healing coating for waterproof workwear (2011). Possible other coatings, such as a fire resistant coating, require further examination. Referring to the Greenland wax of Fjällraven, the coating could be applied at home, which results in a new layer of self-healing capsules in the coating after every application of the wax to the surface (2016);

- Creating a self-healing sewing yarn. The respondents from the survey indicated that every product group has to deal with breaking seams. Van Puijenbroek Textiel informed on the breaking seams for protective workwear. The reflecting parts on a garment require extra abrasion resistance due to the heat of welding sparks and other high temperature dangers. By creating a self-healing sewing yarn, the seams should be able to repair themselves and prevent the disposal of garments. A possible way to create a suitable sewing yarn is to make a core spun yarn. The core yarn would exist of a self-healing fibre and the cover yarn would prevent the core yarn from breaking during the sewing or wearing;

- Since self-healing fibres require more time and proceedings than any kind of man-made fibre, it is likely to assume that self-healing fibres will cost more. The production costs could be minimalized by only applying self-healing fibres in the parts which require extra abrasion resistance. Clothing repair shops indicated that tear and abrasion were not necessarily textile related, but rather product related. Per product group, various parts require extra abrasion resistance. The consumer survey indicated the following line-up of the product groups including the parts which show tear and abrasion;
  1. Socks - Toe/Heel
  2. Trousers - Crotch/Knee
  3. Underwear - Hip
  4. Tops - Armpit/Belt area/Elbow
  5. Outerwear - Pockets
  6. Sportswear
  In general - Seams/Zipper/Buttons
4.3 Possible future application in apparel industry

Consumers are willing to pay more for a product which is sustainable, but they require more information on the results of their sustainable purchase. The purchase of a garment with an extended lifecycle would have a major impact on the volume of resource consumed and waste generated.

Consumers are more likely to dispose of garments for being out of fashion, besides the disposal caused by tear and abrasion. Fast fashion garments have a short trend cycle, but have a high production turnover. Self-healing garments are the opposite of fast fashion. Self-healing garments should provide a reduced production turnover, with timeless designs. The application of self-healing fibres in the apparel industry would not only reduce the production of clothing, but also reduce the waste after production.

For now, socks are disposed of the quickest when showing abrasion. Socks could have self-healing fibres in the toe and heel parts, to keep production costs at a minimum. A self-healing coating is under development for the outerwear. The coating exists of capsules with a self-healing agent. Implementing a self-healing sewing yarn for the outerwear could prevent the pockets from tearing. The application of self-healing fibres in sportswear is more difficult, since the garments are required to be trendy and have a high technical performance at the same time. Workwear and uniforms demand extra protective requirements for their garments, which therefor requires more development and research.

4.4 Conclusion

Research at Delft University of Technology and at the atelier of S. Roos indicated that future research is required to create self-healing fibres which are applicable for the apparel industry. The base material and self-healing capsules within the spinning emulsion should ensure that the fibre and capsules are strong enough to be woven or knitted in a cloth or garment and not break under small tension. The self-healing capsules should still be able to heal the fibre after the production of a cloth or garment. To create a better applicable fibre for the apparel industry, the self-healing fibres should be tested when spun into a core spun yarn. Self-healing garments should not cause allergic reactions to the human skin. These garments should be suitable for washing, drying and ironing.

When the above mentioned underdeveloped items are improved, prototypes could indicate if self-healing garments are beneficial to a curtain apparel sector. For now a good place to start implementing self-healing fibres seems to be in socks. Socks could be manufactured in parts. The toe and heel parts are mostly made of man-made fibres to increase the durability and quality. This provides the opportunity to implement the self-healing fibres, as the new man-made fibre, in the parts which require extra abrasion resistance. In general, socks are not trend related, it is a basic product which requires comfort in wearing. The application of self-healing fibres would just be a change of fibre, but then a more durable one.

During this research other possible applications have emerged. Inspired by the research of SINTEF, other coatings could have the ability to self-heal, ensuring a product is strong enough to deal with natural events. Since various product groups suffer from breaking seams, a self-healing sewing yarn could repair the seams them self. Important for the apparel industry is the manufacturing costs and when trying to keep the costs minimalized, the self-healing fibres or perhaps even self-healing coating could be applied partially.
5 CONCLUSION

Currently there is a need for sustainable innovations for the damaged and seriously affected environment. The apparel industry contributes to the pollution of the environment and over the past decade its impact has only increased. In particular, fast fashion caused increased production rates which resulted in a significant level of annual carbon, water and waste footprints. WRAP organization suggests that extending the life of garments by even a few months could have a major impact on the volume of resources consumed and waste generated (Cooper et al., 2013). To extend the lifecycle of a garment, one must upgrade the durability of a garment. A sustainable strategy to reduce the production of clothing is to implement self-healing fibres in the garments.

Self-healing fibres are man-made fibres which should prevent tear and abrasion of a garment. Self-healing fibres are produced via the wet spinning method. The spinning emulsion of a self-healing fibre include capsules containing a healing agent. After extrusion and drying of the spinning emulsion, the capsules will become visible. When a capsule breaks, the healing agent will be released and restores the default by setting hard.

Delft University of Technology is in the process of developing self-healing fibres, but test results have shown that the self-healing fibres are not suitable yet for implementation in garments. The essential research part is creating an optimal spinning emulsion. This withholds a strong base material and a healing agent which is able to capsulize in the base material. The alginate fibres which were created at the laboratory of Delft University of Technology were not suitable for weaving at the atelier of S. Roos. The fibres could be strengthened by a different base material, but possibly also by creating a core spun yarn of the fibres.

The self-healing fibre should be a strong filament or yarn, including equally divided capsules with a glue-like solution. Preventing the fibre from breaking in a too early stage;

- The capsules with the glue-like solution should still be able to heal after garment production. Unlike the textile glue which already hardens when being capsulized in the spinning emulsion;
- The capsules with the glue-like solution should not break, while wearing, before tear and/or abrasion occurs;
- The glue-like solution should not be harmful for the wearer, nor other garments. Since the capsules should be able to release the glue-like solution and set hard while wearing, in a short amount of time;
- A self-healing garment should be at least suitable for washing, drying and ironing. Meaning the capsules should not break during the process of washing, drying and ironing, but only when showing tear and abrasion.

Research indicated that more than half of online consumers are willing to pay more money for products from company with a sustainable strategy (Chua, 2016). Self-healing fibres undergo more manufacturing steps than other man-made fibres, therefor the self-healing fibres will probably cost more. To reduce the production costs of a self-healing garment, the self-healing fibres could be implemented in particular parts which require extra abrasion resistance. 64% of the survey respondents recognize the added value of garments with an extended durability, mainly for the environment. Tear and abrasion is the main reason for consumer to dispose their garments. When tear and abrasion are no longer a factor to throw away garments due to self-healing fibres, the production rates will reduce.
In 2011, SINTEF researchers started developing a self-healing coating for waterproof raincoats (Zimmer, 2011). A self-healing coating would not only be beneficial for fishermen but for several apparel sectors. It is important to keep the end-use of a product in mind when wanting to apply self-healing fibres or another self-healing technology. Respondents to the consumer survey voted socks as the product group which shows the most tear and abrasion, in particular the toe and heel parts. Socks are also a timeless product group and therefore a suitable product group for self-healing fibres. Sportswear came forward as the most durable product group according to the consumer survey. Since sportswear requires to be trendy besides performance technology, the product group is probably less suitable for self-healing technology. The workwear and uniform sector has been using CORDURA® for the last several years. Possibly it is time to use a different material for parts which require extra abrasion resistance. Another application would be more useful for the workwear and uniform sector, namely self-healing sewing yarns. Self-healing sewing yarns could be used for the reflection parts in garments which should prevent tearing; for instance, caused by the heat of welding sparks.

Throughout the research on the possible applications, the following ideas came forward;
- Creating a self-healing sewing yarn. Through research interviews and survey has been found that every product group has to deal with breaking seams. By creating a self-healing sewing yarn, the seams should be able to repair themselves and prevent the disposal of garments.
- SINTEF research has shown the self-healing application in a waterproof coating for workwear (2011). Perhaps the self-healing coating could be applicable for various coatings in the apparel industry.
- Since self-healing fibres require more time and proceedings than any kind of man-made fibre, it is likely to assume that self-healing fibres will cost more. To keep the production costs at a minimum, the self-healing fibres could be applied only in the parts which require extra abrasion resistance.
- Consumers indicate to dispose garments when being out of fashion. To prevent the disposal of a garment, the self-healing fibres could be applied only in basic timeless garments.
- To make the self-healing fibres in the apparel industry truly beneficial, the consumers need to be made aware of the advantages of extending the durability of the garments.

The possible applications of self-healing fibres in the apparel industry - a sustainable strategy to reduce the production of clothing?

Implementing self-healing fibres in garments is a possible strategy for a more sustainable apparel industry. The use of self-healing technology in various industries is an upcoming trend and an inspiration for sustainable strategies for the apparel industry. The implementation of self-healing garments could reduce the production rates due to an extended lifecycle - a sustainable solution the consumer is willing to pay more for. Currently there are 3 possible applications of self-healing technology in garments which require further research; self-healing coatings, self-healing fibres and self-healing sewing yarns.
6 LITERATURE


Reddit forum (2015), Available at: https://www.reddit.com/r/backpacking/comments/3qwlsz/fjallraven_backpacking_packs_legitimate_long/ (Accessed: 07-04-2016)


7. APPENDIX


<table>
<thead>
<tr>
<th>NATURAL FIBRES</th>
<th>MAN-MADE FIBRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose - Vegetable</td>
<td>Natural Polymers</td>
</tr>
<tr>
<td><strong>Bast</strong></td>
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<tr>
<td>Flax</td>
<td>Viscose</td>
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<tr>
<td>Hemp</td>
<td>Modal</td>
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<td>Ramie</td>
<td>Cupro</td>
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<td>Triacetate</td>
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<td>Kapok</td>
<td>Alginate</td>
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<td><strong>Leaf</strong></td>
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<tr>
<td>Sisal</td>
<td>Rubber</td>
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<tr>
<td>Manila</td>
<td>Rubber</td>
</tr>
<tr>
<td><strong>Protein - Animal</strong></td>
<td>Synthetic Polymers</td>
</tr>
<tr>
<td>Wool</td>
<td></td>
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<tr>
<td>(virgin) Wool</td>
<td>Fluorofibres</td>
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<tr>
<td><strong>Coarse Hair</strong></td>
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<td>Cattle</td>
<td>Fluoro</td>
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<td>Horse</td>
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<td>Goat</td>
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<tr>
<td>Cultivated</td>
<td>Elastomeric</td>
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<tr>
<td>Wild (tussah)</td>
<td>Elastane</td>
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<td></td>
<td>Elastodiene</td>
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<td><strong>Fine Hair</strong></td>
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<td>Polyacrylcs</td>
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<td>Mohair</td>
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<td><strong>Mineral</strong></td>
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<td>Rock fibres</td>
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Spinning emulsion
Laboratory

Spinneret

Extruding spinning emulsion through the spinneret
Alginate fibres with textile glue capsules


7.3 Atelier Sytze Roos

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Tel. 0031 6 528 68 950

7.4 Clothing repair shops interviews

* Zilverschaar - Dennenrodepad 277, 1102 MV Amsterdam
- which product groups are brought in for repair?
  Students bring all kinds of clothing
- any product group whom is brought in more frequent?
  Not specifically
- any particular area in the clothing which shows wear and tear?
  No, mostly adjustments, so the clothing is wearable again.
- any textile which needs reparation more often?
  All kinds of fabrics
- do the customers tell their reason why to repair the clothing?
  They bring the clothes, because it is cheaper to repair then to buy new clothes.

* De Keet - H.J.E Wenckebachweg 3004, 1096 DP, Amsterdam
- which product groups are brought in for repair?
  All kinds of productgroups
- any product group whom is brought in more frequent?
  Mostly trousers
- any particular area in the clothing which shows wear and tear?
  Yes, for the trousers, the crotch needs repairing.
- any textile which needs reparation more often?
  Mostly cotton
- do the customers tell their reason why to repair the clothing?
  The wear and tear usually occurs during bike rides, they think it is a shame to just throw the clothes away.
- which product groups are brought in for repair?
All kinds of products
- any product group whom is brought in more frequent?
Mostly trousers or zippers of jackets
- any particular area in the clothing which shows wear and tear?
The crotch in the trousers, but also adjustments as shortening occurs frequently
- any textile which needs reparation more often?
Fabric of pantaloons, but further not textile specific.
- do the customers tell their reason why to repair the clothing?
Emotionally attached to the garment. I have a customer that comes back every half year with the same jacket.

- which product groups are brought in for repair?
Every sort of garment
- any product group whom is brought in more frequent?
Especially jeans
- any particular area in the clothing which shows wear and tear?
For jeans, the area around the bottom, due to cycling.
- any textile which needs reparation more often?
Denim/cotton
- do the customers tell their reason why to repair the clothing?
When the clothes were expensive, people are more likely to repair them. Or the garment has emotional value.

- which product groups are brought in for repair?
Costumes
- any product group whom is brought in more frequent?
Not particular
- any particular area in the clothing which shows wear and tear?
The crotch of the trouser
- any textile which needs reparation more often?
Not noticeable
- do the customers tell their reason why to repair the clothing?
The customers do not want to throw their clothes away due to the value.

- which product groups are brought in for repair?
All sorts of products are brought in.
- any product group whom is brought in more frequent?
Not in particular.
- any particular area in the clothing which shows wear and tear?
Elbows and collars.
- any textile which needs reparation more often?
Not in particular.
- do the customers tell their reason why to repair the clothing?
Emotional value, too pretty or too expensive to throw away.
* Bubble & Stitch - Overtoom 438, 1054 JV, Amsterdam
- *which product groups are brought in for repair?*
  All sorts of products, but it is more related to the kind of repair.
- *any product group whom is brought in more frequent?*
  Trousers, jackets.
- *any particular area in the clothing which shows wear and tear?*
  Buttons, zippers, small tears.
- *any textile which needs reparation more often?*
  Cotton.
- *do the customers tell their reason why to repair the clothing?*
  Since repairing a garment is cheaper than buying a new garment, people are more likely to repair them.

* De Gouden Rits - Dorpsstraat 9, 1421 AR, Uithoorn
- *which product groups are brought in for repair?*
  All sorts of clothing.
- *any product group whom is brought in more frequent?*
  Not in particular.
- *any particular area in the clothing which shows wear and tear?*
  Besides wear and tear, zippers need reparation. Otherwise the crotch.
- *any textile which needs reparation more often?*
  Not noticeable.
- *do the customers tell their reason why to repair the clothing?*
  Favorite clothing that needs reparation.

* Gouden Schaar - Hoofdstraat 146A, 2181 EH, Hillegom
- *which product groups are brought in for repair?*
  All sorts of clothing, all sorts of textile.
- *any product group whom is brought in more frequent?*
  Costumes.
- *any particular area in the clothing which shows wear and tear?*
  Ripped in the seams, or knees, elbows and crotch.
- *any textile which needs reparation more often?*
  Not noticeable.
- *do the customers tell their reason why to repair the clothing?*
  Mostly for the costs.

* Kledingreparatie Begga - Het Ronsel 32, 5527 GR, Hapert
- *which product groups are brought in for repair?*
  All sorts of clothing are brought in.
- *any product group whom is brought in more frequent?*
  Not in particular.
- *any particular area in the clothing which shows wear and tear?*
  Repairing or replacing zippers is a common duty. Not necessarily repairing in the fabric.
- *any textile which needs reparation more often?*
  Cheaper fabrics, the touch and feel show that the fabrics are cheap.
- *do the customers tell their reason why to repair the clothing?*
  Costumers whom have diet a lot, want their jeans smaller. Or because the fashion changed, they want something different in their clothing.
7.5 Consumer survey

Q1: Gender (98 answered)
   Male 20,41%
   Female 79,59%

Q2: Age (99 answered)
   <25 51,52%
   25-50 24,24%
   >50 24,24%

Q3: Main reason to throw away clothes (100 answered)
   Wear and tear 57%
   Does not fit anymore 41%
   Out of fashion 27%
   Decolouring 11%
   Other 11%
      Not wearing anymore 9%
      Like having new clothes 1%
      Not throwing away, giving or selling clothes 1%

Q4: Main reason to repair clothing (84 answered)
   1. Expensive clothing 18 - 21,42%
   2. Still like the garment 15 - 17,86%
   3. Favorite garment 14 - 16,67%
   4. Good fit 11 - 13,10%
   5. Emotional value 9 - 10,71%
   6. Not repairing 7 - 8,33%
   7. Repair garments myself 4 - 4,76%
   8. Still new 3 - 3,57%
   9. Small reparation needed 2 - 2,38%
   10. No good replacement 1 - 1,20%

   Added value (2, 3, 5, 10)
      39
   Stated value (1, 4, 8)
      32

Q5: How old is the oldest garment in your possession? (100 answered)
   1-5 years: 34
   6-10 years: 31
   11-15 years: 7
   16-20 years: 11
   21-25 years: 6
   26-30 years: 3
   > 30 years: 5
   Secondhand: 1
   No idea: 2
   (Older garments are usually wedding costumes or inherited.)
Q6: The reason this old garment in still in your possession. (100 answered)
1. Still fits 28
2. Emotional value 24
3. Timeless 14
4. Still in use 13
5. Maybe want to wear again 9
6. Forgotten 5
7. Still in fashion 5
8. New value 4

Q7: Which garment shows wear and tear the most?
1. Socks
2. Trousers
3. Underwear
4. Tops
5. Jackets
6. Sportswear

Q8: Which place on the garment is most common to show wear and tear?
1. Trouser (crotch) 45
2. Sock (toe) 14
3. Trouser (knee) 13
4. Top (armpit) 11
5. Top (belt area) 7
6. Seams 7
7. Sock (heel) 5
8. Top (elbow) 5
9. Underwear (hip) 4
10. No idea 4
8. Jacket (pocket) 3
8. Crimp (washing) 3
8. General 3
9. Pilling 2
10. Zipper 2
10. Buttons 1
10. Colouration 1
10. Sizing 1
10. Collar 1
10. Machetes 1
10. Trouser (hem) 1
Q9: Does it add value to extend the user durability of clothing?

Yes 66
- Less buying 10
- Longer period of joy 9
- Better for environment 16
- Saving money 17
- For basics 8
- Fit 5

No 36
- Trends 16
- Bad for the economy 3
- No idea 1

7.6 Van Puijenbroek Textiel

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Interesting possible applications that would be suitable for workwear;
- As the sewing thread; a common issue in workwear is that the thread breaks during welding. The thread must be resistant to heat. The stitching is mostly done in a chain stitch. Take into account that the thread needs to be able to fit into the sewing machine and not break while sewing.
- In a particular part of the fabric. For trousers a cloth of 1.5 meters is needed, when a part for the knees is only 0.2 meters. This would mean less costs, while still using the self-healing fibres.
- As a finish; when it would be possible to apply the self-healing capsules in a later process, it could prevent to break the capsules in a too early stadium. A full garment finish would be cheaper than applying the finish in a particular place of a garment.
- As a spray; to make the parts self-healing that are the most vulnerable. And possible to do it multiple times. Downside is that a consumer needs to do it, a spray could get lost.

Too keep in mind;
- The workwear garment need to be able to be washed on 75 degrees and tumble dried.
- Safety restrictions.
Downsides:
- Price
- Is it sustainable too break down?
- What if the fibre itself breaks?
- Fragile during the production

7.7 Fibre2Fashion

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