SMART DENIM

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Acknowledgement

The work presented in this thesis has been carried out at the University College of Boras at Swedish School of Textiles.

We would like to express our gratitude to our supervisor Erik Bresky Head of School Swedish School of Textiles whose encouragement, guidance and support from the initial level to final level enabled us to develop an understanding of the subject.

We would like to thank the Swerea IVF team for their collaboration in providing us with the raw materials and the test analysis of the samples. In addition we would like to thank Konstsilke SKS for their support and lastly the faculty members of the Swedish School of Textiles whose valuable assistance and advice have been decisive for the outcome of the project.

2010-09-07
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Abstract

The paper represents an integration of existing smart textiles materials with in the fashion apparel. A pair of jeans termed as Smart Denim was developed in facility of Swedish School of Textiles with phase change material provided by the research organization Swerea IVF. The product was tested at every stage of development and results were carried out in form of graphs.

The research work was confined and focused on intelligent textiles taking phase change materials for development of smart denim. Smart denim may influence the ability of the fashion industry to meet the new demands. It will also provide insight of positioning the product with in the fashion market which is quite saturated. Integrating phase change materials within fashionable product denim opens a new way of understanding the fashion market.

Keywords: Smart textiles, Phase change materials, Fashion industry, Product positioning, Denim
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1 Introduction

1.1 Research background

In the area of textiles the development of improving the performance, endurance and accuracy of materials has proven to be a never ending process. From our first generation of textiles that were produced through the spinning and weaving of natural fibers, the second generation of textiles offered us manmade fibers such as nylon, polyester and polypropylene. The latest developments and advances in material and biological sciences, nanotechnology and intelligent systems have set the course to enter the third generation of textiles. It has enabled us to produce intelligent fibers and fabrics that can “think” for them.\(^1\) Materials with certain properties which are able react to its environment. Smart textiles are an important emerging field predicted for tremendous growth that could direct to lucrative market potential. The marketplace is steadily pouring out new innovations and improved solutions to conductive materials, chromic materials, SMMs and PCMs. This field of research with special regards to the integration of technologies in smart clothing is expected to hit the market within the coming 5-10 years.\(^2\) SFIT (Smart fabrics and intelligent textiles including wearable computing) counted for a $340mln business in 2006.\(^3\) A fast growing industry estimated to reach $1.3bln in 2012.\(^4\) Today’s main focus is the research and application within the area of biomedical science, military and high performance garments, clothes with particular functional features of protection and safety. The possible fields of applications of intelligent materials are vast. Some are by now developed and gaining profits of its commerciality, whereas some are still in the development/theoretical stage. The benefits acquired by integrating smart technology in fashion are yet to be discovered.

Parallel to the advances in R&D and the increased consumption of smart material, the fashion lifestyle sector has experienced a continuous growth and showing no signs of decline coming years. The global apparel, accessories and luxury goods market generated total revenues of $1,334.1bln in 2008, representing a compound annual growth rate (CAGR) of 2% for the period spanning from 2004 to 2008.\(^5\) Even though the competition is fierce and the pressure is on to maximize margins as profits, especially in times of economic down turn, there are no signs of a slowdown. Parallels can be drawn to the Swedish market, seen as an indicator for the consumption pattern characterised by western societies. The total revenue for the clothing and shoe industry sector in the Swedish market has increased every year since 1996 and landed last year at $80bln. At HUI the prognosis shows a 3% increase for the year 2010.

\(^1\) http://www.fibre2fashion.com/industry-article/technology-industry-article/chameleonic-textiles/chameleonic-textiles1.asp
\(^2\) http://www.tut.fi/units/ms/teva/projects/intelligenttextiles/smart.htm
\(^3\) http://csnej106.csem.ch/sfit/html/background.html
\(^5\) http://www.researchandmarkets.com/reports/838232/consumer_goods_global_industry_guide
In relation to the global apparel goods market, the denim industry’s market share is forecasted to reach $53.2 bln in 2012\(^6\) and $65 bln by 2015\(^7\). The impact of denim in the fashion lifestyle sector has experienced a worldwide acceptance and serves today as an iconic symbol. Once a piece of practical work wear, today denim has reached the status as a staple wear item in anyone’s wardrobe. Fashion brands, either high-end or mass market brands, are likely to incorporate denim wear into their collections. On one hand to offer consumers a comprehensive “top to bottom” line that is easy merchandised but also to gain profits from its saleability. Key stakeholders are the US-, Europe- and Asian markets who count for 97% of the total demand of denim. The growth of the denim jeans industry and the predicted increase is based on the population growth, spending power and the commerciality of the product on a global level.\(^8\)

1.2 Research discussion

The scope and potential of the application of smart materials provides opportunities for the creation of new products that can generate revenue, not only within the field of technical textiles but as well for the realization of the technology in the fashion lifestyle sector. The merger between smart technology and denim has an interesting potential. On average a global consumer owns around seven pair of jeans and wears them three days a week.\(^9\) Today companies are trying to compete for consumers’ attention and investing on fit, style and fashion appeal. The fierce and competitive environment makes continuous investment in new product development and innovation crucial for survival. To integrate smart technology in a fashion material such as denim would bring in functional attributes to a product used for daily basis, rather than occasional. This new field of application would leave a high impact not only at a consumer level but in the industry as a whole. At the same time brands can sustain its leading positions on the denim market, strengthen the brand value and identity by taking a fresh and experimental approach. Adding a new dimension to the very core of a denim product will make a brand take on a unique standpoint. Previous integration of wearable technology through brand collaborations, have left the core intact. The ambition of the smart denim project is to find a solution for how to bring in intelligent textile innovation to a denim product, keeping true to the characteristics and authenticity of the fabric as a material. The technological advances and inventions are available, the challenge is how to commercialize it and apply it to fashion?

The western societies have experienced a shift in production; from being the major producers of denim in the past, global competition has resulted in a relocation of production to low-wage countries. Today Asian manufacturers supply approximately half of the world’s denim capacity.\(^10\) Even though the textile industry in western society has declined it still represents a

\(^{6}\) http://findarticles.com/p/articles/mi_m0EIN/is_2006_Jan_9/ai_n15989539/


\(^{8}\) http://www.prdomain.com/companies/R/Raymond/newsreleases/20068942405.htm


major industrial sector in Europe and employs around 2,2mln people. The situation has lead to
an increased focus on design, quality, re-organisation, vertical integration, consumer brand
building and innovation.\textsuperscript{11} Differentiation is a key for survival and has naturally raised the
interest for intelligent textiles. It meets the criteria of high added value technology and
competitive advantage and talks about opportunities of new and innovative materials and non-
conventional textile applications. Western brands have experienced a transformation from
being a production and resourced based industry to a knowledge based industry.\textsuperscript{12}

At this moment companies are not only faced with the challenge of the economical recession
but as well of environmental issues, global warming, water scarcity, and energy consumption.
The fashion clothing industry pushes through products out to an already saturated
marketplace. Consumers are overwhelmed with products and commodities that they no longer
can digest. As a result prices are pushed down even lower, brands are experiencing difficulties
to keep high sell through and products pushed out to sale. As a natural reaction to the
economical recession, people buy into products and turning either to the lower-, or the higher
end of the price ladder. In addition consumers are more informed than ever and articulate their
demand for responsibility and transparency through their purchase decision. People’s attitudes
to resource shortages, climate change, sustainability and their level of disposable income will
in the long term affect the consumer demand.\textsuperscript{13} The effect of the supply and demand of denim
is leading to an unbalanced situation; estimation points out an increase by 5-6 percent while
the supply exceeds the demand by 3 percent, leaving it to a buyer’s market.\textsuperscript{14}

There is an opportunity for brands to find business models, products as services that can
flourish in a sustainable way. It is crucial for any jeans brand to continuously evaluate market
conditions and map out next strategic moves to take in order to gain further competitive
advantages. The fashion industry is trapped in an unsustainable cycle, based on an economical
model that is nourished by fast fashion and overconsumption. But a separation should be
made between fashion and fast fashion. To be truly sustainable is highly unlikely to happen
since by then companies would not be producing any products at all. The aim for this project
is not to make yet another denim pant, but to make better products that can defend its
existence. By speaking to the consumer about quality, added value and increased comfort
level, the smart denim pant could in the long run extend its product life cycle. The integration
of smart technology in denim, in this case phase change material, would not only bring in
added value of functionality but as well reduce the use of cotton needed. The next step would
be to replace cotton with synthetics, keeping the look and feel of a regular denim pant.

\textsuperscript{12} http://www.emeraldinsight.com/journals.htm?articleid=875554\&show=html
\textsuperscript{13} http://www.forumforthefuture.org/projects/fashion-futures
\textsuperscript{14} http://www.fibre2fashion.com/industry-article/26/2552/trends-and-patterns-of-denim-jeans-demand-in-
india1.asp
1.3 Purpose of research

The aim of the smart denim project is to integrate smart technology in fashion apparel by finding a commercial solution to an innovative and fashion forward denim product.

1.4 Research question

Main question: Which are the possible options to integrate PCMs in a woven fabric?

The research of finding options of how to integrate PCM into a woven fabric will also put light on the commercial aspect of introducing such product into the marketplace. The research therefore highlights the added value a smart denim product could bring to the end consumer as well as the opportunity brands have to differentiate themselves through innovation.

1.5 Scope of research

The limitations of the research have been done in regards to the field of smart textiles, the type of PCM fiber, the choice of product and field of application.

There are several sub categories to smart textiles, such as shape memory materials, chromic materials, conductive yarns, LED and optical fibers. Due to time restrictions this project has let focus on phase change materials and its application to the fashion lifestyle sector, with a further focus on the denim market. The choice of product has been restricted to the jeans pant since it is a garment worn for everyday use. Other fields of application, such as high performance sportswear, military clothing, home furnishing etc. has been disregarded as the technology is more likely to already be in use and commercialized.

The research has further been narrowed down by the choice of phase change material; in this case the type of yarn and fiber used is what Swerea IVF has supplied. Ideal would have been to compare PCMs from various types in order to understand the differences between them as finding best option for integrating it with denim. Out of cost implications and yarn availability it is not possible to accomplish. The type of PCM fiber used in this research has a core of paraffin wax filled with PCM that is covered with a nylon sheath.

Within the area of smart textiles there are several producers and we have chosen to collaborate with Swerea IVF for the supply of PCM yarn, SKS Konstsilke for the twisting requirements. Warping and weaving of denim fabrics has been done at The Swedish School of Textiles.

1.6 Research perspective

The growth of the denim market is a billion dollar industry and has shown to perform steady sales figures year after year. The popularity and easy consumer acceptance has spread the jeans to reach every corner of the world. New product development is crucial to stand against the competition on an already saturated market place. The product strategies of how to bring
in smart technology into denim could lead to lucrative business opportunities for any jeans brand, therefore this research has taken on a business perspective. At a later stage when the final outcome of the smart denim product is performing, a consumer perspective would be interesting to study in order to achieve a holistic point of view of the research idea, its likelihood to be adopted and worn by consumers.

1.7 Research outline

Chapter 1  Introduction: Brings to light the area of research and discussion around the opportunities of merging smart textiles and denim.

Chapter 2  Methodology: Describes the ways of studying and collecting information as well as the planning and implementation of the paper.

Chapter 3  Theoretical study: Describes current developments within the area of smart textiles in regards to PCM, an analysis of the denim industry, its key players, brand comparisons and market potential and the process of manufacturing denim.

Chapter 4  Empirical study: Accounts for the results and findings after making the two woven trials and the final price and cost structure of making a smart denim pant.

Chapter 5  Discussion and Analysis: The theoretical and empirical studies are analyzed and discussion made around the results. Conclusion and suggestions for further research proposals are given.

Chapter 6  Sources and References

Chapter 7  Attachments
2 Methodology

Methodology is the study of the tools used when collecting information. Following section aims to describe how the paper has been planned and implemented. The tools used in order to arrive at new insights can be visualised by the map below. The chosen path that is highlighted in green has been crucial for the entire framework of the research as well as for the final outcome.

<table>
<thead>
<tr>
<th>Research method</th>
<th>Case study</th>
<th>Experiment</th>
<th>Historical method</th>
<th>Survey</th>
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<td>Study approach</td>
<td>Deduction</td>
<td>Abduction</td>
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<td>Survey method</td>
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<td>Data collection</td>
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Figure 1: Methodology

Positivism and hermeneutics are the two scientific approaches a study can undertake. The first one has its roots in the kind of science where you by experiment reach an absolute understanding whereas the latter one relies on the understanding of relative thinking, deriving from a humanistic orientation. (Thurén 1991). The two approaches can be seen as each other’s opposites, but it is complicated to solely remain within one approach when in practice they often overlap each other. Even though this study has an experimental character, where the outcome has given rise to new knowledge, a pure positivistic approach is almost impossible to achieve. In order to find absolute facts, a positivistic approach requires clearing away from everything you thought you knew but in fact nonetheless you knew. From this foundation you would then be able to build further knowledge. As a researcher you must remain objective and not be influenced by speculations or emotions, just rely on your senses and logic. Often research is done with the use of experiment and quantitative measurements.

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15 Own Illustration
statistics and analytical instruments to find clear connections.\(^{17}\) (Thurén 1991). The empirical section of this report has undertaken such orientation but nonetheless the theoretical study is based on previous research done within different areas of marketing and science. It is difficult when interpreting data to ignore past experiences and learned knowledge and keep critical to observations and statements. Hermeneutics studies tries to understand the correlation of different phenomena, seeking a sort of qualitative and holistic point of view. Therefore we cannot exclude the importance the hermeneutics have had on the theoretical framework. This has further laid the foundation of the structure and route of the empirical research and moreover influenced the outcome, analysis and discussion as well.

The students from Textile School gathered in the cafeteria to discuss about the thesis topics as it was announced by the professors that topics should be selected and updated by end of January 2010. This time professors emphasize to make groups of 2-3 students because of more attendance this year. A group of three students was formed at first with two students from Applied Textile and one from Fashion Management. Later a girl from applied textile dropped the course because of her other activities.

The group with 2 members started discussion about the new opportunities in the field of smart textiles. At first it was decided to look deeply in every aspect of smart textiles and try to relate it with a fashionable product. Fashion brands like G-Star and Levis who have been innovative in integrating new technologies into their product line were taken in consideration. Like G-Raw with only dry process on the denim without wash and Levis RedWire with iPod compatible jeans, there were some ideas of integrating zippers in a jacket which makes sounds when in motion. Using of conductive threads in the stitching of a product like jeans or t-shirt which will lights up on its own in the darkness. Theoretical studies were done on every aspect of smart textiles like phase change materials, shape memory materials, conductive materials, color change materials and photovoltaic materials. Every topic itself was so big that it was hard to find a way to the right destination. With a lot discussion with mentor the group decided to focus on one product which was denim. The group approached fashion brand G-star and updated with their idea of integrating smart textiles into their product line with all the marketing strategies and considering brands point of view. The ideas were welcomed but brand was thinking to integrate solar system into their product line where consumer can get their mobile recharge with sunlight. The base was same which was smart textiles but the routes were different.

The group discussed a lot with many professors and students regarding integrating smart textiles in the fashion product. On discussion with Pernilla Walkenström at THS the group came to know about the new fiber which has thermo regulating properties and Swerea IVF has developed the yarn. Considering the depth of each smart textile topics group decided to focus on one chapter which was phase change material and started doing research on it. G-star option was kept aside for a while because it was not relating to the mandate.

With detailed information group decided to take the PCM yarn developed by Swerea IVF and try to integrate in denim fabric. Although Swerea IVF was not sure about the yarn properties when it is dyed because PCM leaks out from the fiber when expose to high temperatures. But in denim fabric the warp yarns are already indigo dyed and it has to be weaved. Swerea provided some yarn which was used in weaving to develop a new denim fabric with thermo regulating properties. A small sample of less than half a meter was developed in weaving lab of THS and was send back to Swerea for testing.

This journey has been quite a bumpy road, from the very first idea to final results. Initial thoughts were replaced or adjusted by new ones as the process went on. After the outcome of the first woven fabric, this data laid the ground for initiating a second trial. The new information was analyzed and questions were raised for how to further improve the properties of the fabric. This approach has let the research commute between empirical knowledge and theoretical facts which is characteristic for an abductive study approach. It can be seen as an ongoing research where new theory gives rise to new questions; it gets tested and results in new theory, further questions and the cycle goes on. The process strengthens the researcher´s interpretation and understanding of the subject but the amount of empirical study is not relevant. Key has been to chose material to study that could give interesting information to further analyze.

The method of analyzing and process the gathered information has been marked by a qualitative direction. Even though the empirical outcome has been analyzed upon measurements, of analyzing data towards set standards which is a typical qualitative aspect, the overall route of getting there has been based on discussions and interpretations. The study has been flexible since initial ideas were adjusted as the project went on; our problem took new direction and helped us to focus and narrow down the research even further. Our own interpretation formed the discussion of how the theoretical foundation could strengthen product value to the end consumer and the quantitative results of the empirical study enhanced the value adding dimension such a product could communicate. The research has by this manner taken an explorative direction. Facing an unknown problem, the project required to gather a big amount of new information. The purpose was to learn as much as possible within the subject of smart textiles and intelligent materials but also the value aspect of a product, how the manufacturing process works, it different phases and the current market situation denim brands are operating in. Only by taking this approach it was possible to gain understanding and insight which later made it easier to analyze. With the positive results Swerea provided much more yarn to develop a more fabric with different amount of PCM in it. In order to twist the cotton yarn with PCM the group went to Konstsillke which has big facility of twisting two yarns. The managing director Mr.Urban Olsson helped a lot to make it possible within a week. The group did a lot of layman work in the weaving lab and making possible to arrange all the requirements of weaving machine which took more than a week of

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18 Patel, Runa, davidsson, Bo (1994) Forskningsmetodikens grunder: att planera, genomfoera och rapportera en undersokning. Lund: Studentlitteratur
time. Finally another denim sample of more PCM was developed and provided to Swerea for testing. Both the samples and their test results are discussed later in the paper.

During the discussion of selecting topic group approached business developer of FOV Fabrics Mr. Fredrik Johansson who showed keen interest in integrating PCM yarn with the synthetic materials. His objective was to replace cotton from the product and to come up with a new product having all synthetic materials in it. Couple of meetings were done at FOV but finally group has taken decision to focus on PCM denim product which itself takes time. The group managed to develop a denim pair of jeans with all the help provided by sewing lab technicians. The PCM denim was functioning properly but in unwash stage. The group decided to send some tubes to a denim factory to make industrialize wash. The wash tubes were send back to Swerea for results which are discussed later in the paper. During the information gathering process we used different techniques which is preferred having an explorative approach.\(^{19}\) (Patel, Davidsson 1994). The use of secondary sources made up for the main part of the theoretical framework. Previous documented data of scientist within different fields were studied. The external secondary data was mostly found in published scientific reports, articles, literature, lecturers and online sources; whiles the internal secondary data was those reports given by the Swerea IVF. In addition the primary sources were the information gathered through interviews, the communication with various parties and own observation and hands on trials of the experiments in the laboratories. This information was time consuming but nevertheless paramount in order to carry through the research.

The validity and reliability is crucial for the credibility of the research. It needs to present reliable and sustainable results as insights that are essential for the reader as other scientists.\(^{20}\) (Merriam 0994) In this project it has meant that measurements are trustworthy carried out with reliable instruments with small random factor and human error as possible. The validity aspect counts for that the researched subject really is the one intended. High reliability does not necessarily mean high validity. One question can give the same answer or nearly the same at different occasions but still does not measure what it is intended to measure.\(^{21}\) Based on the set problem definition, relevant literature and information was gathered and studied which has strengthened the validity of the project. In order to eliminate risks and strengthen the reliability, test results have been carried out for trial 1 as 2, at three occasions and an average value calculated thereafter.

The overload of information makes it hard to not only choose which source to put emphasis on but to find relevant material that is useful for the subject. This explains the necessity of examine, evaluate, compare and select and additionally to take on a critical standpoint. The reliability is extended through the analyses of comparison. If we find a high conformity it can strengthen the sources reliability. The project has been forced to limit the literature to the

\(^{19}\) Patel, Runa, davidsson, Bo (1994) Forskningsmetodikens gruder: att planera, genomföra och rapportera en undersökning. Lund: Studentlitteratur


most recognized scientists and latest research within the different fields. Part of the theoretical study has meant to mainly look into Aaker’s Brand Equity model of the value adding aspect of a brand in which there is a vast amount of literature available. He is often refered to by other authors within the area of marketing which makes the material more valid. On the contrary, there is a limited amount of information available on the subject of intelligent materials and specifically phase change materials. This study has let focus on the specific information on one hand given by Swerea IVF and the literature published by Woodnotes. To fully understand the different types of PCM and its properties it would have been ideal to have worked with different sources but since this is an ongoing research subject by various researchers as brands, information is kept confidential and not published.
3 Theoretical study

3.1 Product Positioning

Positioning is all about the "battle of the mind", in other words it is the establishment of a company’s product in the mind of the consumer relative to those products of competitors that exist in the marketplace. Positioning has become one of the key aspects of marketing communications and provides guidance when introducing new products to the market. The analysis itself helps firms to identify its resources, capabilities and competences that could generate customer value within a specific market. Asan and Polat argue that a firm’s core competences are the basis on which competitive advantage in the market can be build upon. They continue, that a product which is the ultimate expression of a firms unique competence, should therefore have the potential to deliver superior value to its customers, meaning to occupy a certain place in customers mind. The strategic decisions linked to chosen positioning are therefore crucial since they make up for the offer and image that is perceived by consumers. The matter of positioning a product is somewhat complex due to its multidimensional nature. Consideration has to be taken to competitors and customers, their perceptions, belies and attitudes. Therefore positioning is not an abstract subject to confront due to its relation to psychology. This has lead to the various theories and techniques of how to gain understanding. Kalafatis argues that the concept indeed creates confusion. On one hand you have a series of definitions while on the other hand there is hardly any guidance at an operational level for firms to undertake. He claims that the main problem is that positioning strategies are aimed to customer’s perception of the firm. The choice of strategy is not only matter of marketing communications but has to do with the firms behavior as a whole. Every decision as every part of the organization and its activities must deliver the expectations that that particular positioning is related with and be tailored thereafter. Kotler points out the importance of designing a product with intended positioning in mind. To rely on positioning strategies after the product has been designed is practically doomed to fail. Similar is the opinion of whom Kalafatis who argues that a firm’s means of delivering value should not be a part of your strategy, it has to be the foundation of the firm’s business plan.

According to Kotler positioning is about a product being perceived by consumers in a certain way either by an attitude, benefit, the use or application, price, class or level of quality. In essence you may position exactly the same product in a variety of ways but targeting different markets segments and products needs. Based on the brand perception and the product attributes, Aaker discusses four main factors through which a company can position themselves: credence, competitiveness, consistency and clarity. By having a clear positioning

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25 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing


27 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
statement next to competitors, consumers will gain greater understanding for how to relate the product offer to other deals already available on the market. The product or service should offer superior benefits of those of competitors, communicating a consistent message in order to achieve a clear understanding and right perception of the product characteristics. Similar opinion is of those of Ries and Trout who sees positioning as a form of communication exercise to reach consumers in a flooded marketplace. The product has to stand out and be identified as the number one choice whether it is as the superior quality, more durable, safer option etc. If the positioning strategy lacks this focus, the product will most certainly fail and not be remembered by consumers. Michael Treacy and Fred Wiersema suggests three different positioning- or value disciplines; product leadership, operational excellence and consumer intimacy. The three strategies are dependent on the customer preference whether they value the offer being the number one in its product class or how the firm responds to their wishes. It is significant for the firm to take this into consideration and aim to position themselves to be the best in one of these aspect and at least moderate in the other two. To position your self as the best in all three aspects is both complicated and costly. Kotler points out that there is a risk involved in building a multiple positioning strategy instead of single positioning. If a firm claims to have many superior attributes it could cause disbelief and lack of clarity. Fred Crawford and Ryan Mathews recommends five positioning: product, price, ease of access, value-added service and customer experience. In agreement with Kotler, their research concluded that a firm could be dominating in one of these positioning, perform above average on a second and be at industry par with the remaining ones. Vincent goes on that consumers at max can perceive two or three differentiating attributes or benefits at a time. To position a product with more benefits could lead to confusion, which affects the decision making whether to purchase the product or not.

We can now state that positioning guides firms to find focus and spot those opportunities as strategic options that are available in its environment. Asan and Polat make a distinction between competence leveraging and competence building, those options that a firm can execute today or build for future options. They argue that the analysis of future strategic options may lead the way to a future positioning. The exercise in itself can provide valuable information and the discovery of new competences. To build on future competences could make the firm enjoy the benefits of greater competitive advantage in the future. Further, those new competences that create competitive advantages can be transformed to added value in the realisation of offered products. In agreement Kotler mentions that by being smart about combining the company assets and competences resulting in a distinctive product offer, a company can create a sustainable market position. It is about evaluating opportunities and make sure to take strategic decisions that are aligned with the brand mission, and the culture of the company, its heritage and the values that builds up the core of the organization. Asan and Polat continues, that as competence building makes the firm evolve gradually it also

29 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
30 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
31 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
34 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
creates a proactive standpoint for what the future might hold. Even though to compete in today’s scenario the firm needs to execute on current competences and strategic options.

Drummond, Ensor and Ruth presents perceptual mapping of different parameters as a tool to facilitate firms to gain understanding of where they are currently placed in relation to competitors and from that base identify which strategic moves are interesting to take. A perceptual map consists of two or more axes where each one represents a certain dimension or key attributes. These attributes originate from market research where consumers perception are in focus. Perceptual maps can facilitate the analysis of several dimensions such as price, quality, performance, design etc. Below shows a perceptual map of two attributes which probably do not give a complete understanding of the whole competitive landscape that the company is operating in. In order to gain a holistic point of view, several maps can be developed with even three or four dimensions.

Figure 2: Perceptual Map

When deciding on one strategic positioning immediately closes off other options. If a firm would focus on being the low-price option within their strategic group, other functions within the business such as sales marketing and distribution must orient towards the low cost positioning. According to Aaker, the most successful positioning acts on the firm’s/products strengths. It aims at those customers whos need your value proposition meets, in the appropriate channels and prices.

As the market environment changes whether it takes place at a consumer level, new entrances of competitors or development in technology, the dynamics changes the rule of the game. As customer needs and wants change, resources and capabilities have to be adjusted in order to

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offer desirable products. Positioning is a dynamic process and in order to keep a competitive positioning, firms must constantly evaluate market conditions and set up new objectives as positioning strategies. Therefore the alignment between the firm’s competences and the market is critical. Still decisions must be done with care, especially when repositioning occurs since the firm might lose some customer while gaining new ones. According to Kotler, successful positioning happens when firms have managed to become unique and difficult to imitate. With the same opinion Vincent resumes, to endure a competitive advantage a firm’s technology should be protected and difficult for others to copy. In essence surely a product can be copied from its immediate appearance but it’s very core, all the process that lies behind the organizational structure cannot.

Vincent highlights the differentiation between a firm’s brand, which is about attributes that customers associate with the firm and the positioning strategy, which is about the benefits the product, offers the customer. The error that often leads to a product failure when positioned into the market is that the products have a focal point on its attributes or features and not the benefits derived from it. Now that consumers make their purchase decision based on product benefits and not features it is critical to address the value the customer can benefit from using the product. If any changes were necessary to reposition a product it must be believable and that customers appreciate the advantage it could bring them.

As we can recall, Ries and Trout says that positioning is the battle of the mind. They will further explain that the easiest way of getting into a customer’s mind is to be the first. If a firm is the first one to launch a new product it will be remembered but coming second most probably not. This fact provides a great opportunity, since positioning new products have no earlier perception. Therefore there is no worry to become compared with existing product offer in the market which creates room for effective positioning.

3.1.1 New product development as a differentiation strategy

New product development is crucial in order to stay competitive. According to Kotler only 20 percent of new consumer packaged goods that get introduced to the market succeed. He explains: “Innovate or evaporate...If firms do not innovate they will die”. New product development or innovation is what brings to companies forward and allows them to evolve. It

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41 http://www.marsdd.com/entrepreneurs-toolkit/articles/Positioning-Kotler-on-Marketing
47 http://www.marsdd.com/entrepreneurs-toolkit/articles/Innovation-Kotler-on-Marketing
is the growth that forms the future of new brands. Drummond makes a differentiation between *product modification, product imitation and product innovation*.\(^{48}\) New products do not always mean bringing newness into the market that has never been seen before. In fact new products are seldom new in the sense of being innovative. In reality innovation and unique concept ideas stands for a small portion of total product development.\(^{49}\) The reason behind product modification is for a firm to either maintain its competitive position or to make products fit into a different market segment. Product imitation on the other hand is needed for firms who lack resources or are risk averse. According to Drummond a product imitation strategy pays off if the firm manages to add a new aspect to the new version that brings added value to consumers. Companies that invest in innovation and new product development on the other hand aim to either replace existing products or increase customer benefits or to provide product diversification.\(^{50}\) A firm can basically achieve future strategic positioning by laying the foundation build on an idea-, capital- and a talent market. It requires the whole firm to build competences in its various functional activities from the development of the very idea to concept, business analysis, prototype making, marketing and commercialization.\(^{51}\)

Such diversification that new product development brings can give rise them to new markets opportunities. Taking this approach also involves a higher amount of risking that needs to be analysed upon. The Ansoff matrix can describe the relation between products and markets and indicates four combinations of possible market/product strategies. Every combination proposes a certain growth strategy that firms can undertake. The potential success of a firm is dependent on the combination of current and new products within current and new markets as well as the increased risks involved.\(^{52}\)

![Figure 3: Ansoff Matrix](http://dpj.typepad.co.uk/entrepreneur_zest/images/2008/03/26/ansoff_matrix_4.jpg)

When companies operate in a current market situation with existing products the main aim is the maximize sales. Strategies of sales promotions, competitive pricing and advertising may

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\(^{53}\) [http://dpj.typepad.co.uk/entrepreneur_zest/images/2008/03/26/ansoff_matrix_4.jpg](http://dpj.typepad.co.uk/entrepreneur_zest/images/2008/03/26/ansoff_matrix_4.jpg)

19
facilitate the increase of the market share. Market penetration can be considered as low risk taking since firms are dealing with an already existing customer base and products. The main drawback is that this strategy has its limits for market growth. Market development considers new markets for existing product offer such as expansion to new geographical areas, new distribution channels or new market segments. Entering new markets is considered as a semi risk taking plan since it does not affect the product portfolio. In order for companies to stay competitive, investment in product development is crucial. A well balanced product portfolio with already established “cash cows” is ideal; the revenue of these may be invested into new product development that brings the company forward. This plan is considered to be semi risk taking since it involves a revitalization of the product offer only. Diversification is the most risk taking strategy of them all since it deals with both entering new markets with new products that the company is not familiar with. The strategy can either be linked or unrelated to existing activities. The latter one is less to prefer since being difficult to achieve.54

Firms who invest in ongoing development of ideas together with suppliers and interact with different parts of the organisation as customers in order to shape new products, are more likely to succeed in transforming those competences into a differentiation strategy. In this way new product development enables diversification, which in turn can lead to a competitive advantage and establish future market differentiation. There are a variety of ways of differentiating a product but a successful differentiation strategy should according to Aaker include three characteristics: generate customer value, provide perceived value and be difficult to copy.55 In essence the differentiation strategy is one in which a product offers added value that affects customer choice and satisfaction. A successful firm are those who manage to create superior value proposition that exceeds the experience and product promise.56

3.2 Smart textiles

3.2.1 Definition and classification
Smart fabrics and interactive textiles (SFIT) are fibrous structures that are able to sense, actuate, generate/store power and/or communicate57 and defined as textiles that can react to environmental conditions or stimuli from mechanical, thermal, chemical, electrical or magnetic sources.58 These are textiles which offer new functions through the integration of technology into a fabric. By being capable of responding to external stimuli through the use of its functionalities integrated in the textile structure, it differs from regular materials.59 The concept of smart materials appeared in the US with the introduction of shape memory materials in the 1960’s and intelligent polymeric gels in the 1970’s. The term started to gain acceptance, but not until the late 90’s it was established. Intelligent materials on the other hand first appeared in Japan 1989.60

54 Strategic Marketing: Planning and Control, Drummond, Ensor, Achford 2003
56 http://www.marsdd.com/entrepreneurs-toolkit/articles/Value-Kotler-on-Marketing
57 http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04650403
58 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
59 http://www.fibre2fashion.com/industry-article/textile-industry-articles/sensational-smart-clothing/sensational-smart-clothing1.asp
60 http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf
The definition of smart materials as a field of study, can be classified into three main areas; wearable technology, technical textiles and intelligent materials. The main distinction is that wearable technology is textiles with incorporated electronic technology. The design of a garment usually incorporates a practical function or feature and it is not the textiles itself that is smart or reacts to its environment but the added function the technology brings to a garment. Technical textiles can be understood as more “smart” but should not be confused with intelligent textiles. The general definition of technical textiles is materials and products which are primary produced for their technical and performance properties rather than aesthetics. The interpretation is rather vast but key is to highlight the functional aspect of the textile whether it is waterproof, breathable, flame-retardant etc. Intelligent materials on the contrary can be considered as the next step in regards to its smart properties. These are clever fabrics that can “think” for them by the way they sense but also adapt to their surrounding environment. Parallel to the classification of the different fields, smart textiles are as well categorized either as passive-, active-, or ultra smart textiles.61

**Passive Smart Textiles:** passive smart materials are the type of textiles that can only sense certain environmental conditions or stimulus.

**Active Smart Textiles:** active smart textiles have actuators and sensors. The actuators respond to a detected signal, either directly or from a central control unit. Such adaptive materials include shape memory-, chameleon-, water-resistant and vapour permeable, heat storage-, thermo regulated-, vapour absorbing-, heat evolving fabric and materials.

**Ultra Smart Textiles:** ultra smart materials can sense, react and adopt themselves to environmental conditions or stimuli. An ultra smart textile can be compared with how a human brain functions with cognition, reasoning and activating capacities. The fuse between traditional textiles and clothing technology with branches of material science, structural mechanics, sensor/actuator technology, processing technology, artificial intelligence, biology and so on, have made the production of such material now a reality.

Smart textiles is the subject of integration of sensors, actuators, computing (data transmission and processing), and power sources into the material structure. These function create an interactive communication network but not necessarily all textiles contain all functions.

The “smart” function that intelligent textiles provide refers to its capability to sense and respond to its environment. The smart function modifies the state of the textiles by changing form, structure or colour and sometimes leaving a high visual impact and other times changes are done at a molecular stage. Smart textiles with focal point on intelligent materials can be categorised into various areas: phase change materials for its thermo regulating properties, shape memory materials that can take on various shapes when reaching certain temperature, chromic or the often used term chameleon materials which can change colour reversibly due to conditions in the environment, luminescent materials that emit light, conductive materials for its electrical properties, membranes materials for its breathable and impermeable functions, photovoltaic materials that generate electric current by light excitation and e-textiles that have sensors and microchips integrated in the textile structure to detect and analyse stimuli and provide suitable response thereafter. The smart function can be incorporated to the material at different stages of the production/manufacturing process; such as the spinning-, weaving-, knitting phase or even later applied as embroidery, yarn, at sewing or coating, certain finish, laminating or printing. In general, in order to achieve higher level of functionality especially after use, the functional material should be integrated already at an initial fibre stage for the properties to last longer.

3.2.2 State of the art

Smart textiles represent our third generation of textiles that provides us with infinite opportunities to be actualized in the fashion and clothing industry. Already today the research and development of Smart fabrics and interactive textiles have undergone significant accomplishments. Due to its inter-disciplinary character as a subject, the success is not only to be found in the textile industry. It has also gained importance in the fields of science, technology, design, human sciences etc. Current investment is primary done in the field of military where there is a high demand for clothing that can resist extreme weather conditions.

http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf
http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
but we can foresee increased development and innovative solutions presented not only in the field of military but also sportswear, work wear and healthcare. More and more innovation is trickled down into the area of clothing textiles and the use of it in functional lifestyle garments. Consumer interest is rising and smart fabrics are predicted to be the future of textiles, estimated to reach $1.3bln in 2012. At present the US is leading the development of SFIT but major efforts of research are done in Europe as well supported by governments. The branch is at its infancy but realization has triggered collaboration of different fields of expertise in order to achieve results which are commercially attainable. Only in this way we will find continuous progress that will take the development even a step further. Our future scenario is projected to result in intelligent textiles worn as ordinary clothing for everyday use. There are already commercialized products available on the market and others are facing challenges at a research stage. Products vary great at the level of aesthetics and functionality. Following chapter’s aim is to give a brief overview of the state of art within the field of smart materials and its application within the clothing and textile sector.

### 3.2.2.1 Phase change materials (PCM)

That are used in textiles, utilizes microcapsules filled with paraffin wax at its core that are able to store and release heat at certain temperatures. The materials are given its thermo regulating properties either by the application of a coating on a textile surface or at a fibre stage. Today’s main application is the use of PCM in active wear where there is a need of neutralising the heat released from the body to the surrounding environment. Normal active wear garments cannot deal with the amount of heat that is released which causes thermal stress. OUTLAST produced PCM integrated in textiles that can increase the user comfort when wearing such garment. By absorbing excess heat the user will keep a stable comfort level inside as outside. Thermo regulating products that have been commercialised and using the OUTLAST-, Comfortemp-, or Schoeller PCMs are within the categories: outerwear jackets, first layer t-shirts, shirts, bedding articles, shoes, gloves and car seating’s.

![Figure 5: Kjus Outerwear Schoeller PCM Lining](image1)

![Figure 6: Bedlinen with Outlast PCM Technology](image2)

### 3.2.2.2 Shape memory materials (SMM)

Have the ability to take on different shapes at a pre determined temperature. Shape memory alloys remember the parent shape and return to the initial shape from a temporary shape by

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66 [http://www.outlast.com](http://www.outlast.com)
the application of heat.\textsuperscript{67} This type of material has its derivation from the UK defence Clothing and Textile Agency. There is another kind of SMM that instead of reacting to heat as stimuli it responds to electrical incitement and thereafter called electroactive polymers (EAPs). The latter type has experienced a significant progress in performance and its field of application. The main field of application is in the medical science. EPAs “gel robots” for example are acids used in the medical area as a replacement of muscles and tendons. In the textile clothing area SMMs are used for its protective properties from changeable weather conditions, such as extreme heat. Thereof it has proven to be very suitable in application in the military and homeland security. The SMM alloys are incorporated between the layers of a garment as a film. The space in between the layers is able to extend by activation which results in an increased protection and insulation level to external heat. Due to its protective properties this type of textiles is suitable work wear for fire fighters. Ideal would be to find a solution to a garment that can adjust the air gap between the layers of a garment which would reduced the need for layers of garment.\textsuperscript{68} Within the fashion area Corpo Nove manufactured a novelty shirt made out of smart memory alloy fiber blended with nylon. The sleeves of the garment started rolling up at a pre set temperature. Since the shirt was made out of SMA fibers it returned to its initial state with no need of ironing the shirt afterwards.\textsuperscript{69} The technology is starting to be used in fashion to create an artistic visual impact such as the Outsourcing shape shifting hood that senses the users and subtly transform itself through the memory alloys.\textsuperscript{70}

\begin{figure}
\centering
\includegraphics[width=0.4\textwidth]{Corpo_Nove_Smart_Shirt_SMM.png}
\includegraphics[width=0.4\textwidth]{Outsourcing_Shape_Shifting_Hood_SMM.png}
\caption{Corpo Nove Smart Shirt SMM}
\caption{Outsourcing Shape Shifting Hood, SMM}
\end{figure}

3.2.2.3 Chromic materials

are of interest for the fashion industry due to their unique characteristic of changing colour reversibly either by: radiation-, change or erasing colour. Chromism simply means color change and the materials that demonstrate color change properties are known as Chromic materials. Due to the colour changing properties the term “chameleon” fabric is often used. The transformation from one state to another is caused by external stimuli such as heat, light, electricity, pressure, liquid or gas.\textsuperscript{71} Today there are textured yarns for knitting and weaving available as well as embroidery threads and inks that can be applied directly to the textile surface. The main difference from applying chromatic properties to a material at a fiber stage to an ink stage is the final effect the treatment has on the product itself. When an ink is printed to a textile it will last only a few months of outdoor exposure. The inks that have the

\textsuperscript{67} http://www.fibre2fashion.com/industry-article/textile-industry-articles/shape-memory-polymer-fibers-for-comfort-wear/shape-memory-polymer-fibers-for-comfort-wear1.asp

\textsuperscript{68} HU, Jinlian (2007) Shape Memory Polymers and Textiles Woodhead Publishing

\textsuperscript{69} http://findarticles.com/p/articles/mi_m0HWW/is_31_4/ai_77673321/

\textsuperscript{70} http://www.fashioningtech.com/profiles/blogs/interactive-fashion-gets

highest performance today will only withstand about 20 washings after printing. By pigment
dying the fiber, the chromatic material is not used in coating/printing and does not wash off as
easily. The colour change properties has been tested and approved to withstand 2000
alternations which accounts for the lifetime of a product.72 Already back in 1989 there was a
t-shirt made out of photochromic material (activated by light) introduced on the
marketplace.73 Even though thermochromic materials, that react on heat as stimulus, have
been the most successful types in the textile industry. Solvate chromic materials can be found
in retail stores on garment such as swimsuit that change colour when in touch with water.74
The first fashion garment with thermo chromic properties was introduced in the beginning
90’s but many have the opinion that colour change is a temporary fad that eventually will
come to an end. Therefore the increased performance of the fiber or dye, its endurance and
accuracy, is vital to be improved but also to find suitable fields of application.75 Another
example made at the Swedish Textile School is the swine flu mask that changes colour/pattern
when the temperature of your breath changes.76 Since the function of chromic materials is to
make patterns appear and disappear it has shown to be very useful in military clothing and
camouflage effect. Recent developments are around the “Predator” clothing that can take
digital images of its surroundings and duplicate it into the clothes.77

![Figure 9: Solvatechromic Pattern Changing Swimsuit](image1)
![Figure 10: Thermochromic Swine Flu Mask](image2)

### 3.2.2.4 Luminescent materials

Come in various types, but the ones used in textiles emit light when triggered by either a
stimulus of light (photoluminescence) conduction of light (opticoluminescence) or electricity
(electroluminescence). Photo luminescent materials in textiles have been used in labels with
UV revelation materials for the purpose of revealing counterfeit goods. The “glow in the
dark” effect can also be found on find inks that are applied on work wear garments, which can
store light during the day that in bad conditions start emitting the light. The same technique
can be found on carpets for security reasons, such as the aisle of airplanes. In fashion
garments have been produced that emit light in the dark as a fun design effect. Opticoluminescence materials on the other hand are to be found in optical fibres which are
integrated in the manufacturing of textiles. Curtains with optical fibres can be found on the
market. Luminescent materials that emit light due to electricity are not that common in

73 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
75 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
76 http://inventorspot.com/articles/masks_39973
77 http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf
textiles, but there is electroluminescent yarns available used for fashion garments and protection work wear. This area of smart textiles is undergoing a lot of research due to the development of light emitting diodes. Due to the LED’s flexibility it has experiences success in its use in screens of wearable computers. The Swedish Interactive studios has introduced the Energy curtain that that charges up during the day and use embedded materials to provide illumination at night, the content of the curtain is made out of the blend of cotton, solar collecting and light emitting materials. Illuminated dresses such as the Galaxy dress worn by Kate Perry or the dress designed by Alexandre Vauthier worn by Rhianna, have been seen on the red carpet using a combination of compressing gas systems and video capable LED circuits. Another example is the CO2 dress, a project made at the Danish Design School, which senses the radiation level of pollution and changes pattern according to its environment. The patterns are made out of LED lights powered by soft circuits and conductive yarns integrated in the textile. SKIN is another project done by Philips within the area of soft technology that show emotional sensing translated into light patterns and colour that interact with the environment. The University of Tokyo presented in 2003 the Invisible Jacket using optical camouflage technology. The invisible effect was caused by a video camera that was placed behind the garment sending footage information to a projector which bounced back the image to the front of the garment.

![Figure 11: CO2 Dress, Illumination Dress, Kazutoshi Obana’s Invisible Jacket](image)

### 3.2.2.5 Conductive materials

Functional benefit is to achieve electrical or thermal conductive fabrics. Fabrics that exhibit conductivity or serve an electronic or computational function are often refer to as electro textiles. The material can be split into two categories either intrinsically conductive fibres or the fibres treated to gain conductivity. The first one are conductive materials with metallic content such as aluminium, copper and stainless steel. It is also possible to use materials such as titanium, silver or gold but these are more pricy. Conductive polymers are an alternative to metals which is undergoing development and refers to the use of conductive yarns with content of polythiophene, polyaniline. Both types of materials are lightweight, flexible, durable, cost competitive and suitable for textile manufacturing. The second category of

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80 [http://www.dailymail.co.uk/tvshowbiz/article-1271640/Met-Costume-Institute-Gala-Katy-Perry.html](http://www.dailymail.co.uk/tvshowbiz/article-1271640/Met-Costume-Institute-Gala-Katy-Perry.html)
81 [http://www.talk2myshirt.com/blog/archives/4175](http://www.talk2myshirt.com/blog/archives/4175)
82 [http://diffus.dk/pollutiondress/intro.htm](http://diffus.dk/pollutiondress/intro.htm)
85 [http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf](http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf)
86 [http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf](http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf)
Conductive materials which have been treated in such way to achieve conductivity can be applied as an ink or coating. In this case a metal ink is applied to the textile surface with an addition of nickel, copper, silver or carbon. Depending on desired effect and application the coated ink can vary in thickness. Electro conductive fibres have possess many functions, main benefits are to provide an electromagnetic shielding (EMI), antistatic-, electronic applications, infrared absorption or as protective clothing. Recently conductive fibres are finding new areas of application in the development of electronics integrated in smart textiles. Conductive polymers are used in the area of sportswear due to its increase thermal conductivity, heated clothes for extreme weather conditions, diving suits etc. In order for the fabric to attain its properties, an electric source that generates energy is needed. Today’s main area of application in fashion is the use of conductive textiles for its use as power supply of electronic device in garments, wearable electronics. Wearable systems in textiles work as an interface between the wearer and the garment. Through interaction the textile has the ability to read an activity or status of the user and use this information to adjust the function of the system. The electro conductive function can have different levels of integration in the textiles, from textile adapted to textile integrated and textile based. In the end of the day the electro functions are still not textile components which mean means that you still have problems around washing, durability and comfort.

Figure 12: O'Neill Hub Jacket, H2 Line and H3 Line

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87 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
88 http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf
89 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
90 http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf
Jackets with wearable electronic equipment could be first seen in the sports lifestyle market in the beginning of 2000. The brand O’Neill introduced the Hub Jacket with mobile communications and entertainment in 2004. The snowboard jacket had a removable mp3 player, Bluetooth cell phone system and a fabric keyboard integrated in the garment. Already a year later the new H2 line consisted of an iPod ready jacket, 2 backpacks with iPod control, Bluetooth and additionally solar cells to recharge your mobile phone and iPod. The evolution of the H3 line brought the Fat controller glove to consumers in 2008, which let you control your iPod wirelessly from the glove itself. O’Neills H4 line will be the four generation of wearable electronics and consist of walkie-talkies, access to iPod, mp3 player, headsets and camera equipment.91

3.2.2.6 Membranes materials
Derive from multi-disciplinary research and development of laminating technology of microcoporous and hydrophilic membranes. These membranes are made out of biopolymers or synthetics placed in layers. Membranes are often used in active sportswear to make fabrics breathable or water repellent. Gore-Tex manufactures membranes that have been successfully commercialised; microporous bi component membranes. These are made out of to layers; main part of ePTFE and an oleophobic layer that repels natural oils from the human body. The face of the membranes is coated with another layer of hydrophobic treatment that gives that fabric a water repellent finish. Another membrane that has experienced success on the market is the Lotus effect applied as membranes or coatings. This technology is used for self-cleaning properties in garments which have shown to be commercially interesting.92

3.2.2.7 Photovoltaic materials
Have the capacity to generate electric current by light excitation. There are three different types of solar cells; the silicon type has been successfully commercialised and the energy conversion effect varies between 6% to 30%. The film solar cell with content of cadmium telluride, copper indium (CIS or CIGS) has an efficiency of 11-14% and come with the benefit of lighter weight and thin properties that is suitable to integrate in textiles. The third type is the organic solar cell, which is undergoing extended research. Its efficiency reach around 5% but ongoing technical development is expecting to reach higher performance coming years. You can find solar cells applied integrated in textiles for electronic devices, so called e-textiles. The many examples found today is the use of solar cells for charging batteries that deliver energy for certain devices such as mobile phones or mp3 players.93 Ermenegildo Zegna introduced in 2008 the Solar jacket, a collaboration with Interactive Wear AG and Solar AG.94 The garment had applied solar cells on the collar t which could store enough power to charge a mobile phone, iPod, mp3 player or handheld communication device, by harnessing the suns energy. Research at the Danish School of Design has engaged in the issue of power supply and invented a textile-based screen printed solar panel that can be integrated directly into garments. The solar technology is incorporated in a transparent

91 http://www.crunchwear.com/oneill-4th-generation-clothing-line/
92 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
93 http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
organdie textile and can be manufactured using silkscreen printing techniques. The ILLUM cycling jacket uses printed electroluminescent ink and printed photovoltaic technology that make the external shell able to self charge itself, providing a safety value aspect to the consumer. Another example of a commercialised product is the Voltaic Solar Panel backpack that charges virtually all handheld electronics. The solar panels are light, waterproof and produce 3 power hours of play time or 1.5 hour of phone talk when charging it for 1 hour in the sun.

![Figure 13: Solar Jacket, Printed Solar, Illuminiam Jacket, Solar Bagpack]

### 3.2.2.8 Electronic materials

Refer to the integration of miniaturised electronics as sensors and microchips in textiles that detect and analyses stimuli and respond thereafter. These types of textiles are often referred to as e-textiles or textronics. The main area of research has been within military and medical area, but now efforts have proven to be useful in others fields as well. Garments that carries this technology can monitor the users heartbeat, EKG, respiration, temperature and also could signal is there would be default. In 1996 the US Naval department introduced the Wearable Motherboard or the so called Smart shirt that initially was developed for combat conditions. The sensing devices that were attached to a computerised shirt gave created a flexible motherboard. The device itself is made out of woven plastic optical fibres and other technical threads that are integrated in the textile structure. The benefit is the immediate alert for medical attention that the shirt communicates. The shirt can integrate different types of sensing devices depending on the end use. For fire fighters, the need to monitor oxygen or hazardous gas levels is relevant. Other sensors are able to monitor respiration and body temperature, for example the baby vest. The main commercial application areas today are within medical-, disease-, infant monitoring, athletics and military uses. Other commercialised products are the Life shirt system that gathers data during the user’s daily routine and providing pharmaceutical researchers with a complete picture of the user’s health in real life situations compared to a clinic visit. Electronic materials with interactive and portable devices have shown to be have lucrative market potential. From the innovation of keyboard made out of single layer fabric with sensing electrodes as point of contact, which had the benefit of being flexible, durable and responsive to touch, new products were launched on the market. First out was the KENPO Jacket with integrated mp3 player the

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IPod jeans made by Levis\textsuperscript{100} and later gloves with integrated mobile phones. Now we can also find innovations with focus on security such as integration of GPS in garments to detect the user location, especially for children or extreme sports garments. Ongoing research focus is to develop a wearable computer integrating computer screens, CPU and keyboard in a wearable garment, but this has still not reached the market.\textsuperscript{101}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure14.png}
\caption{Baby Vest, Kenpo Jacket, Smart Shirt, Levi's RedWire}
\end{figure}

\subsection*{3.2.3 Phase Change Materials}

\subsubsection*{3.2.3.1 Body and clothing system}
Whenever a motion is occurred in a body it means that some amount of heat is absorbed. During this absorption the body temperature is increasing regularly. Similarly when a body is cooled down it means that the amount of heat which was stored is released to the environment.\textsuperscript{102} A human body temperature is maintained at 36.5 degrees while a comfortable skin temperature is around 33.4 degrees. However, the temperature differs depending on which part of the body you are referring to, the fluctuations depending on the time of the day and the physical activity. The temperature around head and trunk is around 34-36.5 degrees\textsuperscript{103}, the torso around 33 degrees but the temperature of the feet is around 30C-3 IC.\textsuperscript{104} When the temperature increases or decreases more than 4.5 degrees, the body starts feeling uncomfortable. The heat that a human body releases depends on the physical activity she undergoes can vary between 100 watts at resting and 1250 watts during physical performance. Under physical performance the muscle temperature can increase up to 39-40 degrees.\textsuperscript{105} The body neutralizes the increased heat by perspiration, energy is withdrawn and the body cools down. If the thermal insulation of a fabric/garment would be low at such activity, the body would not need to perspire as much due to the convection of heat.\textsuperscript{106}

Fibers which are commonly used in clothing are cotton, wool, silk, hemp, polyesters etc. have all their own heat insulation properties. The thermal insulation of a garment is dependent on the thickness and density of the fabric but external temperature is nevertheless a major influence.\textsuperscript{107} The loftiness of the fabric stands for the main insulation capacity referred to as

\begin{thebibliography}{99}
\bibitem{100} http://www.ap.levi.com/redwire/
\bibitem{101} http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852
\bibitem{102} http://www.tut.fi/units/ms/teva/projects/intelligenttextiles/index3.htm
\bibitem{103} Matilla. H (2006) \textit{Intelligent Textiles and Clothing} Woodhead Publishing
\bibitem{104} http://www.fibre2fashion.com/industry-article/9/884/phase-change-materials-overview1.asp
\bibitem{106} http://www.fibre2fashion.com/industry-article/9/884/phase-change-materials-overview1.asp
\bibitem{107} http://www.fibre2fashion.com/industry-article/9/884/phase-change-materials-overview1.asp
\end{thebibliography}
passive insulation which limits the heat flux from the body to the environment. At extreme weather conditions, whether it is high or low temperature, the thermal insulation of a fabric is decreased. However, clothes are put on and off in order to get the body at a comfortable temperature. If clothes would have thermo regulating properties of keeping the body at constant temperature then there would be no need of changing layers of clothes so often. The greater the thermal insulation capacity a garment has the thicker it naturally will become, but it would also affect the wearers freedom of movement. Thus, the use of incorporating phase change materials in clothes is to achieve such thermo regulating properties an intelligent material can offer, by controlling the heat flux it lets the user experience an increased comfort level.

### 3.2.3.2 Definition and Classification
According to Outlast Technologies, leading producer of PCM’s, the definition that characterizes phase change materials can be summoned as follows: “PCMs are materials that can absorb, store and release heat while the material changes from solid to liquid and back to solid. This is known as a phase change”.

All materials absorb heat during a heating process when the temperature is rising. In general there are three main states of matter; solid, liquid and gaseous states where the conversion of solid to liquid state and liquid to solid is based on a heat transfer system. Most materials can store heat energy (latent heat) by absorbing it but its capacity depends on the type of materials and the temperature released. For example a metal can get heated up very quickly and take more time to cool down compared to wood. This has to do with the property of the material and its ability to absorb and release heat. Water is another example considered to be a good phase change material because of its freezing and boiling temperatures. It has a boiling temperature of 100 degrees and it freezes at 0 degrees. Water has several phases and changes it states from solid to liquid and then to gaseous state with the increase in temperature. This phase change of materials, from one state to another happens due to the energy released from the material.

When phase change materials are integrated in clothing it gives the effect of thermo regulating properties to a garment. When the body temperature increases, the heat that is released is absorbed and stored by the PCM in the fabric. The temperature of the PCM rises until it reaches its melting point. This causes that the wax at the very core of the PCM starts to melt and changes its state from solid to liquid state. During this phase change the temperature remains constant. An endothermic reaction occurs when the wax is melt which absorbs the excess heat and give rise to a cooling effect. This reaction is opposite when the body temperature is lowered, then the wax becomes hard which provides warmth to the body.

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111 [http://ezinearticles.com/?Pcm-In-Textiles&id=367030](http://ezinearticles.com/?Pcm-In-Textiles&id=367030)
Phase change materials has a melting point ranging from 20 degrees to 40 degrees and a limit of 10 degrees to 30 degree to get back to its solid state. During the phase change energy is absorbed by the material which breaks down the solid structure into liquid. At the time the PCM has fully melted, the storage of heat will stop and there will no longer be any effect of the PCM left. In order for the PCM to work the material it must go through the transition temperature, otherwise there will be no effect at all.\textsuperscript{114} It has been observed that approximately 200 KJ/kg of heat is absorbed in the melting process of PCM. Similarly a normal textile material absorbs about one KJ per kilogram of heat while its temperature rises by one degree Celsius. Within the human comfort range of temperature, PCMs store 5-14 times more heat per unit volume than sensible storage materials.\textsuperscript{115} PCM is considered to be a source of heat storage which is quite logical because the temperature of the PCM remains in constant state during the melting process and crystallization process.\textsuperscript{116}

![Figure 15: Heat Transfer of PCM](image)

### 3.2.3.3 Field of application

The major end use areas of the application of PCMs are in lifestyle apparel (smart jackets, vests, hats, gloves and rainwear) outdoor active apparel (jackets and linings, boots, socks ski and snowboard gloves) protective garments (fire fighter uniforms, bullet proof vests) and domestic textiles (blinds and curtains, floor coverings, chair cushioning, sofa seating’s, bedding, mattresses, pillows and blankets). PCM products can also be found in industrial applications (solar energy storage, building materials, heat pumps, heat distribution systems, air conditioning, coatings of textiles used in roof covering for thermal insulation that gets recharge during night) and automobile interiors. However the suitable effect of a garment is dependent on the design and construction of the product. It is paramount to determinate the PCM quantity that is necessary according to the level of physical activity but also where the PCM should give effect on the product and relate the melting point of the phase change to that particular part of the skin temperature. Commercially available clothes with PCM content can mainly be found in the area of sportswear.\textsuperscript{117}

\textsuperscript{114} http://ezinearticles.com/?Pcm-In-Textiles&id=367030
\textsuperscript{115} http://www.fibre2fashion.com/industry-article/9/884/phase-change-materials-overview1.asp
\textsuperscript{116} http://www.tut.fi/units/ms/teva/projects/intelligenttextiles/index3.htm
\textsuperscript{117} Mattila, H. (2006) Intelligent textiles and clothing Woodhead Publishing
3.2.3.4 PCM Roadmap
Below describes the road map of phase change materials; the different types, its application, spinning method and process. This report describes the different options available in order to show comparable data, advantages as disadvantages.

![PCM Roadmap](image)

3.2.3.5 Categories of PCM
There are four types of PCM compounds which are applicable in clothing. Every category has different heat storage capacity and temperatures and is therefore used depending on the application of the end product.

3.2.3.5.1 Hydrated Inorganic Salts
Hydrated inorganic salts have a heat absorbing temperature at 20 degrees and heat releasing temperature at 40 degrees which means that these compounds are effective for clothing. Their heat of fusion is quite high ranging from 150 to 300 J/Kg². The disadvantage of these compounds is that after continual cooling and heating, they start showing different melting and crystallization points which could be very inadequate for the use in certain products.

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118 A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
3.2.3.5.2 Polyhydric Alcohols
Polyhydric alcohols have a low molecular weight and several hydroxyl groups can be included under this category. The phase change occurs without changing the actual state. It means that they do not have any melting or crystallization points but when heat is applied the change goes from solid to solid states. Since these compounds are very soluble in water they require encapsulation when applying in clothing. A few solid to solid PCM’s have been identified suitable for thermal storage\textsuperscript{119}, the main disadvantage of these compounds is that due to the high solubility rate they become inappropriate for washing and therefore not suitable to use in clothing.\textsuperscript{120}

3.2.3.5.3 Polymers
Different types of Polymers can be used as a PCM in clothing. One type of polymers is Polyethylene Glycol (PEG) which has very high molecular weight. This means that the higher the molecular weight is, the higher is the melting point of the polymer. The disadvantage of PEG is that they are soluble in water which restricts them to be used as PCM in clothing. Another type of polymers is the block polymer which is actually the result of a blend of PEG and PET. These polymers have high molecular weight; a melting point is 33 degrees and can be melt spun into fibers. The third type of polymer is the Polytetramethylene glycol (PTMG) which has maximum melting temperature of 43 degrees. The use PTMG is somehow limited because they have weak interactions between the polymer chains due to which the crystallization point is not achieved.\textsuperscript{121}

3.2.3.5.4 Linear Chain Hydrocarbons
The most commonly used type of PCM for thermo regulating properties and heat storage applications in clothing and textiles are the linear chain hydrocarbons. These compounds are made of by-products of oil refining which are in form of wax. They are available on the market under the brand name Rubitherm. The main advantage is that the various melting points and crystallization points available that are dependent on the amount of carbon atoms\textsuperscript{122}. PCM is encapsulated into microcapsules in order to avoid dissolution from the fabric or fiber when it is in a liquid form. The size of the capsules ranges from 1-30\textmu m in diameter but minimum size can be 1/20 with a shell around it which is 1\textmu m thick. To prevent these hydrocarbons to leak the core is covered by a thin polymer shell in order for the phase change to occur within the shells.\textsuperscript{123} The shell of the capsule must be strong and durable so that it can withstand chemicals, mechanicals motions and heat without breaking.\textsuperscript{124} The size of the microcapsule and the encapsulation process determines the effect of PC temperature. The larger the capsule the closer melting point is to the core materials. The smaller the

\textsuperscript{120} A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
capsule the greater difference between the melting point and crystallization point of the PCM.\textsuperscript{125}

Various types of paraffin waxes are attached to different fibers of fabrics which are filled with microcapsules. The most common waxes that can be used for PCM are: Eicosane, Octadene, Nonadecane, Heptadecane and Hexadecane. All of them have different melting and freezing points as well as ability to absorb and release the heat. When these are integrated into a microcapsule their temperature is maintained at 30-34 degrees which is quite suitable for the body temperature\textsuperscript{126}. Below table shows different types of linear chain hydrocarbons with comparable melting points, crystallization points and heat capacity storage. In order to achieve desired melting point outside the range, a mixture of different waxes is possible.

<table>
<thead>
<tr>
<th>Phase change material</th>
<th>Melting temperature in °C</th>
<th>Crystallization temperature in °C</th>
<th>Heat storage capacity in J/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eicosane</td>
<td>36.1</td>
<td>30.6</td>
<td>247</td>
</tr>
<tr>
<td>Nonadecane</td>
<td>32.1</td>
<td>26.4</td>
<td>222</td>
</tr>
<tr>
<td>Octadecane</td>
<td>28.2</td>
<td>25.4</td>
<td>244</td>
</tr>
<tr>
<td>Heptadecane</td>
<td>22.5</td>
<td>21.5</td>
<td>213</td>
</tr>
<tr>
<td>Hexadecane</td>
<td>18.5</td>
<td>16.2</td>
<td>237</td>
</tr>
</tbody>
</table>

Figure 17: Waxes Chart

The durability of PCM depends upon the heat capacity stored and the amount of PCM used in the process. The usage of the end product should be clear so that temperature level and amount of PCM used can be defined. Every product has different usage and PCM should be applied for that particular use. For example, inner layers like undergarments are much closer to the body while outer layers like jackets are not that close. So amount of PCM used in both of the product varies because of different temperatures which will be closer to the bodies.\textsuperscript{127} Since this is a byproduct of petroleum, one of the main advantages is the cost competitiveness of this type of compound, on the other hand the low resistance to ignition is negative but can be solve by adding fire retardants.

3.2.3.6 The incorporation PCMs into Fabric

Microencapsulated PCMs can be added to a fabric in different ways, either the PCM is build in at a fibers level already or it is applied as a coatings on top of the textile structure or fiber. Foam made out of PCM is another area also available on the market. The two methods for applying PCM are normally referred to as: coating pre-formed fibers/fabrics and the fiber spinning process. Coating of pre-formed fibers or fabrics can be further classified into four sub-categories; Coating of fibers, Microencapsulated PCM’s applied as coatings, Impregnating fibers and the Filling of hollow fibers. PCM on the other hand can be integrated during spinning process either through microencapsulation of PCMs or through multi component fibers. Both methods will be described below.

\textsuperscript{126}http://ezinearticles.com/?Pcm-In-Textiles&id=367030
3.2.3.6.1 Coating Pre-formed fibers of fabrics

**Coating of fibers**
The development of the use of applying PEG as fiber-coating in clothing has undergone a lot of research since the 80’s. Due to the PEG characteristics of being soluble in water it has challenged scientist to come up with new solutions for how to protect it from water in order to be suitable for clothing. Cross linking of different acid catalysts with PEG has been one of them. This technique let the PCM solution be padded onto the fabric in water, which was measured after drying. The results showed that the thermal storage and release properties could undergo around 150 cycles; the degree of cross linking was paramount in order to increase the thermal activity of the fabric.\(^{128}\)

Outlast invented another technique for coating fibers with the use of polymer film in which the PCM is incorporated. The polymer film containing PCM was laminated onto the fabric directly which reduces the breathability of fabric. The PCM made this way is suitable for non woven protective garments in which fabrics doesn’t need the same breathability properties as everyday clothing. The PCM polymer film was applied as a thick layer inside the garment. The outcome of the test results was positive; the increase in temperature of a non woven garment without PCM was much higher compared to the non woven garment containing PCM. Additionally, the technique made it possible to reach a high amount of PCM per unit area, resulting in that the weight of a garment could be minimized.\(^{129}\)

**Microencapsulated PCMs applied as coatings**
Within the area of integrating PCM as coating onto a textile, the technique known as most successful is the coating individual fibers or fabric with a polymeric binder that contains microcapsules of PCMs. The main drawbacks of applying PCM as a coating is the fabric stiffness and low elasticity, the decreased air permeability and vapour moister that affects the thermal comfort of a garment. In addition the microencapsulation of PCM in itself is a rather complex and expensive process. Extended research in this field has given rise to several patents showing different methods of improving the performance of a fabric treated with such coating.\(^{130}\)

One of the first patents that explained a new coating method of deposition of PCM microcapsules onto fibers, were registered in 1994 by Bryant and Colvin. The coating contained a polymeric binder and PCM microcapsules. This method recommended the use of linear chain hydrocarbons and polyhydric alcohols as PCM compounds which was interesting since it brought up to light that different types of PCMs could be incorporated into the same fabric. The inventors claimed that this method gave much better results as the fiber or fabric easily could resist wash and there was no possibility of PCM leakage. Later research showed that coating equipment sometimes failed to evenly spread out the microcapsules into the fabric, making it less durable. In addition the solvent printer and the temperature used could

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\(^{128}\) A report on *Phase Change Materials* from *Swerea IVF* provided by Bengt Hagström  
\(^{129}\) A report on *Phase Change Materials* from *Swerea IVF* provided by Bengt Hagström  
\(^{130}\) A report on *Phase Change Materials* from *Swerea IVF* provided by Bengt Hagström
harm the microcapsules while processing. The application of even more binder could solve the possible gaps of microcapsules in the fabric but the main drawback was that the fabric itself got even stiffer. This problem was worked out by Zuckerman who offered a solution that included a coating with added surfactant, a dispersant, antifoam agent and thickener. In 2001 Shim, McCullough and Jones research concluded that PCM in clothing should have little effect on the temperature of a human body or the wearer’s perception of thermal comfort. This was based on real hands on studies made of a knitted fleece polyester fabric with a PCM coating. This method worked out when applied in the inner layer of a garment because then the thermo regulating effect would react with the body temperature. While applying it on the outer layer of a fabric it would react with environment temperature and not be affected by the body temperature. Test results showed a 15 minutes long thermo regulating effect when the garment was temporarily heated or cooled down. In addition the more PCM the garment contained and the more coverage of the body, the better the effect would be.\(^\text{131}\)

This was later confirmed by Sutter and Lotenbach who presented research that showed that in order to gain thermo regulating for a longer period of time, the amount of PCM should be high. This method consisted of the application of microcapsules containing PCM in the form of naps. By applying it through a printing process the spread out of the microcapsules could be controlled. Small pre determined gaps where left unprinted with coating in order for the garment to later keep its properties of elasticity, breathability, less stiffness and increased comfort.\(^\text{132}\)

**Impregnating Fibers**

In 1989 a patent was registered by Salyer which explains another way of incorporating PCM through the crosslinkage of linear chain hydrocarbons and polyolefin composites. The cross linkage process was achieved by a high density polyethylene in which polyolefin was immersed in hot melting temperature with PCM. This process showed to be not that successful because after wearing and washing the PC material was migrating from the textile structure of the fabric.\(^\text{133}\)

**Filling Hollow Fibers**

The term hollow fiber was first introduced by Hansen back in 1971. He came up with the idea of blending gas and PCM in sealed filaments which when exposed to an environment where the temperature would go down, the gas would be less soluble and the PCM would turn into a solid state. While the temperature would drop the more inflated the fiber would become, resulting in a thermo insulating effect. The reversed procedure would make the gas go into a liquid state and thereof reduce the fiber diameter and the thermo insulating properties of the material. Other attempts to incorporate plastic crystal materials into hollow fibers with a rayon or polypropylene sheath showed to be not that suitable for clothing since they were open end fibers and could therefore not handle washing and laundering standards.\(^\text{134}\)

\(^{131}\) A report on *Phase Change Materials* from Swerea IVF provided by Bengt Hagström


\(^{133}\) A report on *Phase Change Materials* from Swerea IVF provided by Bengt Hagström

\(^{134}\) A report on *Phase Change Materials* from Swerea IVF provided by Bengt Hagström
Lamination of PCM foam
Foam pad insulating materials containing PCM are also applicable for lining in clothes, gloves outerwear etc. The foam pad is usually added on to the fabric of the garment through stitching, lamination or fusion. PCM’s are mixed to a polymer solution before foamed with the addition of a hardening agent. After foaming the capsules get embedded onto the material. The main benefits of the use of foam pad are that a larger amount of PCM capsules can be integrated and different types of PCM can be used.\textsuperscript{135}

3.2.3.6.2 Fiber Spinning Process

Microencapsulation of PCMs
Bryant and Colvin presented a patent in 1988 describing the incorporation of PCM microcapsules, not coated into the fiber but as being part of the fiber itself. Results show that when microcapsules were integrated in the fiber the more durable the textile became. This method allowed washing and laundering with great success. To achieve this type of microencapsulation of PCMs, the fiber has to go through either dry, wet or melt spinning process of the polymer solution. Knitting materials, woven and non woven materials have better thermo regulating properties with this process because microcapsules are protected by the wall of the compound as well as the wall of the fiber. In this way the fiber can provide better breathability properties. Another advantage is that the fabric does not get stiff or hard as compared to the use of PCM coating.

The integration of PCM’s in the melt spinning process and the spin ability of the polymer solution has a relation to the melt flow index. When low microcapsules (4-24 %) were integrated at a fiber stage, the melt flow index was increased and reversibly, with high microcapsules (40-50%) the melt flow index decreased which means the spin ability of melt spinning was lowered as well. In order to achieve a better spin ability, PCM’s was integrated in the wet spinning process instead. The results for the melt flow index were found to be the same as in melt spinning process, but with the major difference of the efficiency of enthalpy which means that the melting and crystallization points of PCM were found much better in the wet spinning process.\textsuperscript{136}

The collaboration between Outlast and Kelheim fibres resulted in a development of viscose fiber for the incorporation of PCM in the spinning process. This opened up a new path for the development of PC materials as now cellulose fibers could be used offering the benefits not only of being thermo regulating but bringing in properties as increased softness, handfeel, moist absorption capacity and comfort. Similarly, Meister presented a report on the use of microencapsulated PCM’s into cellulose fibers with Alceru technology. The drawback of the use of organic materials is that after washing the heat capacity is reduced as a result of leakage.\textsuperscript{137}

\textsuperscript{136} A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
\textsuperscript{137} A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
Multi Component Fibers

Another way of locking the PCM within the fiber without letting the core be microencapsulated is to use bicomponent fibers. The bicomponent fibers consist of both polyesters and PCM at the core with a sheath of PET. Due to the low melt viscosity of the polyester fiber, the spinning process is difficult to go through. This problem can be solved by mixing polyesters with co-polymers. A study done by Zhang et.al in 2003 on the effect of thermo regulating properties of meltspun PCM of nonwoven fibers (PCM blend with polyethylene and ethylene-propylene at the core and sheath of polypropylene) show that results were positive and concluded that a higher amount of PCM the longer the effect of thermo regulating properties would be achieved. Further Zang discovered that the fiber diameter had no effect on the thermo regulating properties.138

3.2.3.7 Measuring PCM properties

In order to measure the thermal property of PCM fabrics, Bo-An et.al. affirmed in the study 2004, that three parameters should be followed: the thermal regulation capability, the static thermal insulation and the thermal psychosensory intensity. The test instrument called the Fabric Intelligent Hand Tester (FIHT) was introduced that could measure these factors. The machine used sensors, pressure, temperature, friction, displacement and heatflux to calculate the thermal functional performance of any fabric.139 Prior to Bo-An et.al invention, there was no standardized method available for measuring PCM. An instrument that measured the insulation value was recognized but only suitable for regular fabrics. From this platform a new instrument that measured and simulated a wearer’s activity (skin, apparel and environment) was later developed by Hittle and André. Cold plates at constant temperature simulated the environment and the varying heat to the hotplate simulated human activity. This machine gave rise to a new metric: the temperature regulating factor (TRF) which was established as standard test for determining steady state and dynamic thermal performance.140

3.2.3.8 PCMs and Brands

Outlast® Technologies, Schoeller®-PCM™ and Comfortemp® are the main trade brands which are commercially producing products containing PCM. The three brands use similar methods of microencapsulated PCM that are applied as fiber and/or coating and foams. However there is little published work on the thermal performance of the garments containing PCM fabrics which has most likely do with the confidentiality of the manufacturing process but also the possibility that the insulating or “cooling” effect is not that pronounced. Outlast even state on their website that several products containing PCM are available on the market claiming having thermo regulating properties, but that they in fact only are promoting regulating temperature by moisture management and not a phase change. This reality makes an absolute comparison between the brands rather difficult to achieve.

138 A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
139 A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
Outlast® Technologies

Since the mid 90’s Outlast Technologies Inc. being the market leader within the industry, has several patents registered of different processes of incorporating PCM into textile products and seen as.\(^{141}\) Their wide product offers spans over the area of sportswear, protective clothing, car seating and technical textiles. They are now exploring the new markets such as home furnishing, labels, medical applications and industrial applications.\(^{142}\) Initially PCM was used in fibers, fabrics and foams, today they recently introduced a lightweight high performance PCM lining that can be used as an interface layer in both summer as winter garments. Outlast claims that their products can improve the comfort level of the user by minimizing the temperature changes, and state that it takes around 90 seconds for the thermocules (Outlast microcapsules) to adapt to the body temperature.\(^{143}\) These thermocules are spun into acrylic fibers but also into nylon and polyester fibers.\(^{144}\) Recently Outlast presented a new process of incorporating PCM with the use of viscose fiber which broke the ground for future developments of using cellulose fibers as an option to synthetics. Outlast does not state what type material the core of the thermocules have but say it is “similar to paraffin wax”.\(^{145}\) The size of the microcapsules is small ranging from 1/2 to 1/20th the diameter of a human hair with a stable polymer shell. Once the PCM’s are microencapsulated into thermocules, they can be blended into compounds and applied as a finishing on fabrics or infused into fibers during the manufacturing process. Outlast claims that when these products are washed out, the coated material from the fabric does not wipe out and therefore has the ability to sustain home laundry and dry cleaning.\(^{146}\) In order to analyze and test the thermo regulating properties of the PCM, Outlast let their products go through a Bally temperature and humidity controlled testing chamber which is capable of controlling a temperature interval of -18 to 38 degrees with 20-85 percent humidity. Additionally a standard test procedure ASTM D7024 measures the effect of the fabrics capacity to absorb, store and release energy.\(^{147}\) Products manufactured are both first layer as second layer garments such as; underwear, pants, jackets, gloves, insoles, socks, safety wear, helmets and beddings. The PCM coating can be found in sleeping bags, lining in jackets or as a semi layer in a

\(^{141}\) A report on Phase Change Materials from Swerea IVF provided by Bengt Hagström
\(^{142}\) http://www.sti.nasa.gov/tto/spinoff2004/ch_1.html
\(^{144}\) http://www.fabriclink.com/Features/Assets/KA_Outlastfall02.pdf
\(^{145}\) http://www.sti.nasa.gov/tto/spinoff2004/ch_1.html
\(^{146}\) http://www.outlast.com/index.php?id=341
\(^{147}\) http://www.outlast.com/index.php?id=92
garment. Outlast have had collaborations with renowned sportswear brands such as Adidas, The North Face and Burton.

**Schoeller® - PCM™**

Just as Comfortemp and Outlast, Schoeller uses microencapsulated PCM’s. These microcapsules can be added during the finishing process of the fiber or fabric (coating). It can also be added in the spinning process of the fiber. Schoeller state that their textiles are very breathable and allow moisture regulation and the melting point of the different PCM’s varies from one product to another depending on the end use.\(^{149}\) The coatings and foams having PCM are added to garments such like fleece, fabrics and tricots.\(^{150}\) Schoeller has had collaborations with sportswear brands such as Helly Hansen, where the PCM could be found in outerwear jackets. The Fiber technology has shown to be suitable for safety protections in motor bikes wear and for providing extra comfort.\(^{151}\)

**Comfortemp®**

Comfortemp produces only non-wovens textiles in which phase change materials are integrated. The brand manufacturer’s products for different areas and can also have many different properties. It can be placed in filters, sanitary products, technical applications, in garments as interlinings or in shoes as linings and insoles. The PCM is added at the fiber stage and then fixed to non-wovens.\(^{152}\) The Micro capsules have the size of 10-35 microns and offered in three different melting points depending on the desired performance of the material and needs of the wearer. Comfortemp states that the apparel that contains PCM are very durable, have a soft feeling and is also very breathable\(^{153}\) but also that PCM do not have an infinite capacity to keep absorbing heat or to keep discharging heat. Further they claim that in the external environment, the PCM changes state over time with the impact of the physical activities of the user, meaning that the PCM are able to “recharge” themselves and thereof keep performing.

As discussed earlier that encapsulation of PCM can be done with coating process but it has some disadvantages. Incorporating PCM during fiber spinning process has the advantage of durability especially after washing process which is not found in the coating process. The time taken by PCM to absorb heat and to release heat is rather short. The effect of the PCM is only temporary when the temperature changes from warm indoor temperature to cold outdoor temperature the effect will last for about 10-15 minutes. This is only an approximate number and the time will vary depending on the selected PCM and the environment.\(^{154}\) Results from the application of PCM with coating or during spinning process indicates that in order to increase the effect of thermo regulating properties, the amount of PCM should be higher than

\(^{151}\) [http://www.mcoden.se/butiken/product_info.php/products_id/856?ssCsid=6c11fb7530b186e0a34f127eae923a2a](http://www.mcoden.se/butiken/product_info.php/products_id/856?ssCsid=6c11fb7530b186e0a34f127eae923a2a)
\(^{152}\) [http://www.comfortemp.com/htm_english/index2.htm](http://www.comfortemp.com/htm_english/index2.htm)
\(^{153}\) [http://www.comfortemp.com/htm_english/index2.htm](http://www.comfortemp.com/htm_english/index2.htm)
10% which is the normal amount at the core.\textsuperscript{155} A drawback with the increased amount of PCM in the fiber spinning process is the reduction of the fiber strength. Similarly increasing PCM through coating of pre-formed fibers make the garment stiffer and reduces the breath ability properties. Bi components fibers that have PCM at the core also affect the fiber strength when the amount increases.\textsuperscript{156} There are only few companies having PCM garments commercially on the market but as a matter of fact all effect of thermo regulating in those garments is rather low. Researchers are still finding a way to discover a fiber with PCM having thermo regulating properties which can resist in the garment in the long perspective. Till today research is going on in regards to the possibility to increase the amount of PCM and increasing the fiber strength.

\textsuperscript{155} A report on \textit{Phase Change Materials} from Swerea IVF provided by Bengt Hagström

\textsuperscript{156} A report on \textit{Phase Change Materials} from Swerea IVF provided by Bengt Hagström
3.3 Denim Making Process

3.3.1 Denim

Manufacturing of denim fabric consists of four main steps which are: spinning, dyeing, weaving and finishing. Below flowchart explains the denim manufacturing process which starts from cotton cultivation process of ginning. Spinning is the very first process where all the cotton dirt and impurities are removed to merge it into a fine yarn. The two types of spinning process open end and ring spun are commonly used in this process. This yarn is then spun through with two types of spinning process which are either the Open End-, or the Ring Spun process. The main difference between these two processes is the less twist per inch that is characteristic for the open end as compare to ring spun. The ring spun yarns are transformed into an aligned rope structure which results in more twist per inch.\(^\text{157}\)

![Denim Flow Process](http://www.lib.ncsu.edu/theses/available/etd-20011115-182006/unrestricted/etd.pdf)

The yarn goes later through warp beaming before dyeing process. Dyeing for denim is done in two ways; rope dyeing or beam/slasher dyeing. The major difference between the two processes is the cost and time included. The rope dyeing process is much more expensive and a number of indigo shades can be achieved while slasher dyeing can give less shades. Indigo dye has the properties of giving a faded look after the denim garment is washed extensively with different washing process. The quality and performance of denim products totally depends on consistency of indigo dye. Indigo dye has a wide variety of colours and designs which can be seen on denim materials. Indigo has very low chemical attachment to cotton fibres so for this reason yarns are prepare in rope form to get more affinity towards cotton fibres. The indigo dyes concentrates in outer core of the cotton fibres and this produces an

\(^{157}\) Own Illustration

158 Own Illustration
intense ring of colour around a white core in the cotton yarn. Indigo dye is insoluble in water and its normal form is vibrant blue.\textsuperscript{159}

Sizing is a process of making cotton yarns thick by encapsulating it with a chemical called starch. It helps to improve the strength of yarn and friction resistance capacity by chemically coating the surface of cotton yarns.\textsuperscript{160} This coating of starch helps to avoid abrasion of yarns in weaving process. It is a protective coating which reduces yarn hairiness and prevents yarns from entangling with one another. It also helps to avoid rubbing of indigo dye from the cotton yarns in the weaving machine. Sizing chemicals and concentration are based on the end product of denim cloth.\textsuperscript{161} Sizing is done in a different step for rope dyeing and it is done on the same machine in slasher dyeing.

Weaving is the next process where interlacement of yarn is done to form a fabric. Denim weaving is usually done on air-jet looms. The speed of the air jet looms are much better than projectile and rapier looms. The standard weave design in denim is 3/1 twill weave which means after 3 warp yarns there is an insertion of 1 weft yarn. The yarns are taken pass from drop wires, heddles and a comb like device called reed from the beam and then it is weaved with the insertion of weft yarns and fabric is collected on the other beam. The common denim fabric weight ranges between 14 Oz for 100% cotton and 11 Oz for stretch. Lighter denim can also be made by changing the construction of warp and weft insertion. Denim weaves 3/1 twill, 2/1 twill, 3/1 broken twill and 2/1 broken twill.\textsuperscript{162}

The beam from the weaving is followed on the finishing machine where different types of chemical finishes are applied on the denim cloth to make it softer and increase the fabric properties. This process includes brushing, singeing, washing and de-sizing. Singeing and brushing eliminates the impurities from the fabric and washing is done to manage the shrinkage of the fabric cloth. De-sizing on denim fabric helps to remove the size chemicals which were earlier applied after the dyeing process to make the surface of the denim soft.\textsuperscript{163}

At the finishing machine, the fabric first gets brushed to remove the lint afterwards the singeing process is done. Singeining process helps to burn out the fibres which are on top of the denim fabric to make it smoother. Denim is pre shrunk at the fabric stage in order to avoid extra shrinkage at garment stage. It is chemically treated with size, wetting agents and lubricants. Skew results are also taken at the fabric stage to prevent skewing at garment level. The finishing machine consists of entry end, shrinkage machine, drying, folding or batching.\textsuperscript{164}

\textsuperscript{159} http://www.scribd.com/doc/22694931/Denim-Fabric
\textsuperscript{160} http://mytextilenotes.blogspot.com/2008/05/manufacturing-process-of-denim.html
\textsuperscript{161} http://www.scribd.com/doc/22694931/Denim-Fabric
\textsuperscript{162} http://www.scribd.com/doc/22694931/Denim-Fabric
\textsuperscript{163} http://www.teonline.com/knowledge-centre/manufacturing-process-denim.html
\textsuperscript{164} Philip E. Slade: \textit{Handbook of fiber finish technology} New York, Marcel Dekker, cop. 1998
Mechanical finishing is done to improve appearance of the fabric by using chemicals and other lubricants. Luster, smoothness, softness and residual shrinkage are the properties which are enhanced on the denim after mechanical finish.\textsuperscript{165}

Those treatments which change the chemical properties of the fabric are termed as chemical finishes. These treatments are done to achieve specific properties on the fabric. Like for cotton fabrics easy care finish is required, for synthetic fabrics antistatic finish is required and anti-felt properties are required for wool. The fabric later passes through the finishing bath with all finishing chemicals and after the sufficient dips are done, it is squeezed out, dried and cured.\textsuperscript{166}

3.3.2 Denim Costing

The costing chart below explains the general fabric and garment costing of a denim jeans product. This costing includes all general parameters which are done practically at supplier level, even though details may differ for different types of denim products.

The initial step of denim costing is the fabric costing which includes the process from yarn to finish fabric. This is estimated to land at 2.75 USD. This price may increase or decrease at spinning stage and finishing stage. The reason behind spinning stage is fluctuations of cotton prices in the global market. In finishing stage the brands could add some extra finishes or coatings which are expensive in order to add value to the product. Prices for other processes like dyeing, weaving and sizing remain constant.

Garment costing is very vital because it has many details included at every process. The total price estimated 11.35 USD which is for basic design denim garment or in technical terms it is basic 5-pocket. Cutting of fabric is sometimes done automatically or manually which can increase or decrease some cents on the final price. But fashion brands don’t show keen interest on this part because it depends on supplier how it can be managed in proper way while taking quality aspects into consideration. Stitching is considered to be a very technical process because every time there is a new design with different styling which focuses on details. Like adding extra pocket in the garment or having embroidery on back pockets etc. Every fashion brands has new style details every season which affects the costing price. The more the styling the more machines will be inducted in garment making line. Also types of threads used in the garment are also considered because the threads can be local made or arranged by the supplier on its own rather than importing it from other countries.

It has been noticed that from last decade denim is all about wash effects. There are a lot of state of art machineries used for giving a denim garment a worn out look. Bleaching chemicals, stone enzymes and dry processes like sand blasting or making whiskers required a lot of technical work. The garment is treated very carefully at every process in washing department which is considered to be the time consuming several times. Due to which washing of denim is considered to be very expensive from all the process. The price factor

\textsuperscript{165} Philip E. Slade: \textit{Handbook of fiber finish technology New York}, Marcel Dekker, cop. 1998

\textsuperscript{166} Philip E. Slade: \textit{Handbook of fiber finish technology New York}, Marcel Dekker, cop. 1998
can be increased much more depending on the workmanship of the garment in washing process.

Finishing and packaging cost remains almost same for every garment. Total price estimated is 14.1 USD for a pair of jeans.

<table>
<thead>
<tr>
<th>Fabric Costing</th>
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<tbody>
<tr>
<td>Specifications:</td>
<td></td>
</tr>
<tr>
<td>Width: 160 cm</td>
<td></td>
</tr>
<tr>
<td>Weight: 11 Oz</td>
<td></td>
</tr>
<tr>
<td>Weave: 3/1 RHT</td>
<td></td>
</tr>
<tr>
<td>Color: Blue</td>
<td></td>
</tr>
<tr>
<td>Costing</td>
<td>USD</td>
</tr>
<tr>
<td>Spinning Cost</td>
<td>0.35</td>
</tr>
<tr>
<td>Ring spun</td>
<td>0.35</td>
</tr>
<tr>
<td>Warping Cost</td>
<td>0.10</td>
</tr>
<tr>
<td>Rope Warping</td>
<td>0.10</td>
</tr>
<tr>
<td>Dyeing Cost</td>
<td>0.4</td>
</tr>
<tr>
<td>Sizing Cost</td>
<td>0.15</td>
</tr>
<tr>
<td>Weaving Cost</td>
<td>0.40</td>
</tr>
<tr>
<td>Air jet</td>
<td>0.40</td>
</tr>
<tr>
<td>Finishing Cost</td>
<td>0.60</td>
</tr>
<tr>
<td>Mercerizing</td>
<td>0.15</td>
</tr>
<tr>
<td>Sanforizing</td>
<td>0.25</td>
</tr>
<tr>
<td>Singeing</td>
<td>0.10</td>
</tr>
<tr>
<td>Coating</td>
<td>0.10</td>
</tr>
<tr>
<td>Overheads</td>
<td>0.35</td>
</tr>
<tr>
<td>Profit Margin</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Total Price/ meter</strong></td>
<td><strong>2.75</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Garment Costing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>1.35</td>
</tr>
<tr>
<td>Stitiching</td>
<td>2.50</td>
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<tr>
<td>Washing / Dry Process</td>
<td>3.00</td>
</tr>
<tr>
<td>Finishing / Packing</td>
<td>1.50</td>
</tr>
<tr>
<td>Overheads</td>
<td>1.00</td>
</tr>
<tr>
<td>Profit Margin</td>
<td>2.00</td>
</tr>
</tbody>
</table>
Considering phase change materials in the costing of denim fabric so it depends on Swerea when they launch it properly in the market. At this stage research work is in process and it is somehow difficult to analyze the exact cost of PCM. But as a matter of fact the cost of the fabric will be increased but not to high level. The melting temperature of yarn and spinning process plays the vital role in manufacturing of PCM.

Another aspect of PCM cost can be of mass production of this yarn. Swerea right now has facility to produce but not in mass production. It has to be outsourced and the raw materials requirements and quality measures of PCM has to be deeply looked upon. In that case the price of PCM yarn can be high which will impact the final price of denim fabric. The cost of the denim fabric will remain same which is 2.75 USD per meter in addition to it the price of PCM yarn will make it higher. The major impact will be on the process of weaving and spinning where PCM yarn will get weaved with cotton. According to Swerea team the price of PCM will be increase to a little extent.
3.4 Sustainability

Nowadays every human life is dependent on an electrically driven infrastructure and products consist of petroleum, coal and other non-renewable materials as feedstock. Some drastic changes occur in early decades which reflect upon the development of chemical and engineering process along with their applications. Chemicals are now found in most of the products which are harmful for the life as well as for environment. The dependency of a human life with all these factors which includes chemicals and polluted items is hardly to remove but can be controlled. Looking in textile productions a lot of products have been introduced with new technologies and still this is an ongoing process. New products with new designs and new technologies increase new pollution ways to harm the earth.

It is hard to eliminate all forms of waste in every area of business like textiles. But some harmful emissions can be controlled by eliminating toxic substances from the products. Energy can be renewable and it can be benefit out in the longer term production like solar energy, wind etc. Another way is to redesign the process and make it in cyclical order where all the material flows in one pattern and waste materials can become raw materials for the other processes. While focusing on the cost of production in economic way considering environmental and social impacts new business models can be introduced. Working with denim production the most part of chemical applications is done during processing where several kinds of chemicals such as bleaching agents and harmful dyes are used. The supplier producing the goods is often unaware of the fact that the product itself is not leaving any positive impact on the environment. Their main objective is to fulfil the requirements of the brand and to produce mass production. It is costly to improve the production of goods to make it environment friendly so that less damage can be caused to the environment. Another aspect of this issue is that it has been neglected. The reason for this is because it is difficult to change the behaviour and mentality of a supplier to look after environmental hazards. Most of the brands work with a corporate social responsibility CSR which states all the details but still a lot needs to be done. The entire supply chain of a process has to be re-looked to make the process sustainable and the people around it has to take care of social, economical and ecological issues and benefits. The processes can be made environmental friendly by preserving energy and reducing waste. Although the design approach has to be change but the road towards sustainability should be continued to achieve a better environment.

Considering life cycle assessment of a denim product means to analyze the process of denim manufacturing from yarn stage to finished garment. The amount of waste produce, energy consumption and harmful emissions of dyes are calculated and compared. The life cycle of jeans depends on the use by end consumer. It can be used for one year, four years or maximum six years. The process starts with the cultivation of cotton where a lot of fertilizers are used in order to avoid dirt from the cotton when it is ginned. Then spinning process and processing of a denim fabric. This denim fabric is then export to the countries where it can be sewn with best quality and most of the stitching part is done in South Asian countries. Garments are then shipped to the brands in Europe and US where they are further distributed.

http://www.renewablealternatives.com/default.asp
http://www.truetextiles.com/sustainability/
Biodegradable and sustainable fibres, edited by R S Blackburn, Woodhead Textile Series No 47, 2005
Recycling in Textiles, Edited by Y Wang, Georgia Institute of Technology, USA, Woodhead Textile Series No 50, 2006
in stores. So the factors which damages the environment while producing a pair of jeans are energy consumption of natural resources due to which harmful gases are exposed in our environment causing damage to the earth and therefore world faces drastic climate changes. Cultivation of cotton requires great amount of water, fertilizers, pesticides and diesel. It is then transported to the countries by means of ship or air where the production of denim has to be done. During the manufacturing a lot amount of indigo dyes and colours are used which after process are drained in the water creating damage to the rivers. Although there are water treatment plants but still it is not satisfactory to drain the indigo water in rivers. Till the fabric is completely finished an excessive amount of energy is used and water effluents are generated. Moving in the garment manufacturing the major damage is done in washing of the denim where chemicals like bleach is used to give a worn-out look to a pair of jeans. Then transportation process occurs which takes around weeks to export from South Asian countries to Europe and US.

According the study done by Bio Intelligence Service for the department of Eco-Design and sustainable development of French Environment Agency (ADEME) the life cycle of jeans can be divided into two phases which are manufacturing and end use by consumer. 59% of environment is damaged in manufacturing and remaining 41% is done by end-consumer. Consumers washed and iron the jeans several times thus using an extra amount of electricity and water. In order to reduce the effect the consumers can make a change in their purchasing behaviour like buying denim made of organic cotton and used the denim in more sustainable way. For example a non-bleach denim is not required extensive washing and ironing and thus a lot amount of energy and water can be saved. Cotton is considered to be the most water and pest sensitive crop which consumes 11% of the world’s pesticides. Using organic cotton helps in decreasing cultivation pollution, improving soil fertility and preventing soil and air contamination. By just getting the organic cotton denim a consumer can save primary resources of water and energy, emissions of hazardous gases in the environment and toxic risks which harms humanity and aquatic life.

![Figure 20: Sustainability of Denim](image)

In this case where smart denim materials contains 25% phase change material and 75% cotton we could have a different scenario. Phase change materials can be produced from paraffin

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waxes which are petrol derivates. Another class of paraffin waxes are derived with natural alcohol through different chemical reactions, fatty acids and mixtures of fatty acids can also be used as BIO based PCM’s. The bio based PCM are solely from natural products and those which are derived from fatty acids are available from plants and animals.\(^{176}\) It is understood that PCM used by Swerea can be a sustainable product once commercialized. Till now the experiment in the form of smart denim has been done to reduce the amount of cotton by blending it with PCM. Reducing the amount of cotton in denim can make a drastic change on the use of 100% cotton for a pair of jeans while ideally the main objective would be to replace the cotton once and for all and produce a 100% PCM product. In addition there are several possibilities of blending cotton with synthetics and PCM is one of them.

\(^{176}\) Email by Alain Alterman, Research Scientist at Centexbel Gent, Dated 11-June 2010
4 Empirical study

The empirical study consists of the different trials based on the main research question of how to integrate the PCM in a woven twill fabric focusing denim. The study has followed the given structure of the theoretical framework provided. The research is divided first into the two trials followed by its results analysed in regards to the thermo regulating properties and visual expression. The second part consists the influence of the PCM has on the cost structure of a denim garment and final retail price. The product management aspect, which is the first section of the empirical study, has concentrated on the examination of three premium denim brands. The theoretical study itself has framed the research and comparisons have been made according to the different brands product positioning-, innovation-, differentiation strategies. The value adding aspect of introducing smart denim has been included in the analysis. Aaker’s perceptual map and the Ansoff’s matrix have been used to illustrate the different brands positioning and will further facilitate the understanding and analysis in conclusion chapter.

The second section of the empirical study examines the practical development of the smart denim textile as well as the prototype making process. The results of the various trials are shown continuously in order to easy follow the development process.

4.1 Denim brands

The three brands have been selected for the reason of representing the premium segment of the denim industry. By choosing a particular segment the research comparisons are more efficient to make since all brands operate within the same strategic group and therefore are considered as competitors. The similarities as well as differences in vision, brand promise, values, positioning as go to market strategies are of interest to examine. The main questions that can lead to the success or the failure of the smart denim project is the evaluation of how it could be beneficial for the brand as consumer, deliver superior value and whether it is aligned with the company culture and vision or not.

4.1.1 Acne Studios

Acne was created in 1996 by four creatives with the ambition to develop a lifestyle brand offering desirable products, not only their own but as well as others. There vision combines art and industry, whether this is through apparel, film, printed media or advertising. The foundation itself of Acne started with the launch of 100 unisex jeans with its characteristic red stitching. The Swedish Elle was early to recognize the potential upcoming brand and let the jeans be display in the magazine. Shortly after the word took off and the buzz hit the town. The acne jean became soon a desirable item for anyone’s wardrobe. The recognition and consumer adoptance can be explained by the several prestigious design awards that have been piled up through the years. The brand has left its design footprint on the market of what Scandinavian design stands for leaving path for others to follow, but their success has also opened up new doors into new markets. Today the brand report a revenue of approx. $55 million in 2009 and operates in nine countries with own stores and yet another countries through franchise and are still expanding.177

177 www.acne.com
4.1.2 Levi Strauss & Co

Levi Strauss & Co. created the world’s first blue jeans back in 1873 and has been in the front run bringing innovation to the marketplace ever since. The brand is one of the world’s largest branded apparel companies and the global leader in jeans wear. They are available in more than 110 countries worldwide and reported net revenues of $4.1 billion in 2009. Throughout its history the brand’s objective has not only been to offer denim products but to change the marketplace as well as the workplace they operate in: “We believe that business can drive profits through principles, and that our values as a company and as individuals give us a competitive advantage.” (John Anderson, President and CEO).

Levi’s states its brand promise clearly which constitutes of four main values: empathy (by listening and responding to the needs of customers, employees and stakeholders they pay attention to the surrounding world), original (by being authentic and innovative in terms of product and practice they stand out), integrity (by their code of conduct and social responsibility they take action in society) and courage (by simply having courage they stand up for their beliefs and convictions). Their vision reflects on how the company wants to bring energy and to inspire people with a pioneering spirit.

4.1.3 G-star Raw

The Dutch brand G-star was founded in 1989 and designs, manufactures, markets and retails denim products worldwide. Even though their revenue figures are not in public domain, their rapid expansion and success can be explained by their strong brand concept. The brand’s philosophy emphasizes on “Just the product”. They claim to be the first ones on the luxury denim market for the streets by combining craftsmanship with street edge resulting in a new denim sector – the positioning of raw denim. In addition their innovative mindset reflects on the architectural and 3D thinking into denim construction and the development of distinctive silhouettes. Continuous development and investment in new materials and styles, cuts, washes and treatments have made them to stand out and become unique. Their raw edginess and street wear influences in combination with tailored sophistication and detailing has lead to their success and delivered premium quality products to its loyal consumer base.

4.2 Product positioning

In the competitive climate of denim, brands really have to pay attention to the flourishing needs of consumers and constantly reinvent their product offer bringing value to the market. As earlier discussed in the theory chapter, a firm’s product is the ultimate expression of a specific competence. The identification of a firm’s competence is therefore crucial. This analysis can help to further strengthen the brand’s core competence, build on its competitive advantage and thereof finding the right positioning direction for future products. In this case having smart denim in mind, the research has let focus on identifying the three different brands competences by analyzing its product offer. Through the analysis of the product offer one can establish the current positioning strategy each brand has which most certainly accounts for their competitive advantage. Knowing the competitive advantage leads us automatically to the identification of core competences.

178 www.levis.com
179 www.levis.com
180 www.gstar.com
By creating a four dimensional perceptual map it will reveal the different brands current product positioning strategies. The main objective is to gain an understanding for how the brands stand in relation to each other and how the offer and image is perceived. Below shows a perceptual map created out of four parameters; design, quality, price and sustainability. The chosen parameters have been selected to explain the key aspects of the different brands business approaches. Just as Kotler and other theorists mentioned in earlier chapter; price, quality and design are common aspects examined when defining positioning strategies since this is the spectrum in which companies operates today. Denim brands on the premium jeans segment offer good quality at a mid-high price level. Key is design and competition is on to deliver newness in terms of design lines, shapes, silhouettes, fits, different washes and treatments to deliver value to consumers.

Chart 1: Denim Brands

4.2.1 Parameter 1: Design

Acnes main message, which is communicated through its collections, is to deliver understated items of clothes that should feel cool, personal and effortlessly stylish. As Jonny Johansson Creative Director explains; “Fashion is the best form of self-expression. We like to design pieces that together form the coolest wardrobe, but is ultimately wearable. It becomes one way of thinking as individual pieces, but together creates a strong, modern and considered statement.”\(^{181}\) The brand concept is based on the idea of art meeting industry and promises to deliver that subtle luxury in every piece made. The total product offer ranges from tanks to sweaters, dresses, coats, shoes to jeans. Even though the jeans was what the brand initially started off with it does now play a secondary role. Jeans surely works as the essential base of the collection but are more of a compliment to the more edgy mainline than a key piece. If you would pick up a pair of jeans out of the line and rip off the label, nothing would tell you it

\(^{181}\) www.acne.com
is a pair of Acne jeans you are holding in your hands. The red signature stitching that initially created the buzz has been dropped and today the jeans look like any other five pocket pant available on the market. Efforts have been made to elevate the jeans through seasonal collaborations with the fashion house Lanvin. Products have been visible in fashion magazines but not gained much attention from their customers. The low adoption could have to do with the value-price-design relation. Products have basically been priced far too high for what it is actually worth. The design language has not reached any significant expression that would make them desirable for early adopters to buy.

G-star and Levis on the other hand have both managed to create a specific design language that truly makes their jeans stand out from the rest. Obviously Levis has been active in the business far longer than anyone else but both brands have succeeded in making iconic pieces that are recognised worldwide, with or without branding. Take for example Levis 501 model, the engineered jeans or G-stars Elwood model with its distinctive design lines. In the perceptual map G-star has been placed at the top of the design parameter. The brand constantly re-invents their jeans offer and pay close attention to new design details and features, finishes and washes. It is truly “just the product” as they communicate to consumers. The denim offer promises innovation in materials as in construction that undoubtedly sets them apart from other brands. With their considered line, the raw edgy denim concept comes alive. Items are differentiated from the mainline through the choice of material as the more sophisticated tailored denim look that they are increasingly becoming recognised for. Products clearly reflect the company values of bringing newness to consumers, which they refer to as innovation, pointing the future for denim fashion. Levis on the other hand has had a rocky history, even though being the number one denim brand it has experienced its fall downs due to heavy competition. Its design features are even though evident, the red tab line well established in the minds of consumers and the awareness is high. The brand has a clear focus on its heritage and authentic features from the past, which has been hold on to when veneering styles. This strategy is evidently successful since consumers recognise the brand signature, which makes any product extension become believable.

4.2.2 Parameter 2: Price
The three brands are positioned at a similar level in terms of price points. Acne and G-star are placed slightly higher due to their products are more expensive on the retail floor. The strategy has certainly payed off and stands against competition due to its brand appeal and status among consumers. Levis and G-star mainline is primarily targeting the mass-market consumers who are brand conscious and rather price sensitive. G-star’s considered line, Levis Authentic line as the Acne jeans are targeting a more fashion forward consumers who are able to spend above average on a pair of jeans. These lines are naturally more design driven and probably cover costs on product development and marketing efforts that have to be taken into consideration.

4.2.3 Parameter 3: Sustainability
The sustainability aspect has been added in the map due to the subject has been very much brought up on the agenda lately. How many brands do we not see on the market with a “green collection”, call it fair trade or eco friendly. Surely we saw this trend coming and going in the 90’s but today brands have become more conscious about their responsibility towards the environment and are making drastic changes to grow in a sustainable way. This does not only include the use of organic cotton but looking into the wholes supply chain, making sure every
part of the process is revised and looked upon. According to the President and CEO of Levis, John Anderson; *Our company leaders around the world aspire to create the most innovative and relevant products in the marketplace, while upholding our values of empathy, originality, integrity and courage.* Levis, focused on building sustainability into everything they do. In order to find information about how climate change, water and energy impacts the manufacturing of a pair of jeans they commissioned a scientific life cycle assessment (LCA) which concludes that one of the biggest impacts a pair of jeans have on the environment is the after use of consumer. They definitely do encourage and inspire consumers to take action as well. Last year they commenced the “Care to Air” challenge and let people present solutions for how to find innovative, covetable and sustainable ways of dry clothes and influence set behaviour. The company earlier launched the “Care Tag for Our Planet” campaign and changed the product care tags in jeans to include instructions about different ways to reduce the environmental impact of clothes after leaving the store. In comparison to G-star and Acne, Levis is very much on the front row when taking action for a more sustainable approach, yet the term sustainability can vary and is up to each company to define. G-star is in process of implementing CR policies and performance measurements covering areas of supply chain, product, operations and community involvement. Their ambition is to deliver products that satisfy their customer needs but leaves minimal environmental impact. Constant work is done on cleaner manufacturing and finding alternative sustainable fibers that could replace cotton. The main objective is to reduce the use of conventional cotton and increase the consumption of organic cotton and other alternative materials. This year the brand launched the 2010 RAW sustainable program that consists of the use of organic cotton that does not compromise on quality, comfort or design. Besides organic cotton, materislas includes nettle and recycled blends of waste material from old garments. Acne jeans on the contrary does not communicate anything on the subject of sustainability. The larger the brand gets and the more international it becomes, these questions will definitely be of their interest to pursue. The fact that the company still is small, resources could be the main reason for not offering sustainable products as systems.

4.2.4 Parameter 4: Innovation

Levis governs all new product development in terms of new materials as patents and have people placed especially for bringing the brand forward. Innovation has been key for the evolution of the brand. Levis constantly aspire to find new solutions to comfort and fit and recently introduced curve ID which emphasizes on a new fit system that focuses on shape. In addition to the launch a global digital fitting room had been set up where women can find their own curve ID formula. But the brand has taken the idea of innovation even a step further. Levis was one of the first denim brands to blur the lines between fashion and technology. Back in 2006 they introduced the first Levi's RedWire DLX Jeans that brought wearable technology into a denim product. G-star vision and brand statement brings up innovation as a key aspect of the brand. As far as their product concerned, it is more about product modification than real innovation. Newness comes in fit, design lines as washes and finishes that catches the consumer eye. Real innovation in terms of material development does not exist. Several collaborations have been initiated where technology has been main focus, but this has not involved the core of the business, which is the jean. Acne follows a similar product strategy, even though their product development or modification hardly affect their jeans offer in the same extend as G-star. Their product offer is quite basic with traditional washes and design lines, around 10% accounts for statements denim pieces including the collaborations with external party.
Our perceptual map exposes the different brands product strategy in aspects of design, price, sustainability and innovation. Several maps could be included to demonstrate a more complete view but chosen parameters have given an indication for what key aspects fashion brands find relevant today. The differences in positioning strategies, shows us the relationship between the brands and in which aspect each possess a competitive advantage. Clearly the brands heritage and values are linked with its competitive advantage and from where certainly their competences derive from. To stand out and be unique brands should offer superior benefits in comparison to competitors. If you take into consideration what both Kotler, Fred Crawford and Ryan Mathews states in regards to positioning strategies, a company should bring its all focus and try to become the best one on one positioning, be above average on a second positioning and third equal to competitors. This is also what the outcome of the perceptual map shows us. The three brands compete for the attention of a similar customer group but have positioned themselves in distinction from each other:

**Positioning 1:**
Levis is identified as the innovator of the three. They bring new solutions to products in terms of quality, fit, materials and technology. G-star focus is on the contrary on the design aspect such as features, cutlines, finishes as washes and offer constant newness to its customers. Acne jeans products are priced 1-2 pp higher merely based on brand image and marketing efforts not product attributes.

**Positioning 2:**
Levis design language is authentic, recognised but they do not re-invent the wheel one season to another. G-star acts above average in terms of new product development and products are placed as well slightly higher than regular denim brands.

**Positioning 3:**
Levis offer products ranging from mid to high price level which makes jeans an affordable product to the mass market. Acne jeans do not bring much newness in terms of product development or innovation in denim. Their basic jeans are rather plain, traditional washes and fits, which work as a compliment to their edgy apparel line. On the contrary the denim collaborations with Lanvin are priced high and offer more design value.

In general the sustainable aspect should not necessary be a positioning or marketing strategy but as a natural part of product development and business management. It might not deliver immediate cash flow but in the long run make the brand take on a unique standpoint in customers mind. By communicating responsibility and being transparent about how the company operates it will gradually generate trust and bring value to customers. The three positioning strategies the firms undertake according to the perceptual map are based on their competitive advantage, which further is built on the specific competence the brand owns. Levis is the market leader in bringing innovation to the market. They invest heavily on new product development to strengthen its competence. The competence is transformed to value through the benefits the product brings to consumers. You could argue whether Acne should focus on its heritage and bring back what the jeans once was recognised for. G-star to truly bring innovation by investing in material and new product development, moving away from product modification. In the end positioning strategies are dependent on the preference of a person and what he or she values. Key for success is to build on such competence that makes you unique and difficult to copy. It is not for nothing that Levis has specific teams in charge for developing new materials and govern patents of textile constructions. They build competence for the future (competence building/competence leveraging according to Asan
and Polat) and are therefore always a step ahead of competition in terms of finding new competences that could bring them to a future positioning strategy. Just as seen in illustration below, the circle of evaluating current positioning and product offer, helps to identify the core competence that deliver a competitive advantage. By further build and develop the brands competence, new opportunities can be discovered that give rise to new products which eventually directs the brand to adjust for a future positioning strategy.

Chart 2: Positioning

When Kotler exclaims: - innovate or die!, new product development clearly stand as crucial strategy for brands to sustain its market position. This is exactly what Levis does. They were Nr. One on the denim market – and they still are. G-star has experienced a tremendous growth but will need to keep the momentum by exploring new ways of making products that distinguish them from the masses. But for Acne, Innovation is not a primary aspect of their business strategies. They do not either claim that it should be. The brand promises to deliver subtle luxury pieces and the term is not associated with the brand image they like to portray. It is apparent that innovation is not aligned with the brand mission and the culture of the company. Product modification surely is, just as in the case of G-star. The difference is that G-star has the potential of being a truly innovative brand by the ethos and values they communicate.

The smart denim project aim is to bring innovation to the marketplace. Taken the three premium denim brands into the picture, its is evident that the product strategy is better suited for brands such as Levis and G-star who has a heritage or the vision for braking traditional practices. Both brands have an innovative mindset and welcome the blurring of traditional apparel manufacturing with other fields of technology and science. In the case of Acne, their focus lies on the aesthetical/artistic aspect of apparel and explore its capabilities within that field. The brand can be categorized as a low to semi risk taker (see figure of Ansoff’s Matrix). After maximizing sales of existing products on the Swedish market the brand soon came to realize that going international would mean bringing more profits and revenue to the company. Today the brand is expanding and opening concepts stores in key cities in Europe and The States but still the product offer has not progressed in terms of new development or innovation. The smart denim project brakes the regular positioning strategies of design, price and quality and moves beyond to a more explorative route. This approach can open up doors to new lucrative market opportunities. Even though consideration has to be taken to the risk involved. As Ansoff explains, a brand that already has a solid foundation of products that
bring in necessary revenue has more room to take a chance on investing in innovation. They simply can afford to fail. The smart denim project is such strategy, since the concept is new and no similar project has been launched before, the risk is high but can ultimately lead to diversification that is beneficial for the brand to sustain its market position. In the end the alignment between the consumer and the product concept is decisive. If you fail in understanding the consumer and how they perceive the product your idea is doomed. As a brand you need to make sure to that those benefits you “charge” the product with are superior than others, perceived as added value that the consumer will gain from and can influence customer choice.
4.3 Method of construction

Woven twill fabric are produced and manufactured in a variety of ways. The preferred twill weave structure of a denim fabric is characterized by its diagonal pattern which is exposed to the surface. The different weaves constructions are chosen to attain the right desired look of the fabric. The effect of the diagonal angle (wale) can differ from low to sharp sloop but the most commonly used for producing a denim cloth is the 3/1 woven twill. The 3/1 twill indicates the number of harnesses that are raised. In this case three harnesses are raise and one lowered when the weft thread passes horizontally through the three warp threads. The face of the weave is the side with the most obvious wale and used as the fashion side since it’s more visible. In a denim cloth the warp yarns that run through the length of the loom are indigo dyed and the weft yarns white. The result is a blue indigo colour covering the face side of the fabric (since more warp yarns are visible) with white weft yarns coming through the weave which gives the distinctive diagonal effect. The white weft yarns cover most of the back side, leaving it less colourful. The Following research trials; 1 and 2 are both using the 3/1 twill construction.

Main parameters were set in order to find guidance and achieving the right feel and look of a regular denim cloth, on one hand in terms of the visual expression of the fabric structure and on the other hand the measurement of the thermo regulating properties of the final material. Commonly projectile and air jet weaving machines are used in the denim making process. Both trials were made with a rapier loom or so called gripping machine.

4.3.1 Trial 1: Integration of PCM through weft

In preparation for the integration of the PCM, a synthetic yarn was run through the gripping machine in order to find the right density of the fabric. The weight of a regular denim cloth ranges between 8-14 Oz, which left suitable density of 24 weft threads/cm.

At the first attempt to produce a smart denim jeans cloth, consideration was taken to the visible effect of the twill construction. The blue indigo dyed cotton threads were run through the warp and the un-dyed white cotton threads were substituted with PCM. Intentionally the PCM was run in the weft because in a 3/1 twill the weft is covering most of the back side of the fabric. As a result the user would feel an increased comfort level of thermo regulating properties since the PCM surface would be directly in touch with the body. Due to the construction of the twill weave 3/1, the amount of cotton ended up three times higher than the one of PCM, leaving a material content of 75% cotton and 25% PCM.
The two cones of PCM used had a melting point of 28 respective 32 degrees Celsius. The biko fibers (polyamide fibers) were not 100% perfect due to 4-8 out of the 48 filaments in the yarn did not have a complete covered sheath structure that let the core peak through. The negative effects after weaving resulted in a lot of smell and could lead to PCM leakage when washing or ironing. Additionally the melt spun PCM yarns were not intermingled which caused difficulties when running it through the weaving machine. Out of the PCM yarn available, two samples were made which had different variables of melting point, joule per gram and NF.

### Phase change material

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample 1</th>
<th>Sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Tm</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>J/g</td>
<td>45</td>
<td>40</td>
</tr>
</tbody>
</table>

**Figure 22: Samples of Trial 1**

#### 4.3.2 Trial 1: Lab test and results

The outcome of the two samples had visually the look and hand feel as a regular cotton denim, a raw blue indigo colour on the face side of the material, but due to the shine of the PCM, the back side of the cloth had a glossy surface. The shine effect could be reduced by the use of PCM yarn with a polyester sheath, treated in order to achieve a dull or semi dull effect. This would give the fabric a more natural and authentic look of a cotton weave.

The inner body temperature of a human being is around 37 degrees with an outer surface of approx. 32 degrees. This means that our body normally is warmer than the surrounding environment and therefore releases certain amount of heat from the body. In the R&D of the construction of clothes it is paramount to know the heat flux that can pass through one or several layers of materials. Due to this very reason different lab methods have been developed.

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182 Own Illustration
At Swerea IVF there is an ongoing research and testing done for measuring heat flux from seating furniture. In this case the compression of the research object is essential. Due to this reason a body impression was developed in order to simulate a human being’s back/seat. The body impression has a temperature of 35 degrees with sensor attached underneath that measures the heat flux in W/m² (flow of energy per unit of area per unit of time). Through the pressure of the body impression against a surface with a certain force you could measure a simulated use of the object. Even though the body impression was constructed for the purpose of measuring the heat flux from seating furniture, it has proven to be useful to measure other kinds of textile materials as well.\(^\text{183}\)

The influence of the denim cloth with PCM on heat flux from the heated body was measured and analyzed. The temperature of the body impression was 34 degrees and the heat flux measured from the bottom centre. The machine used to measure the heat flux is called an Indentor.

![Indentor](image)

**Figure 23: Indentor**

At first the reference sample of the cotton/synthetic blend was measured which would later be used to compare against the outcome of the two samples. The integrated heat flow was measured at an interval of 2 min, later 10 min and at last 60 min. After every measurement the denim cloth was cooled down for around 2 ½ hours in order for the PCM to return to its crystallized state. This test was done with two different methods, with 1 layer and then 3 layers with following fabrics.

- Normal reference denim fabric
- PCM denim fabric with 28 degrees of melting point
- PCM denim fabric with 32 degrees of melting point

Fabrics were placed between indentor and a foam for different time intervals as explained above. Unfortunately the results with 1 layer were not productive due to human error.

The readings obtained from graph for the both the layers are as follows:

\(^\text{183}\) Swerea IVF, Alf Börjesson, 2008-01-23
The table above shows the reading of all the three fabrics with 1 layer and 3 layers with different time intervals of 2, 10 and 60 minutes. As discussed above those readings of layer 1 was a human error. With 3 layers the reference fabric gave different kilowatts per square meter at different time intervals. Like after 2 minutes it shows 17.9 and as the indentor was in kept contact for around 60 minutes, the heat flow the energy increases till 71.9 kW/m².

The PCM fabric with 28 and 32 degrees of melting point gave more kilo watt per square meter with different time intervals. PCM having 28 degree melting point starts with 24.9 and after an hour it gives 78 kW/m² which is high from the reference fabric. Similarly PCM having 32 degrees melting point gives higher reading comparatively. It shows that phase change materials having high melting point has higher absorbency and can gives more energy.

The reason of measuring these fabrics in terms of energy is just one way to know about the material and behavior of the fabric. It can be measure differently. At Swerea IVF it was measured in terms of energy for better explanation. Above explanation was on the basis of energy for all the three fabrics with 3 layers. Now the discussion will explain more about graphical representation of two fabrics, reference fabric and PCM with 32 degrees melting point which will give better understanding of PCM functionality and readings.

The reference fabric with 3 layers was placed between the indentor and foam and the results shows that it absorbs the heat flow of 256 watt per square meter. The graph 1 shows that reference fabric was absorbing heat for 4 minutes. The reason behind absorbing of heat is a natural process when a fabric is in contact with another material and heat is transferred. An example of this transfer of heat would be when a human body changes clothes and body temperature changes for a little moment.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Layer</th>
<th>2 min</th>
<th>10 min</th>
<th>60 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference fabric</td>
<td>1</td>
<td>13.6</td>
<td>30.7</td>
<td>73.5</td>
</tr>
<tr>
<td>PCM 28 degr</td>
<td>1</td>
<td>17.9</td>
<td>29.3</td>
<td>68.8</td>
</tr>
<tr>
<td>PCM 32 degr</td>
<td>1</td>
<td>17.8</td>
<td>28.8</td>
<td>63.8</td>
</tr>
<tr>
<td>Reference fabric</td>
<td>3 (max 256)</td>
<td>17.9</td>
<td>32.0</td>
<td>71.9</td>
</tr>
<tr>
<td>PCM 28 degrees</td>
<td>3 (max 315)</td>
<td>24.9</td>
<td>39.1</td>
<td>78.0</td>
</tr>
<tr>
<td>PCM 32 degrees</td>
<td>3 (max 397)</td>
<td>25.0</td>
<td>45.5</td>
<td>85.7</td>
</tr>
</tbody>
</table>

Figure 24: Indentor Readings

The table above shows the reading of all the three fabrics with 1 layer and 3 layers with different time intervals of 2, 10 and 60 minutes. As discussed above those readings of layer 1 was a human error. With 3 layers the reference fabric gave different kilowatts per square meter at different time intervals. Like after 2 minutes it shows 17.9 and as the indentor was in kept contact for around 60 minutes, the heat flow the energy increases till 71.9 kW/m².

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Figure 25: Trial 1 Fabrics
The denim fabric having PCM material of melting temperature 28 degrees was placed between the indentor and foam. When it was in contact it starts giving reading. The heat was transferred from the indentor to the fabric. PCM fabric which has the absorbing ability absorbs the heat it for the first 10 minutes and it sustain the pressure which was 315 watt per square meter. After 10 minutes the denim fabric stops to absorb the heat energy provided by indentor and it starts decreasing and react as a normal reference fabric.

Denim fabric with PCM material of melting temperature 32 degrees was then placed as same as other fabrics. After 10 minutes the fabric again stops to absorb the heat and reacts same as normal reference fabric. It sustains the pressure of 397 watt per square meter. The difference between two PCM denim samples is of pressure is because of different melting points.

The graph 2 below shows the heat flow of PCM denim having 32 degrees of melting point and normal reference fabric. The blue line represents the normal reference fabric and the red line represents the PCM denim fabric. It is obvious that when both the fabric were made in contact with indentor the PCM fabric has better absorbing properties as compare to reference fabric and it can sustain better heat flow than the reference fabric. The reason behind this change is because of PCM material which has the absorbency power and it starts working for the first 10 minutes. But after 10 minutes it is exactly at the same level of reference fabric. All the fabrics were kept in contact for 60 minutes as explained above.
So the results achieved from above graphs shows that PCM denim starts functioning immediately when it is in contact with any type of temperature difference. But it last for 10 minutes and then it acts as same as reference fabric. The fabric will again start functioning when it is kept at rest for around 2 hours and by that time PCM inside the denim will recharge itself. After reviewing all the results decision was taken to integrate more PCM in denim. For trial 1 the denim contains PCM only in the weft but now it should be integrated in the warp as well.

4.3.3 Trial 2: Integration of PCM through weft and warp
The outcome of the first trial gave rise to the question of how to increase the properties of the PCM in the denim cloth; theoretically the more PCM is integrated into a woven fabric the higher the effect would be. Since the first trial already had 100% PCM running in the weft the solution would be to integrate PCM in the warp as well. In order to keep the visual look of a denim cloth, the decision was made not to substitute any of the cotton warps with PCM, but instead twist the cotton yarn with a PCM yarn. The material construction would in that case dramatically increase the amount of PCM, ending up with a material content of 62.5% PCM and 37.5% Cotton. Each one of the three warp threads were twisted with PCM. The 2/1 twisting consisted of one cotton and one pcm thread, with a tension of 220 turns/mtr. The twist of cotton and PCM yarn was done at Konstsilke. The PCM provided by Swerea for this process have the melting temperature of 32 degrees.
The amount of PCM available for the second trial was 0.84kg and the requirements needed for the weft and warp would mean to divide the amount in two. The same gripping weave machine was used for the second trial, but in order to achieve an increased length, a calculated estimation indicated that a length of around 2.5 mtrs of denim cloth was possible to produce if the width of the fabric would be reduced to 40 cm (machine length 160cm).

Warping of yarn was done for 960 threads and a beam of 40 cm width was prepared in our school weaving lab. This beam was then placed on the weaving machine which has total width of 160 cm. The weft was same as done in the first sample. The output was nice denim fabric of around 2.5 meters. The fabric contains 40 cm of denim fabric having PCM in the warp and weft as shown in the sample 2. This is very dizzy structure which can be a type of herring bone structure. The rest of the 120 cm fabric is same as sample 1 which will be used to produce a prototype.

Warping the yarn of 960 thread ends equals 40cm width of PCM/cotton warp the rest of the width was used for 100% cotton warp.

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184 Own Illustration
4.3.4 Trial 2: Lab test and results

The results for the second test of smart denim containing 63% PCM with a melting point at 28 degrees temperature are shown in graph below. Here again the comparison is made between the energy consumed which is the heat flow and the time measured in minutes. In figure 1 when the smart denim came in contact with the indentor the values started changing and the peak touched 250 watt/square meter and lasted for approximately 10 minutes. In figure 2 the values are taken of the smart denim fabric containing 25% PCM. The time of the “PC effect” in both the cases can be compared and shows us to be the same in length but as a result the cooling effect itself of the PCM functions more in the 63% PCM fabric than 25% PCM fabric. It is quite clear that the when the amount of PCM increases from 25% to 63% the effect of heat flow increases to a huge extent but the time of the effect remains the same. The two graphs shown below were the second trial results and it is done of unwash fabric.
4.4 Jeans Prototype

The fabric received from the weaving machine was around 2.5 meters with 160 cm in width. 40 cm of the width contained smart denim fabric with 63% PCM and remaining fabric with 25% PCM. The smart denim fabric was handover to a sewing lab where a garment was stitched in a women style size 38 using double stitching machines.

The overall hand feel of the garment was soft and had a clear cooling effect while touching. A wear test was done of one hour with an outside temperature above 25 degrees. No measurements where done but the overall cooling effect was actual and garment comfortable to wear. It was found that the indigo dye colour was transferring from the garment bleeding onto other fabrics while wearing. The reason behind bleeding was that the fact that the fabric received from the weaving lab did not passed through any finishing process and was raw denim from start. Even though the garment felt like it was washed and the main reason behind the softness was of amount of PCM in it.
4.4.1 Jeans Prototype: Lab test and results

The jeans garment was only rinse washed which is a process of washing the garment light in water without any chemicals and then it is dried. The reason for doing the rinse wash was to remove the indigo colour and make the surface of the garment smoother. Only one prototype was developed so a decision was taken to not process the garment with extensive denim wash in order to avoid damage. The jeans prototype was tested in the same manner and under the same circumstances measured with the indentor at Swerea.

![Test object: Jeans 25% PCM (28 degrees) and Reference Fabric](image)

Figure 34: Comparison of Jeans Prototype 25% PCM and Reference Fabric

Results show that the jeans prototype acts in the same way after light wash as it was before (Kindly refer to figure 2). The time of the effect remains the same so as the peak effect of the PCM. Although the jeans prototype was not tested in 3 layers due to its form as a garment, conclusion can be drawn that it acts same as a smart denim fabric cloth with a content of 25% PCM.

4.5 Wash Treatment

After making the denim garment it was decided to make two denim tubes out of the same fabric containing 25% PCM and one tube out of fabric containing 63% PCM. When the sample were tested at Swerea IVF, they were tested unwashed. Having the end product use in mind, the PCM denim should be wash extensively like a regular denim in order to that look and feel which is common in most of fashion denim brands products.

The decision was taken to send the three tubes of denim to a factory in Karachi, Pakistan called Artistic Garment Industries which is a garment supplier of various re-owned European and American fashion brands. Having a state of art washing facility the tubes were washed with different process:

- Tube 1, 25% PCM: Stone enzyme wash for 30 minutes
- Tube 2, 25% PCM: Stone enzyme bleach wash for 45 minutes
- Tube 3, 63% PCM: Stone enzyme bleach wash for 45 minutes
The tubes were received and sent back to Swerea IVF for further testing. The reason behind this test was to know how the PCM would react after being washed extensively.

4.5.1 Wash treatment: Lab test and results
The washed tubes 1 and 2 have the same results of heat flow and time. The only difference between the two tests was the time of washing and chemicals used. As discussed above, washed tube 2 passed through the bleaching process at 45 minutes.

Results show that the PCM effect remains at the same level as it was in an unwashed form. It means none of the washing procedures left a negative impact on PCM fibers. The hand feel of both the tubes got softer and it was not damaged from any end.

Figure 35: Tubes 1, 2 and 3

Figure 36: Washed Tube 1 with 25% PCM
Wash tube 3 passed through the bleaching process at 45 minutes which is the most vigorous way of washing a denim garment. The sample received was in a proper shape without any damage.

Results shows in figure 6 that the PCM fibers were not affected by any washing procedure but the cooling effect were lowered down to a little extent as compare to the unwashed fabric of 63% (Kindly refer to figure 1). The time is almost the same which is again approximately 10 minutes.


5 Discussion and Analysis

Every business should constantly look upon its innovation index. This figure tells the proportion of a firm sales derived from products that are less than three years old. According to Kotler no firm can survive with a zero innovation index. Any traditional business will struggle if the innovation index is below 20 percent. When it comes to fashion the bar is set high. Fashion brands need to reach 100 percent innovation index to become successful. This is where the smart denim project comes into the picture.

Innovation has become the new mantra for companies that exclaim they are pioneers and pointing the future of fashion. In fact the portion of product development is hardly new in terms of innovation. Products are either; updated, modified or copied of already existing ones. The former definition of innovation has to do with the pure aesthetics of a product; the packaging that leaves the core of the product intact. It is just the shell of the products that changes. Still the intention is there but what do companies actually do about it? Innovation has to do with changing established ways of working. The whole creative process of product developing as practices has to be challenged. Results show us that investment in competence building is crucial to bring any company forward. Brands have to evolve parallel to changes in a dynamic marketplace. It is a proactive approach of preparing for what is to come whether it is new product entries or players, innovation is the key for differentiation and future positioning.

The link between a brands competences and the market is paramount since this type of product strategy is concerned with the commercial application of an idea. Companies have to evaluate the commercial potential, the investment required and try to project the profitability of introducing the strategy. New product development and in this case an innovative product that is not yet available on the market, makes it even more difficult to make such prognostics. Alongside the concept, a marketing strategy needs to be outlined at an initial stage in terms of product positioning, identify the competitive advantage and benefit the product promise to deliver – does it stand out? What segments to target and through which distribution channels to reach consumers? New products require a campaign around it to deliver the message, informing the end consumer of the superior value that that particular product has to offer. A firm has to take calculated risks and commit to long term growth and profits. They will need to balance the risk involved with the potential return on investment. In essence the higher the risk the greater the potential return should be.

Successful commercialization of innovation depends if there actually is a market for such products at all. It is significant to determine that there actually is a need for a smart denim product and question whether the innovation delivers value or not. The mistake often done of launching new technology has to do with focusing on developing the technology itself but forgetting the link to the market. This aspect needs to be involved at an initial stage. It helps to identify key features and benefits that the target market considers most valuable and be able to tailor the product to match accordingly. At the end of the day the product has to deliver benefits superior of those of competitors since it is the consumer who judge whether the new innovation becomes adopted or not.

The aim of the smart denim project was to find ways of integrating smart technology in fashion apparel. With this objective in mind several trials were made to incorporate phase change material into a woven fabric. Results show us that not only the initial idea was realistic to achieve but also commercially interesting. The set parameter of finding a marketable
solution to an innovative fashion forward denim product has shown to be feasible. The smart denim prototype both looks and feels like a regular denim fabric, with the added value of a thermo regulating property. Phase change materials could play an interesting role in the future of the fashion industry due to its potential of being a lucrative business strategy. Smart denim is about innovation and functionality. It breaks the set triangle of key aspects that fashion firms are focusing to deliver value on: design, quality and price. Through the innovation, a new value aspect is added to the product. It offers consumers benefits that cannot be compared to what is currently seen on the market. Thereof also difficult to read how the market eventually could react.

Going back to the main research question hold: which are the possible options to integrate PCMs in a woven fabric? Clearly trials have shown that the most effective and long lasting way of integrating PCM into a fabric is to do it at a fiber stage. Other alternatives of coating or foam were quickly disregarded since earlier research done in the subject has demonstrated to have less thermo regulating effect. Through the trials made, results show that PCM yarn can be incorporated both through the weft and warp of a 3/1 twill structure. Either in the pure yarn form or through the blends with cotton. The thermo regulating effect of phase change materials has proven to give effect after integrating it in a denim fabric. Results were found positive of both un-washed and washed trials of the PCM denim with duration of approximately ten minutes. The research progress of the PCM fibre at Swerea is at a developing stage. Continuous research is done to increase the time limit of thermo regulating effect. The ambition is to find other use of application besides denim. When the project started it was not possible to dye this type of PCM yarn but recent developments shows that it has become possible to process the yarn in dyeing machines under hot temperatures without the risk of migrating paraffin wax. In the denim production phase the PCM yarn was weaved after rope dyeing so it was not exposed to hot temperatures. Now there are more ways to integrate PCM yarn and thereof also increase the PCM content without losing the twill effect of the typical denim structure. Results can also be applicable to various other product types in woven or knitted materials.

Apart from the added value of thermo regulating property, the benefits also accounts for reducing the amount of cotton in denim. This is positive sign that turns the direction of the market to the use of synthetic materials. Next step could to fully replace cotton with synthetics and let the integration of PCM yarn become 100 percent in smart denim product rather than in a blend form. There are possibilities of linking the advantages of this new technology along with sustainable thinking. Eco labelling, recycled polyester, recycled cotton and the looking for a greener environment are hot topic discussion nowadays. The manufacturing of a sustainable product does not always have to be called “organic cotton” but could instead be achieved by thoroughly take the use of PCM and its derivatives into consideration.

Right now the phase change material garments are useful in those areas where the time of thermo regulation property is low. Take for example when considering a country in the Middle East where the temperature remains constantly high and everyone is used of air-conditioning. The malls, cars, buses, trains and all other public places are fully equipped with cooling machines. The proper use of this garment which is off approximately ten minutes can be found from one point to another. Getting out of the mall to the parking area takes at least 7-8 minutes and at that point the smart denim starts working and is able to bear the scorching sunlight. When looking into the comfort zone, the PCM fabric itself is very soft unwashed and becomes even softer after enzyme wash.
The cost of manufacturing a smart denim product has shown not to be high due to the availability of resources as compared to regular jeans. At this stage research work is in process and it is difficult to analyze the exact cost of PCM. With the integration of PCM the total cost of the denim fabric will be increased but not to a drastic level. Another aspect of the cost of PCM can be the mass production of yarn. Swerea has facilities available to produce but not in mass production. It has to be outsourced and the raw materials requirements and quality measures of PCM have to be deeply looked upon. In that case the price of PCM yarn can be risen which will impact the final price of the denim fabric. The cost of the denim fabric will remain same which is 2.75 USD per meter in addition to it the price of PCM yarn will make it higher. The major impact will be on the process of weaving and spinning where PCM yarn will get weaved with cotton. According to Swerea the price of PCM will be increase to a little extent. This tells us that the when launching a smart denim product there is more freedom when deciding on price positioning. The main challenge is that there are no current smart denim jeans in the market from which to benchmark. One must therefore estimate the superior value derived to consumers when using the product. To establish the minimum price one must include both direct and indirect costs for the development and marketing of the jeans. At the same time a firm must consider the price that consumers are willing to pay for it. One must find the right balance and have in mind that price indicates the quality level the product has.

### 5.1 Conclusion

- Smart denim could become a lucrative business strategy as well as a unique product positioning strategy against competition.
- Smart denim could bring added value to consumers through the innovation aspect and its function of increased comfort due to the thermo regulating properties.
- The total cost for manufacturing a pair of smart denim pant is more or less equal to the production of a regular pair of cotton denim pants.
- The duration of the smart denim pant last for approximately 10 minutes before acting as a regular cotton denim fabric.
- Washing, bleaching and finishing does not harm the PCM effect of a smart denim fabric.
- To increase the content of PCM, you could let both weft and warp run with PCM yarn.
- The dying of PCM is possible and essential for producing denim since it is made out of Indigo dyed coloured yarns.
- The current PCM has a glossy surface and further trials would be needed to achieve a more matt effect.
- PCM is a more sustainable alternative to traditional cotton
5.2 Suggestions For Future Research

During the research process we realize on one hand that certain areas restricted our study and others touched point on new angles of the subject that brought ideas of other related fields that could be interesting to examine:

- To extend the duration effect of PCM.
- The set up of test standards for measuring products containing PCM.
- To explore the possibilities of blending PCM with other materials compositions.
- Explore the possibilities and the effect of the PCM through the integration of the material into other woven or knitted structures.
- Research different dyeing techniques for PCM.
- Is 100% PCM Denim possible? Find solutions to replace cotton with synthetics that has the same feel and look?
- Asses a LCA of PCM. Let the outcome show the benefits by comparing 100% cotton denim with smart denim.
- Apply the smart denim concept through a consumer perspective.
6 Sources and References

Electronic Sources

Fiber2Fashion.com (April 2010)
http://www.fibre2fashion.com/industry-article/technology-industry-article/chameleonic-textiles/chameleonic-textiles1.asp
http://www.fibre2fashion.com/industry-article/textile-industry-articles/sensational-smart-clothing/sensational-smart-clothing1.asp

Tampere University of Technology of Finland (April 2010)

Cluster of EC co-financed projects on Smart fabrics, interactive Textile (April 2010)

Emerald Research (2010)
http://www.emeraldinsight.com/journals.htm?articleid=875554&show=html

Research and Markets (April 2010)
http://www.researchandmarkets.com/reports/838232/consumer_goods_global_industry_guide

Clevertex; Development of a strategic Master Plan for the transformation of traditional textile and clothing into a knowledge driven industrial sector by 2015, Report on Intelligent Textiles (October 2009)
http://www.clevertex.net/Image/documents/State%20of%20the%20art.pdf

Fashion Futures 25; global scenarios for a sustainable fashion industry, Levi Strauss & CO. Fashion Forum 2010
http://www.forumforthefuture.org/projects/fashion-futures

IEEE Explore Digital Library (June 2010)
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04650403

The Indian Textile Journal (June 2010)
http://www.indiantextilejournal.com/articles/FAdetails.asp?id=852

Outlast.com (June 2010)
http://www.outlast.com
http://www.outlast.com/index.php?id=95
http://www.fabriclink.com/Features/Assets/KA_Outlastfall02.pdf

Comfortemp (June 2010)
http://www.comfortemp.com/htm_english/index2.htm

Schoeller (June 2010)

BNet Articles (May 2010)
http://findarticles.com/p/articles/mi_m0HWW/is_31_4/ai_77673321/

Zegna Sport (June 2010)

NASA (July 2010)
http://www.sti.nasa.gov/tto/Spinoff2004/ch_1.html

Renewable Alternatives (July 2010)
http://www.renewablealternatives.com/default.asp

True Textiles (July 2010)
http://www.truetextiles.com/sustainability

ADEME ORG (August 2010)

Books


HU, Jinlian (2007) Shape Memory Polymers and Textiles Woodhead Publishing


R S Blackburn, (2005), *Biodegradable and sustainable fibres* Woodhead Textile Series No 47


**Report**

A report on *Phase Change Materials* from Swerea IVF provided by Bengt Hagström

Philip Kotler (2003) “*Positioning: Kotler on Marketing*” Published by John Wiley & Sons., Hoboken, New Jersey

Ries, A., Trout, J. (1999-2010), “*Positioning*”, QuickMBA


Figure 43: PCM melt spinning process