Seamless warp-knitted socks / photo by Petra Haikonen

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Advanced Knitting: Warp Knitting, Fully Fashioned and Seamless Knitwear

SusTexEdu

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The objectives of the project concern Textile and Clothing (TC) sector, focusing on textile and clothing materials, sustainability and circular economy (CE). The project will create an open platform with study material and recommendations for developing an integrated formal and informal education which concerns the subjects mentioned.
https://www.metropolia.fi/en/rdi/rdi-projects/sustexedu-erasmus

The Coordinator: Metropolia UAS
The partners: Hogent (BE), Mome (HU), Omnia (FI), TTHK (EE), TTK UAS (EE), University of Borås (SE)
Funding: Erasmus +
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About this learning unit

CONTENT DESCRIPTION

- the concept of warp knit manufacturing
- the properties and manufacturing methods of seamless and fully fashioned knits

LEARNING OUTCOMES

Student will be able to:

- understand the differences between the different manufacturing methods
- select appropriate materials and knitting techniques (warp knitted, seamless and fully fashioned) in order to obtain a knitted structure with imposed specifications and properties
- understand the connection between the manufacturing method and product longevity
- understand how the manufacturing method influences the amount of production waste

STUDENT WORKLOAD

- contact teaching 4h
- group work (on-site) 1h
- individual assignment 7h
- reflection and discussion1h
- Independent work 14h

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Preface of the learning unit

This piloting study material is created for 2nd year students of Fashion and Clothing bachelor's degree programme at Metropolia UAS (level 6) for their course Textile Technology and Re-Engineered Fibers (5 ECTS). The theoretical course is held on-site.

This learning material is targeted for students that require technical knowledge about apparel textiles to understand the connection between the fabric structures, production methods and product longevity.

The course has a prerequisite course Textile Fibers and Clothing Materials (5 ECTS).

Content of the learning unit

Warp-knitted fabrics / photo by Petra Haikonen

1 Warp Knitting

Advanced Knitting
PART 1

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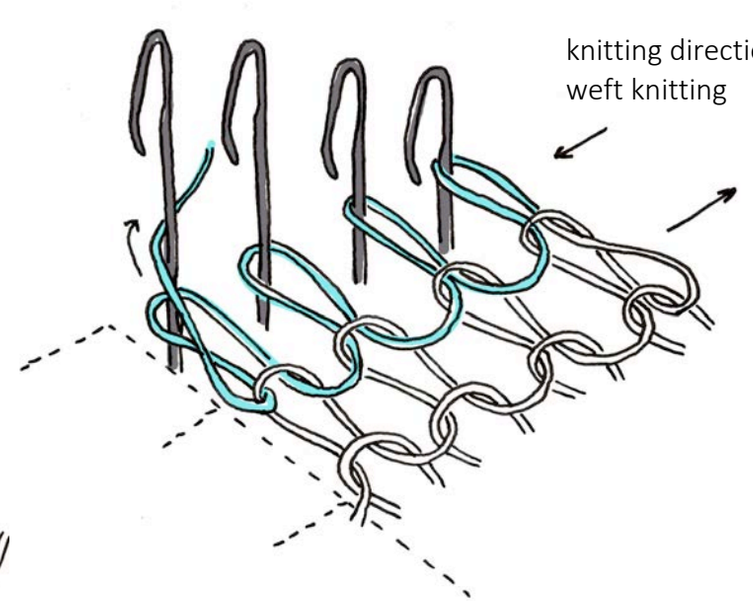
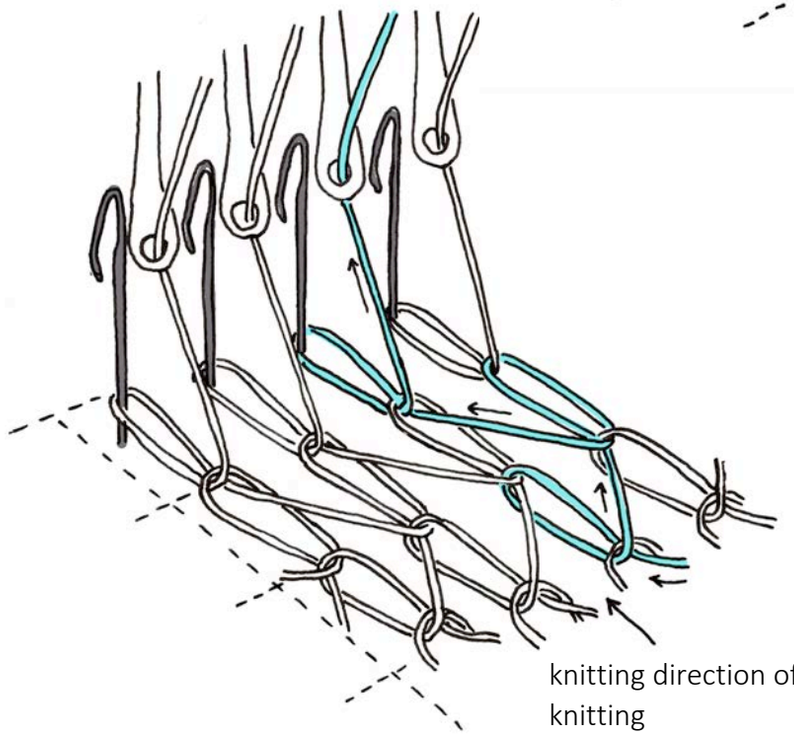
Introduction to warp knitting

Unlike in weaving that utilizes two yarn system, warp and weft yarns, knits are commonly produced with one yarn system. However, depending on the direction of how yarns run, knits are separated to weft and warp knits. With warp knits there are one yarn for each wale and the yarns run parallel to the fabric selvedge (like in the direction of warp in woven fabrics), whereas in weft knits there is one continuous yarn that run perpendicular to the fabric selvedge (like in the direction of weft in woven fabrics).

The different production method separates warp knitting from weft knitting, but also the fabric performance is different. Generally, warp knits are more stable, more shrink resistant, and they do not run or ravel. Warp-knitted fabrics are widely used both in apparel and interior uses, but also in technical textile applications.





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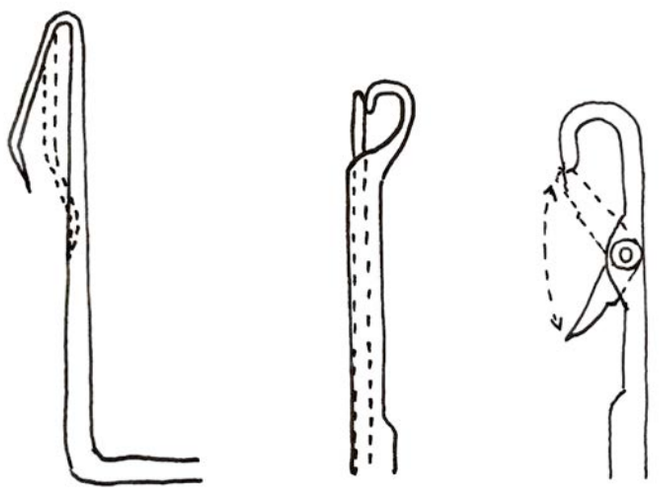
Warp knitting machines and needles

The warp knitting machines are more complex than weft knitting machines. They can be divided into two main categories: tricot and raschel machines, of which the latter can produce much more complex structures. With both machine types the fabric construction is made by loop formation from yarns coming as a parallel sheet from the warp beams.

Warp knitting machines use either bearded needles, compound needles or latch needles. In the past, warp knitting machines were categorized by the type of needles they used, but this is no longer a valid way to group the machines since the use of compound needles has become increasingly popular (used in most high-speed warp knitting machines). Nevertheless, it is still more common for tricot machines to use bearded needles and raschel machines to use latch needles.



Spring bearded needle (Tricot), compound needle (both machine types), and latch needle (Raschel)

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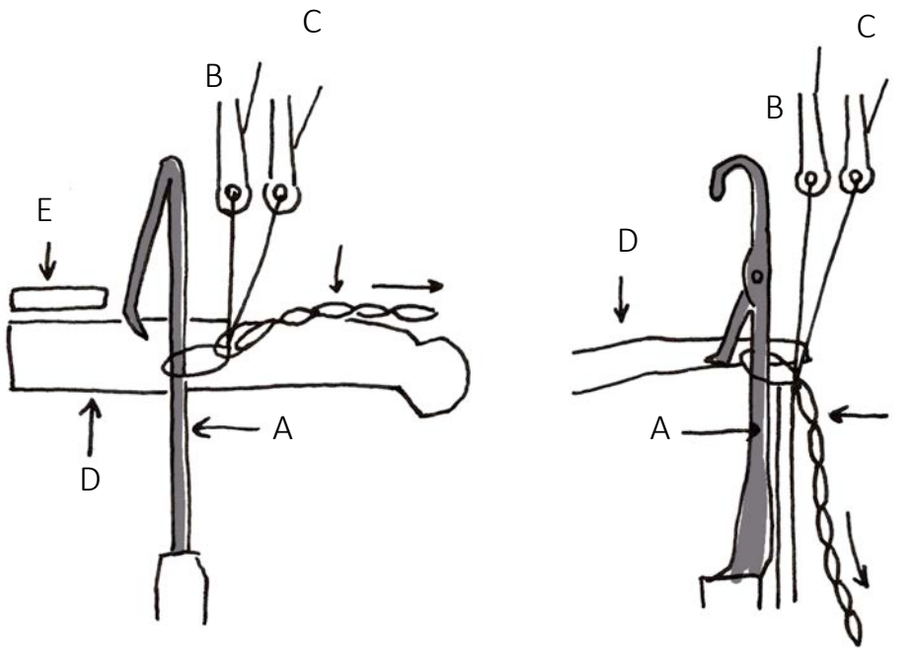
Warp knitting machines



Knitting zones of Tricot and Rachel warp knitting machines

The fundamental elements involved in the stitch formation are:

A) Needle bar (one or two): unlike in weft knits, needles in warp knitting machines do not move individually but the entire bar moves with all its needles. Therefore, all the loops in a course are made simultaneously.

B) Guide bar (minimum usually two): In warp knitting, every needle is fed by a separate yarn. Guide bars guide these yarns around the needles (as with needles, the guides move as one bar). The amount of guide bars has a great influence on the complexity of knitted structures that can be manufactured with the machine at hand. Most tricot machines have only two guide bars.

C) Warp beams: each needle requires its own yarn, so to keep the yarns in a uniform tension, the yarns are warped to warp beams like weaving. The beam width is generally the same width as the needle bar and the number of warp beams equals the number of guide bars.

D) Sinker bar to keep the fabric down when the needles rise and thus aid in the stitch formation.

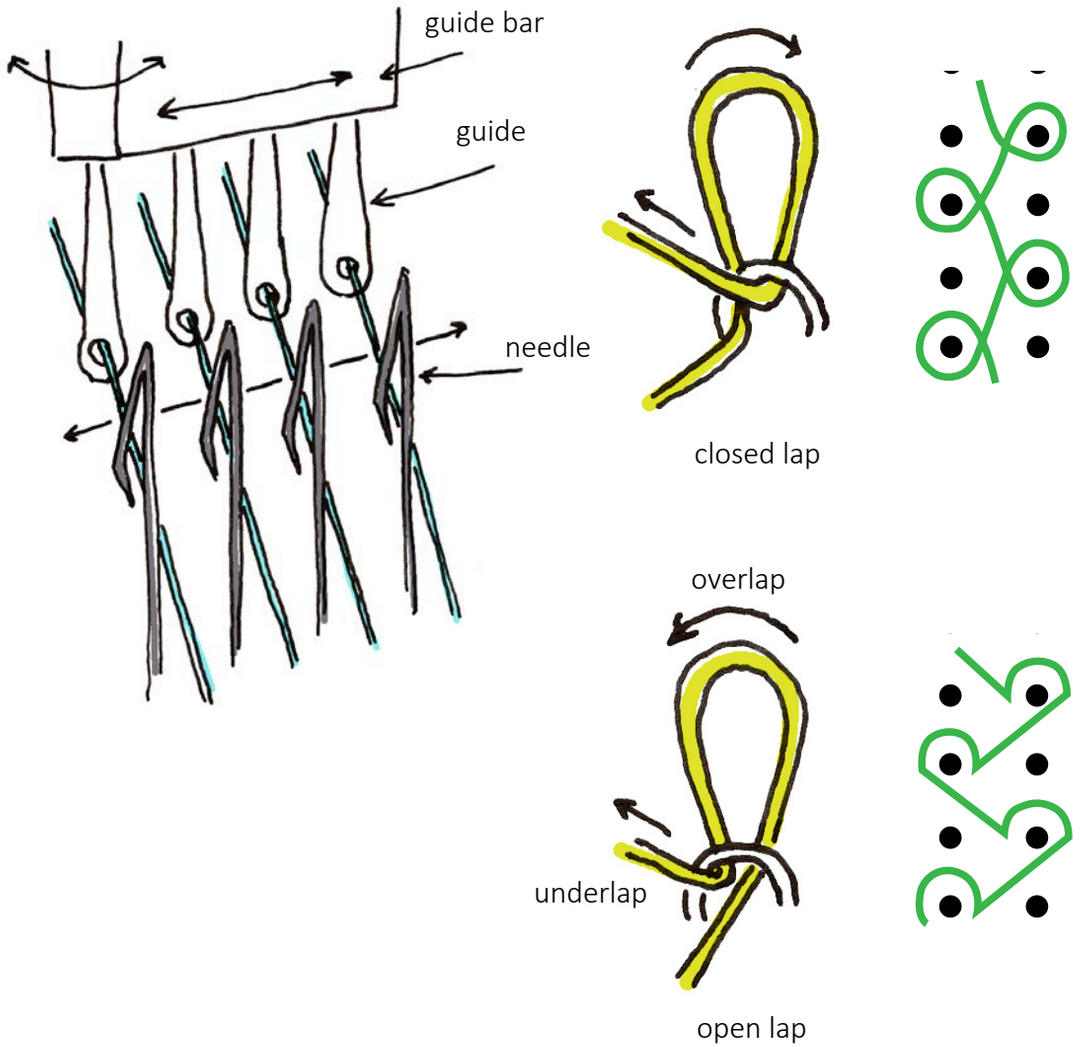
E) Presser bar: In case bearded needles are used, a presser bar is needed to close the needle and enable stitch formation.

Stitch formation

In order to wrap the yarn around the needle and form a new course of stitches, guide bar(s) and needle bar(s) need to move with respect to each other. Guide bar guides the yarns to new needles and wraps the yarns around the needles for the stitches to form a new course.

Depending on the movement of the guide bars with respect to the needles, either open or closed laps are being formed.

Warp knits consisting of closed laps are heavier and more compact, but less extensible than knits with open laps (if comparing fabrics where other parameters, such as the number of needles per inch, the yarn used and the structure remain the same).



Basic types of lapping produced with warp knitting machines

Basic types of lapping in warp knitted structures can be knitted with only one needle bed and one guide bar producing underlaps and overlaps. However, these structures are seldom used in fabric production as they are but are combined to create more complex and durable structures.

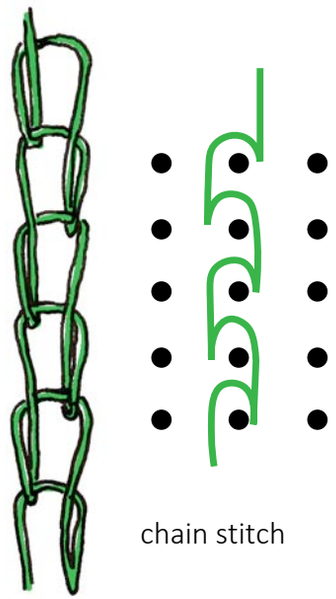
The basic lapping types discussed in this lecture are:

- chain/pillar stitch
- tricot lapping
- cord, satin and velvet lapping
- atlas lapping

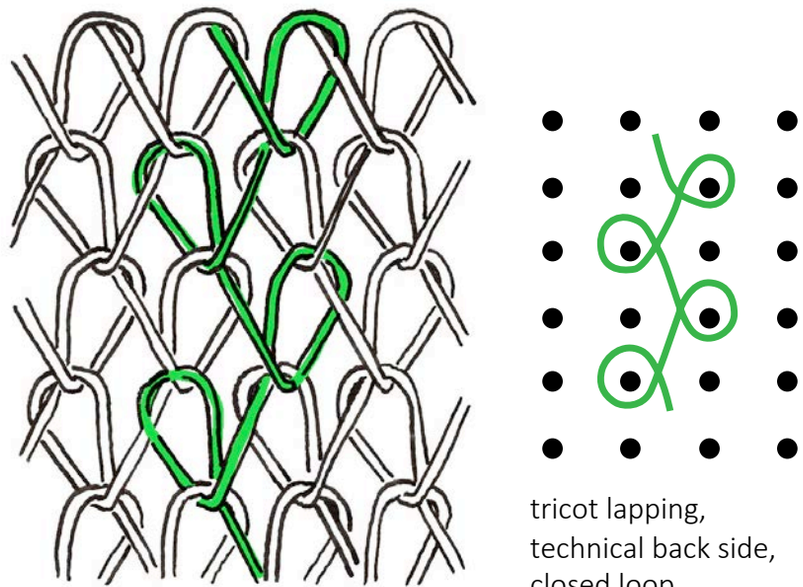
Chain/pillar stitch and tricot lapping

Chain (or pillar) stitch is the simplest warp-knitted structure. In chain stitch, each guide wraps the same yarn around the same needle on every course, so the adjacent yarns will not be connected to each other. Chain stitch structure is most used as a part of more complex structures, such as knitted tulle. Chain stitches can also be used in warp knits to bind the inlays.

Tricot lapping is the simplest lapping to create a continuous fabric on warp knitting machines. It is created by moving the guides by one needle and then back.



chain stitch

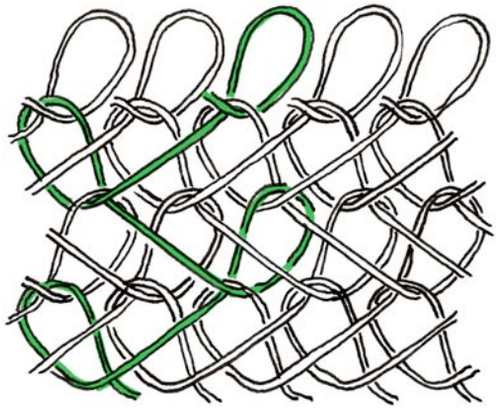


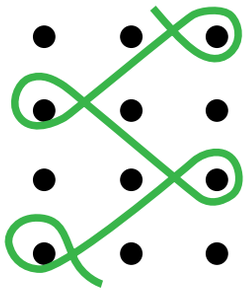
tricot lapping, technical back side, closed loop

Cord, satin and velvet lapping

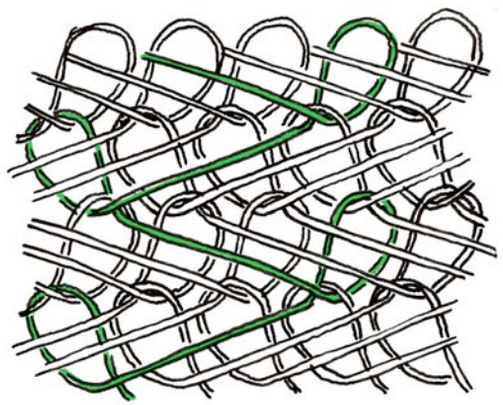
Cord, satin and velvet lapping are similar to tricot lapping, but the guides move even more: by two needles in cord lap, by three needles in satin lap and by four needles in velvet lap.

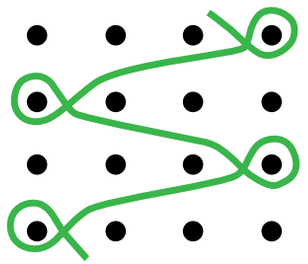
The longer underlaps may result in stronger, more opaque and heavier fabric, since the structures require more yarn.



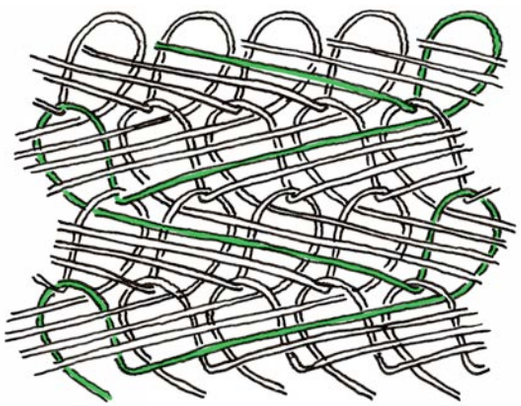


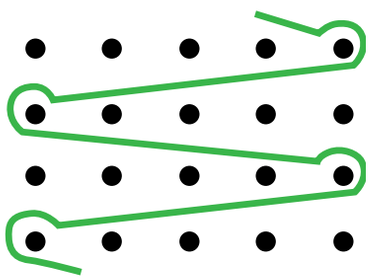
cord lapping, technical back, closed loop





satin lapping, technical back, closed loop





velvet lapping, technical back, open loop

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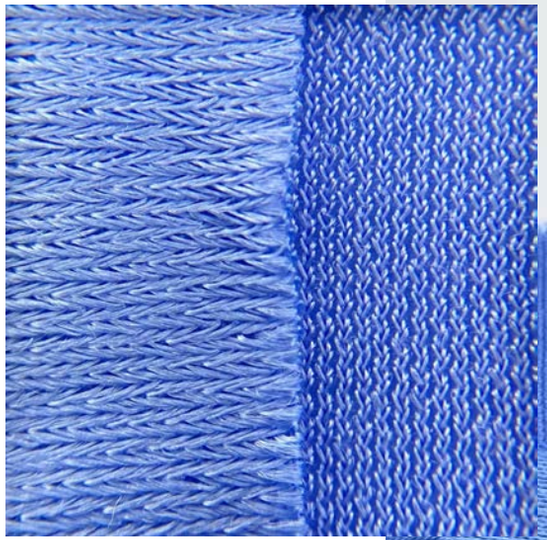

Satin-tricot fabric, that combines both satin lapping and tricot lapping (note! This is a compound structure, not just basic lapping) / photo by Petra Haikonen

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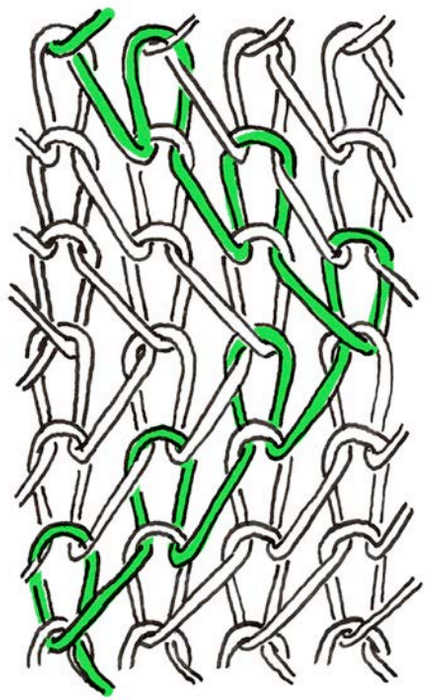
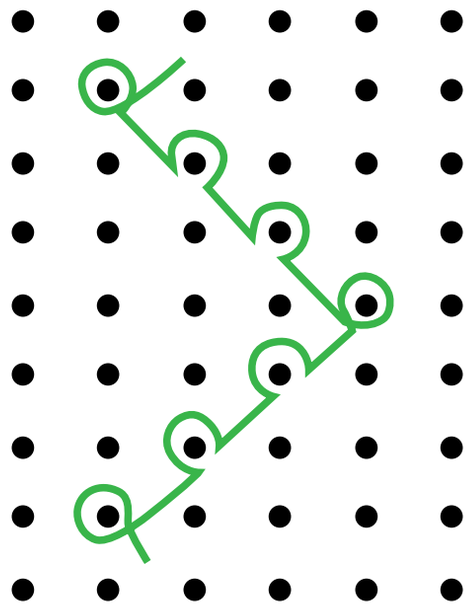
Atlas lapping

With atlas lapping the guide bars move several times in one direction, then change direction and move back as many times. The atlas lapping creates a fabric with a striped appearance since the yarns leaning in different directions reflect light differently.



Atlas lapping, technical back



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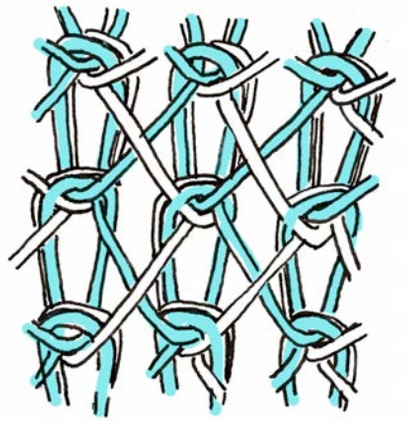
Double guide bar structures

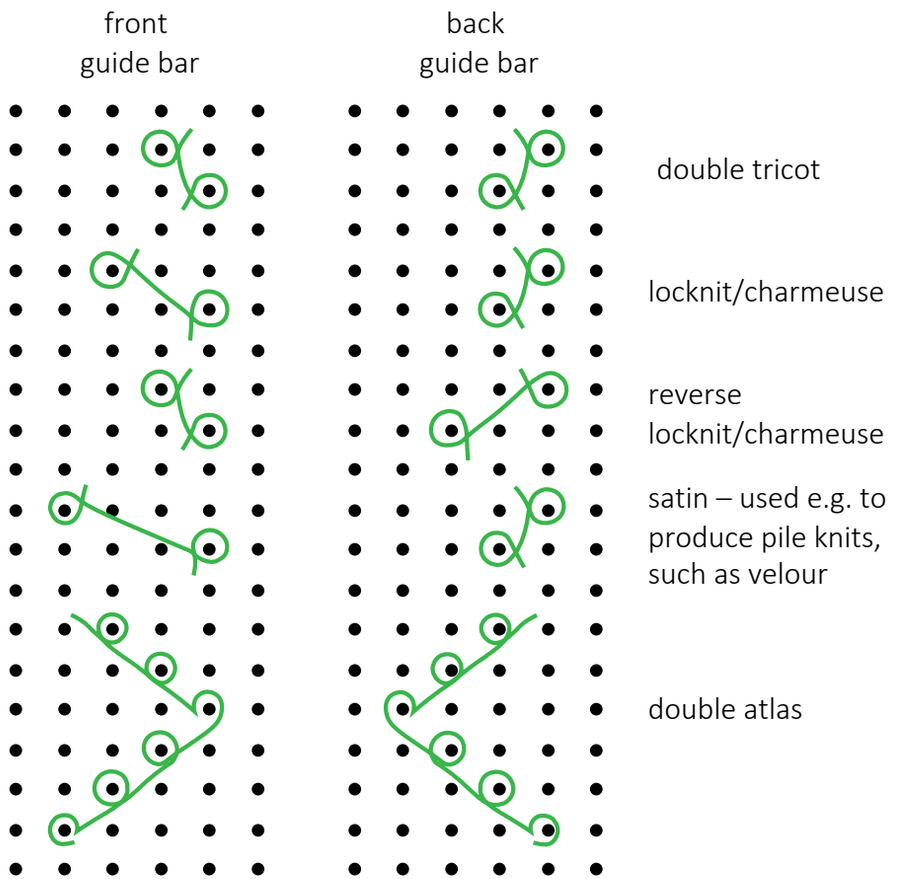
Double guide bar structures are the most common type of warp knitted structures. In these fabrics, needles are simultaneously knitting two yarns provided by two different guide bars that are moving differently from each other.

Common double needle bar structures are:

- double tricot
- locknit/charmeuse
- double atlas
- pile knits such as velour and plush
- different types of mesh knits



The technical back of a double tricot



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Double guide bar structures

Double tricot is the simplest of the two-bar structures and is used in underwear. **Locknit/charmeuse** is the most popular of all warp-knitted structures and it is common as underwear and lining material. Double Atlas is also used in underwear, but sometimes also in sportswear. **Double Atlas** knits often have diamond-shaped patterning.

Double tricot fabrics/
photos by Petra Haikonen

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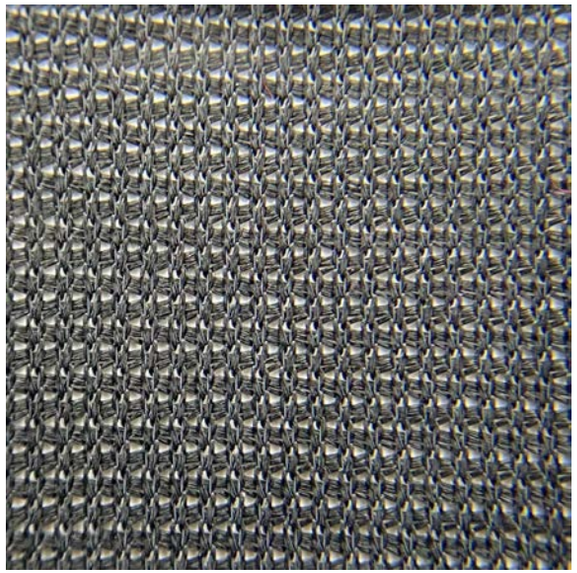

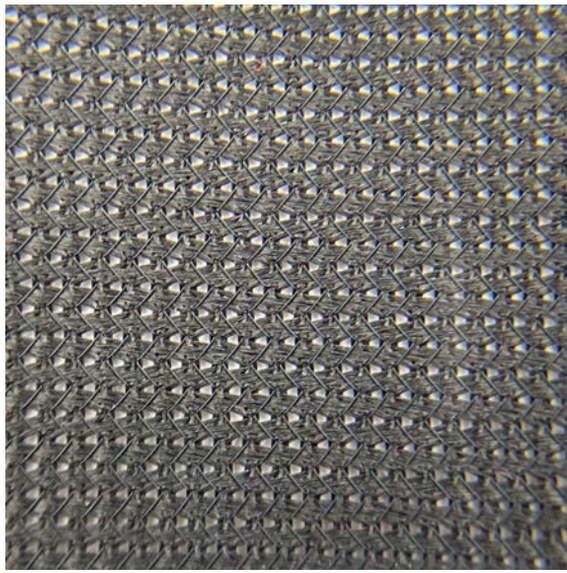

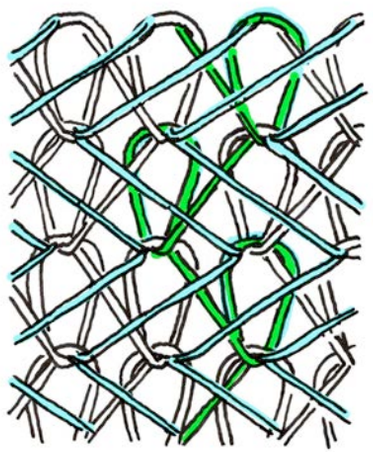

Charmeuse lining fabric; left close-up with technical front, and right close-up with technical back (illustration with technical back) / photos by Petra Haikonen

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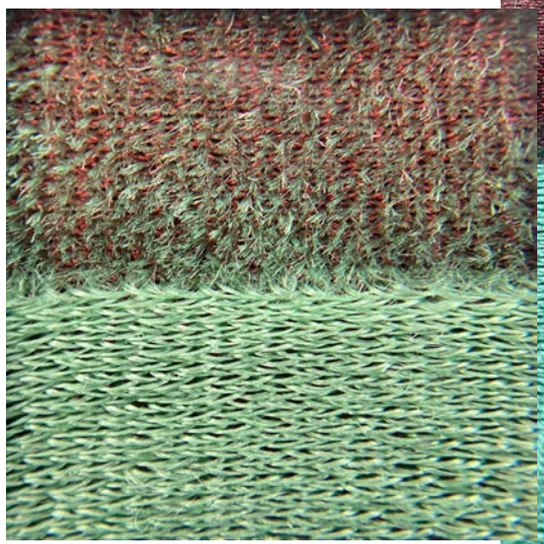
Double guide bar structures

Pile knits, such as velour, can be knitted with double guide bar, where the back guide bar creates a tricot lapping and the front guide bar either a satin or velvet lapping. The underlaps are then cut open.



Velour with red yarn knitted with tricot lapping and green yarn with satin lapping; the lower part of the sample is still uncut /
photos by Petra Haikonen

Double guide bar structures

Different types of mesh knits are created when some guides are left without a yarn. That enables the creation of structures with holes. The yarns on adjacent needles bind together only occasionally. Mesh knits are commonly used in sportswear and underwear, and as lining material.

Different types of mesh knits / images by Petra Haikonen

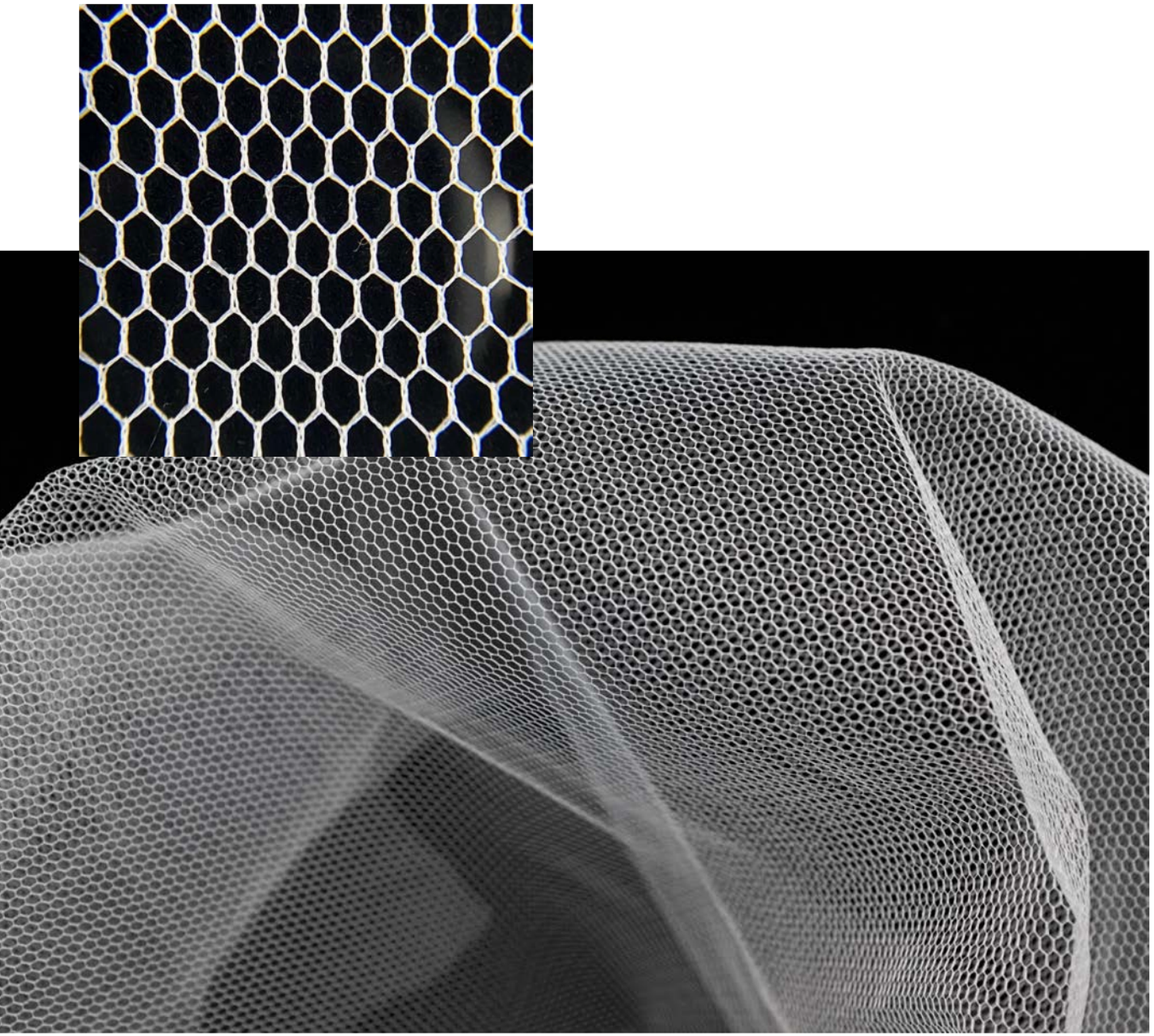
Double guide bar structures with raschel machines

As the amount of guide bars can get up to several tens (guide bars from 4 to 78), especially in raschel machines, a large variety of complex structures can be knitted with these machines. Also, inlays can be added. Weft inlays can go across the entire width of the fabric, or back and forth only on specific areas of the fabric.

Common structures produced with raschel machines are:

- knits with inlays in the weft and/or warp direction
- raschel tulle
- raschel lace

Different raschel laces /
photo by Petra Haikonen



Left: raschel tulle; right: raschel lace, with both tulle ground and weft inlays as patterns / photos by Petra Haikonen

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Fabrics produced with double needle bar warp machines

So far, all the presented structures have been knitted with one needle bar and a varying number of guides. In these structures (like one needle-bed weft knitting machines), the technical face side and the technical reverse side of the fabric look different. Both tricot and raschel knitting machines can also have two needle bars, showing knitted stitches on both sides of the fabric.

These machines are used to create openwork net-like fabrics (such as stockings), outerwear fabrics, pile fabrics (such as plush and fake fur fabrics) and pleat-effect fabrics. Like weft knitting machines, these machines allow the creation of knitted tubes, which is a highly welcome feature in hosiery, underwear and seamless applications.

Wolford's patterned warp knitted lace socks / photo by Petra Haikonen

Left: double needle bar tricot; right: warp knitted fake fur fabric / photos by Petra Haikonen

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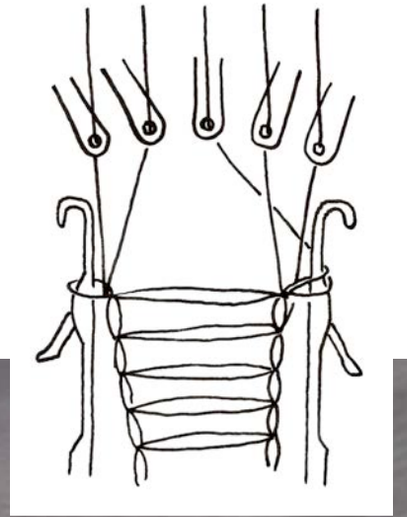
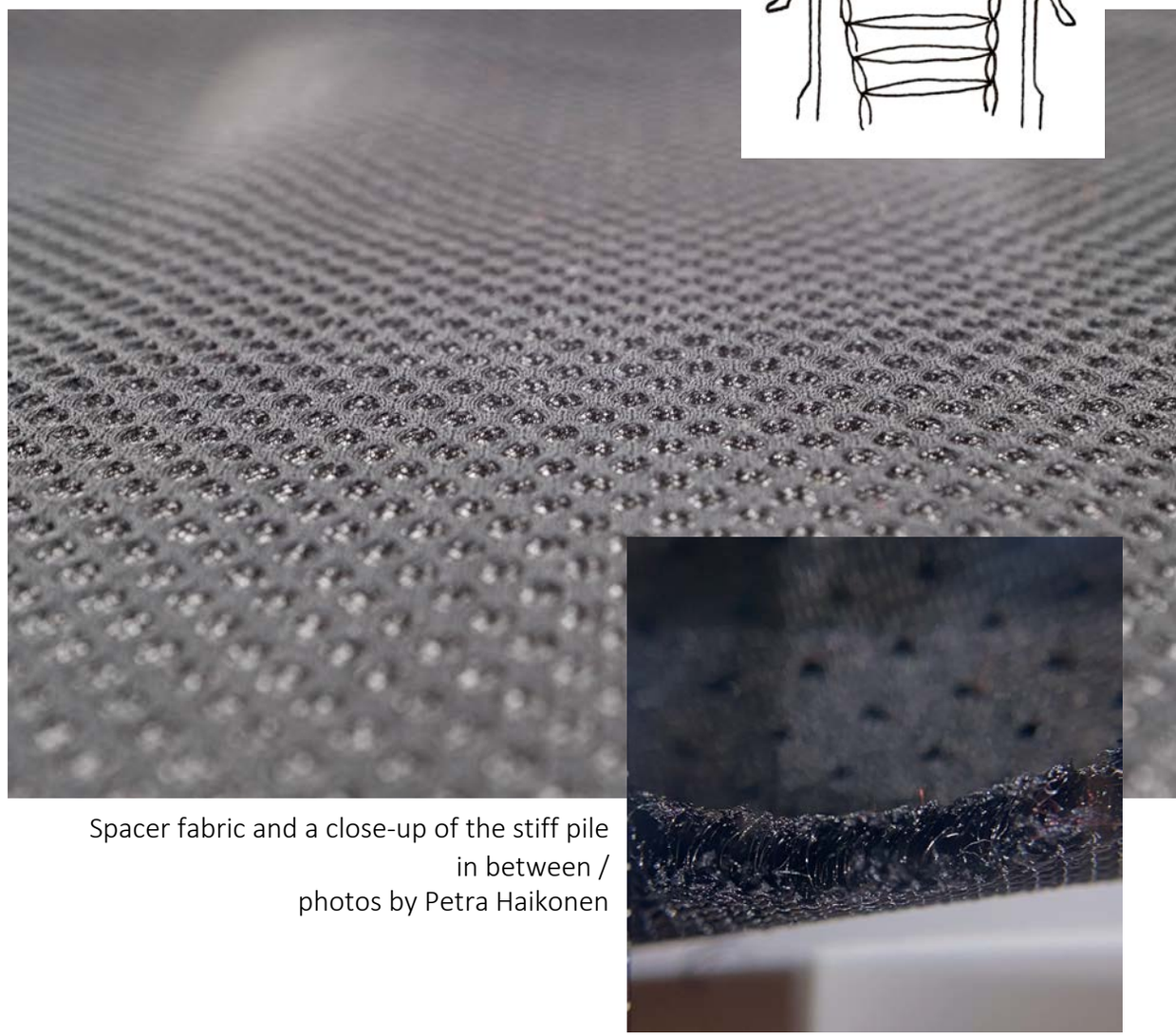
3D warp-knits – Spacer fabrics



Structures knitted with double needle bar machines include spacer fabrics, which have increased thickness due to the pile inserted between the fabric back and face (see image). Spacer fabrics are commonly used in mattresses and seat covers due to their high breathability, and in back panels of backpacks and other sports accessories for the same reason.



Spacer fabric and a close-up of the stiff pile in between /
photos by Petra Haikonen

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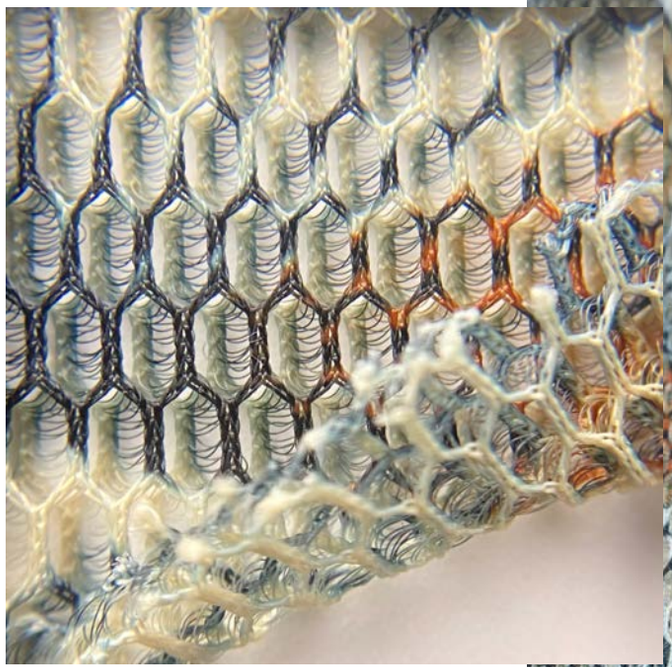

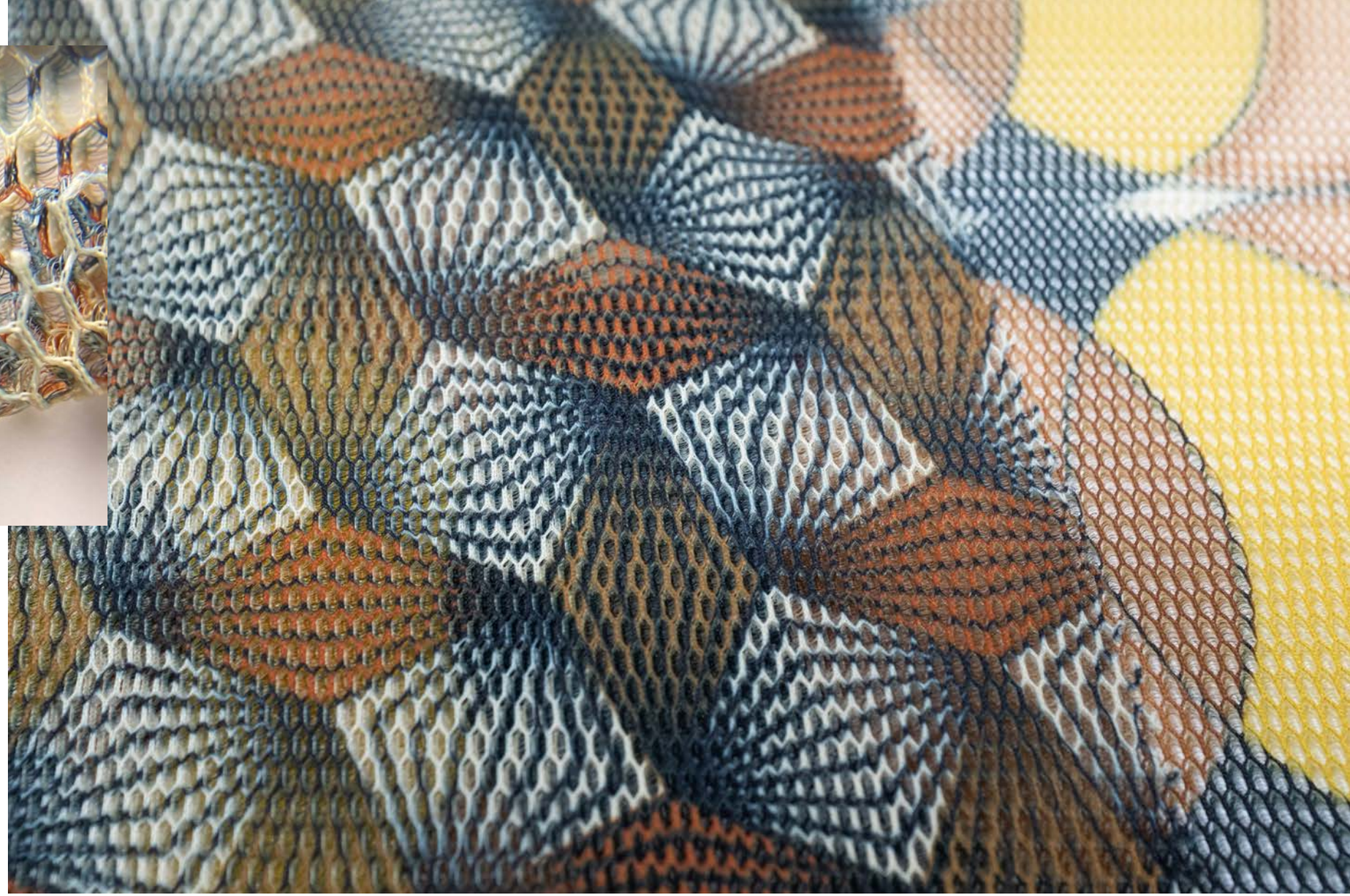

Digitally printed spacer fabrics, 100% PES /
photos by Petra Haikonen

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Other warp knitting options and their contexts of use

Co-We-Nit machines produce knits that are known by the same name as the machines. These fabrics use extra warp inlays and highly resemble woven fabrics in their characteristics. In the clothing industry, Co-We-Nits are used especially in women's and men's outerwear.

Crochet machines are commonly used to knit narrow width laces, bands and ribbons.

Elastic bands and a close-up from the technical back / photos by Petra Haikonen

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Comparing the properties of warp-knitted fabrics to weft-knitted fabrics

- Warp-knitted machines are, on average, finer gauge and use more often filament yarns. Compared to weft-knitted jersey the warp-knitted tricot fabrics are usually more light-weight and smoother due to smaller stitches and commonly used filament yarns.
- Weft knits unravel when left cut. Warp knits don´t unravel (at least as easily), which means that edges can be left unfinished. This enables the production of underwear without trimming the edges of cut clothing panels, thus increasing the production efficiency and comfort of use.
- If adding inlay yarns, it is possible to create warp knits that resemble woven fabrics, both visually and regarding other characteristics.
- Weft-knitted fabrics are more extensible than warp-knitted fabrics.
- Setting up the warp-knit machine takes longer than weft-knit machines because of individual warp yarns that require warping and threading through the machine and the guide bars.

Unfinished edge of a tricot fabric / photo by Petra Haikonen

Summary and sustainability aspects

Warp knits represent a vast variety of fabric qualities. The use of warp knits ranges from technical textiles (car seats and even artificial veins for medical purposes) to eveningwear (raschel tulle and lace), underwear and sportswear. The warp knits used in clothing applications can be generalized into three categories: bi-directional stretch fabrics used in functional clothing, compression fabrics with supportive properties, and fabrics with aesthetic value (such as nets, laces and jacquards).

The recent warp knitting machines are of high-speed and technologically advanced. They are capable to manufacture a huge variety of products from light-weight fabrics to complex seamless garments. A high-speed tricot machine can produce fabrics at considerably higher speed rate than weaving or other knitting machines, and therefore the production rate is more effective.

Warp knits combine the technical properties of both woven and weft-knitted fabrics. Warp knits can be extremely stable like woven structures, or very extensible like weft knits. With technical textiles that are commonly produced as non-woven or woven fabrics, warp-knitted fabrics can offer e.g., better drapability, knitting to shape, open-work, lightness in weight, and higher production rates than woven fabrics.

Warp-knits are commonly used in swimwear / photo by Petra Haikonen

Summary and sustainability aspects

It is quite difficult to assess the environmental load of warp knitting, since it depends on the used machines, yarns and their fibre content. Considering the environmental load of knitting it is higher than with non-wovens because of the required yarn processing stage that is needed for knitting and weaving technologies. However, the consumption of energy and therefore the related environmental load of knits is lower than with similar woven fabrics. However, warp knitting requires an additional phase of building the warps, and that consumes more energy and other resources than the production of weft-knits.

It is impossible to entirely remove the environmental load from any textile manufacturing operation, but it is possible to reduce it with technology improvements and by selecting the appropriate manufacturing methods considering the product's end-use and its longevity.

References

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Ray, S. C. (Ed.). *Fundamentals and advances in knitting technology* (CRC Press, 2012), Chapters 12-16 and 24 (pp. 144-184 and 283-292).

Ray, S. C. & Blaga, M. *Warp-Knitted Fabrics*. In Textile and Clothing Design Technology edited by T. Cassidy & P. Goswami, (Boca Raton: CRC Press, 2018), Chapter 9, pp. 227–258.

Spencer, D. J. *Knitting technology: A comprehensive handbook and practical guide*, (Elsevier Science & Technology, 2001), Chapters 6, 23, 24, 28 and 30 (pp. 48-59, 286–297, 298–312, 340–356 and 370–379).

Thompson, R. *Manufacturing Processes for Textile and Fashion Design Professionals*, (London: Thames & Hudson, 2014), pp. 144–151.

Optional reading (in Finnish):
Räisänen, M., Rissanen; M., Parviainen, E. & Suonsilta, H. *Tekstiilien materiaalit* (Helsinki: Finn Lectura, 2017), 165–173.

Extra video material from YouTube to support teaching (not CC-licenced videos):
Stitch formation: *Karl Mayer Pre-Owned: Demonstration of Knitting; How Karl Mayer tricot machine Work*
Double guide bar raschel machine: *MJ 52/1S – A Lace Machine by KARL MAYER*
Double needle bar raschel machines: *RDJ 5/1 – A double-bar raschel machine by KARL MAYER*
Spacer fabrics: *RD 7/2-6 EN – SPACER EXPRESS; RDPJ 6/2 EL MC – MULTI-COLOUR SPACER machine | KARL MAYER*

All illustrations drawn by Petra Haikonen

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Assignment: group work (on-site)

Analyse knitted sample swatches in small groups (I hour)

- Identification: separating warp-knits from weft-knits
- Describe the properties of the given samples
  - curling and ravelling
  - stretching in horizontal and vertical direction
  - observing the technical face vs. back: do they look the same/similar/different?
- With a microscope or a pick glass try to figure out the structure of the given samples

Warp-knit and weft-knit/
photo by Petra Haikonen

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Seamless knitwear/ photo by Petra Haikonen

2 Fully Fashioned and Seamless Knitwear Compared to Conventional Methods

Advanced Knitting
PART 2

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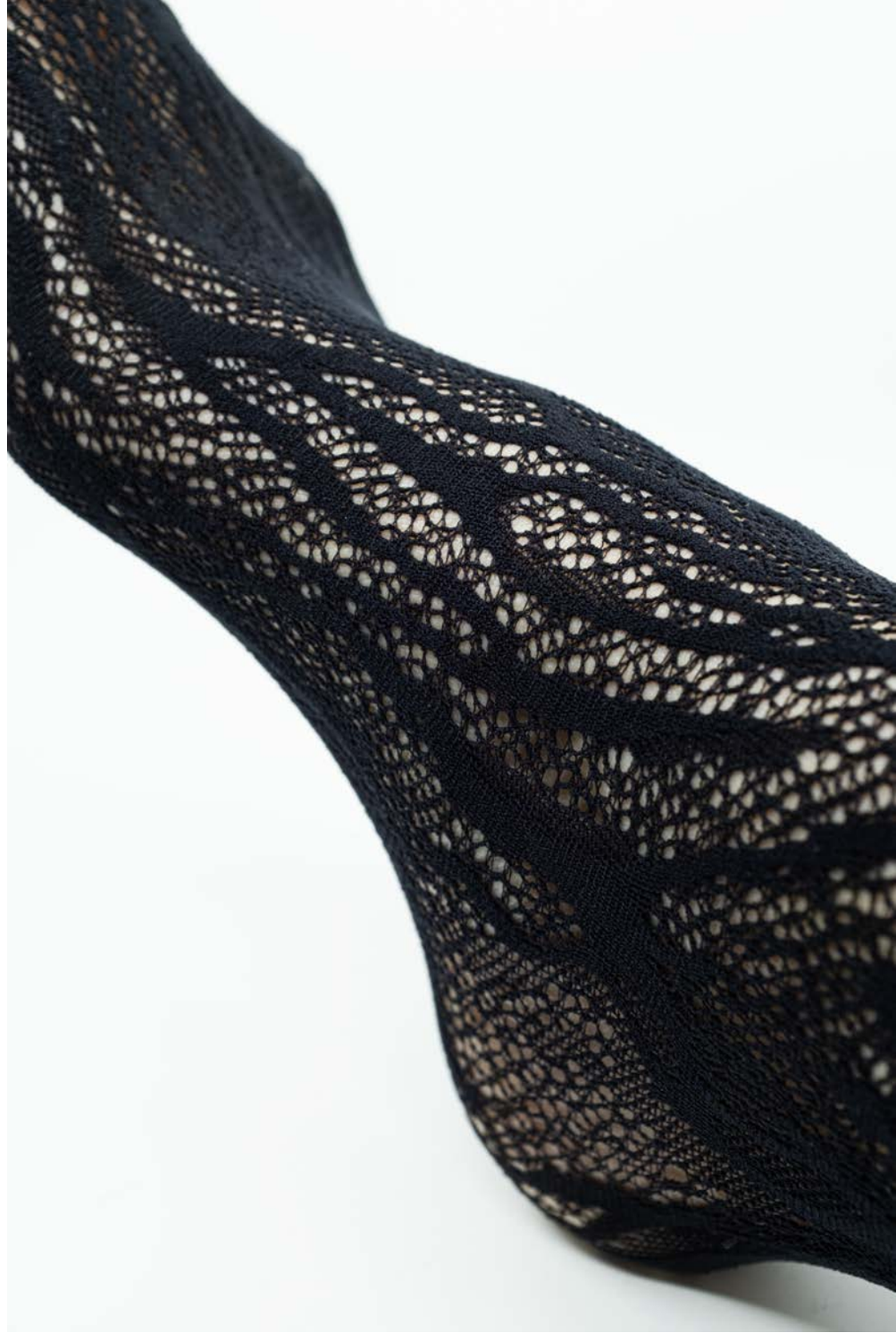
Production methods of knitwear

There are four garment production methods for knitwear that requires their own design and production methods, and in some cases also separate machinery.

The methods of garment production are:

- Fully-cut garments
- Cut stitch-shaped garments
- Fully Fashioned garments
- Integral/seamless garments

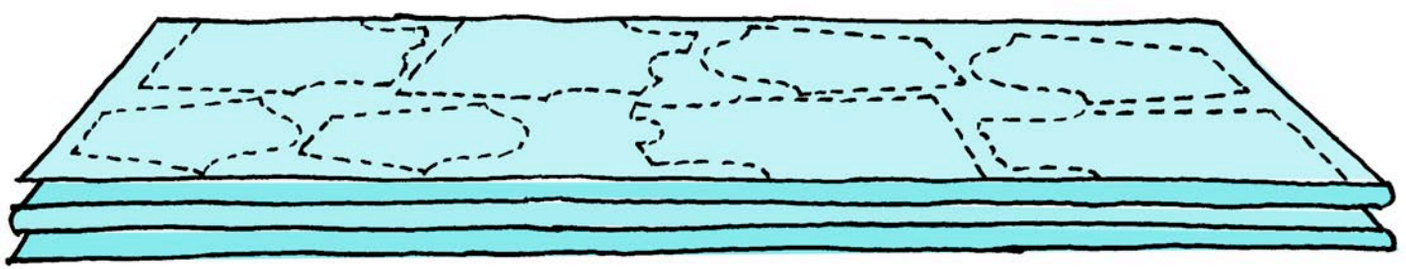
Names of the categories from Brackenbury, T. (1992) Knitted Clothing Technology, London; Boston: Blackwell Scientific Publications, added with synonyms commonly used in the industry.



Wolford's seamless warp knitted lace socks / photo by Petra Haikonen

Constructing a knitwear – Fully-Cut

Resembles the production of garments from woven fabrics: (weft or warp) knitted fabric is produced in lengths, laid flat, cut into garment panels and sewn together. It is the most basic production method, and therefore the cheapest. It is especially suited to simple products, such as T-shirts made with fabrics produced by circular knitting machines.



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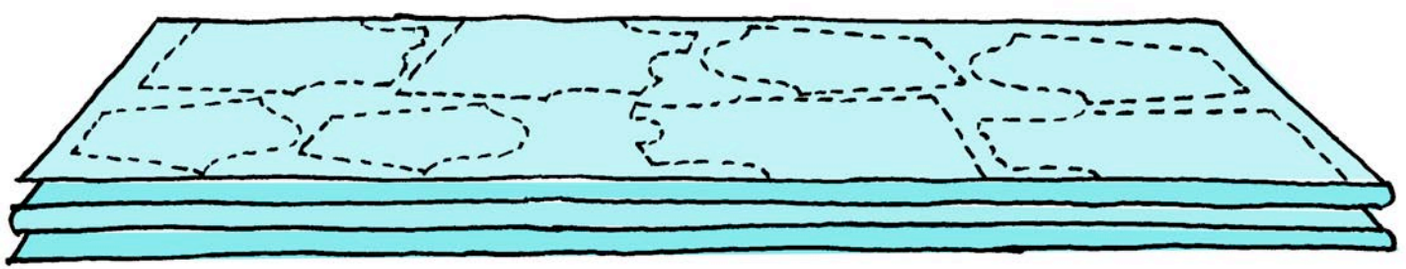
Pros and Cons of Fully-Cut Knitwear

\+ The same knitted fabric can easily be cut into different shapes and sizes. The fabric can be produced with high production efficiency without spending time adjusting the shapes of garment panels. The panels can be cut into precise shapes without such compromises that are needed with fully fashioned panels.

– Potentially high amount of cutting waste (the exact amount depends on panels shapes and the cutting plan. Also, zero-waste fully-cut garments are possible with zero waste patterning and well thought cutting plan.



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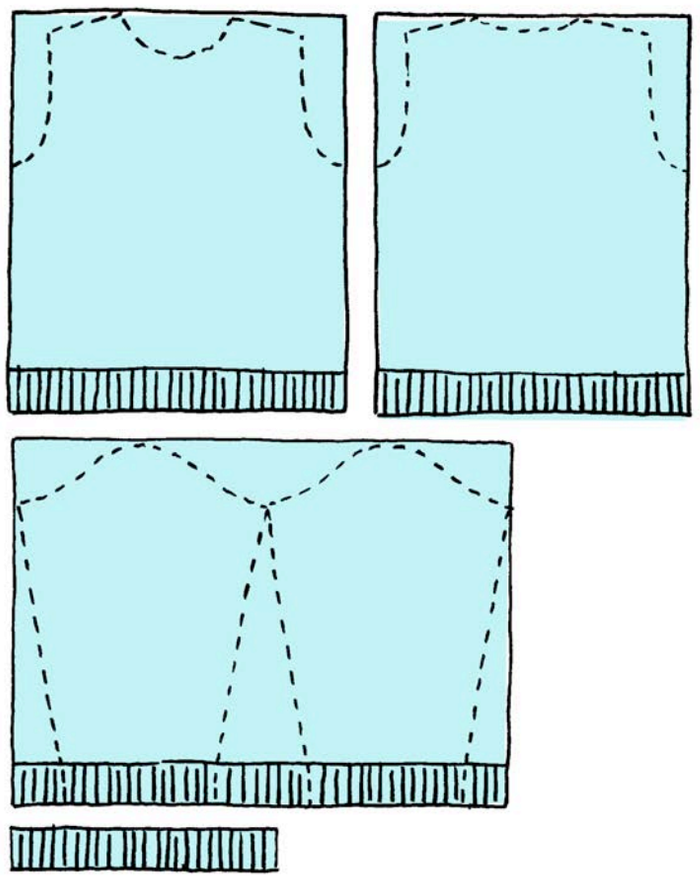
Constructing a knitwear – Cut Stitch-Shaped Garments

Instead of cutting garments from one large piece of fabric, as in fully-cut method, the garment panels are knit directly to the right width, and they can include e.g. hem ribs. Therefore, the side seams will not unravel and can be attached with a linking machine. The armholes and necklines are cut and need to be sewn with an overlocking machine. The fabrics are generally produced with flatbed machines.



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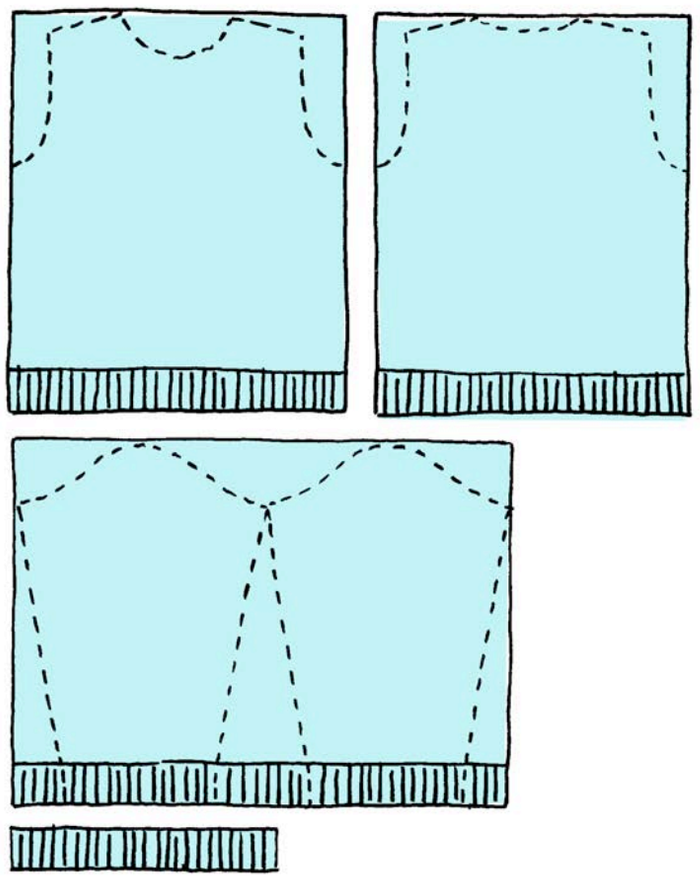
Pros and Cons of Cut Stitch-Shaped Knitwear

\+ The start of the panel (usually the hem or the cuff) and side seams are neat selvedges and thus less prone to unravelling than cut edges. The production speed is higher than in fully fashioned production. The ribbed hem (or other cast-on structure) is knitted together with the panel, so no joining is needed.

– The process of cut stitch-shaped knitwear may produce less waste than fully-cut method, but depending on the shape of the garment, the amount of cutting waste can still be significant, e.g., from the armhole area.



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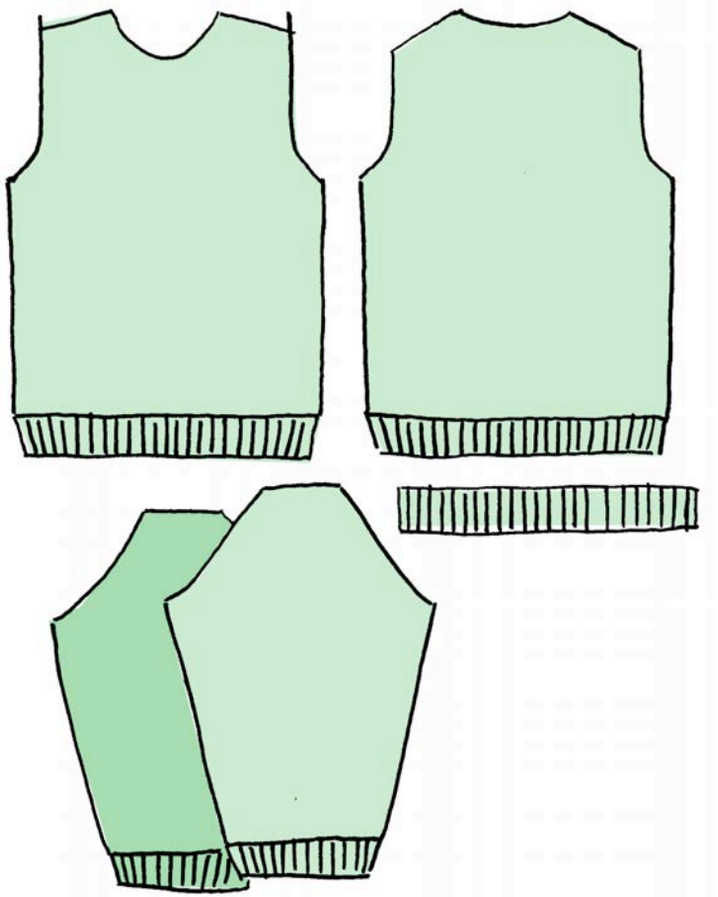
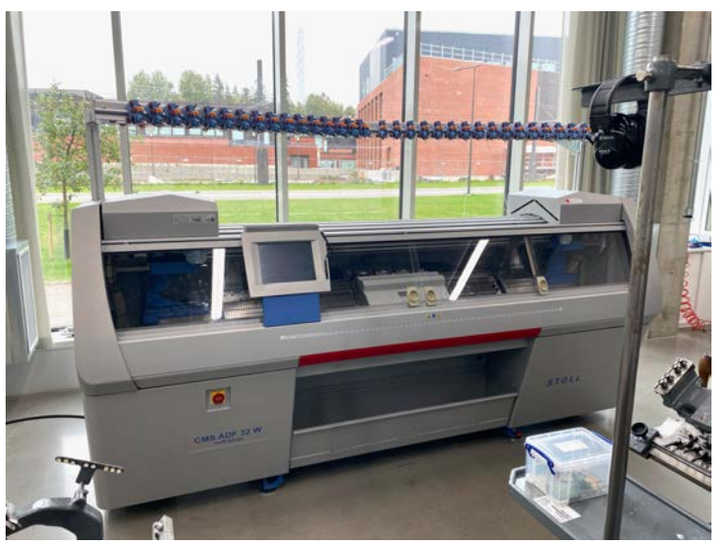
Constructing a knitwear – Fully Fashioned

The garment panels are knitted directly to the desired shape. This technique is slower than the production of cut stitch-shaped panels since increasing, decreasing and casting off stitches takes time. Modifying the shape of the garment by changing the number of needles at work is called fashioning, and there comes the name “Fully Fashioned” (commonly abbreviated as FF). This technique is mainly used with flat-bed weft knitting machines.





Stoll’s ADF flat-bed weft knitting machine at aalto University in Finland / photo by Petra Haikonen

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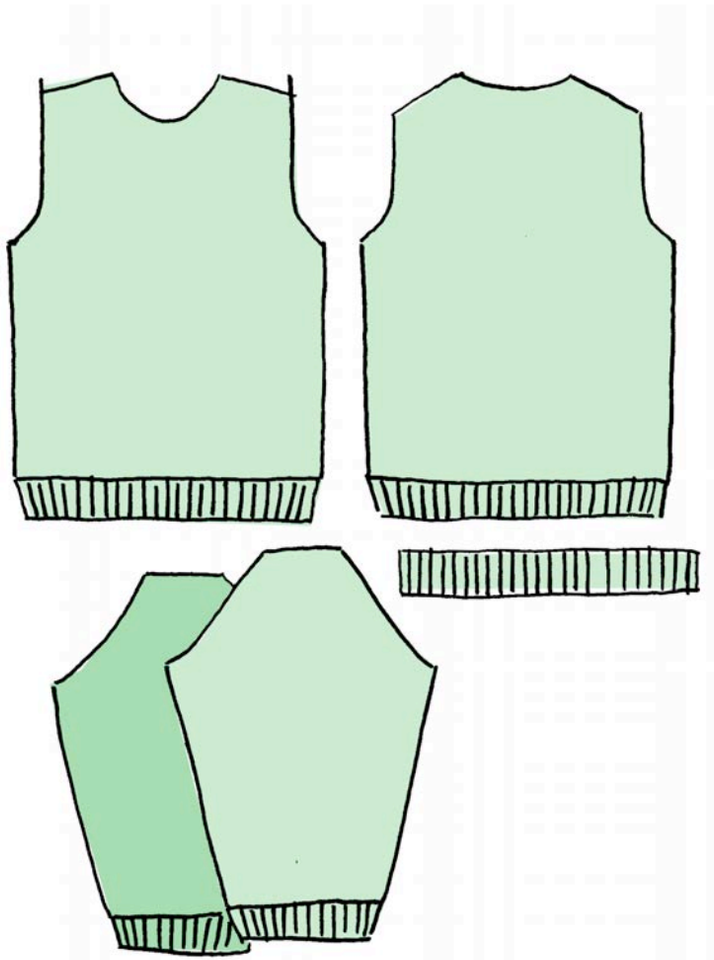
Pros and Cons of Fully Fashioned Knitwear

\+ Creates only a little cutting waste (but still some due to the waste yarn used while casting on). Neat edges throughout the garment.

– Product development takes more time than in previous options (depending on the complexity of the panel shapes and the used knitted structure), and the production rate is slower. The precision of the panel shapes is limited by the stitch density of the piece.



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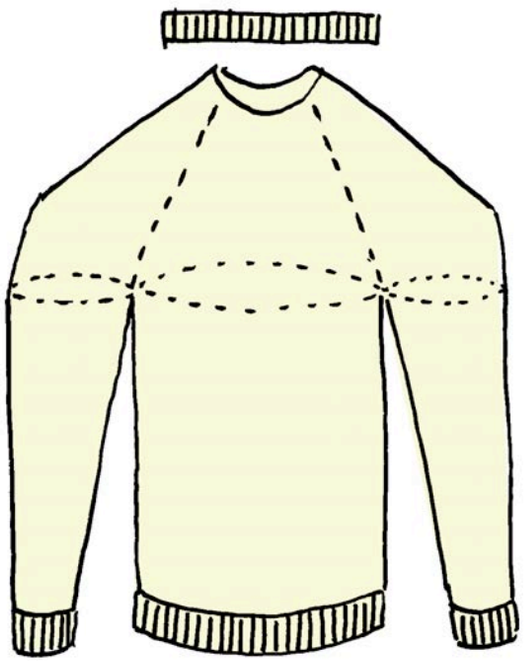
Constructing a knitwear – Seamless/Integral Garments

Integral or seamless knitwear is the most advanced of the knitwear methods. The entire garment is knitted as one piece, though it is usual to add some final trims after knitting, most commonly the collar. Socks, tights, gloves and seamless sportswear are created with the method. Complete garments can be created with circular and flat-bed weft knitting machines, but also with warp knitting machines.



Pros and Cons of Seamless/ Integral Knitwear

\+ After the initial product development phase, the required labour cost per garment is low (no sewing nor linking required). In addition, the amount of production waste is smaller than in other methods (though garments produced with circular weft knitting machines require some amount of cutting and cannot be truly labelled as seamless or wasteless). Some waste is always created because the knitting machine uses some waste yarn whenever casting on new stitches. The elimination of seam allowances also reduces the amount of material consumed. Seamless garments are also more comfortable because there is no skin irritation caused by seams. Often stress is concentrated at seams (seam slippage), so that is also eliminated in integral garments.

– The initial product development phase is longer than in other methods, increasing costs especially when producing small series. Skilled specialists are needed to realise the designs with the machinery. If there are problems in production (e.g. dropped stitches), the entire garment can turn into waste (as opposed to knitting one of the panels twice), therefore it is important to optimize all the settings prior to production.

Pierre Robertin saumattomat urheiluliivit / kuva Petra Haikonen

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Methods of producing seamless garments, and their advantages and limitations

A) Sock and glove machines

Highly specialised but limited in what they can produce.

B) Flat-bed weft knitting machines

Flat-bed weft knitting machines can make more sophisticated seamless shapes than circular weft knitting machines, but they do not produce very fine gauge knits suitable for sports or underwear applications.

V-bed machines (two needle-bed machines):
These machines are most commonly available, but they set limitations to the design of seamless garments. Two needle-beds are already required to knit a tubular shape, so including two needle-bed structures (such as links-links or jacquard) into seamless garments made with V-bed machines is challenging.

X-bed machines (four needle-bar machines):
To increase the versatility of knitted structures that can be incorporated into seamless knitwear, Shima Seiki has introduced a novelty 4-bed configuration, the X-bed machine.

Saumaton sukka /
kuva Petra Haikonen

Methods of producing seamless garments, and their advantages and limitations

C) Circular weft-knitting machines

Circular weft knitting machines can produce fine knits suitable for sportswear, but adjusting the product dimensions (e.g., the diameter) is difficult. Some amount of cutting and sewing is needed to connect the sleeves with the body, so the garments are not entirely seamless nor the production wasteless.

D) Warp knitting machines

So far, the most complex seamless products for sports and underwear applications have been produced with warp knitting machines (an example of a forerunner company is Italian company Cifra). With warp knitting machines, it is easier to adjust the diameter of the product if compared to circular knitting machines, but achieving equally high or even higher gauges is possible.

Sleeve and top part of a warp knitted seamless shirt /
photo by Petra Haikonen

Summary and sustainability aspects

Fully Fashioned and seamless knitting are more advanced manufacturing methods compared to traditional methods involving cutting and partially cutting from metered fabric. Various knitting machines, such as Shima Sheiki's WholeGarment flat knitting machines, Stoll's Knit and Wear flat knitting machines, Santoni's seamless circular knitting machines, and Karl Mayer's warp knitting machines, have been introduced by equipment manufacturers.

The environmental impacts of seamless knitting, compared to traditional fabric manufacturing methods, are smaller because there is little or no need for cutting and sewing processes. Therefore, seamless knitting production also saves on labour, time, and costs, although more resources need to be allocated to the design of seamless products.

References

Brackenbury, T. *Knitted Clothing Technology*, (London; Boston: Blackwell Scientific Publications, 1992).

Brownbridge, K. *Seamless Knitting and Its Application*. In Hayes, S. G. and Venkatraman, P. (Ed.) Materials and Technology for Sportswear and Performance Apparel, (Routledge, 2016), Chapter 9, pp. 231–243.

Cassidy, T. *Knitwear Design Technology*. In Cassidy, T. & Goswami, P. (Ed.) Textile and Clothing Design Technology, (CRC Press, 2018), Chapter 16, pp. 441–461.

Palamutchu, S. *Textiles and Clothing Sustainability* (Hong Kong: Springer, 2017), Chapter 6, 14–16.

Optional reading (in Finnish):
Räisänen, M., Rissanen; M., Parviainen, E. & Suonsilta, H. *Tekstiilien materiaalit* (Helsinki: Finn Lectura, 2017), 149–155.

Extra video material from YouTube to support teaching (not CC-licenced videos):
Sock and glove machines: *Santoni Star S Sock Knitting Machine*
Flat-bed weft knitting machines: *STOLL CMS 822 KNIT AND WEAR*; *Shima Seiki Whole Knitted Garment Design Tools*; *Client Testimonial - WHOLEGARMENT shortens lead time and improves quality : Andari Fashion Inc.*
Circular weft-knitting machines: *Santoni - Knitting your goals*
Warp knitting machines: *WKS, Warp Knit Seamless by Cifra: the Knitting Revolution (Patented Technology, wks-cifra.com)*; *The difference between Warp Knitting Seamless (WKS) and Weft Knitting Seamless (Santoni machines)*

All illustrations drawn by Petra Haikonen

Assignment: individual work

Read an article “Seamless Knitting and Its Application” (Brownbridge, K.) in *Materials and Technology for Sportswear and Performance Apparel*, edited by Hayes, S.G. & Venkatraman, P., 2016

Referring to the article write an analysis of a seamless product that you can find from your own wardrobe. You can also utilize internet if you cannot find any garments at home.

- Write an analysis about the product and its use: different knit structures and their properties (stretching, stability, breathability etc), 3D shape, garment comfort etc. Use the article as a reference.
- Include close-up images from the different knit structures to the presentation
- Return the written analysis with images (1–2 pages A4) as a PDF file

Pierre Robert’s seamless sportsbra / photo by Petra Haikonen

SusTexEdu

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Visit the project website to see all the intellectual outputs of the project.

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