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Nils-Krister Persson holds a PhD from Linköping University and master degree from Lund University. Presently he is head of the Smart Textiles Technology Lab (STTL) which is the technological research body within the Smart Textiles initiative in Sweden. The aim is to develop advanced functional textile materials and processes. Research embraces multifunctional textiles, conductive organic fibres, environmental friendly coatings, multiscale modeling and thermo-driven shape changing.

Anna-Carin Jonsson, BSc in Textile Engineering from the Swedish School of Textiles. She is working with product development and quality assurance in the textile and fashion industry.

## Rethinking Available Production Technologies – the case of a thermally insulating footwear concept

Nils-Krister Persson, Anna-Carin Jonsson,  
The Swedish School of Textiles, University of Borås  
Nils-krister.persson@hb.se, annacarin.jonsson@gmail.com

### Abstract

Consumption reduction is often regarded as profound for sustainability. The overwhelming studies are on the general public and its behaviour. Here we discuss a way for the company to lower consumption by avoiding inventory investments. Added value in terms of sustainability can be gained by using standard manufacturing technologies frequently found in the textile industry to produce new products beyond present paradigms. Specifically we develop knitting techniques on a circular knitting machine to enable production of a thermally insulating textile composite for a multi-component footwear system. Four cornerstones defined the project; *sustainability, availability, comfort* and *flexibility*. The first two relate here to the production, while the last two are coupled to the wearer's experience of the product.

Two key questions initiated this project. The first question elaborated on the possibility to produce an untraditional material for a new type of product on a circular knitting machine, which is generally used for high speed production of full-width fabrics. The second question explored the possibility to apply the three-layer principle - generally used in sportswear - on footwear. We show that we can answer both these questions positively.

Using an elaborated functional design tool the footwear system was theoretically divided into functional layers; inner, middle and outer, combined with an inner and outer sole. These detachable layers together create a flexible footwear system. A ready-made product, the middle layer with thermal insulating properties, was practically developed, taking use of a heat and water soaking protocol for inducing relaxation in the material and by this air encapsulation.

**Keywords:** footwear, knitting, three-layer principle, comfort, thermal insulation.

### Introduction

Consumption reduction is commonly regarded as profound for achieving sustainability (Allwood, 2006). Talking within a textile context it is for example better to prolong the life span of the T-shirt than buying a new one (Chouinard et al., 2011). The overwhelming focus on consumption studies is on individuals, households and the general public (Newholm and Shaw, 2007). Still investments by companies stand for a

very large amount of yearly national gross expenditure in many countries. Any purchase of instruments and machinery creates a seismic wave through the economy. Energy must be used in the machine factory. Transport must be performed for moving the items from the machine plant to the buying company. Oil or electric energy must be produced for this. Raw materials must be found - minerals transformed to metals, oil to plastics and so on. All this adds to the global burden of resource use. Naturally it is also the case that new machinery is more efficient with energy, water and chemicals than older generations. Old machine parts can be reused and metals be re-melt. New equipment can be placed in geographically better sites than before, minimizing distance to costumers. All this lessens the negative environmental impacts. Our focus will be when the company is in a situation investigating a new equipment purchase that is needed for the company, given its present market. Re-use of a process could be an alternative. By avoiding machine investments, prolonging the life span of the equipment, but still reaching new markets both an economical advantage for the company and a positive effect on the environment is obtained. The aim is here to give a concrete example of ways to do this. The philosophy is to use standard manufacturing technologies for cheap mass production to produce new kinds of products. Rethinking both choice of technology for a certain product and what is possible to do with a given assembly of machinery could enable an enhancement of the sustainability profile of the company. We exemplify the former issue by presenting a systemic footwear concept realised by using specialised yarns, and the latter by explicitly showing how to produce one of the components in the system by the common circular knitting technology.

Experiments aimed at developing a structure that would have thermally insulating properties and be possible to produce on the circular knitting machine. Experiments involved machine adjustments needed to enable the machine to knit the composite, the pattern of interconnecting knitting loops, material and after-treatment, cutting and assembling. Before this an elaborate design process was performed, first described.

## The Basis for the Product Development

Product development should lead to the realization of the demands and requirements which define the product and the production thereof. Here we work according to the idea of Function analysis (Pahl et al., 2007, Hubka et al., 1988) as a means to learn how to think and express the product in functions rather than in ready solutions and physical objects. By Functional analysis, function (for definitions see (Kikuchi and Nagasaka, 2003),

(Umeda and Tomiyama, 1997) and the very physical realisation in a certain object are disentangled, creating a freedom in mind. The process is inherently iterative; starting with a main function a decomposition into subfunctions is performed. These are elaborated. Eventually the subfunctions are associated with physical realisation.

The project is defined by the following four cornerstones;

- The **comfort** aspect includes creating, supporting and maintaining a comfortable microclimate under various kinds of external climate and levels of physical activity. Comfort embraces also other aspects – such as size fit, cushioning (Drez, 1980) etc. These will be of secondary focus here.
- **Flexibility** refers to the footwear system's ability to be convertible in order to suit shifting conditions. For example adapting to changes in level of activity, changing weather condition, from outdoor to indoor, from wet to dry or from dirty to clean.
- **Sustainability** focuses on resource efficiency from the perspective of the company. Striving towards optimizing production processes through minimizing the use of energy and chemicals, as well as reducing the amount of waste produced. Packing material, stock and transport should also be rationalised in order to minimize storage, space, weight and so on.
- **Availability** focuses on innovative use of existing, accessible and widely distributed production equipment, as well as developing new techniques and applications for these machines. Availability focuses on the development of new knitting techniques on existing equipment rather than development of new machines. This enables production of rare textile structures by applying and combining techniques that are not commonly used or known of.

The first two cornerstones relate to the wearer's experience of how the product meets its aim, and the last two relate to the production of the product.

The concept of Gestalt – which originates in perception psychology - has been adopted by the design community (Monö and Knight, 1997). It refers to an arrangement of parts which appear and function as a whole, and whose value is more than the sum of its parts. Between the parts and the whole the meronymic relation (Persson N.-K, 2012 in preparation) holds. Meronomies are inherently coupled to emergence (Emmesche et al., 1997 ).

Properties of the whole are divided into resultant (i.e. found also among the parts) and emergent (i.e. existing only at the whole-level) with empty intersection, according to the law of Excluded Middle. Gestalt is a valuable tool which can be used to describe the product developed in this project with a continuous change and rechange of perspective of the parts visavi the wholes of the parts. The footwear as a whole consists of separate functional layers that can be used separately. Together all the parts add up to a whole footwear system, which can provide a greater functionality than each individual part can do separately.

Heuristics refers to methodologies for circumventing problems. It has a philosophical and psychological origin (Hector D et al., 2009, Silver, 2004), but has been mostly adopted in the computer community (Mullermerbach, 1985). It has a high potential within the field of product development. Our approach is closest to what is called divide-and-conquer heuristics and embraces the down-breaking of the problem into two or more sub-problems, do the same with these, until the problems at hand become simple enough to be solved directly.

Development thus requires an elaborated analysis of functions. We sketch the basis of the methodology in the following, analysing the biophysiological restrictions, the concept of comfort, the function thermal insulation - and means of realization.

## The Biomechanics of the Foot

The foot can be divided into the rear foot, midfoot and toes, where each section has its own special function. The back of the heel bears the bodyweight while standing and also absorbs shock while walking. The midfoot or spring section of the foot absorbs shock. The toes keep the balance of the foot. The foot functions as one link in a biomechanical kinetic chain (Steindler, 1977), where movement at one joint influences movement at other joints in the chain. When the foot hits the ground it is subjected to dual forces, the ground shock of heel strike and the vertical stress of weight from above.

Walking puts up to 1.5 times our bodyweight on our foot, and running three times our bodyweight (Fourchet et al., 2012, Dixon, 2008). An individual takes between 8000-10 000 steps each day (Dai et al., 2006). During walking the foot becomes longer and is stretched forward and rearward at the heel area; at the same time the waist and joint area of the foot becomes wider. During running the foot passes through both pronation (appr 25% of the time) and supination (appr 75%) (Drez, 1980). Thus movements are inherent and have to be considered in any design. The heel counter on a shoe stabilises the heel area. But

a too rigid shoe does not provide any greater protection against impact and may affect the gait cycle (Lohman EB et al., 2011).

## The Concept(s) of Comfort

Comfort is dependent on the surrounding climate (temperature and humidity), activity and clothing. Comfort can be divided in different ways. One way is to use a two-fold perspective as follows: *Physio comfort*, dependent on physical and physiological factors and embracing thermophysiological aspects such as the bodies' loss (or gain) of energy, the physical work being done by the person, and the environment (ambient temperature, air humidity and air movement), which for a garment and footwear boils down to heat insulation, air-permeability, vapour retention, water-absorption, wettability and water-transport ability. Added to this are also other sensorial factors such as the sensation of how the fabric feels against the skin. This feeling addresses fabric properties like prickling, itching, stiffness or smoothness. The garment fit considers the ergonomics of the clothing, its freedom of movement, tightness and weight. Fit influences the thermophysiological sensation. As an example a loose fitting garment may be perceived as cool during summertime.

On the other hand, *comfort from a socio-cultural perspective*, which includes fashion styles, emotional colours that the garment communicates as well as the suitability of the clothing for the occasion etc. This has a subjective nature and is possibly more difficult to measure quantitatively than physio-comfort.

## Air as Thermal Insulation

Vacuum provides no atoms and molecules and is a great form of insulator, since the heat can not move by conduction. Since vacuum is difficult to use in clothing, insulation uses the next best approach, which is to approximate a vacuum by minimizing the amount of matter through which the heat can move by using a gas.

In most porous insulation, the surrounding air is the gas that is used. Since air is easily moved by convection and pressure differences, an open air space does not work well as insulation. For better insulation values porous insulation is used, it holds the air in place by using small quantities of solid material as a matrix. The solid material is distributed so it occupies as much of the space as possible. The contribution of the fibre itself to the thermal insulation comes second. Many gases have better insulating properties than air. However some of these gases can effect the atmosphere and all insulation that uses alternative gases requires closed cells to keep the gas from escaping and being replaced by air, even if the gas is encapsulated it

can in most cases slowly diffuse through the plastic (Wulfinghoff, 1999).

### Three Layer Principle, Textiles and Footwear

In order to achieve a comfortable microclimate in different weather conditions and for varying activity levels, the layering principle is frequently used and validated (Ren and Ruckman, 2004, Ruckman, 2005) in various clothing systems, not least in outdoor (Shishoo, 2005), uniform (Scott, 2005), sports (Shishoo, 2005) and workwear (Scott, 2005). The three layer concept is an example of application of the functional decomposition methodology.

The three layer system incorporates layers of materials, each with a specific function, from inner to outer - transport of moisture from the body, thermal insulation and protection against wind and wetness. The layers are separable so that the system can be regulated by the wearer who can add and exclude layers to enable comfort. Fundamental in this respect is the thermal insulation, realised by encapsulation of air to achieve a comfortable microclimate.

To dress a foot resembles the challenge related to dressing the body, with the exception that footwear is often exposed to more harsh mechanical strain than most clothing systems and the sole of the footwear is partly in direct contact with the ground. While a functional clothing system consists of detachable layers which can be freely combined, shoes are often equipped with functional materials which are permanently incorporated into the shoe. The division of the clothing into detachable functional layers should be possible to be applied to the foot. This would make it possible for the wearer to divide the footwear in its functional layers, and through this reach comfort giving optimal microclimate.

Textiles play a prominent role for footwear (Kanakaraj and Priya, 2007) being used as lining, upper materials, backing and reinforcement. Even if definitions are un-sharp, most often footwear is only partly consisting of textiles having leather, rubber and plastics as main components. Woven and non-woven are the types of textiles frequently used. Knitwear often has the risk of fraying (Goel, 2010). Still examples of studies of knitted linings exist (Blaga et al., 2011).

For textiles related to footwear moisture and thermal management have been a focus for research (Neves et al., 2011, Bertaux et al., 2010) (Barker R L, 2002) and related to this many examples can be given of model building and numerical calculations (Wu

and Fan, 2008) (Ren and Ruckman, 2004) Hollow fibres which incorporate small amounts of air into the structure use encapsulation of air. A study (Kunz E and X., 2005) investigated which structural parameters of the 3D hollow fabrics are optimal to support ventilation and thus, thermal comfort. In (Wu and Fan, 2008) different types of fibrous battings and their positions were studied to gain knowledge about moisture accumulation and thermal insulation performance of clothing assemblies. It was found that placing the hygroscopic wool batting closer to the body and the non-hygroscopic polyester batting furthest away from the body resulted in less moisture accumulation in the system, which minimizes heat loss. In (Long H-R, 1999) the water transfer properties of a two-layer weft knitted fabric was investigated. It was found that the permeability rate is closely related to the porosity within the fabric while the transfer depends mainly upon the water absorption properties of the fibres.

Three-dimensional knits, also called spacer fabrics, have large capacity to trap air and offer extremely lightweight high-performance thermoregulation but can be regarded as advanced, and leaning upon our cornerstone of availability we use only 2D knit. Layered footwear were studied by Kuklane et al., 2000. Within the footwear community the perhaps most active field is shoes that fall within the sportswear realm. Here shoes are regarded as the most innovative field, compared to other garment and textile accessories (Thiry, 2008). Recently also socks have experienced fast development (Thiry, 2008) with for example ready-made items direct from machine, seamless toe with protruding parts. Compression functionality (McCurry, 2010) and moisture management (WSA, 2005) have also been active directions for development of hosiery. Still the scientific research literature that directly addresses textile aspects of footwear is limited. Non-direct paths have to be used.

Orthopedics and physiotherapy have naturally been interested in footwear (Dai et al., 2006, Drez, 1980). Studies has been performed in a context of prosthetics, (Sanders et al., 1998) which provides a controlled study on compression of different sock material and friction between these materials and skin. But it is not immediate how to transfer these results in the detachable footwear concept.

Shoes, development of new footwear concepts, and hosiery have been highly interesting from a military point of view (Dyck W, 1992, Rosenblad-Wallin, 1988). Even if this literature is huge the technological knitting and production aspects are secondary. Regarding shoes and socks as one system, it's not new with concepts such as SIS, sock-insole-shoe (Thiry, 2008) and boot-winter

or summer insole – outer sock, inner sock (Rosenblad-Wallin, 1988), being presented. But these do not provide a detachable system. The conclusion is that few studies explicitly apply the three-layer principle to footwear.

### Principles for a New Footwear Design and Production

To start with, the footwear system was theoretically subdivided into functional layers: inner, middle and outer layer, together with an inner and an outer sole. All the detachable layers together form a flexible footwear system, fig 1. Shape and size of one of the author's (ACJ) feet were used for modelling the footwear layers.

#### Distributing Functions in Separate Layers

To enable comfort during shifting levels of activity, the footwear must be changeable. This can be done by the wearer, by adding or excluding units. This way of regulating the microclimate can be achieved only if the footwear is subdivided into detachable layers, where each layer of the footwear incorporates a function.

The project illustrates how the choices made during product development influence a wide range of aspects; individually for the user and in a wider perspective the production, its availability and environmental issues. Eventually all these aspects can be summarized in the four cornerstones that were chosen to frame this project; comfort, flexibility, sustainability and availability.

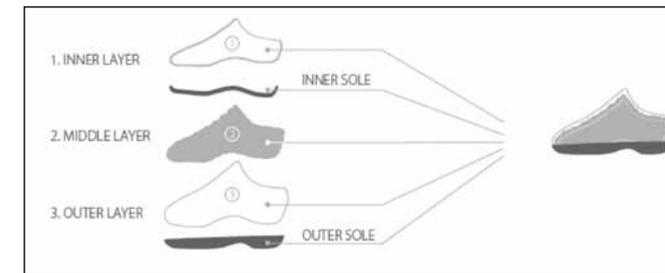


Fig 1: Detachable layers that together forms the footwear system.

*The outer layer* main function is to enable protection against penetration of wetness and wind, while still being breathable. The outer layer could for example be constructed of a plain-woven polyester which is laminated to a microporous film. The seams of the outer layer must be taped. *The middle layer* main function is to offer thermal insulation. In order to achieve this, the material of the middle layer can be designed to enclose large volumes of air, which can work as a buffer to temperature shifts.

*The inner layer* function is to transport moisture away from the body to reach thermophysiological and sensorial comfort. To achieve these properties a fibre with low moisture absorption could be used combined with a suitable knitting structure. If the inner layer is knitted as a bilateral structure, which is connected with distributed knitting loops, the inner layer will act as two socks, hindering the development of blisters as well as more easily transporting moisture away from the foot.

The sole of the footwear is divided into two parts. The inner sole or the footbed, which is located close to the foot, compensates for the differences of the feet, and helps the body into a healthy posture as well as absorbing shock while walking. The outer sole enables protection against mechanical strain and wetness as well as absorbing shock while walking. The outer sole is moderately stretchable, which makes it easy to slip into by pulling the rear end of the sole over the heel and fixate it onto the outer layer of the footwear system. In the present study the middle layer is in focus and the following refers to the design and production of that.

#### Development of Shape

Requirements related to the wearer's experience of comfort and aspects related to the sustainability and availability of the production process were equally important during the development of the footwear system. Several experiments were conducted using different materials and approaches. From this work a footwear shape, meeting the requirements of the cornerstones in varying degrees evolved.



Fig 2a: The origami inspired phase for minimizing material  
Fig 2b: The three-dimensional shape of the footwear was received through folding a two-dimensional material

The initial experiments were inspired by the Japanese paper folding technique origami (fig 2).

Starting with a rectangular shape (A4) and folding this into three dimensional shaped sketch models, aimed at finding a space filling three-dimensional (3D) shape where its two dimensional (2D) shape tessellates the plane. In this way the material could be utilised efficiently and the laying of the pattern is made easy as well as that the amount of sewing is reduced.

Further test shapes were constructed in textile and modelled on the foot in order to give an idea of the shape and fit of the footwear. A range of different test models evolved during this phase. The choice of the model was based on the four cornerstones and the gestalt interplay between parts and wholes. The formation of the pattern for the footwear aimed at achieving a way to communicate how the forthcoming 3D shape would be formed, which is in line with the cornerstone concerning efficient production.

Minimizing the amount of material used to produce one footwear unit, including waste material cut away in the production, as well as utilising a larger percentage of the material, leads to more efficient production, and economizing with materials.

The same shape is used in all the layers of the footwear. This makes the production easier. It also gives the separate layers a common idiom, in spite of the difference in material and structure.

### Introductory Production Remarks

Since the circular knitting machines are mainly used for high speed production of full width fabrics, it is a challenge to develop a structure that will enclose air and hold it still inside the textile composite, meanwhile being possible to be produced on this kind of machine.

A circular knitting machine with two needle bars can technically produce a bilateral textile structure without connecting points and thereby the materials can be detached from each other. In order for these two sides of the knitted structure to be separated from each other and thereby be able to encapsulate air, a non-knitted filling yarn can be incorporated between the material layers, separating the two textile units and thereby creating space for the air to fill. The two textile layers are interconnected by knitting loops in selected places to divide the composite into smaller sections. The distance between interconnecting knitting points has to be optimized so that the two material units can be separated enough to encapsulate the porous material, but not

become too big and thereby lose its stability. The amount of non-knitting filling yarn that is possible for the machine to handle and lead in between the textile units had to be determined, this also defines how thick composite the machine can produce with this technique.

Knits are characterised by being flexible and stretchable structures. Footwear needs to be flexible to meet the comfort requirements, but also rigid to support the position of the foot and achieve a correct body posture. Therefore the knitted structure had to be modified to, besides being flexible, also offer enough rigidity for a footwear layer. The hypothesis that was tested was to incorporate a yarn in the construction that could pull the composite together and thus make the structure more stable. If the structure could be pulled together by the contraction of a yarn within the structure, then the height of the composite would increase, creating more space for the filling yarn to expand in and allowing the structure to encapsulate more air per area. This idea could therefore add to the product by both making it rigid as well as increasing its thermal insulation.

## Experiments and Results

### Circular Knitting Machinery

All experiments were conducted in-house with a double-bedded circular knitting machine OVJA 36 with 36 knitting systems, 20 needles per inch, npi, and electronic needle selection. It is equipped with 1872 needles in both the cylinder and dial. The machine speed is 18 rpm. It is imperative that the machine is double-bedded for it to be able to knit a two layer structure. The machine can be programmed either mechanically, or digitally by translating a drawn pattern of knitting loops into binary language (knit or do not knit). In most cases a combination of these two ways, mechanical and digital, is used. To enable the circular knitting machine to knit a double structure with a non-knitting filling material, several adjustments was made on the machine. The adjustments concerned increasing the distance between the two needle beds and lowering the knitting systems thread guides to allow the filling material to be lead into the textile structure without interfering with the needles. The loop size and the yarn speed were adjusted individually depending on the task of the knitting system.

### Knitting the Composite

Three different patterns were created to experiment with the placement of the interconnecting knitting loops. The patterns were computer drawn. The machine relates to the pattern by reading one pixel as one needle movement.

Depending on the dimension of the knitting loop the pattern has to be adjusted in order to have the right pattern dimensions of the knitted material. The loop measurements can not be foreseen exactly before the structure is knit, so measurements of the loop dimensions were made on the first finished textile (after heat-treatment). As seen on the picture (fig. 3) the patterns include areas where nearly every loop interconnects the textile layers, opposed to areas which do not include any interconnecting loops. Neither one of these scenarios was optimal. The areas that caused the least amount of problems while knitting were areas where the courses either had or did not have interconnecting loops exceeding five to ten loops without interruption. This is due to the incorporation of the non-knitting filling yarn.

Depending on the number of needles that go up into knitting position, the filling yarn is left without guidance from the needle. If many needles in a row go up, or stay down, both scenarios influence the stability of the filling yarn, risking the filling yarn to intertangle with the needles. Ideally every other needle should go up into knitting position and thus keep the filling yarn on track. On the other hand, to have many binding points in a row on a wale creates no problem since the different binding points in a wale are created separately by different knitting systems.

This ended up in a final pattern with no more than five interconnecting loops or five loops not interconnecting in a row (course). The pattern of interconnecting loops is large on the upperside of the footwear layer to enable high insulating capacity. The pattern was scaled down on the sole of the footwear layer to achieve higher stability (fig. 3). The attempt to optimize processes and minimize misunderstandings between production stations lead to the idea of incorporating as much information into the pattern and the knitting process, as possible. Therefore the pattern was designed to have lines, visualised by interconnecting loops, as a guidance to the later process stage of cutting.



Fig 3: Two sizes of the pattern

### Achieving the Air Encapsulation

To enable the composite to contract in width and expand in height, a yarn with the ability to contract must be incorporated into the composite. The idea here is to take advantage of the shrinkage property, which most often is regarded as unwanted. Three materials were tested regarding their ability to contract the composite.

The materials were incorporated into the structure in the knitting process and constituted 50% of the back layer of the composite. The materials tested were Lycra/Elastan, wool (40/2) and Pemetex (Pemetex undyed, Jet tex dull CS. 400F120x1). Pemetex is a variant of Trevira flame-retardant textured filament polyester yarns. It is a bicomponent yarn with a low melt component that results in a stiffening of the textile surface at the finishing stage.

The aim of the experiment was to see which material that would add the most to the composite's thermal insulation and at the same time stabilise the composite. Lycra is knitted into the structure in an elongated state. When it relaxes from the tension, it pulls the surrounding structure together. The wool is knitted into the structure, and its corresponding composite is subjected to heat. When the wool shrinks, this will contract the composite. Pemotex is also knitted into the structure and since it is a heat sensitive bi-component yarn, it will shrink when the temperature reaches beyond the temperature at which it has been fixated (in the expanded state). Thereby it pulls together the rest of the structure in width, and since the composite has no physical restrictions in height, it will expand in that direction, resulting in a thickening of the composite.

### After-treatment

Application of heat can be done in different ways, here we used two methods. Experiments were made to evaluate the difference between a) applying heat through puffing steam from an iron set at 200°, and b) with heat application by standardised household washing, at 60° followed by hang drying. Washing thus includes both heat, water and mechanical processing.

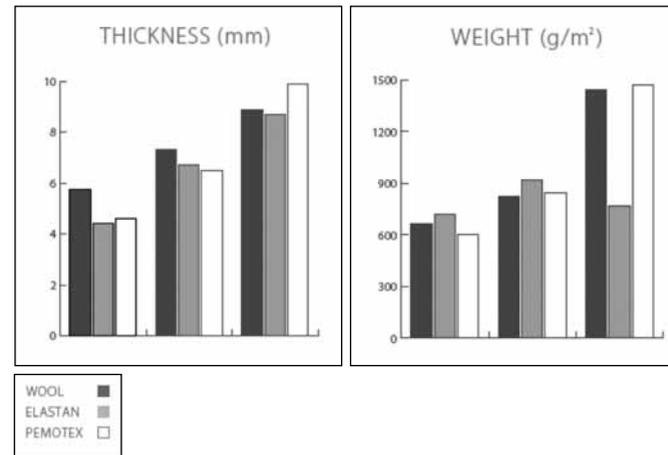


Fig 4: Results from measurements of the composite's thickness and weight per square meter after its been subjected to three different after-treatments; A: before after-treatment, B: after-treatment steam, C: after-treatment washing.

The result of the experiments (fig 4) indicates that the washing treatment resulted in the highest degree of contraction in width and the best expansion (fig 5, fig 6) in height. Of the three materials Pemotex has the most significant properties in this respect, increasing in height by approximately 100%. Consequently the thermal insulation capacity was doubled.



Fig 5a: Thermally insulating composite from above. before heat treatment.  
Fig 5b: Thermally insulating composite from above. after heat treatment



Fig 6: Cross-section of the composite, before (above) and after (underneath) heat-treatment.

### Cutting and Assembling

The raw material from the knitting machine was cut along the pattern, which is formed by the interconnecting knitting loops. The tight position of the interconnecting knitting loops allowed for the material to be divided without exposing the filling material. Appropriate for this product would be to punch out the pattern parts with a continuous and heated punching-machine. Since all the fibres used in the footwear system are synthetic, the heat from the punch-machine would melt the edges, forming a closed textile edge. This would be desirable in the assembling process, avoiding the filling material from the composite to entangle and cause problems in the assembling process.

Two methods of assembling the footwear were tested; before and after the heat treatment. Finally the former was chosen, since it resulted in a more satisfying shape. The product is shown in fig 7.



Fig 7: The final prototype of the thermally insulating layer included in the footwear concept.

### Conclusions

The *tangible result* of the project is a three layered footwear concept, of which the thermally insulating middle layer was developed and produced on a circular knitting machine. The subdivision of the footwear into three separate and detachable functional layers enables it to meet the requirements of thermal *comfort*. To achieve and maintain thermophysiological comfort the footwear system needs to be convertible, to suit and shifting weather conditions and levels of activity. Adopting the idea of the three layer principle, the footwear concept uses the technique of adding and excluding functional units, and thereby fulfils the requirements of *flexibility*. In line with the *sustainability* requirement the footwear's 3D shape (pattern) is designed to utilise the material effectively in cutting, minimizing the amount

of waste and optimizing the production process. Since the pattern of the footwear is visible as a knitted pattern on the textile, the pattern for cutting is an integrated part of the fabric, which makes the cutting process easier. All units of the footwear system origin from the same pattern. High *availability* is achieved by the possibility to mass-produce the 3D shape on a circular knitting machine. This is an example of a frequently occurring machine within the textile industry. By this an example of rethinking what kind of product that can be produced on a certain machine or in a certain plant is given.

Since the material for the middle layer was developed to expand in height after the production process, the technique enables production of thicker materials than what is actually possible to produce on the knitting machine used in this project.

The *cognitive result* of the project is that it has been shown that existing production equipment can be re-used for new products, reaching new markets. By this, machinery can be given prolonged life time in a plant, avoiding the need for environmentally impacting investments. The concept of re-using is expanded not only to embrace physical objects and materials but (industrial) processes. We emphasize the importance of design in realizing sustainability. The immaterial design phase has large consequences for the material usage.

In total we have given one concrete example for the company on how to earn both a higher sustainability profile for itself and win environmental benefits for the world by not buying another machine for mass-production of the same thing.

Naturally what we have presented is just one example using the philosophy of rethinking both choice of technology for a certain product and what is possible to do with a given assembly of machinery. The hope is that it will inspire further endeavour along these lines.

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