PART OF A SERIES ON HOW ENGINEERING SUPPORTS THE CREATIVE INDUSTRIES AND ARTS

Engineering and the Creative Industries: Textiles

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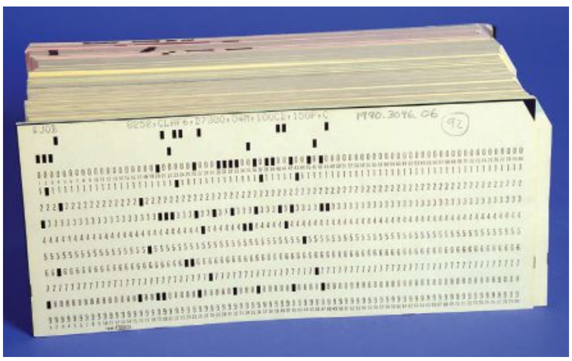
Figure 1 (above): Moon Landing in Canterbury Cathedral, July 2025. See the sidebar on page 11 for more information. Image by B. A. Moorman.

Introduction

The *American Heritage Dictionary* defines a textile as a "cloth, especially one manufactured by weaving or knitting; a fabric." A fabric or cloth has a highly utilitarian purpose: to cover something such as a body, floor, table, window, or even as in the past an airplane wing. This covering usually is for protection while also being decorative. Textiles and/or cloth have been manufactured for thousands of years with concomitant technological improvements providing the ability to manufacture many different types of textiles for ever more expanding purposes. Moreover, some of the technologies used to produce textiles have been spun off for use in other industries, such as the punched card technique used for programmed color changes in jacquard looms being analogized for use in computer punch card programming.[1]

Weaving and Knitting

The two main techniques for making cloth are weaving and knitting. Weaving uses looms, which have yarns strung parallel vertically (warp) and with the use of treadles to lift or separate the warp yarns or swifts, another yarn is 'threaded' horizontally (weft) using a shuttle over and under the warp yarns interlocking the two yarns together into a two-dimensional flat surface. By altering the numbers of yarns passed over and/or under, different surface patterns can be produced in the cloth.



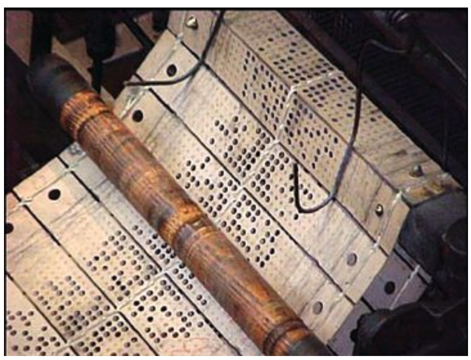


Figure 2 (left): IBM punch card used with a PDP-9 minicomputer from the mid-1960s.[2]

Figure 3 (right): Jacquard engaging square reading drum on the right. (Gessler photo).[3]

In contrast to weaving, industrial knitting is usually done on cylindrical machines and the yarn is interlocked into successive loops. Depending on how the yarn is drawn through the loops, either through the front or back of the loop, different surface patterns can be produced on the cloth.

YARN AND CLOTH MATERIALS

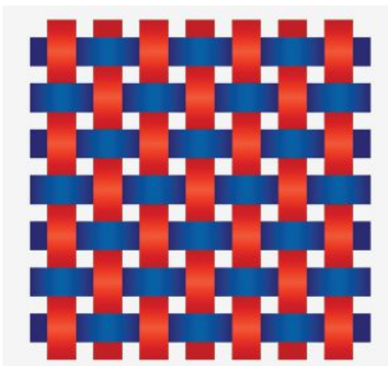
Before cloth can be produced, yarn must be produced. Yarn is measured by its thickness indicated by wraps per inch (WPI). The higher the number of wraps, the thinner the yarn with ranges from lace weight to various bulky weights. Cloth drape is mainly a function of the yarn thickness used in production. The ply or number of strands in a yarn that are twisted together also alters yarn thickness. Additionally, multi-plied yarns can use different materials as the plies, producing yarns with varying material properties.

The materials used in producing yarn are either organic, inorganic, or a combination. Each material has specific properties to meet use requirements of the cloth being produced, including: cost, durability, drape, color, and more recently, sustainability. Increasingly today, cloth is made with organic and inorganic yarn blends to take advantage of the benefits of the different materials, while minimizing the more undesirable characteristics. For example, wool or cotton can be blended with acrylic to make the cloth more durable, more easily washed with minimal cloth distortion, added cloth flexibility, less or more drape or stiffness, better color saturation and fastness, and an increase in the ability to re-use materials for sustainability goals. If one has purchased a pair of jeans or denim lately, it seems as the addition of elastane is de rigueur in most brands, demonstrating how adding a percentage of an inorganic yarn/fiber to an organic one enhances certain characteristics of the denim as listed above.

Organic materials are usually animal hairs or plant fibers. Inorganic materials are usually long chain polymers produced in very long running bats. The nature of organic materials is such that the fibers have uneven lengths which have a natural affinity to catch along the ends and form longer strands. Inorganic materials are produced in very long, even lengths and during processing are broken into uneven lengths to prepare the material for spinning. In other words, the inorganic material is processed to behave like an organic material in the downstream yarn processing steps.

CLOTH COLOR

Color is an important aspect of cloth, mainly from an aesthetic perspective. Different materials interact with different dyes such that the hue and saturation may reflect a different visual frequency in the final product. Cloth designers take this into account when designing as they are endeavoring to invoke an emotional response with the cloth color and design.



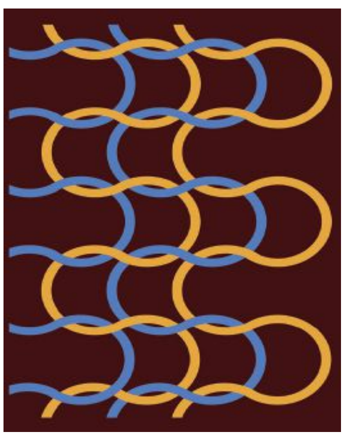


Figure 4 (top): Weaves versus knit: Types of weaves - vertical warp (red) and horizontal weft (blue).

(bottom) Knit showing interlocking loops.

YARN PRODUCTION

I visited Spectrum Yarns on July 2, in Huddersfield, UK, and met with Richard Stoker – technical manager.[4] This original cotton spinning mill was established and converted to spin wool and acrylic in 1986. This mill takes raw materials and creates yarn. There are two sides to the mill, one creating yarns for commercial uses and fabrics, and the other side creating yarns for handcrafts. Making yarn, converting a fiber into a yarn, is the most difficult and intricate of the textile processes. The process of turning the raw material into yarn includes dying it, stretching it, breaking it, re-breaking it, drawing it out into successively thinner slivers, spinning it, plying and twisting it, balling and then packing it. They use thirteen machine steps and processes from raw material to the final product, a ball of yarn.

Figure 5: Spectrum Yarns Mill.[5]

"With an inorganic material we want to make it act more like an organic material – organic materials have different lengths so lend themselves to 'drafting,' i.e. slipping past each other more easily to turn slivers into yarn. Woolen yarn, made of natural fiber, is coarser and used in carpet yarn as well as in fine knitwear."

Some of the material is pre-dyed. If not, then the material cake goes into a dye vessel for 4-4.5 hours. It is then hydrated and dried (spun dry) to remove 60-70% of the moisture. To finish drying the cake, it is then placed in a high temperature vessel at atmospheric pressure. This type of drying process is a bit more expensive than using a radiation process, however, the radiation process modifies the material at the molecular level which then negatively affects the final yarn material properties.

FIBER

The first stage of Polyacrylonitrile (PAN) fiber preparation is fiber conversion (endless fiber lengths converted into multiple length fibers) with 97% of fiber breakage occurring with the first breaking machine and the last 3% done with a re-breaking machine (**Figure 6**). This part of the process, stretch breaking, stretches the fibers and breaks them into different lengths by running the fibers over rollers running at different speeds.

One must have varying lengths to make a yarn; if they are too short, the yarn pills. The fibers must have the right amount of length to 'behave' because if they stayed the same length, the yarn would not be 'level' or have a consistent diameter, resulting in varying gauges or yarn thickness along the length.

By stretching the sliver producing varying lengths of fiber, they are trying to simulate natural fibers as they want the material to respond like wool, an organic fiber, when they spin it.

Figure 8: Dye vats and slivers. Used courtesy of B. A. Moorman.

The breaking and stretching process takes a 100kg cake and ends with a 96kg cake (4% waste). That waste and plastic dust is then re-cycled and re-processed. They can also mix slivers, i.e. blend, with other materials in this process. There are four companies in the world who produce raw PAN (**Figure 7**) for spinning purposes and Spectrum Yarns has found blending the different acrylics does not work well, i.e. it does not produce an even gauge yarn. Mixing the slivers and blending produces a more level or even gauge over the length of the sliver. Using the re-breaking, stretching and then successive drawing processes takes the sliver from thick to thin. A bit of twist, termed a false twist, is added at the end of the breaking, stretching, and blending to enable the next steps in the process: drawing and spinning.

Drawing prepares the slivers for spinning by straightening and aligning the fibers, reducing the bundle sizes for spinning. Spinning is where one yarn is created and wound onto a bobbin. After spinning, the full bobbins are put into a winding machine, checked for irregularities, and rewound onto cones. The wound cones are 5 kgs which are then further divided down to 100 grams per ball. Spectrum Yarns produces 10.5km of single yarn per kilo of PAN material. Each initial winding assembles one yarn, then several yarns are twisted, plied or assembly wound, and given a final twist to the final yarn configuration (they ply/assemble three yarns into one assembled yarn for balling; the ply determines the final yarn diameter/thickness).

Figure 7 (below): Raw PAN. Used courtesy of B. A. Moorman.

Figure 6 (right): Breaking machine. Used courtesy of B. A. Moorman.

Figure 9: Yarn relaxing and balling.[7]

"Twist is inserted to the staple yarn to hold the constituent fibers together, giving strength to the yarn while producing a continuous length of yarn. Twist also induces lateral forces in the yarn; friction created by these forces acts to control fiber slippage in a strand under tension. Fine yarns require long staple fibers and high twist. Coarse yarns can be produced with short fibers and low twist." [6]

After the final twist is applied to the assembled yarn, it is relaxed and then balled. To relax the yarn, a machine steams yarn, air dries it, (**Figure 9**) and then prepares it for balling by aligning and spooling it into spirals along a conveyor belt providing a buffer to the pulling for the balling process. In balling, the machine rotates the yarn into a skein, places a label around the skein (it takes 30 seconds to make each ball/skein), and then packages 10 balls/skeins to a plastic bag. There are no knots in the final product sold through their retail channels. They will sell a knotted skein but only in a mill end sale.

Throughout the yarn processing, a quality control function is applied with the QC personnel checking the end product: ball weight, count checks, meterage/length per ball, presence of any fasteners or knots, etc. They also test each machine to make sure it is working correctly. QC is the main feedback mechanism into all of the processes.

Spectrum Yarns purchased cast-iron spinning machines from a decommissioned mill in America and shipped them to the UK. The other machines used for breaking, re-breaking, and blending are a mixture of German and French machines. Most of the machines used in the mill are mechanical and electrical. Steam is only used for dying the material and relaxing the yarn before balling. Water is extracted from a natural ground source 150 feet below, which contains elements and minerals that soften the water. Water is recycled and they have a team of mechanics to maintain the machinery and stock the materials. Spectrum runs a 24-hour shift (0630-0630 – 12 hour shifts) Monday through Thursday; Fridays are for maintenance with weekends off, unless more maintenance is required.[8]

The cloth requirements and end use drive the yarn production characteristics. As an example, suppose airplane seating cloth is being produced. The requirements of durability and fire-retardant would be of high priority, and would depend upon the material blending for the yarn used to produce the cloth. The number one constraint when engineering the material is cost: what is the optimum raw material that meets the material requirements for the quality desired. Those materials used in making the yarn may also affect the machinery. Wool, cotton, and other organic materials are dirtier than plastic, so the material quality can affect the cost due to machinery wear and tear/maintenance.

THE WEAVER AND DESIGN

I visited the Margo Selby Studio in Whitstable, UK, on November 21, 2024 and interviewed Margo Selby.[9] She is an award-winning UK graphic and textile and graphic designer who weaves for both commercial and art purposes. When designing for commercial purposes, Margo takes into account many variables which affect the end product: usability, durability, color fastness, the cloth maintainability, and the technology constraints of the cloth factories to include the size of the looms, the thread/yarns/colors available and most suited for the looms. The processing of the yarn can also affect color fastness as dye is absorbed differently by certain materials, changing the textile end result, which may, for example, contribute to increased fading.

Different factories specialize with expertise in the end textile products, such as bedding, toweling, upholstery, and material for clothing. Most of the large mills are located in India and China. When Ms. Selby works with a cloth manufacturer/mill she want to collaborate making it easy for them to produce her design. As with most production, time equals money and complexity of a weaving design increases the cost, so if she can manifest her design using the specific loom characteristics and materials, her cloth design can be produced efficiently.

Figure 11: Industrial fabric production.

Figure 10 (left): Marge Selby Studio. Used courtesy of B. A. Moorman.

She has at times walked through the mills and on the looms to get a sense of what is possible, how the threads will interact and in order to attain her vision, how large a pattern she can use for repeatability, etc. While interacting with the mill and loom engineers, she will change one aspect or variable at a time while testing her design with the loom.

There are machine loom width and length restrictions with widths ranging from 1 m 40 cm/60 inches with most industrial looms being 3 m wide/120 inches. Warp, the vertical threads, is the most difficult aspect of a loom setup; it is easier to make changes with the weft, the horizontal threads. Threads per inch designates the 'resolution' of the cloth which defines both the possible design resolutions and affects the final cloth 'density.'

The thicker the thread/yarn used, the thicker the end cloth. Weaving involves areas of interaction with the warp and weft threads. In general, weaving is two dimensional with regard to design options. Finishing techniques can also change the final product with regard to color, sheen, and the introduction of three dimensional affects.

Cloth drape is determined by the thread or yarn used in weaving. Durability is provided by the density of the weave; for example, upholstery cloth is very tightly woven and dense due to its end use and expected lifetime of 40 to 50 years, both in use and color fastness.

The weave structure also affects the drape and durability of the final material. A plain weave with alternating warp and weft threads produces the most interlocked and straight cloth with the shortest floats. Floats are the yarns that are seen on the surface of the cloth (not the interlocking areas).

Three dimensional effects can be attained by using different yarn/thread materials in weaving which when combined cause material distortion. The distortion becomes apparent in cloth finishing techniques after weaving. For example, a tiny bit of acrylic can be sandwiched (stentored) with silk such that with processing, the acrylic shrinks and tightens up with the silk remaining on top of the cloth as the acrylic is hidden in the weave. Cloth finishing techniques include: felting-fulling (agitation of the cloth to cause tighter adhesion between the thread fibers), 'burn-singeing' hairs or excess fiber off the cloth surface to obtain a shiny sheen, heating the cloth to activate certain yarns and their properties (such as shrinking or relaxing) to obtain a specific cloth characteristic, and scouring, which washes out the oils and/or grass from the cloth.

The colors she uses in cloth are also of prime consideration. Color is instinctive and is used to evoke an emotional response and maintain interest.

Ms. Selby's color theory is to entice optical excitement. She tries to maximize this by juxtaposing light and dark, bright and neutral, and saturated and non-saturated colors. She also designs patterns within patterns for visual stimulation.

ENGINEERING AND TEXTILES

Weaving/textile making is an ancient skill which has benefited from mechanical, chemical, electrical, and computing expertise. Cloth is also something that will always be required for day-to day living. Something so seemingly simple and ubiquitous has a fairly complex set of steps to achieve the desired outcome of a cloth that optimizes many requirements: affordability, drape, specific protection from the elements, re-usability, and feel. Engineering is and has been a major component of manufacturing textiles, and engineers work hand-in-hand with the designers to achieve a product that is both useful and beautiful.

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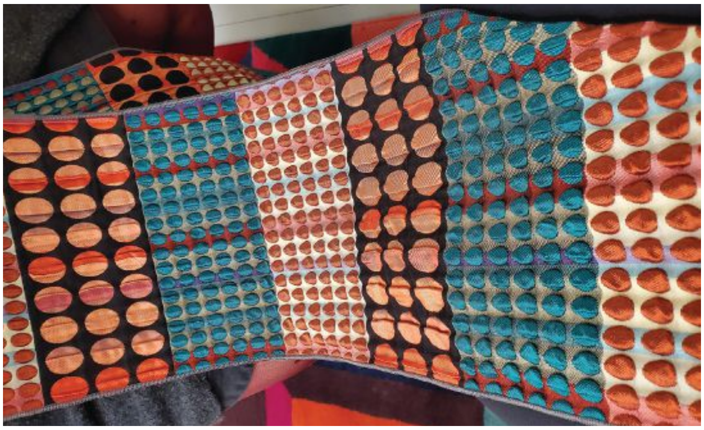

Figure 12: Margo Selby textile. Used courtesy of B. A. Moorman.

MOON WALK

Ms. Selby hand wove a large tapestry titled "Moon Landing" in collaboration with Ms. Helen Caddick, a composer, in response to a call by Collect 2024. The inspiration for the work was the story of female Navajo weavers, while working for Fairchild Semiconductor, using their knowledge and traditions of intricate weaving to create the integrated circuits and memory cores that contributed to the successful 1969 Apollo 11 Moon Landing.[10] The moon landing weaving is approximately 1600 cm x 140 cm and depicts an undulation and stepping motion of colorful stripes and geometric patterns which reflect a visual interpretation of Ms. Caddick's musical composition. Figure 1 on page 6 of this article shows the tapestry suspended over the nave of the Canterbury Cathedral.

– B. A. Moorman

Figure 13: Margo Selby color studies. Used courtesy of B. A. Moorman.

REFERENCES

1. *Base Camp Math*. Base Camp Math. *https://www.basecampmath.com/computing-and-jacquard-weaving*, accessed 2025, October 17.
2. Figure 2 image from: *https://www.si.edu/object/punch-cards-used-pdp-9-minicomputer:nmah_1378547*
3. Figure 3 image from: *https://people.duke.edu/~ng46/topics/jacquard.htm*
4. Stoker, R. (2025, July 2). *Spectrum Yarns Mill tour* (B. A. Moorman, Interviewer) [Review of *Spectrum Yarns Mill tour*].
5. Spectrum Yarns. (2019). Spectrumyarnsltd.com. *https://spectrumyarnsltd.com/about*, accessed 2025, October 2025.
6. Mazharul Islam Kiron. (2012, February 14). *Calculation of Twist, Twist Constant of Ring Frame*. Textile Learner. *https://textilelearner.net/calculation-of-twist-twist-constant-of-ring-frame/*, accessed 2025, October 1.
7. LanaGattoTeam. (2023, December 19). *Yarn balls, a journey inside manufacturing process - Lana Gatto*. Lana Gatto. *https://www.lanagatto.it/en/yarn-balls-a-journey-inside-manufacturing-process/*, accessed 2025, October 17.
8. Unfortunately, due to economic circumstances Spectrum Yarns ceased manufacturing at the end of October 2025. They will continue selling craft yarns which they source from the suppliers who originally manufactured for them to their specifications. During the tour, it was stated that China and India dominated the craft yarn manufacturing market in which Spectrum Yarns competed. A brief review of the textile business statistics shows that Asia-Pacific dominates the textile market with Western Europe following.
9. Selby, M. (2024, November 21). *Tour of Margo Selby Studio, Whitstable, UK* (B. A. Moorman, Interviewer) [*Review of Tour of Margo Selby Studio, Whitstable, UK*].
10. *Navajo Women's Impact on One of the World's Greatest Technological Advancements*. (2024, May 2). International Relations Review. *https://www.irreview.org/articles/navajo-womens-impact-on-one-of-the-worlds-greatest-technological-advancements*, accessed 2025, October 2017.