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Chapter 1

Textile Application: From Need to Imagination

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Additional information is available at the end of the chapter

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Abstract

To understand textiles and their application today, as well as future applications, it is necessary to comprehend the development of textiles and their applications throughout history. The gradual development of textile production processes and the use of different materials, influenced the development and application of materials themselves. Numerous innovations made since Industrial revolution, events in technology development and international competition have shaped the industry and continue to affect the textile production even today. Nowadays, textiles can be divided into two main sectors according to their application: conventional textiles (textiles for fashion clothing) and technical textiles with numerous applications for nearly all society needs. Due to market needs and technology development, the interference of all areas of science occurs, resulting in amazing innovations that follow existing trends and set future trends in terms of interactivity, digital and electronic functionality, social and environmental awareness, esthetics, etc. These are the reasons for great freedom, development prospects, expression of creativity and thus of innovativeness. The need for them today is greater and more important than ever before in the history of textiles and their application.

Keywords: textile history, development, materials, technical textiles, future trends

1. Introduction

Textiles have been important in human history and reflect the materials available to a civilization as well as to the technologies that had been mastered. From the ancient times to the present day, methods of textile production have continually evolved, and the choices of textiles available have influenced how people carried their possession, clothed themselves, and decorated their surroundings. The social significance of finished products reflects their culture. Archeological findings reveal many secrets about the history of textiles, their application and development, as well as art, and numerous historical documents. Knowledge of such

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materials remains inferential, since textile deteriorates quickly compared to stone, bone, shell, and metal artifacts.

2. Textiles in prehistoric age

Historical facts give strong reasons for believing that humans began wearing clothes 100,000–50,000 years ago. The evidence supporting such beliefs is genetic analysis that indicates the fact that the human body louse, which lives in clothing, may have diverged from the head louse 170,000 years ago. These estimates predate the first known human exodus from Africa [1, 2].

Our knowledge of ancient textiles has expanded in the recent times thanks to modern technological developments. Possible sewing needles have been dated to around 40,000 years ago and the earliest dyed flax fibers have been found in a prehistoric cave in the Republic of Georgia and date back to 36,000 BC, which suggests that textile-like materials were made even in prehistoric times [3].

The earliest evidence of weaving comes from the impressions of textiles, basketry, and nets on little pieces of hard clay, dating from 27,000 BC and found in Dolni Vestonice in the Czech Republic. At a slightly later date (25,000 BC), the Venus figurines were depicted with clothing (**Figure 1**). Evidence exists of flax cultivation from 8000 BC in the Near East [4, 5].

It is believed that the first actual textile, as opposed to skins sewn together, was probably felt. Many cultures have legends about the origins of felt making. A Sumerian legend claims that the secret of felt making was discovered by Urn Amman of Lagash. Another early textile method dated from 6500 BC is Nålebinding, a fabric creation technique predating both knitting and crochet [7].

The earliest known woven textiles of the Near East may be fabrics used to wrap the dead, excavated at a Neolithic site at Çatalhöyük in Anatolia, carbonized in a fire and radiocarbon dated to 6000 BC.

In Europe, Near East, and North Africa, from prehistoric times to early Middle Ages, two loom types dominated the textile production: the warp-weighted and the two-beam loom. The width of woven fabric is determined by the length of the cloth beam and could be 2–3 m wide. Woven clothing was very often made from full loom widths draped, tied, or pinned in place.

Neolithic period (around 5500 BC) is characterized by Ancient Egypt from where evidence of the flax fabric production originate. Documentation of domesticated wild flax cultivation, likely imported from the Levant, exists from 6000 BC. Other fibers like rush, reed, palm, and papyrus were used alone or with linen, to make rope and other textiles. Production and use of wool in that period are not significantly documented. The inhabitants of the Indus Valley Civilization used cotton for making clothing as early as 5000–4000 BC [5, 6, 8].

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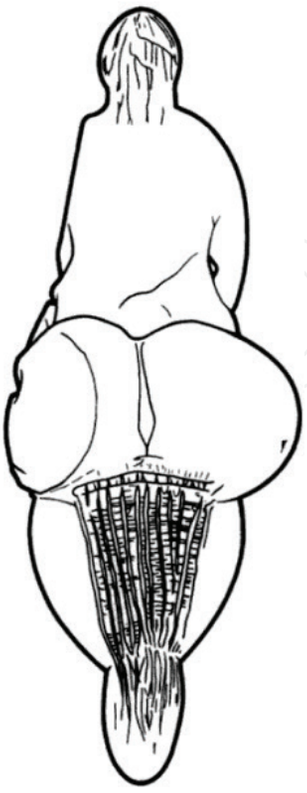


Figure 1. Paleolithic Venus figure wearing a skirt of twisted strings [6].

Around 3000 BC, the breeding of sheep with woolly fleece, rather than hair, occurs. At that time, different spinning techniques were used (drop spindle, hand-to-hand spinning, rolling on the thigh). The yarn was also spliced, and the horizontal ground loom was used for weaving process. From the period of New Kingdom, a vertical two-beam loom was introduced, probably from Asia [9].

3. Textile in ancient history

Ancient History is divided according to cultures whose traces have been kept until today (3500 BC–fifth century AD). The most important civilizations are Ancient Mesopotamia, Ancient Egypt, Ancient China, Ancient India, Ancient Greece, and Ancient Rome. Textiles and its development had a major impact on the development of its application and thus on the development other society and culture of these civilizations.

Time between 5000 and 3000 BC was a period from which the earliest evidence of silk production in China date back, found at the sites of Yang Shao culture in Xia, Shanxi. Another, with the remains, rich sites of Hemudu culture in Yuyao, Zhejiang, reveals fragments of primitive loom, dated to about 4000 BC, while in a Liangzhu culture site at Qianshanyang in Huzhou, Zhejiang, were found silk scarps, dating back to 2700 BC. Other valuable fragments have been

recovered from royal tombs (1600–1046 BC) of the Shang Dynasty. Clothing of the elite was made of silk in vivid primary colors [10].

Linen bandages were used in the burial custom of mummification, and such linen, woven with 540 threads per inch, was found on an Egyptian mummy (2500 BC). Art depicts Egyptian men wearing linen kilts and women in narrow dresses in various forms of shirts and jackets, often of sheer-pleated fabric and goddess Isis holding a shuttle (**Figure 2**) [5].

The earliest evidence of weaving in Japan is associated with the Jōmon period. Cloth fragments made of bark fibers and hemp fibers were discovered. Some pottery pattern imprints depict fine mat designs, proving their weaving techniques, and also show clothing with patterns that are embroidered or painted arched designs. Since bone needles were also found, it is assumed that they wore dresses that were sewn together [12].

The classical Filipino clothing varied according to cost and current fashions and so indicated social standing. In ascending order of value, textiles were made of abaca, abaca decorated with colored cotton thread, cotton, cotton decorated with silk thread, silk, imported print stuff, and an elegant abaca woven of selected fibers almost as thin as silk.

Fabric in Ancient Greece was woven on a warp-weighted loom. The first extant image of weaving in western art comes from a Terracotta lekythos (**Figure 3**). The vase 550–530 BC depicts two women weaving at an upright loom. Wool was the preferred fabric in Ancient Greek

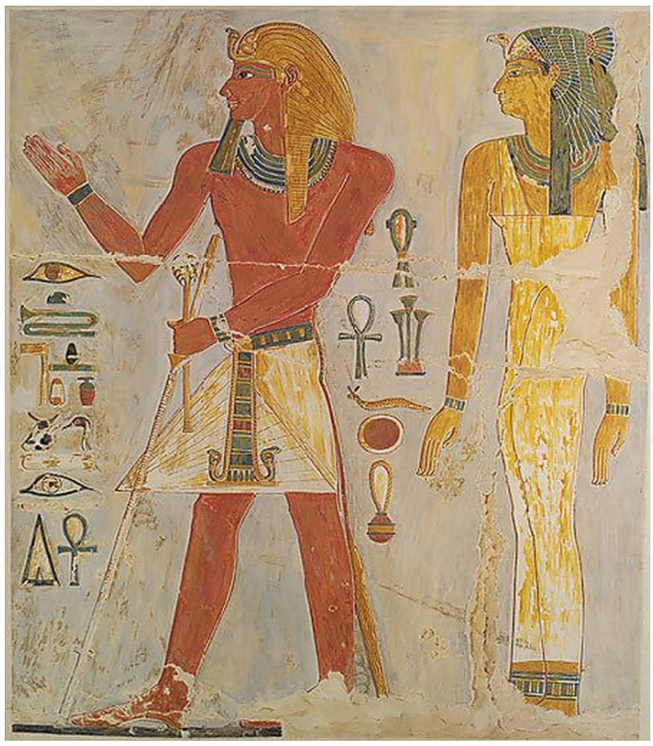


Figure 2. The Mural "Relief of Thutmose I," showing men's and women's clothing, around 1500 BC [11].

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Figure 3. Terracotta lekythos (oil flask), display weaving, Greek [13].

clothing, although linen, hemp, and small amounts of expensive imported silk and cotton were also worn. Ancient Greeks and Romans developed an enormous trade in textile (300 BC). Silk became the luxury cloth in Rome, while around 65 BC, cotton awnings were used [5, 9].

3.1. Silk road: the ancient textile trade route

The Silk road was network of a series of ancient trade and cultural transmission routes, through regions of the Asian continent, linking East and West, China with Mediterranean Sea. The trade route was initiated around 114 BC, although earlier trade across the continents had already existed. Trade on the Silk road, where the exchange of luxury textiles was predominant, was a significant factor in the development of the great civilizations of China, Egypt, Mesopotamia, Persia, the Indian subcontinent, and Rome and helped to lay the foundations for the modern world. For the West World, silk was the most important merchandise that passed the Silk road. The development of silk weaving can be traced back to 2000 BC. The production of silk in sufficient quantities and for export developed only completion of "time rival empire" in the third century BC. At the time, silk was an extremely rare material in the West, like purple and glass counted in luxury goods of the Roman Empire. During the Middle Ages, simple clothing was favored by the majority of people, while only the richest could afford finer materials such as silks and linens, even at the modest prices (**Figure 4**). At the time of the Augustan peace, the Roman upper class expressed an increased "appetite" for silk, spices, and jewels, because they wanted to emulate the rich lifestyle of the Far East [10, 14].



Figure 4. Silk woven fabric from China, the Western Han Dynasty, second century BC [15].

4. Textiles in the medieval period

The elite of early medieval Europe imported silk and cotton from the Byzantine and later Muslim, as well as bleached linen, dyed wool. Besides weaving, embroidery was very widespread. Lower classes wore local or homespun wool, very often undyed, trimmed with bands of decoration (various embroideries, tablet-woven bands, or colorful borders) woven into the fabric in the loom. Evidence exists from 200 AD of earliest woodblock printing (flowers in three colors on silk) from China, while the oldest samples of cloth printed by Woodblock printing from Egypt date from 600 AD. Finely decorated examples of cotton socks made by true knitting using continuous thread appear in Egypt around 1000 AD [9].

At the same time, a great expansion of wool industry was present in England. Henry I sponsored the first woolen cloth guild and relocated skilled Flemish weavers to English villages to increase production. In 1153 AD, the first annual cloth fair was held in England. England became a European center of textile production.

During thirteenth century, great progress in the dyeing and wool processing has been made, which was the most important material for outerwear of that time. For the clothing that was in direct contact with skin, the linen that could be laundered and bleached in the sun, was increasingly used. Raw cotton was imported from Egypt and elsewhere, and was used for many applications such as padding and quilting, as well as cloths such as buckram and fustian.

Valuable knowledge of fine textiles like light silks was brought to Western Europe from Levant by the Crusaders. Silk that was imported in Northern Europe, was very expensive luxury material (like exclusive woven brocades from Italy), which could afford only the well-off. Fashionable Italian silks of this period featured repeating patterns of roundels and animals, deriving from Ottoman silk-weaving centers in Bursa and Yuan Dynasty from China [16].

5. Modern age: flourishing of textiles

The Renaissance, which marked a break with the Middle Ages, is one of the most creative periods in history. It is one of the largest movements in the culture of Western Europe, which has led to a reversal in all segments of the Arts and Sciences, including textiles.

Further development and progress in the process of dyeing and tailoring, in Western Europe during the fourteenth century, accelerated the expansion of fashion and drastically changed worldviews and ways of thinking. In subsequent centuries, clothing and draperies became increasingly elaborate, but still retaining the manufacturing methods.

Raw materials such as flax and hemp were highly represented in the fabrics production during the Renaissance Europe, but wool has still remained a dominant material. Wool fabrics were available in a wide variety of qualities and processing, from rough undyed, to fine dense broadcloth with a velvety nap, dyed in rich colors (red, green, gold, blue). High-value broadcloth was the most important export product and the backbone of the British economy.

By the fifteenth century in the Mediterranean, silk fabric was established as a luxury product and it was extensively used in the Italian fashion to dress high-class citizens (silk velvets with silver-gilt wefts) (**Figure 5**).

The prosperity increase during the fifteenth century influenced the textile industry, where the middle class, following the fashion of elite class, began wearing more complex clothes and materials.

During the sixteenth and seventeenth century in Europe, the great flowering of needle lace occurred. Geometric reticella deriving from cutwork was elaborated into true needle lace, which reflected the scrolling floral designs popular for embroidery (**Figure 6**). Lacemaking centers were established in France to reduce the outflow of cash to Italy [16, 18].

In 1589, William Lee invents stocking frame, the first and hand-operated weft-knitting machine. During the seventeenth century, England passed numerous laws that for example forbade English textile craftsmen to emigrate to America, forbade English colonies in America from trading wool materials, required all persons to be buried in woolen cloth (because more cloth



Figure 5. Velvet silk with silver thread (fifteenth century), Italian, Venice [17].



Figure 6. Italian needle lace, seventeenth century [19].

was being produced than could be sold). All the secrets of weaving crafts were strictly kept in family circles. Until 1842, there was a law, which allows death sentence in the case of loom exports out of the country.

In the late seventeenth and early eighteenth centuries a great number of innovations and patents emerged which greatly enhanced the production and use of textiles. The flying shuttle, patented in 1733 by John Kay, doubled the weaving productivity, which led to even greater imbalance increase between spinning and weaving processes. The flying shuttle became widely used after the invention of drop box in 1760 (by John's son Robert). Wool spinning with even greater thickness was enabled with patenting of roller spinning frame and the flyer-and-bobbin system, by Lewis Paul, who in 1748 along with Daniel Bourn also patented carding machines. Lewis's invention was later developed and improved by Richard Arkwright in his water frame and Samuel Crompton in his spinning mule. James Hargreaves invented the spinning jenny, which he patented in 1770, while the spinning frame or water frame was developed and patented in 1769 by Richard Arkwright. Samuel Crompton's Spinning Mule, introduced in 1779 was a combination of the spinning jenny and the water frame, which was able to produce finer thread than hand spinning and at a lower cost. Mule spun thread was of suitable strength to be used as warp, and finally allowed Britain to produce good quality calico cloth. Edmund Cartwright developed a vertical power loom, which he patented in 1785 and in 1786, he patented a two-man operated loom, which was more conventional. 1804 was the year when Joseph Marie Jacquard presented the first mechanical weaving loom, which used punched cards in a continuous sequence to enable a single weaver to produce complex patterned fabrics, and thus simplified the production. This is an early example of precomputer technology [5].

Since about 1760 to sometime between 1820 and 1840 was the period of transition to new manufacturing processes, known as Industrial Revolution. Textiles were the dominant industry of the Industrial Revolution in terms of employment, value of output and capital invested; the textile industry was also the first to use modern production methods. The industrial revolution has enabled the application of waterwheels and steam engines for mechanization of

textile production. As a result, small cottage-based production was switched to mass production based on assembly line organization. Opposite the fabric, clothing production was still made by hand.

Mechanized textile production spread from Great Britain to continental Europe in the early nineteenth century, with important centers of textiles in Belgium and later in France. Since then industrialization has spread throughout much of the world. A large number of power looms were beginning to be installed in the factories in America (1816).

New advances of the Industrial Revolution such as steamboats, canals, and railroads, have significantly influenced the changes in the transportation sector, in the form of cost reduction, which also contributed to the price reduction of finished textile products. Therefore, textile has become more accessible and hence cheaper, despite a dislocated but industrial production, as opposed to more expensive hand-made goods produced locally. Such triggered production influenced the development of the national market, which has from 1810 till 1840 tripled the output, causing a slow neglect of hand weaving.

Most of the employees in the textile factories were women, who began working for various reasons, but all leading toward gaining a sense of independence and growth as a personal goal. This can be considered as the beginning of women's emancipation.

In the early 1880s, Joseph Swan invented the first synthetic fiber, drawn from a cellulose liquid. In 1889, Hilaire de Chardonnet developed the first manufactured fiber—artificial silk (Chardonnet silk). The first successful process of producing artificial fibers was developed in 1894 and was called Viscose, while the commercial viscose was first produced by the UK Company Courtaulds Fibers in 1905 by the name Rayon [20–23].

In period between 1865 and 1948, textile industry has expanded to such an extent that the most prestigious educational institutions such as UC Davis, University of Nebraska-Lincoln, Iowa State University, and many others, have established various departments of textiles and clothing. Textiles have even entered high school and high school libraries, with various books collections on the history of clothing and textiles.

6. Contemporary history: the birth of the textile future

After the World War I comes the period of unstoppable development. Textile industry is one of the fastest growing industries, whose production has been altered almost beyond recognition by industrialization and the introduction of modern manufacturing techniques with automation, advanced textile processing techniques, and applications.

In 1935, Wallace C. Carothers developed the first synthetic fiber— Nylon, while polyester, acrylic and other artificial fibers were introduced between 1940 and 1950.

Knitting machine controlled by computer that produced fabrics with highly complex patterns at tremendous speed was presented in 1970. In early 1980s, first robots were introduced into the textile industry [23].

Electronics, automation, and robotics became the new trends, which resulted in more productivity with less labor and operational costs. By late 1980s, textile mills used high-speed looms with darts (many tiny shuttles) and with a jet of water or air carrying the filling through the warp up to 1000 times a minute, while industrial looms today incorporate air-jets to weave at speeds over 2000 picks per minute.

The 1980s was the period of digitalization and the CAD/CAM systems (computer-aided design and computer-aided manufacturing) have also impacted the textile industry. This tool, offers benefits such as improved product design, increase in productivity, higher utilization, better quality control and enabling companies the retain their profitability and competitiveness (**Figure 7**). Machine designs became increasingly sophisticated and precise, enabling innovations in specialty fabrics.

With the development of nanotechnology, and in 1980s with the full development of the sol-gel and electrospinning techniques, the use of nanoparticles and nanofibers to produce specialized nanofabric became a huge subject of interest. In the coming decades, an increase in global funding accelerated nanofabric research studies. It was believed that the future of fabrics would be nanotechnology-based.

The textile industry is growing rapidly with increasing demands in the global market. The invention of modern technologies has benefited the textile industry in automating long and complex textile processes. This resulted in improvement in speed, quality, and cost of textile manufacturing. Textile processing includes many processes like preparatory processes, desizing, scouring, bleaching, dyeing, printing, and finishing. There are also innumerable machines in the market for basic functions such as spinning to the most advanced functions of decorating textiles like embroidery. Now, it is easy to carry out most of these processes on textile processing machinery. The results are reduced labor costs, efforts, and time for production.



Figure 7. Textile engineers are developing high-tech textile products through computer-aided design [24].

In this period, activities in the textile industry extended far beyond clothing and home furnishings. Former conventional textiles received a companion on the path of incredible textile developments that generated a completely new world named "technical textiles."

7. Textile applications: from needs to needs (from the earlier needs to today's needs)

Looking at the distant history, the emergence of textiles and their uses succeeded leather. First textiles were crude and simple, but over time, the technology advanced and textiles became more beautiful and comfortable to wear and for other applications. Throughout years, we use textiles for different purposes, improve them, and make them more attractive. Some are fashionable, some fall out of fashion, some come back, and some are just useful. The history of textiles is as entangled as textiles themselves.

Throughout history, textiles have been used for different applications. The origins of textile application can be traced back to ancient human history, as well as the development of textile application. It is considered that the first application of textiles was for clothing, which is exclusively human trait. It is also a feature of most societies, in social, economic, cultural, and traditional sense. Although the initial reasons for wearing clothes were not identical to present ones, anthropologists believe that the animal skins and vegetation were used as coverings for body protection against external conditions. There is another view that the original coverings were used for the purpose of magic, decoration, cult, or prestige, and later founded the application of practicality [25].

The most obvious function of clothing, from the very beginnings to the present day, is to improve the comfort of the wearer by protecting the wearer from various elements of external factors. It performed a range of social and cultural functions, such as individual, occupational, gender, and religion differentiation as well as social status and standard of modesty. These features have changed through historical periods and regions but have retained their essence to the present day (**Figure 8**).

Throughout history, clothing has been made from a very wide variety of materials, ranging from leather and furs to woven materials, to elaborate and exotic natural and synthetic fabrics, which were enabled by the development of textile raw materials, production, and application. Different cultures have evolved various ways of creating clothes out of cloth. One



Figure 8. Clothing in history, showing (from top) Egyptians, Ancient Greeks, Romans, Byzantines, Franks and thirteenth through fifteenth century Europeans [26].

approach simply involves draping the cloth. Another approach involves cutting and sewing the cloth, but using every bit of the cloth rectangle in constructing the clothing [16].

In thousands of years that humans have spent constructing clothing, they have created an astonishing array of styles, many of which have been reconstructed from surviving garments, photos, paintings, mosaics, as well as from written descriptions. Costume history serves as a source of inspiration to current fashion designers, as well as a topic of professional interest to costumers constructing for theater or films and historical reenactment.

Throughout history, people have created the textiles and clothing inspired by the historical remains of different objects, mosaics, written documents, and photographs, complementing them with new knowledge, capabilities, and current situations. Even today, the history of textile is an inexhaustible source of inspiration for fashion designers and artistic costume designers.

Mechanization of the textile industry made many varieties of cloth widely available at affordable prices. Styles have changed and the availability of synthetic fabrics has changed the definition of trendy and stylish. Nowadays, clothing may also function as a form of adornment and an expression of personal taste or style [16, 18].

Different techniques of making textiles were gradually developed and improved. Production methods and techniques are closely related to the application of the product for which the material is intended.

Felting is the oldest technique, which involves pressing a mat of fibers together in a liquid to create a tangled, flat material. A liquid, such as soapy water, is usually added to lubricate the fibers and to open up the microscopic scales on strands of wool.

Weaving is a textile production method, which implies the interweaving of two thread systems, vertical system, called warp, and a horizontal system, called weft. The process of weaving is carried out on the loom of different types. There is also a manual way of making fabrics, hand weaving, and the manufactured products are unique and expensive.

Knitting involves interlacing loops of yarn, which are formed on a knitting needle, together in a line. Knitting has several active loops at one time on the knitting needle waiting to interlock with another loop.

Lacing is a technique that uses fine woven fabrics with open holes throughout the piece, through which yarns are interlaced, resulting in a layer known as a pile, which is prominent in the manufacture of carpets and velvet. Lace can be produced either by hand or by machine.

Nonwoven textiles are manufactured by the bonding of fibers to make fabric. Bonding may be thermal or mechanical, or adhesives can be used.

Special fabrics like carpets, rugs, velvet, velour, and velveteen are made by interlacing a secondary yarn through woven fabric, creating a tufted layer known as a nap or pile.

Braiding is a technique that implies interlacing minimum three separate yarns or fabric strips, forming a complex structure in flat or tubular form, with exceptional strength properties.

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Laminating and coating are techniques by which textile materials obtain properties that were not originally its features. The difference between two is in application method: coatings are applied in their preparatory state (mostly in liquid form), while lamination process requires the prepreparation of a laminate membrane which is applied to the fabric. Due to great possibilities of added properties, application of such materials, within technical textile field, is also very wide.

Embroidery is a technique of decorating finished textile materials and one of the few methods that have not changed throughout history. However, it is important to note that the technical achievements and a high standard of production from the distant past, today can rarely be achieved.

3D textile materials imply flexible textile products with significantly prominent third dimension compared to the other two planar dimensions. 3D textiles manufacturing methods include braiding, weft or warp knitting, weaving, stitched assemblies, as well as combined proprietary technologies.

Besides application for clothing, from way back in the history, textile has been used for the purpose of decorating the interior, as dominant part of textile-based products in the market. The world of conventional textile began to change, as new cultural influences meet technological innovations. Researches and processing technologies have been resulting in development of fabrics that can serve functional purposes of products well beyond their traditional roles of clothing and furnishing (application in vehicles, construction, agriculture, health care, defense and security, power and environmental technologies, and many more) [27].

The original feature of clothing, body protection, evolved due to technological developments and application needs, in extreme but necessary aspects of protection (protective clothing). However, the distinction between conventional and protective clothing is not always clear-cut, since clothes designed to be fashionable often have protective value and clothes designed for function often consider fashion in their design.

Protective clothing is just one segment of the large field of nonconventional textiles, called technical textiles, which has been primarily developed and produced for its performance or functionality, to meet the exacting specified high-performance requirements of end-use, and not for its appearance or esthetics, unlike conventional textile. Such a brief definition and description of technical textiles leaves a significantly large space for explanation of technical textiles, especially due to the increasing number of products that contain a combination of distinct properties, decorative appearance and function in equal measure (fireproof furniture, breathable footwear for recreation). Technical textiles cover one of the most dynamic and most widespread areas of textiles, materials, processes, products, and applications. They change so fast that they could not be specifically defined and documented and be able to describe and classify their goal. They often require the in-depth material knowledge, engineering capacities, high manufacturing, and quality control standards, as well as close development of collaboration with end-users. As a result of cooperation between different industrial sectors and areas of application, users of those areas are extremely important in the process of innovating technical textiles, because with their functional, technical, and performance requirements, influence and define textile-based products [27].

Technical textiles, besides earlier mentioned protective clothing, include textile structures for a wide range of application, their usage and associated products.

Agrotech includes technical textile products used in agriculture, horticulture (including floriculture), fisheries, and forestry. Applications for technical textiles in agriculture include all activities concerned with the growing and harvesting of crops and animals. They are used for crop protection fabrics against sun and rain, further for fishing ropes, nets, tarpaulins, horticulture twines, shade fabrics, etc.

Buildtech area includes textiles or composite materials used in the construction of buildings and structures for various applications, such as facade foundation systems, concrete reinforcement, insulations, interior construction, visual protection, noise prevention, protection against the sun and building safety, air conditioning, and many more.

Clothtech is part of technical textiles, which mainly comprises textile components used for specific functional applications in garments, shoes, and bags. These components are largely hidden e.g., interlinings in shirts, sewing threads, shoelaces, labels, hook, and loop fasteners.

Geotech includes textile products most commonly used in geotechnical applications, because of their separation, reinforcement, filtration, drainage, and protection functions. This category of products includes permeable fabrics or synthetic materials, wovens or nonwovens, which can be used with geotechnical engineering material. Application areas include civil engineering (roads and pavements, slope stabilization and embankment protection, tunnels, rail-track bed stabilization, ground stabilization, drainage, etc.), marine engineering (soil erosion control and embankment protection, breakwaters), and environmental engineering (landfills and waste management).

Hometech is field of technical textiles, which includes products for household, primarily for interior decoration and furniture, carpeting, floor and wall coverings, cushion materials, textile reinforced structures, filters, sun protection products, and others. These products can create comfortable, practical, hygienic, and beautiful solutions for modern living. Recent developments in the home furnishings industry include the creation of nonwovens that kill dust mites in bedding, repel dirt, and contain antimicrobial qualities.

Indutech includes technical textile products used in the manufacturing sector like filters, conveyor fabrics, industrial belts and hose, abrasive products, etc.

Meditech products are textile materials used in hygiene, health, and personal care as well as surgical applications. The Meditech products are available in woven, knitted and nonwoven forms based on the area of application (surgical gowns, drapes, dressings, masks, caps, sutures, medical implants, sanitary napkins, diapers). Their use is based on a number of typical basic textile properties like softness and lightness, flexibility, absorption, filtering.

Mobiltech segment of technical textiles is used in the construction of all sorts of transport for human or cargo. Products belonging to this area can be divided into two categories—visible components (seat covers, carpets, seat belts, airbags) and hidden components (noise vibration, harness components, cables, tyre cords, liners). They provide good performance and safety,

reduce the weight of the car, enhance the comfort and esthetics and provide advanced insulation, fire retardancy and resistance to water, fuels, extremes of temperature, and abrasion.

Ecotech segment refers to the use of technical textiles in environmental engineering, primarily for environmental protection. The primary segment is landfill waste management, which refers to the use of geosynthetic products to secure landfills against leakage of municipal or hazardous waste. Other areas include secondary protection in chemical/oil industries. For this purpose, recycled schemes, products for oil spill treatment, and insulation products are used.

Packtech includes several flexible packaging materials used for industrial, agricultural, consumer, and other goods. It ranges from synthetic bags used for industrial packaging to jute sacks used for packing food grains. It also provides innovative packing solutions such as oxygen scavenging, packaging for foodstuffs and antistatic packaging for computer equipment. With the advantage of moisture proof quality, they are used for packing moisture sensitive goods.

Protech, as already mentioned, is a collection of textile materials and products used to protect the body during exposure to hazards in the working environment. Protech includes clothing and accessories that provides protection against harmful chemical and extreme temperature conditions, low visibility and garment for ballistic protection (space suits, air conditioned clothing, armor, motorcycle leathers, high-visibility clothing, clothing against heat and radiation for fire fighters, against molten metals for welders, etc.).

Sportech segment includes technical textile products used in sports and leisure such as shoes, sports equipment, flying and sailing sports, climbing, angling, cycling, winter and summer sports, and indoor sports and other [28].

Textiles can be made from many materials of different origin: natural (animal, plant and mineral) and synthetic fibers. Simultaneously with the discovery and development of synthetic fibers and their fast growth production, new technologies and techniques were developed to manufacture technical textiles. The main processes used for technical textiles are knitting, weaving, braiding, nonwoven, tufting and others, whereby nonwoven technology predominates.

8. Textile fibers: shaped nature for developed application

Natural fibers are used since the earliest days of human civilization. The most used plant natural fibers, throughout history and today, are cotton, flax and hemp, although sisal, jute, kenaf, and coconut are also widely used, while the most used animal fibers are silk, wool, angora, mohair, and alpaca. Mineral fibers are fibers obtained from mineral sources and may be used in their naturally occurring form or after slight modifications. Their use was more present in recent times than throughout history.

After World War II, there was an enormous rise in the production of synthetic fibers, and the use of natural fibers significantly decreased. In recent years, strengthening of environmental

awareness has contributed to the revival and increase of the use of natural fibers in the textile, building, plastics, and automotive industries. In those existing application areas, further improvements will be achieved in the performance of existing products that will expand the areas of application and at the same time affect the reduction of environmental burdens.

Wool is one of the earliest used fibers for textile materials and due to its very good heat insulation properties it was used in very cold and very hot climates. Wool is a multifunctional fiber with a range of diameters and with ability to absorb and release moisture, which makes it very comfortable. Therefore is wool suitable for various applications (clothing, household fabrics, and technical textiles), but nevertheless, two-thirds of the total produced raw material is used in the manufacture of garments. In combination with other fibers, wool adds drape, and crease resistance. One-third of produced fibers is used in hometech sector for household textiles because of its inherent resistance to flame and heat, making it one of the safest in this field. In industry it is mostly applied as a thermal and acoustic insulation.

Silk and its manufacturing process were held as the greatest secret under the threat of death penalty in China. However, nothing can stay secret forever and when it was discovered, cultivation and silk processing spread rapidly in other countries. Because of its beauty and comfort properties it is mainly used for high-fashion clothes, lingerie, and underwear. It is also used for technical textile as household textiles (upholstery, wall coverings, carpets) and as medical textiles (surgical sutures, biodegradable micro tubes, molded inserts for bones, teeth reconstruction).

Another material, which is one of the earliest textile products, is flax (linen). It was highly regarded from the times of the earliest civilizations until today for its quality and beauty. Flax is highly respected fiber for its retention properties of cooling during hot days (symbol of breezy summer elegance), and for that reason its application is the largest in the production of clothing (over 70%). Like other natural fibers, its application is significant in the field of household textiles (bed linen, furnishing fabrics, interior decoration accessories), but also as reinforcement and fillers in automotive industry and other consumer products.

Cotton has been part of human history for 7000 years. Today, it is practically an irreplaceable material for clothing (60% of cotton production) and many other applications, but over time, it shaped the history of many countries and peoples as it does now. Cotton is also used to make home furnishings (draperies, bedspreads, and window blinds), and it is the most commonly used fiber in table and bed linen. It is made into specialty materials suitable for a great variety of applications: fire-proof apparel, cotton wool, compresses, gauze bandages, sanitary towels, and cotton swabs. Industrial products containing cotton include book bindings, industrial thread, and tarpaulins.

Hemp has been used for centuries to make rope, canvas, and paper. Long hemp fibers can be spun and woven to make crisp, linen-like fabric used in clothing, home furnishing textiles, and floor coverings. Blending with cotton, linen, silk, and wool gives hemp a softer feel, while adding resistance and durability to the product. Hemp fiber is raw material with a valuable characteristic suitable for multiple industrial applications (insulation products and composites) [29, 30].

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The invention and development of synthetic fibers is related to the first half of the twentieth century. The production of synthetic fibers accounts for about half of all fiber usage, with applications in every field of textile technology. Synthetic fibers and fabrics are all made from a type of polymer, but they each have unique properties and characteristics making them useful for specific applications. Among a number of different synthetic fibers, the most valuable and dominant fibers are four of them—nylon, polyolefin, acrylic, and polyester (approximately 98% of all synthetic fiber production, with polyester alone accounting for around 60%). The main advantages of synthetic fibers are strength, thermoplasticity, abrasion resistance, low absorbency, durability, resistant to moths and fungi, easy maintenance, availability, and inexpensiveness.

Nylon (1931) is the fiber of great properties: durable, strong, resists stains, hides soil, resists mildew and bacteria, prevents static, resistant to abrasion and wrinkling, does not absorb water, and it dries quickly. Nylon can be used in carpet, and high-filament nylon yarns are often blended with spandex and used in athletic apparel, swimwear, and hosiery.

Glass fiber (1938) is used in the production of technical textiles for industrial, automotive application, home insulation, specialty papers in battery separators and filtration, as reinforcement of composite materials (flame-retardant and protective fabric, soundproof, fireproof, and insulating fabrics). Glass fibers are woven and coated with Teflon to produce beta cloth, a virtually fireproof fabric that replaced nylon in the outer layer of United States space suits since 1968.

Metal fibers (1946) have a variety of uses, including the elimination and prevention of static charge build-up, conducting electricity to transmit information, conduction of heat, adding metallic properties to clothing for the purpose of fashion, production of cloth-of-gold and jewelry.

Polyolefin fibers (1949) have great physical-mechanical properties—strength, resistance to abrasion, and its advantages includes resistant to stains, sunlight, odor and chemicals, mildew, rot, and weather. They are fast drying and have a high wick-ability making them useful for spill cleanup.

Acrylic fibers (1950) are unique among synthetic fibers because they have an uneven surface. This fiber is called artificial wool because it has the warmth and softness of wool but does not absorb water. It is often used as cold weather fiber for blankets and sweaters.

Polyethylene fiber (1950) with high molecular weight (HMWP) is one of the world's strongest and lightest fibers. Polyethylene fiber is pound-for-pound 10 times stronger than steel. The material floats, resists chemicals and water, and exhibits superior fiber-to-fiber abrasion. Polyethylene fibers are used in police and military ballistic vests, helmets and armored vehicles, sailcloth, fishing lines and lifting slings, cut-resistant gloves, and a wide range of safety apparel.

Polyester (1953) is the most important synthetic fiber. It is versatile and has low raw material and production costs. Polyester is resistant to abrasion, has the ability to spring back into shape, does not absorb water, and dries quickly. It is utilized in all types of clothing, home furnishings, and as a reinforcing fiber in tires, belts, and hoses. New insulating polyester fiber-fills are used in high-performance outdoor wear.

Spandex (1958) is a lightweight manufactured material that can be stretched over 500% without breaking. It is a soft fabric that is resistant to abrasion and can resist body oils, perspiration, and detergents.

Carbon fiber (1958) is a polymer, sometimes known as graphite fiber, which on top of being strong and light, has high stiffness, tensile strength, chemical resistance and thermal expansion, and can be mixed with other materials. The material is used to produce high-quality devices and can be used for composites in many industries such as aerospace, automotive, military, and recreational applications [31, 32].

A number of those fibers are used in conventional textile manufacturing, but the growing textile industry has resulted in growing demands for various textile processing and applications, and thus fibers themselves. Among other innovations, textile engineers developed and still develop high-tech fibers that are made from synthetic fibers by the modification process, i.e., are mostly regenerated with high physical and chemical properties [33].

There is a long list of synthetic fibers, which are available today and frequently used in every new product. Today, a majority of technical textiles are manufactured from a variety of synthetic fibers based on the desired properties of the end product. Nevertheless, some raw materials hold a good market share for the technical textile industry: cotton (Buildtech, Clothtech, Packtech, Mobiltech, Meditech, Sportech, Hometech, Indutech), jute (Buildtech, Geotech, Packtech, Agrotech, Sportech), silk (Clothtech, Meditech, Sportech), and coir (Hometech, Geotech) holds a good market share as a key raw material for technical textiles.

9. Yesterday's fiction-today's reality-tomorrow's history

The majority of textile-based products are manufactured long before they are sold to the end user. Product developers, manufacturers, and distributors collectively try to guesstimate actual demand and exact customer preferences. The various unpredictable factors can negatively influence and result in destruction of economic value of the product.

Mass production that dominated for many years was able to satisfy the basic market needs in the field of clothing, home furnishing and some standard industrial uses. However, the development of technology and the emergence of different needs, make changes from standard production process to customization process of textile manufacturing. This process involves many segments like logistics, communication, financial transactions, IT, and software providers for product development, production organization, and supply chain management. Therefore, the involvement and cooperation of experts from all fields of science and industry is crucial. The fact, that every customer is different and individual for himself, with its own wishes and needs, is now accepted. Uncompromisingly optimal satisfaction of user specific requirements is increasingly required feature of the finished product. Textile plays a major role in user personal identification and expression. Therefore, textiles represent ideal products for customization and personalization [27].

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Big investments in the development of new products are present with the objective of innovation, maintaining manufacturer market position, and creating new potential areas of business. Innovations enter all areas of textile with the aim of improving properties and tracking of trends for the needs of the market. The development of textiles is not only determined by the end-use needs, but also by the development of science and technology in general, which is implemented on the textile base—fiber or through treatment of finished materials. As already mentioned, interference of all scientific areas is present, resulting in the deletion of sharp boundaries between areas, leading to great freedom, creativity, and innovation. The possibility of expressing creativity and the need for innovation is bigger today and more important than ever before in the history of textiles.

Remarkable innovations in textiles were achieved in the past. Examples are innovations in: aerospace textiles (aircraft, space suits, space shuttles, space transportation), medical textiles that provide bioreceptive and biocompatible materials (artificial heart valve), sport textiles which provide light weight material with safety features like breathability, waterproofness, conductivity, durability, flexibility, comfort, eco-friendliness, digital printing, etc.

Textiles science and technology constantly evolve increasingly integrating other fields of science in order to achieve better and more advanced features. Some examples of recent development in the field of technical fibers are: hollow fibers, blended fibers, ultra-microfibers, ultra-lightweight, and high-stretch synthetic fibers; while a few examples of fabrics are: breathable artificial fabrics, thin and light reflective fabrics, metallic textiles, exquisite fabrics, phase change materials, 3D structured fabrics, etc.

The latest innovation in textile sector imply: development in nanopolymer technology (nanopolymer coatings that impart properties to material like increasing effectiveness, decreasing maintenance time and cost) (**Figure 9**), nanocoatings for stainless materials, sensing T-shirt (with textile pressure sensors to increase the comfort and effectiveness of spinal braces), edema stocking (monitors and measures changes in leg volume), EQ-top seismic wallpaper (composite of strong glass fibers to create durable and elastic panels) (**Figure 10**), new life polyester yarn (made from 100% postconsumer recycled plastic bottles, mechanical processed), mushroom material (home-compostable bio-plastic), and many others.



Figure 9. Nanotechnology used to achieve antimicrobial performance in textiles [34].



Figure 10. EQ-Top seismic wallpaper can save lives in an earthquake [35].

Understanding the basic textile structure provides a foundation for development of materials with different qualities or properties that by upgrading and adjusting, according to desired properties, results in interactive textile structures. Textile structures have become an important basis for high-tech innovations that affect the use, design, and esthetics of textile products. Innovation achievement in conventional materials (woven, warp knitted, weft knitted fabrics) is possible by applying specific structures and raw materials, as well as integration of various elements, in order to achieve the properties of added values (social-ecological awareness, comfort properties, sound and light insulation, various aspects of protection, regulation of body temperature, vibration muscle control). The development of science and technology contributed to the advanced way of thinking and realizing needs, resulting in innovations such as 3D textiles, based on emphasizing the relationship between three dimensions (x, y, z), with almost limitless variety of application solutions. Such textile may be braided, woven, knitted (warp and weft knitted), nonwoven, stitched, embroidered or made by some new special forms (**Figure 11**). Diverse uses include almost all aspects of technical textiles and even fashion [36].

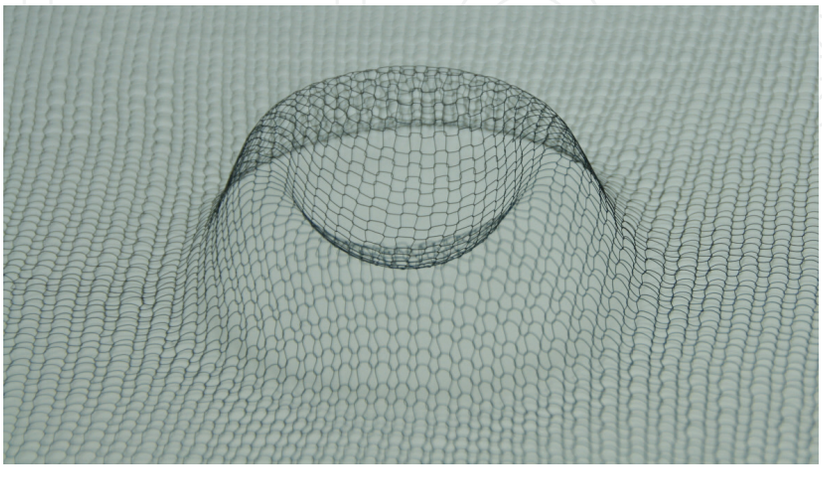


Figure 11. Thermally activated 3D textile with shape memory [37].

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Spacer fabrics are very exciting group of 3D textiles, which offer some of the most innovative solutions of today. Their construction offers the unique possibility to combine various properties, functions, and fibers, all within one 3D structure. Those structures are truly multifunctional and provides a number of exceptional properties: high strength, stability, structural integrity and compression elasticity, breathability, and air permeability, adjustable vapor transport and temperature regulation, cushioning, insulation, light weight, age resistance, recyclable, ability to form complex shapes, design flexibility, and much more (**Figure 12**).

There is one term attracting particular attention and that is Smart textiles. It represents the next generation of textiles intended for fashion, furnishing, and technical textile applications, which are designed and manufactured to sense and respond in a predefined manner to environmental stimuli. The degree of smartness varies and it is possible to enhance the intelligence further by including the technologies that provides the increased functionality. Materials integrated into smart textiles include optical fibers, metals and conductive polymers (**Figure 13**). The market is primarily driven by the increasing usage of nanotechnology in these fabrics, giving them special functionality (**Figure 14**). It is also driven by the rising demand of wearable technology, which is one of the most important factors at a global level market. Due to the miniaturization of electronic components, it has been possible to integrate electronic components (sensors, actuators, control unit) into textiles, making them as a part of wearable textiles (e-textiles).

These textiles have numerous potential applications, such as the ability to communicate with other devices, conduct energy, transform into other materials and protect the wearer from environmental hazards (**Figure 15**). Smart textiles are also applied in field of Medtech and Sportech (fabrics that: release medication or moisturizer into the skin, control the vibration of muscles during athletic activities, and regulate body temperature). In the fashion segment, smart textiles fulfills esthetic requirements, like color change, light up in patterns, display pictures, or videos (**Figure 16**). From the last mentioned, it is evident that the area of electronics

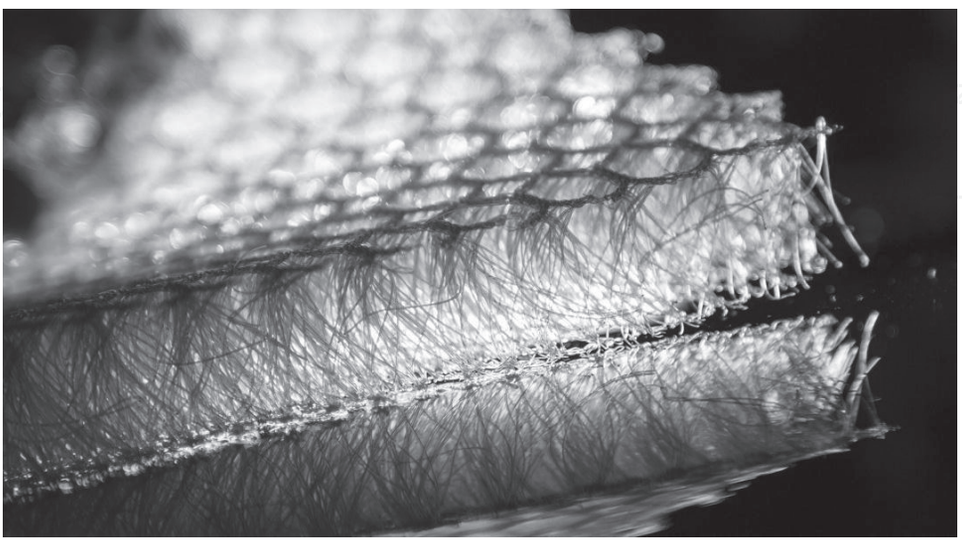


Figure 12. 3D spacer fabric [38].



Figure 13. LED jacket, fabric woven from optical fibers within nylon and steel fabric [39].

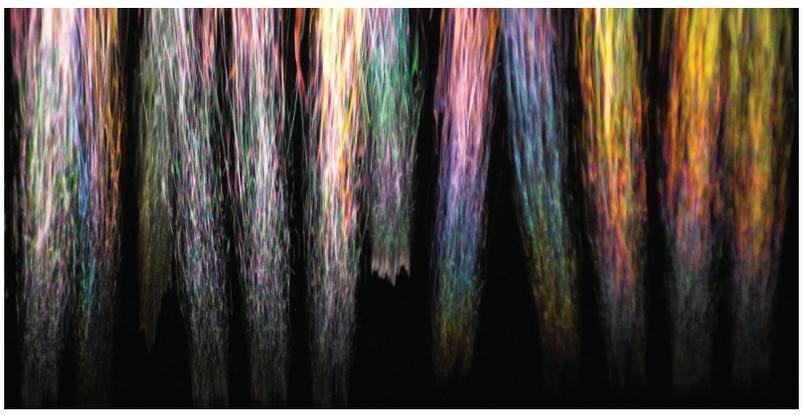


Figure 14. The nanofiber composite reinforcement veil [40].

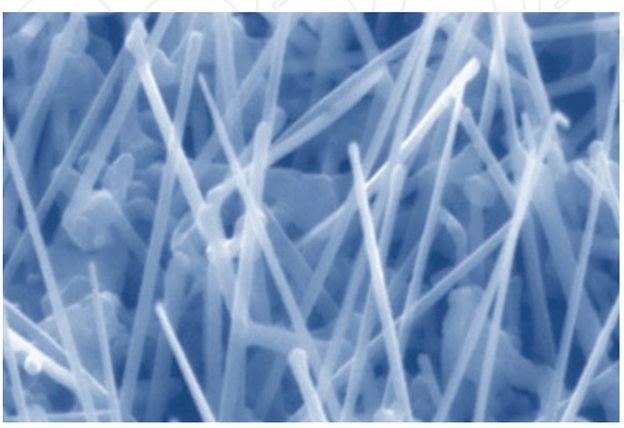


Figure 15. The prototype systematic fiber-based electrochemical micro-super-capacitor is composed of flexible electrode, fine plastic wire and fiber electrode made of Kevlar—alternative to batteries and rechargeable batteries for energy storage [42].

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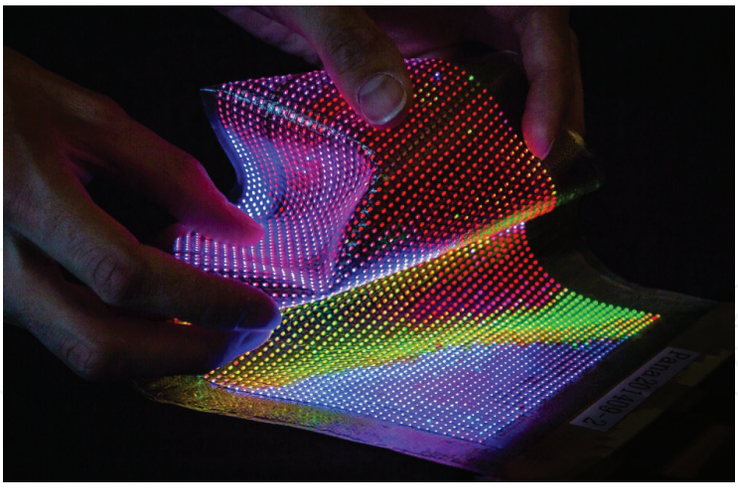


Figure 16. The world's first stretchable and conformable thin-film transistor (TFT) driven LED display laminated into textiles developed by Holst Centre, Imec and CSMT [43].

(smart textiles) enters into the area of conventional textiles for clothes (fashion textile), based on which it can be concluded that there are no longer clear boundaries and separation between these areas. Advanced technologies enter into all textile segments [41].

The increasing number of research and development in recent years indicates one of the major opportunities in the global textile market, enabling the existing technology to be improved and delivering new innovative products in the future. Some of them will be definitely in the field of sports and military industry as fabrics that help regulate body temperature, reduce wind resistance, and control muscle vibration; in the health and beauty industry as drug-releasing medical textiles and fabrics with moisturizing, perfuming, and antiaging properties. There are also indications that future textiles will be self-repairing (with microcapsules containing glue-like substance, which is released if the garment snags, filling in the gaps and hardens), esthetically smart (with illumination properties and properties of collecting and utilization of energy from the environment by harnessing vibration, sound or heat and react to input), interactive (digital functionality, interaction of fabric with an external device) and three-dimensional (with applications in the medicine and aerospace industry). The development of future yarns is oriented towards direct embedding of electronics into yarn and size reduction in diameter (0.2 mm), and also to the exploitation of natural resources (Ingeo– fiber from fermented corn starches, silk-like fiber derived from spoiled milk). The trend of combination and correlation between natural and synthetic sources is about pushing the limits, reacting to the challenge, and delivering the desired level of performance. The emphasis in future trends of textiles is also based on material structure, comfort, and protection properties and strong social and environmental awareness [44].

The trend of the future is to do something different, something new. It is all about pushing the boundaries. A rebellious and freethinking mood is an inspiration for this textile trend, which is, not quite breaking the rules, but more about bending them. There is a spirited thinking that something does not have to be perfect, but still should deliver performance. In this way, one is looking away from traditional perfect surface applications to something more unruly and unique. It is essential to look to innovative fiber content through to textures, finishes, and

printing—multiple performances and multiple applications, in delivering apparel with an edge and more importantly, next generation attitude. Rethinking old traditions and delivering new concepts, exploring what we have and how we can reengineer it to create the next generation material is the way the future of textile should develop [45, 46].

The development of technology, and thus the development of textiles moves at a speed that is hard to track and even harder to understand. Its possibilities cross the boundaries of reality and pass into a fictional world, so beautiful, so free and without limitation.

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