BEGINNER LEVEL

COURSE 2: FOUNDATIONS OF SMART TEXTILES: SUSTAINABLE DESIGN AND SENSOR INTEGRATION FOR FUTURE TECHNOLOGIES

Task: WP1

Responsible partner: TITERA d. o. o.

Participating partner(s): SmartTex Netzwerk Germany, Textile ETP Belgium

Project Number: 2024-1-DE02-KA210-VET-000253979
KA210-VET - Small-scale partnerships in vocational education and training (KA210-VET)

Skills for Smart Textiles: Identification of required skills in the smart textile industry and development of online training content in two levels.

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Introduction

Welcome to **Course 2: Smart Textiles Fundamentals.**

This document complements the accompanying PowerPoint video on our YouTube site. It explains design and prototyping principles with a focus on sustainability and introduces sensor technology with AI and IoT.

This document covers two main topics:

- Designing and prototyping smart textiles with a focus on sustainability in the development process
- Advancing textile sensor technology: Innovations in IoT and AI integration

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Design and prototyping of smart textiles with a focus on sustainability in the development process

Smart textile prototyping and design are an intersection of utility and innovation, as they integrate advanced materials and cutting-edge technology to create reactive textiles or textiles that perform certain functions. But as we design smart textiles to ever greater levels of performance, and with sustainability topics being highlighted, it is important to focus on sustainability throughout the design process. This ensures that the manufacture and design of these textiles not only meet technological and functional standards but also try to minimize the environmental impact.

Textiles are the fourth largest sector after food, housing, and transport for the use of raw primary materials and water and the fifth largest sector of greenhouse gas emissions. It has been estimated that less than 1% of textiles globally are recycled into new garments. The EU textile sector, which consists mainly of small and medium-sized enterprises (SMEs), is on the recovery path after a protracted restructuring. Still, 60% of the clothing in the EU, measured in value terms, is produced outside the region[1].

Wearable technology, including smart clothing and textiles, is becoming more popular and is expected to keep growing. However, this growth comes at a cost. Since both electronics and textiles have short life spans, combining them could make products outdated even faster, leading to more waste. While there is a lot of research on fashion sustainability, efforts are also done regarding the sustainability of smart textiles and clothing.

This second course will explore the principles of sustainable design in smart textiles, such as sustainable materials, energy-efficient methods, and minimizing waste while creating prototypes that are innovative and sustainable.

Smart textiles incorporate electronic functions through various methods, such as weaving, knitting, and coating, with different levels of integration. The combination of electronic components with textile materials disrupts traditional recycling methods. Many smart textiles use materials like polyester and cotton, which already have sustainability concerns due to high water usage and high chemical usage. Additionally, embedded electronics often contain toxic materials and rare metals, making disposal and recycling more difficult.

To address these concerns, researchers are exploring alternative sustainable materials for smart textiles. Innovations include mycelium-based fabrics, biodegradable textiles, and microbial cellulose materials that integrate technology while remaining environmentally friendly.

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Innovation in textile materials towards sustainability

There have been multiple innovations regarding sustainable materials used in textile industry. We are familiar with organic cotton, recycled polyester, cork fabric and hemp and bamboo fabrics. But multiple advancements have been also made with unconventional materials like making leather-like materials from cactuses and mushrooms or even milk protein fibres.

Mycelium based materials are an innovative and sustainable alternative to conventional textiles, plastics, and even leather. When grown under controlled conditions, mycelium can be used to create biodegradable, durable, and versatile materials.

MycoTEX[2] is a European-based company that is using mycelium for fabric applications. They are based in the Netherlands and are working on developing sustainable textiles made from mycelium. MycoTEX creates biodegradable, eco-friendly materials by growing mycelium, which can then be processed into fabrics. These materials are an alternative to traditional textiles and leather, with potential applications in fashion, interior design, and automotive industry.

Another company, based in New Your, USA, working with mycelium is **Ecovative Design**[3]. Its focus is on products and innovations, particularly in packaging and textiles industries. They focus on using mycelium to create sustainable materials like foam, insulation, and even fabrics that are both biodegradable and renewable.

Mercedes-Benz is integrating sustainable materials like cactus leather and mushroom-based alternatives into their vehicle interiors[4]. These eco-friendly options align with the company's commitment to reducing environmental impact. By using these innovative materials, Mercedes-Benz is advancing in sustainable automotive design, contributing to a shift towards greener manufacturing practices.

Milk protein fibres, also known as casein fibres, are made from the protein found in milk. These fibres are biodegradable, renewable, and offer a soft, smooth texture like silk. **QMILK**[5] is an eco-friendly, patented process that transforms non-food milk into biodegradable fibres. Made from 100% renewable raw materials, these fibres are water- and energy-efficient, zero-waste, and decompose in compost within weeks. The milk used is typically discarded as waste, amounting to about 2 million tons annually in Germany. QMILK fibres were recognized for their sustainability with the Green Tec Award in 2015.

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Development process of smart textiles with a focus on Sustainability

Smart textile development is offering solutions to a range of challenges across industries like healthcare, fashion, and environmental monitoring. However, in developing these products, it's crucial to begin by asking: *What problem are we solving with smart textiles?*

Whether it is creating wearable health monitoring systems, fabrics that respond to environmental stimuli, or materials that can aid in reducing waste, the focus should always be on addressing real-world issues.

Reducing the environmental impact of smart textiles requires a holistic approach addressing the product lifecycle, from material sourcing to end-of-life management. Eco-friendly materials like organic cotton and recycled polyester should replace resource-intensive materials, and electronic components should be sourced from suppliers committed to responsible mining. Manufacturing processes must reduce water and energy consumption through closed-loop systems and renewable energy. Designing for longevity and recyclability is crucial, with modular designs allowing for easy component replacement and the separation of electronics from textiles for proper recycling. Consumer education is also vital in promoting responsible consumption habits and proper care for smart textiles.

Recycling smart textiles involves several key principles to ensure more sustainable approach:

- **Material Separation:** Designing textiles with easily separable electronic and fabric components for efficient recycling.
- **Biodegradable or recyclable materials:** Using eco-friendly, sustainable carriers and/or components to minimize waste.
- **User Involvement:** Encouraging responsible disposal of this type of products.

Advanced materials like bio-based polymers, conductive polymers, and nanomaterials offer sustainable alternatives to conventional materials. Bio-based polymers reduce reliance on petroleum, conductive polymers replace heavy metals, and nanomaterials enhance performance with less material.

Innovative manufacturing techniques like 3D printing, digital printing, and laser processing reduce waste, energy use, and chemicals. 3D printing enables complex designs with minimal material waste, digital printing cuts water and chemical use, and laser processing ensures precise shaping with lower energy consumption[6].

Recycling technologies, including chemical and mechanical recycling, help recover valuable materials from end-of-life smart textiles. Chemical recycling breaks polymers into monomers for reuse, while mechanical recycling shreds and melts materials for new products. Advancing methods to efficiently separate electronic components from textiles is essential for reducing smart textile waste and promoting sustainability.

Sustainable production also involves efficient use of energy, water, and resources. Additionally, designing devices for easy disassembly is crucial for recycling at the end of their life cycle. The

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integration level of electronic components affects sustainability; lower integration can facilitate reuse, recycling, and updates, involving users in the process.

Emerging trends in smart textile development focus on sustainable processes with minimal environmental impact. For wearable e-textiles, digital printing is an attractive option due to its low cost and ability to utilize existing machinery. However, it is still evolving, particularly in the development of robust and highly conductive inks[7].

Nevertheless, some solutions in smart textile development require use of electronic components as sensors, actuators and different materials used as conductors. Conductors are crucial in e-textiles, enabling electronic functions and added features. Traditionally, metal inks made from silver, copper, or gold are used due to their high conductivity. However, these materials are expensive and not environmentally friendly. They also require high sintering temperatures, limiting their use with certain textiles. As a result, there is a need for affordable and eco-friendly conductive materials that can be processed at lower temperatures. This could involve sustainable materials like metal-based, conductive polymer-based, or carbon-based options, which are suitable for biodegradable wearable electronics[8].

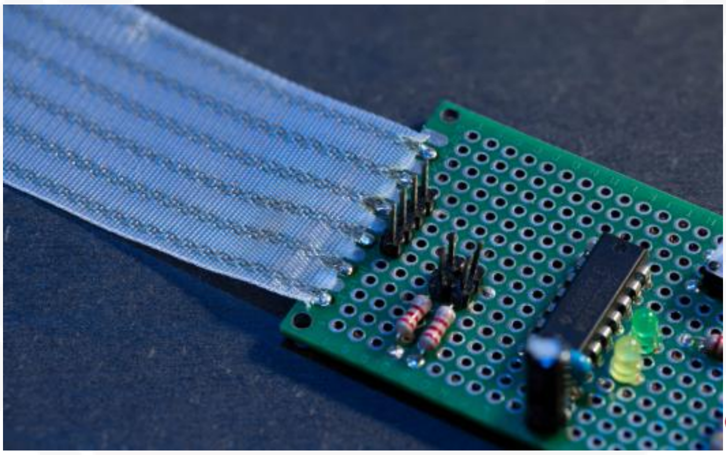

Figure 1: A conductive textile element connected to an electronic component, with emphasis on the precision of the contact points, which plays a critical role in ensuring optimal performance and long-term reliability of the smart textile system. Image courtesy of ITP GmbH, Germany.

Carbon-based materials, such as graphene, are excellent conductors for wearable electronics. They offer several advantages, including nanoscale diameters, outstanding electrochemical functions, high electrical conductivity, and biocompatibility. These materials are thermally stable and have higher electrical conductivity than conductive polymers, making them ideal for fabricating electrochemical devices and wearable sensors. Their unique properties enable them to be used in a variety of applications, from strain detection to health monitoring, enhancing the performance and versatility of wearable electronics [9, 10, 11].

One of the major challenges in developing wearable electronic devices is the need for flexible, lightweight, thin, safe, and portable **energy storage.**

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One of the major challenges in wearable electronics and e-textiles is the power supply. Traditional batteries often have limitations such as short lifetimes and bulkiness. As an alternative, energy can be harvested from various sources using garments or textiles. This includes using sunlight, mechanical movements, friction, or heat to generate electricity. For example, special fabrics can convert sunlight into power or capture energy from movements like walking. Another approach uses friction to generate electricity, while some materials can turn heat into power[12]. However, these methods still have limitations, such as producing low amounts of energy. Overcoming these challenges is important for creating sustainable and self-powered wearable devices.

There are currently available on the market different sustainable energy harvesting products in form of power-banks that are made from recycled materials. For example, **Gomi**[13], an UK based company has developed a power-bank which is made almost entirely from the post-consumer's waste.

Zinc-ion batteries show great promise for wearable electronics due to their safety, cost-effectiveness, and environmental friendliness. Zinc has been found to dissolve slowly in both aqueous systems and biofluids, which is beneficial for biocompatibility. Additionally, magnesium is biodegradable and conductive, making it suitable for certain electronic applications[8].

Currently, e-textiles are often evaluated based on their electronic performance and physical properties, with less focus on sustainability, but in theory, mitigating the environmental impact of smart textile manufacturing requires a comprehensive approach integrating life cycle assessment (LCA), circular economy principles, and socio-technical systems analysis.

LCA helps quantify environmental impacts across the product lifecycle but needs refinement to account for electronic components and obsolescence. The circular economy promotes resource efficiency and waste reduction through closed-loop systems. Socio-technical analysis highlights the role of social, economic, and institutional factors in shaping sustainable practices, emphasizing the need to consider consumer behaviour, business models, and policy incentives.

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Advancing Textile Sensor Technology: Innovations in IoT and AI Integration

Textile sensor technology is revolutionizing the integration of sensing capabilities into wearable devices, enhancing the future of IoT and AI applications. This technology involves embedding sensors directly into fabrics to monitor various physiological and environmental parameters, such as movement, pressure, and temperature. Recent advancements include textile capacitive sensing, which uses conductive patches to track human body movement without direct skin contact, offering improved comfort and versatility in applications like medical rehabilitation and athlete training[14].

Figure 2: The image shows an advanced smart textile component used in smart textile development. It is more flexible and more durable under bending, which makes it better suited for reliable data and energy transmission in wearables, in comparison with traditional materials used (such as wires and stranded cables). Image courtesy of ITP GmbH, Germany.

The Internet of Things (IoT) refers to a network of physical devices, vehicles, appliances, and other objects that are embedded with sensors, software, and network connectivity. This allows them to collect and exchange data with other devices and systems over the internet, often without requiring human intervention[15].

IoT devices can range from simple household items to complex industrial machinery, and they play a crucial role in enhancing efficiency, decision-making, and customer service across various industries[16].

The connection between IoT and smart textiles is pivotal, as IoT enables smart textiles to collect, process, and transmit data in real-time, enhancing their functionality and interactivity.

Below are some examples of this connection:

- **Embedded Sensors:** Smart textiles are embedded with IoT-enabled sensors that can monitor various parameters such as vital signs (heart rate, body temperature), environmental conditions (temperature, humidity), and physical activities (movement, pressure)[17].
- **Data Transmission:** These sensors transmit data wirelessly using protocols like Wi-Fi, Bluetooth, allowing smart textiles to communicate with other devices and systems over the interne[16].

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- **Real-Time Monitoring:** IoT enables real-time monitoring and analysis of data collected from smart textiles, which can be used for health monitoring, fitness tracking, or environmental sensing [18, 19].
- **Integration with Other Devices:** Smart textiles can integrate with other IoT devices and systems, such as smartphones, wearables, or cloud services, to provide comprehensive feedback and insights[16].

IoT significantly enhances the functionality of smart textiles by enabling real-time data exchange and interactivity. Through IoT, smart textiles can collect and analyse data on various parameters such as temperature, humidity, and physiological signals like heart rate and breathing, transmitting this information wirelessly to the cloud for real-time insights. This interactivity allows smart textiles to provide feedback and alerts through mobile apps, enhancing user experience and functionality. Furthermore, IoT facilitates the integration of smart textiles with other technologies like AI and VR, creating sophisticated applications in healthcare, sports, and entertainment.

Artificial Intelligence (AI) refers to the technology that enables machines to simulate human intelligence, including learning, reasoning, problem-solving, and decision-making. AI systems work by analysing large datasets to identify patterns and make predictions, often using techniques like machine learning and deep learning[20].

AI is transforming industries by enhancing efficiency, innovation, and decision-making. It automates tasks, provides data-driven insights, and improves customer experiences. In textiles, AI optimizes manufacturing, detects fabric defects, and predicts fashion trends[21].

AI is transforming the textile industry by optimizing various production stages. It enhances demand forecasting by analysing market data, helping manufacturers plan production efficiently. Fabric grading benefits from computer vision, ensuring quality control and reducing waste. In material preparation, AI-powered robotics streamline operations, while in weaving and knitting, AI detects anomalies to minimize defects. AI also improves dyeing and finishing by controlling variables like temperature and chemical usage, ensuring consistency and sustainability. However, the article does not specifically mention smart textiles or fabrics embedded with electronic components[22].

Electronic textiles can combine digital components like conductive yarns and microprocessors with AI algorithms, allowing fabrics to sense and react to their surroundings in real-time.

AI is also revolutionizing smart textiles by making them incredibly responsive to what's happening around them and to the people wearing them. When AI is combined with e-textiles, these fabrics can gather information from tiny sensors and change their properties in real-time. For example, some AI-enabled garments use special fibres to track how a person moves, which helps them understand what the person is doing and provide personalized feedback[23]. AI also helps textiles adjust to their surroundings, like changing how warm or cool they feel based on the temperature or even changing colour when exposed to different light conditions. This blend of AI and textiles opens exciting possibilities in healthcare, sports, and fashion, creating clothing that interacts with you and adapts to your needs in a way that feels almost suitable[24].

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Smart textiles with IoT-enabled and AI driven processes do raise concern regarding data privacy and potential security risks due to their ability to collect sensitive personal information. That information can be biometric data, persons location, and different activity patterns[25, 26].

The primary concerns include unauthorized access, data breaches, and misuse of personal information beyond the user's intended purposes. Hackers could exploit vulnerabilities to steal data for identity theft, create targeted scams, or even control other connected devices, active on the same network [26].

To mitigate these risks, robust security measures are essential. Data encryption, which transforms readable data into an unreadable format, is crucial for protecting data both in transit and at rest[27].

Data minimization, which limits the collection of data to only what is necessary and obtaining user consent before collecting any personal information are also vital[26, 27].

Secure data storage on servers with strong access controls, regular security audits, and updates are necessary to address potential vulnerabilities. Transparency in data practices and providing users with control over their data, including the ability to access, modify, and delete it, are paramount for building trust[25, 27].

Regulatory frameworks, such as GDPR (General Data Protection Regulation), play a crucial role in ensuring data protection by establishing clear guidelines for the collection, storage, and use of data. Standardized security protocols, continuous updates to address emerging threats, and the development of privacy-enhancing technologies are needed to create a more secure environment for smart textiles[28]. Collaboration between technology developers, manufacturers, and policymakers is essential to prioritize privacy in the design and development of smart textiles and wearable technology[25].

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WANT TO LEARN MORE?

Articles:

- **AI and Fabric Innovation: Smart Textiles for Tomorrow's Clothes,** https://www.linkedin.com/pulse/ai-fabric-innovation-smart-textiles-tomorrows-clothes-tanveer-2j0of/

Fairs:

- **TechTEXTIL Frankfurt, Germany:** https://techtextil.messefrankfurt.com/frankfurt/en.html
- **Performance Days, Germany:** https://www.performancedays.com/
- **Milano Unica, Italy:** Italian textile fair - Milano Unica
- **HeimTextil, Germany:** Heimtextil – International Trade Fair for Home and Contract Textiles

Interesting companies to explore:

- **MycoTEX, Netherlands:** https://www.mycotex.nl/
- **Ecovative Design, USA:** https://ecovative.com/
- **QMilk, Germany:** https://www.qmilkfiber.eu/
- **Gomi, UK:** https://gomi.design/
- **ITP GmbH, Germany:** https://itp-gmbh.de/?lang=en
- **Born GmbH, Germany:** https://born-germany.de/en/
- **Polisilk, Spain:** https://polisilk.com/
- **SunFibre, Czechia:** https://sunfibre.com/

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