SMART TEXTILES AND THEIR APPLICATION IN CONTEMPORARY FASHION DESIGN

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Review paper
UDC: 677.017:687.1
DOI: 10.5937/tekstind2602047Z

Abstract: *Smart textiles represent a modern group of advanced materials that are currently in a phase of intensive development and are based on the application of new technological achievements. They constitute an interdisciplinary field that integrates textile engineering, materials science, electronics, informatics, and design. These materials have a unique ability to detect, react to, and adapt to various external stimuli (mechanical, thermal, chemical, electrical, etc.), enabling the development of functional and interactive textile products. This paper reviews their main characteristics, classification, applied technologies, as well as the various areas of application of smart textiles, with a special focus on their role in fashion design.*

Keywords: Intelligent textiles, wearable technology, interactive clothing, fashion design.

PAMETNI TEKSTIL I NJEGOVA PRIMENA U SAVREMENOM MODNOM DIZAJNU

Apstrakt: *Pametni tekstil predstavlja savremenu grupu naprednih materijala koji se trenutno nalaze u fazi intenzivnog razvoja i zasnivaju se na primeni novih tehnoloških dostignuća. Oni čine interdisciplinarno područje koje integriše tekstilno inženjerstvo, nauku o materijalima, elektroniku, informatiku i dizajn. Ovi materijali imaju jedinstvenu sposobnost da detektuju, reaguju i prilagođavaju se različitim spoljašnjim stimulansima (mehaničkim, termičkim, hemijskim, električnim itd.), što omogućava razvoj funkcionalnih i interaktivnih tekstilnih proizvoda. U ovom radu se daje pregled njihovih osnovnih karakteristika, klasifikacije, primenjene tehnologije, kao i različite oblasti primene pametnih tekstilnih materijala, sa posebnim osvrtom na njihovu ulogu u modnom dizajnu.*

Ključne reči: inteligentni tekstil, nosiva tehnologija, interaktivna odeća, modni dizajn.

1. INTRODUCTION

The textile industry is one of the most important industrial sectors globally, as well as in our country. Despite the intensive technical and technological development, it remains an important segment of the world economy and trade [1].

Historically, the development of textiles is closely linked to the evolution of human society, with their application continuously expanding across various areas of everyday life. Textile materials are traditionally used in the clothing industry, interior design, architecture, aerospace, medicine and many other sectors, which indicates that their influence is present in almost all domains of modern life [2, 3].

With the development of science and technology, the textile industry is experiencing a significant transformation, especially through the development of smart and intelligent textiles. These modern materials represent a new generation of textile systems with high functionality and added value. Smart textiles are characterized by the ability to respond to various external stimuli of mechanical, thermal, chemical or electromagnetic origin and to perform certain functions, such as monitoring physiological parameters, adapting to wearing conditions and interacting with the environment.

The first forms of smart textiles were initially introduced at the end of the 20th century with the development of materials with a memory effect, especially in Japan. Since then, the interest in these materials has been constantly increasing, due to their wide application and potential for innovation [4].

Modern research is aimed at developing wearable systems based on textiles, which enable monitoring of health parameters, improving safety and improving the quality of life. In addition, textiles with special functions are being developed such as color change, temperature regulation, energy storage or harvesting, as well as the release of medicinal substances directly onto the skin.

The application of smart textiles covers a wide range of areas, including protection and security, medicine, sports, the fashion industry, architecture and smart homes, etc. Their role is becoming increasingly important in modern society, where materials are required not only to provide protection and comfort, but also to actively participate in communication with the environment and to improve human performance. In Table 1 are presented some of the areas of application of smart textile materials [4].

Characteristics and potential of smart textiles make them one of the fastest growing and most innovative areas in the modern textile industry, with broad prospects for further development and application in various scientific and industrial disciplines [5, 6].

2. CLASSIFICATION OF SMART TEXTILES

In scientific literature, there are different approaches to classification of smart textiles and there is no single, strictly defined division of smary textile materials. One of the most commonly used approaches classify these materials into two basic categories based on their function, namely aesthetic and functional.

Aesthetic smart textiles represent a significant direction in the development of modern textile design, where technology is integrated into fashion to achieve visual and interactive effects. These materials enable dynamic aesthetic properties, such as light emission, color change, and visual transformation depending on external influences or user interaction. Typical examples of this category are luminous garments and luminescent dresses, which already have wide commercial applications [7].

Table 1: Areas of application of smart textiles [4]

Sector	Functionalities	Applications
Protection and security	Real-time data tracking, remote team monitoring, security identification, profiling, hazardous materials detection (HazMat), geolocation, protective equipment (PPE);	Military, emergency services, rescue operations, environmental monitoring.
Medicine and healthcare	Vital signs monitoring (blood pressure, heart rate, electroencephalography (EEG), electrocardiography (ECG), blood sugar levels), chronic disease monitoring, wound healing, continuous patient monitoring, weight and energy management, stress, sleep and emotion monitoring, drug delivery patches; motion analysis.	Remote patient monitoring, implants, chronic care, rehabilitation.
Sports & Fitness	Performance tracking, physical activity, heart rate, steps, sleep tracking, movement analysis, posture correction, navigation, stress monitoring; muscle electrostimulation.	Sportswear, fitness equipment, training systems.
Home & Architecture	Integrated displays and control systems; structural monitoring of objects; activity tracking (movement, falls), interactive learning, augmented reality (AR), real-time streaming, HUD systems	Smart devices for everyday use, digital communication, education.
Fashion & Lifestyle	Visual effects, changing light and patterns, emotional response, decorative displays, interactive lighting effects	Smart clothing, LED textiles, interactive design.

In this context, the role of textile designers is of particular importance. Their knowledge of the characteristics of materials, combined with the ability to use this knowledge creatively and technologically, enables creation and development of innovative textile solutions. By experimenting with new materials and technologies, designers contribute in creating new kinds of connection between the textile product and the consumer, where clothing is not only a functional or aesthetic element but also a medium for communication and expression.

From a functional point of view, smart textiles are most often classified into three main categories (table 2). The operation of these smart textiles is enabled through the integration of three basic components: sensors, actuators, and control units. Sensors detect external or internal stimuli (for example, temperature, pressure or biochemical signals), actuators enable an appropriate response (in active smart textiles), while control units process the information and coordinate the system's response (in advanced or "ultra-smart" textiles) [6]. To achieve these functionalities, materials such as metal fibers, conductive polymers, nanomaterials (e.g., graphene and carbon nanotubes), and conductive inks are incorporated into the textile structure. These materials provide key properties such as electrical conductivity, flexibility and responsiveness, enabling localized or dispersed functionality within the textile structure.

More recent research includes the development of self-powered smart textiles, washable and durable electronic fabrics, and the integration of artificial intelligence for real-time data analysis and adaptive reactions. These innovations significantly enhance the potential of smart textiles, positioning them as crucial components in the next generation of wearable technology and sustainable material systems [8].

2.1 Passive smart textiles

Passive smart textiles represent the simplest form of smart textiles. They have the ability to detect external stimuli and sense the changes in the environment, but their functionality depends mainly on the structure of the material and they do not show an active reaction. These materials actually function as sensor systems and contain only sensors. Examples of this kind of materials are: UV-protective clothing, plasma-treated clothes, textiles with optical sensors, as well as temperature-sensitive materials [9].

2.2 Active smart textile materials

Active smart textiles, also known as second generation smart textile materials, differ from passive materials in that they are capable not only to detect external stimuli, but also to actively respond to them. This is achieved through the integration of sensors and actuators, which allow changes in shape, structure, temperature or other properties in real time. Active textile materials use various energy sources to support these functions, which makes them significantly more sophisticated compared to passive materials [9, 10].

These textile materials can possess various functionalities, such as shape memory, creating a chameleon effect, maintaining a constant temperature (thermoregulation), water resistance, vapor absorption, as well as the ability to generate and store heat or energy. These characteristics make them real "smart" systems that can be applied extensively in various fields. Active smart textile materials find uses in phase change materials, shape memory materials and heat sensitive dyes [7].

2.3 Ultra-smart textiles (intelligent textiles)

The highest level of development is represented by ultra-smart textiles, regarded as the third generation of intelligent textile systems. These materials not

Table 2: Classification of smart textiles

Type of smart textile		Incorporate devices			Functionality		
		Sensors	Actuators	IPUs/ CT	Sensing	Reacting	Responding/ Adapting
1.	Passive smart textiles	✓	-	-	✓	-	-
2.	Active smart textiles	✓	✓	-	✓	✓	-
3.	Ultra smart textiles	✓	✓	✓	✓	✓	✓

IPUs - integrated processing units, CT - communication technologies only are able to detect and respond to external stimuli but also can analyze the obtained information, make decisions and adapt to the dynamic environmental conditions [10, 11].

These systems contain processing units and communication technologies that allow for automated, responsive and adaptive functionality. They are able to respond to a wide range of stimuli, including thermal, mechanical, chemical and magnetic stimuli and to adjust dynamically to the surrounding conditions. In essence, ultra-smart textiles operate as integrated systems that possess an incorporated “intelligent” or “brain” structure, capable of analysing data, making decisions and initiating appropriate reactions. Representative examples include spacesuits, I-wear garments, sports and music jackets, as well as various forms of wearable electronics equipped with biomonitoring and autonomous adaptive functionalities [12].

3. MAIN TYPES OF SMART FABRIC TEXTILES

3.1 Shape memory textiles

Shape memory fabrics are an advanced class of smart textiles that have ability to change and restore their original shape under the influence of external stimuli, such as temperature, mechanical stress, light, or electric and magnetic fields. This property is enabled through the integration of shape-changing materials (Shape Memory Materials – SMM), among which the most important are shape memory alloys (SMA) and shape memory polymers (SMP) [7, 13].

SMMs materials are characterized by pseudoelasticity, high deformability with reversible recovery, as well as adaptive behavior associated with phase changes.These materials can change their physical properties (shape, stiffness, elasticity strength, etc.) in response to changes in their environment. In textiles, they can be incorporated by spinning into fibers or as part of yarns, which are further used in production of textile (woven or knitted) structures.

Shape memory alloys, especially nickel–titanium (NiTi), function by a reversible phase change between austenite (a high-temperature, more ordered phase) and martensite (a low-temperature, more deformable phase). The material transforms to the martensite phase under thermal or mechanical stress, but upon reheating it returns to the austenite phase and recovers its original shape. These alloys also exhibit a two-way shape memory effect, which means they can remember two different predetermined shapes at two different temperatures, making them appropriate for repeating and cyclic applications. They can recover large amounts of deformation, although their ductility is often more limited than that of shape memory polymers.

On the other hand, the shape memory polymers have a mechanism based on their cross-linked molecular structure. Their behavior is determined by the glass transition temperature (Tg). Below Tg, the material is rigid and retains its temporary shape, but above Tg it becomes very elastic and can revert to its original shape. This mechanism involves the stabilization of a temporary form upon cooling and its subsequent release upon reheating.

Additionally, temperature sensitive polymers and UV-sensitive (photosensitive) polymers have also been developed.These materials have various advantages such as low density, great flexibility, low production costs and superior processability, which makes them particularly ideal for textile applications.

Due to these characteristics, shape memory textiles find wide applications in various fields. They are used in the fashion industry to create innovative and adaptive designs, in protective garments to increase thermal insulation, and in medicine where they are used in surgical sutures and implants for minimal invasive procedures. Furthermore, these textiles ofer additional functionas such as wrinkle resistance, better recovery after deformation and dynamic control of heat and moisture balance [14].

With the development of new materials and technologies, shape memory textiles represent a significant step forward in the field of smart textiles, offering multifunctional, adaptive and high performance solutions for modern applications.

3.2 Color changing textiles

Color-changing textiles are an advanced category of smart materials capable to change their color under the influence of external stimuli. This capability is achieved by incorporating chromic or “chameleon” materials in the textile structure, which enable controllable and reversible color changes.

The color change is most often due to the change of the molecular structure or electron density of the chromic materials when exposed to specific stimuli, and when the stimulus disappears, the material return to its original more stable state, which makes the process reversible and repeatable [13, 14].

Chromic materials are classified into several classes depending on the nature of the external stimulus: photochromic (light), thermochromic (temperature), electrochromic (electrical current), solvatochromic (solvents), halochromic (pH), tribochromic (friction), and mechano- or piezochromic (mechanical pressure). These systems can be incorporate into textile materials by several technological processes, including dyeing, spinning, coating and printing.

Of special interest are thermochromic materials that change color with temperature and simultaneously influence the thermal characteristics of the cloth. For example, at high temperatures they can become more reflective and brighter, whereas at lower temperatures darker tones help retain heat. This property is especially used in protective clothing, such as firefighter uniforms, but also in fashion and decorative textiles.

Color-changing textiles are used in a wide variety of products ranging from clothes to bags, hats and other accessories, most often for aesthetics but also for functional purposes. Due to their ability to visually react to the environmental conditions, they have great potential for future development, especially in combination with sensor and smart systems for monitoring and adapting to surrounding environmental conditions.

3.3 Phase-changing textiles

Phase change materials (PCM) are a type of smart materials used to store heat and regulate temperature changes by absorbing and releasing latent heat during a phase change (most often from solid to liquid states and vice versa). During this change the material maintains an almost constant temperature, while a significant amount of energy is stored or released, which provides a stable thermal environment [7, 14].

In the textile industry, PCMs are typically applied in the form of microcapsules with diameters between 1–30 μm. These microcapsules are integrated into fibers, coatings or fabric structures. The capsules must be stable and durable to prevent leakage and withstand mechanical stresses during use. The most frequent PCM compounds are paraffin waxes due to their tunable phase change temperatures based on their chemical structure.

PCMs works on the principle of latent heat storage. As the substance is heated, thermal energy is used to change the material from a solid to a liquid state. When cooling, it releases this stored energy during the crystallization process. This reversible mechanism enables the material to maintain an almost constant temperature, by significantly improving thermoregulation. Compared to conventional heating media, such as water, PCMs can absorb and store considerably larger amounts of heat due to the phase change process. In addition to paraffin based PCMs, inorganic hydrated salts, such as Glauber's salt (sodium sulfate), are also used especially in cooling textiles.

The development of PCM technology began in the 1980s within the framework of NASA space research programs, with the aim of protecting astronauts and equipment from extreme temperature fluctuations. The technology was later further developed and commercialized, especially by companies such as Outlast Technologies, which introduced the integration of microencapsulated PCM systems into textile products.

Today PCM technology is incorporated in various types of clothing, providing thermoregulation, improved thermal comfort and adaptation to external conditions. Today's solutions like a mesh lining with PCM coating allow fabrics to keep a porous structure while controlling heat, absorbing excess thermal energy and releasing it when required (particularly in hotter areas) [6,14].

3.4 Waterproof and breathable textiles

Waterproof and vapor-permeable textiles are among the most important groups of functional materials which offer simultaneous protection of the human body from external environmental conditions and physiological comfort. During physical activity, the human body produces heat and perspiration that needs to be efficiently transported away from the skin surface to the external environment. These textile materials should have two important properties: their waterproofness, to prevent the entry of liquid water from the outside, and their permeability to vapor, to allow the vapor of water from the body to pass through the fabric. This balance is accomplished by a unique construction of the textile material [8].

A key parameter for evaluating waterproof and vapor permeable textiles is the Moisture Vapor Transmission Rate (MVTR). This value indicates how effectively water vapor passes through a fabric and is especially significant for intense physical activity, such as sports activities or firefighting. In such cases, the increased sweating may reduce the thermal insulation of the clothes and lead to the condensation of moisture on the inside surface of the garment, which negatively impacts comfort and overall performance [14,15].

Depending on their structure and functional mechanism, these textiles can be categorized broadly into three major groups. The first group is densely woven fabrics, where the fibers are closely packed together and very small pores are formed that restrict the passage of liquid water but enable the movement of water vapor. A classic example is the Ventile cotton fabrics where the cotton fibers swell spontaneously in contact with water reducing the pore size further and increasing the water resistance [16].

The second group is microporous membranes, which work by the difference in size between water vapor molecules and liquid water droplets. These membranes contain microscopic pores that block the passage of liquid water but allow the transfer of water vapor. The most popular materials in this group are polytetrafluoroethylene (PTFE) and polyurethane membranes.

The third group are non-porous, or hydrophilic membranes, where water vapor transport occurs via molecular diffusion through the material. They are not porous but have some hydrophilic components which absorb and transfer moisture from the inside to the outside. Their efficiency rises under conditions of high humidity and temperature.

In addition to the basic properties, these textile materials should also offer additional features such as wind protection, thermal stability, low weight, mechanical strength, fast drying and overall wearing comfort. Despite significant technological progress, there is currently no material that meets all requirements under all conditions.

The performance of these textiles is also influenced by environmental conditions, for example wind can increase moisture vapor transfer, while rain can decrease it. Due to their functionality and wide application, waterproof and vapor-permeable textiles represent a key segment in the development of modern technical and sportswear, with significant potential for further innovation.

3.5 Wearable electronics smart textiles

Wearable electronics smart textiles are a new class of intelligent materials that can dramatically improve quality of life by enabling increased safety, health and comfort in a range of applications.

These textiles have the ability to detect external stimuli, such as temperature, light and humidity, to react to them and adapt to environmental conditions. At the same time, they can also collect, store, and process data for information and communication purposes, becoming intelligent systems that can support and monitor vital human functions [17].

The basic components of these systems are conductive materials, sensors, communication modules and energy sources. Their integration into textiles is realized through three main approaches: embedding conventional electronic devices into the textile structure, developing electronic components using textile-based technologies (textronics), and producing fibers with built-in electronic functionality (fibertronics). The first approach is relatively simple to implement but has limitations in terms of flexibility, durability and maintenance. The other two options, on the other hand, give a higher degree of integration and increased functionality but are far more demanding and sophisticated in technological terms.

The application of wearable smart textiles is particularly significant in the fields of medicine and sports. In healthcare, they provide continuous monitoring of vital parameters, such as heart rate, respiration and body temperature, improving patient care and increasing mobility. In sports, these systems contribute to the analysis and optimization of performance by monitoring various physiological and activity-related parameters.

They also play a significant part in protective garments, helping to improve safety in dangerous and harsh work conditions by monitoring the condition of the wearer and allowing rapid communication. Modern options include clothes for biological monitoring (ECG and respiratory systems), medical textiles for diagnostics and therapy, sensor based textiles for body fluid analysis and contactless monitoring systems [18, 19].

Despite the technological challenges associated with power supply, durability and system integration, wearable smart textiles have a high potential and represent a major area for the future development of healthcare, sports and industrial applications.

4. APPLICATION OF SMART TEXTILES IN FASHION

Today, fashion trends are characterized by higher demands of consumers who, besides the aesthetic value, require functionality, interactivity and innovation in textile products. With the growth of living standards and dynamic lifestyles, there is an increasing interest in clothing and accessories that are not only visually attractive, but also offer additional functions, such as automatic adaptation to environmental conditions or facilitating everyday activities [20]. Fashion is one of the most difficult fields that constantly change according to the wishes of its clients and moves in line with time, events and changes [21, 22].

Thanks to technological progress, smart materials are increasingly used in fashion design. Of particular importance are materials that react to external stimuli, such as chromatic pigments (photochromic, thermochromic), which change color under the influence of light or temperature, as well as phase-change materials (PCM), which enable thermal regulation. In addition, shape memory materials (shape memory alloys and shape memory polymers) also allow clothes to change shape depending on environmental conditions.

These technologies allow to produce dynamic and interactive fashion goods, where the shape, color, texture or structure of garments can be changed according to the external conditions or to the activities of the user. In this way, fashion is moving from a static system to an adaptive and functional one, where design is not only visual but also technologically oriented.

The development of these concepts is the consequence of greater multidisciplinary collaboration between fashion designers, engineers and technologists. Today's designers are progressively including the integration of technological knowledge in the design process, allowing the development of products with both aesthetic and functional value [23]. This includes clothes that can automatically change their shape or structure in response to body temperature as well as textiles that react to external influences in order to improve comfort and safety.

Smart textiles are also used in the production of protective and functional clothing, for example, fabrics that warn of increasing exposure to UV radiation or materials that change their structure in order to improve ventilation or minimize noise. These innovations expand the role of fashion, transforming it from a simply aesthetic discipline to an integrated system that combines design, technology and wearer comfort. Considering these development trends, intelligent materials are an important driver for the future of the fashion industry, enabling the development of adaptive, functional and personalized textile products [24].

Table 3 shows examples of the application of smart textiles in fashion design, through different designers, used technologies and their functional effects.

Designer Ying Gao makes interactive garments that respond to light, sound or movement with photochromic and electrochromic fabrics and sensors that change color and appearance in real time. She approaches fashion design in a subtle and conceptual way, exploring the intimate relationship between technology, the human body and public space. Her work emphasizes interaction, perception and emotional response, critically examining the role of technology in contemporary society.

Table 3. Application of smart textiles in fashion design

Designer	Technology	Effect / Functionality
Ying Gao	Photochromic and electrochromic materials, sensors, microelectronics	Interactive garments that respond to light, sound, movement and viewer interaction, changing color, texture and appearance in real time.
Iris van Herpen	3D printing, computer modelling, laser cutting, smart materials	Sculptural, dynamic and biomimetic structures inspired by nature that respond to movement and environment; fusion of fashion, science and technology.
Hussein Chalayan	Mechanical systems, electronics, animatronics, shape-memory materials	Transformable garments that change shape, structure and form in real time through programmed mechanisms and interactive systems.
Issey Miyake	Thermoresponsive materials, pleating technology, innovative textile processing	Garments that change shape, texture and drape under the influence of heat, movement and wear; development of adaptive "living textiles".
Anouk Wipprecht	Biosensors, robotics, microcontrollers, wearable technology	Interactive clothing that responds to biometric data (movement, proximity, physiological signals) and adapts behavior in real time.
CuteCircuit	LED technologies, embedded electronics, microcontrollers	Garments that emit light, display text and animations, functioning as dynamic digital communication interfaces.
Ralph Lauren	Biometric sensors, wearable electronics	Smart clothing for real-time monitoring of heart rate, respiration, physical activity and overall performance.

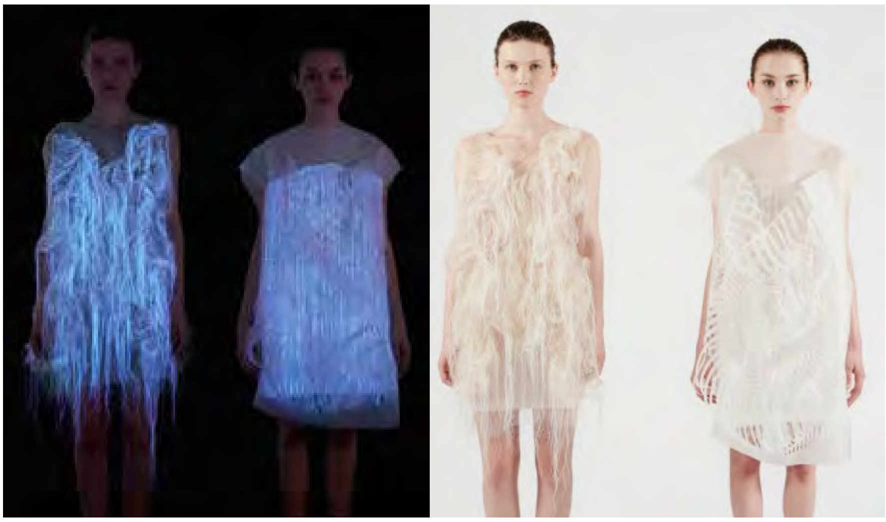


Figure 1. Ying Gao. *(No)where (Now)here), 2013*: an interactive dress that responds to the viewer's gaze by switching its lights off and illuminating when direct eye contact is detected, demonstrating her approach to garments that react to human attention and presence [28]

Gao uses technology as a mode of artistic expression, creating garments that respond to movement, breath, light and interaction with the viewer. These designs act as 'relational objects' that provoke engagement and create unexpected connections between the wearer, the viewer and the clothes themselves.

Despite her technological sophistication, her work is firmly anchored in fashion design, mixing traditional materials such as leather and organza with sensors and dynamic systems. In this way, her garments act as "second skin" structures that dynamically respond to the body and environment, redefining fashion as an interactive interface between humans, technology and space [25].

Ying Gao uses two main methods of integrating technology into fashion design. The first is a direct method, where microelectronic components such as sensors, cameras, and microprocessors are physically incorporated into garments with flexible, non-fixed structures that enable them to assume various forms. The second is an indirect method, where technology serves as an invisible source of inspiration that guides the design through data, software and conceptual processes [26, 27].

Iris van Herpen is one of the most original and forward-thinking fashion designers working in the world today and is renowned for her pioneering work that combines fashion, technology, art and science. She is one of the first designers to mix traditional

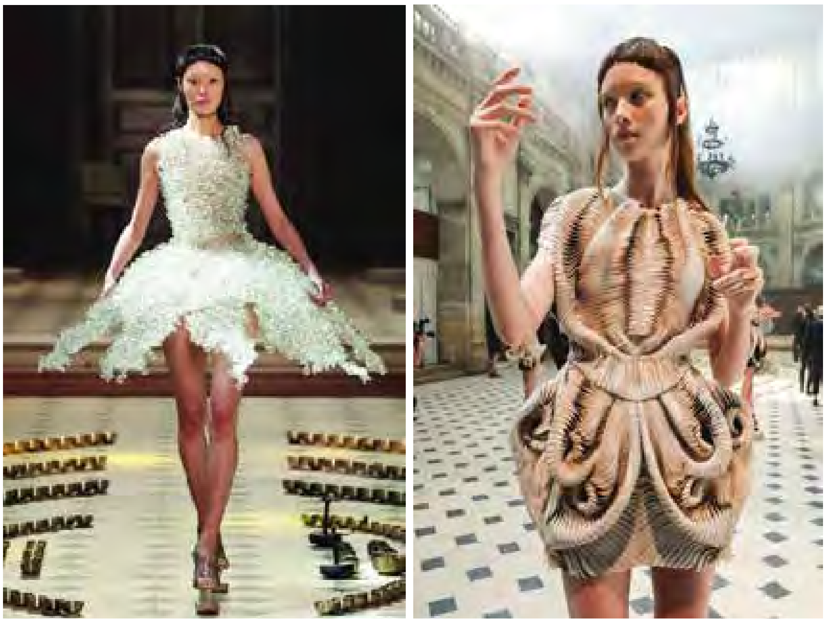


Figure 2. Iris van Herpen, Seijaku, F/W 2016 [32]

handcrafting with 3D printing, computer modelling, laser cutting and other sophisticated technology in haute couture [27, 29]. Her designs are characterized by organic, three-dimensional and sculptural forms inspired by nature, such as coral, waves, spider webs and biological structures. By experimenting with materials and techniques she produces "fractal" and fluid forms that frequently reflect movement and the dynamics of the human body.

Van Herpen's work is related to posthuman and new-materialist concepts, since she integrates the human body, nature and technology into one whole. Her designs are often described as wearable sculptures that turn fashion into an interactive space between the digital, the material and the organic [30, 31]. Her design process is characterized by ongoing experimentation, interdisciplinary collaborations with scientists and artists and the creation of a new visual and material language in fashion, where clothes are a dynamic, innovative, conceptual and technologically driven form.

Hussein Chalayan is a Cypriot Turkish-British fashion designer generally recognized as one of the most innovative and adventurous characters in modern fashion. He is noted for combinig fashion with technology, engineering, architecture and conceptual art to make clothes that go beyond standard fashion design. A key feature of his work is the creation of electronically driven and "transformative" clothes, commonly described as animatronic or interactive clothing. These designs use robotics, electronics and mechanical systems to simulate movement, change shape or modify appearance. Garments can grow, shrink, stretch or transform into whole various shapes with the push of a button or through programmed mechanisms, turning clothes into a dynamic, responsive system.

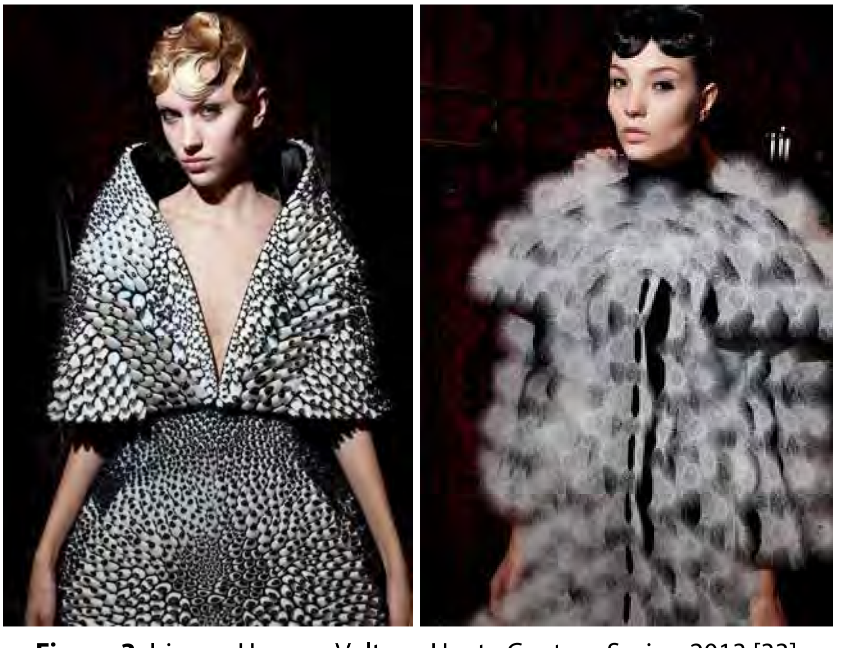


Figure 3. Iris van Herpen, Voltage Haute Couture Spring 2013 [33]

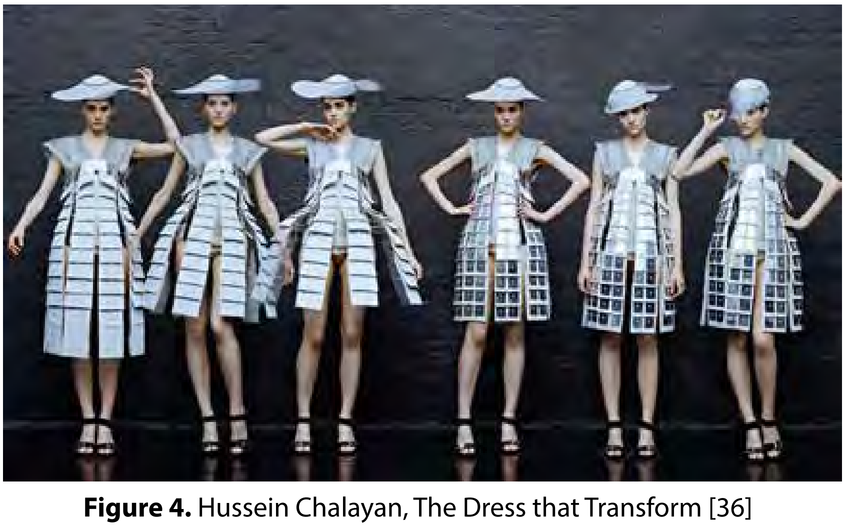


Figure 4. Hussein Chalayan, The Dress that Transform [36]

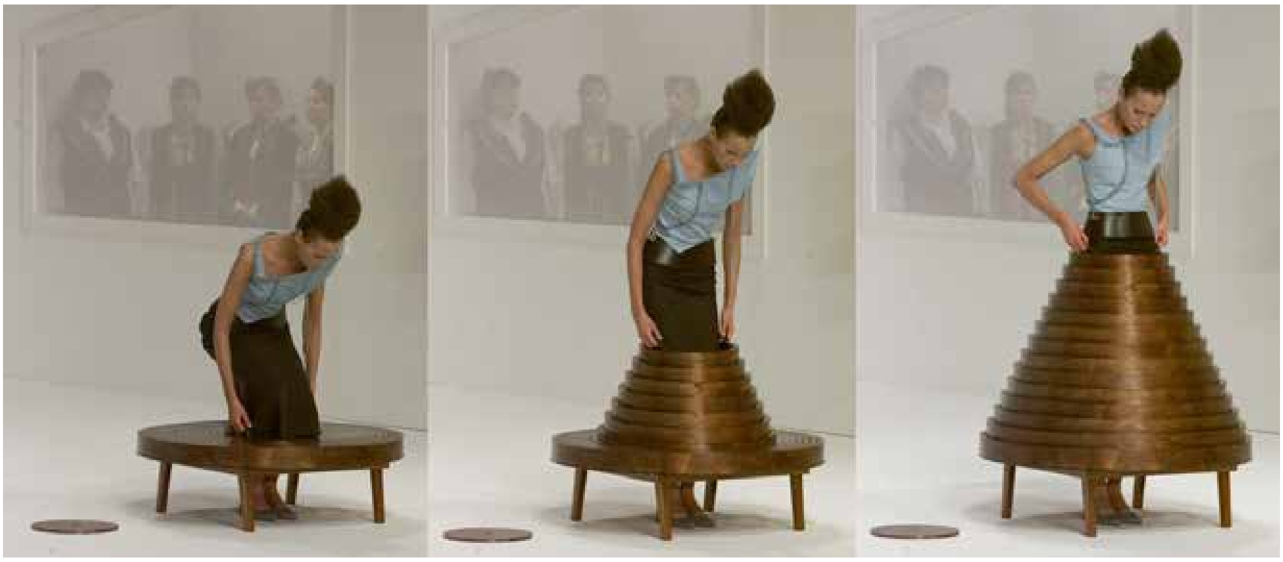
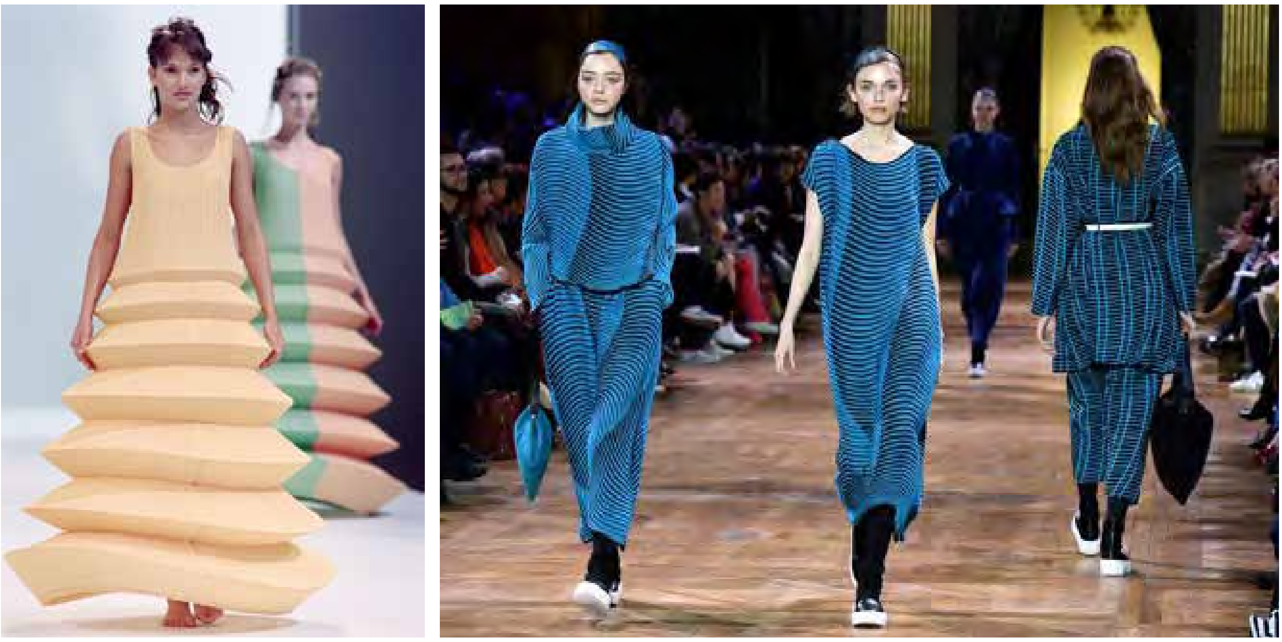


Figure 5. Hussein Chalayan, Coffee Table Dress A/W00 [37]

Chalayan frequently uses non-traditional materials and electronic components in his work, creating pieces that respond to light, sound and movement. This allows his outfits to be part of a multimedia performance where fashion, environment and technology are in harmony. His runway shows are then not only presentations of clothing, but immersive theatrical experiences [34]. Architecture, philosophy, anthropology and contemporary science profoundly impact his design style. Many of his collections reflect deeper ideas about politics, culture, identity, and human experience. He utilizes fashion as a platform to explore social and emotional themes, through minimalist yet highly conceptual designs.

His work has been exhibited in major museums and exhibitions throughout the world, solidifying his status not just as a fashion designer but also an artist and innovator. Chalayan's pioneering work has had a major impact on the disciplines of wearable technology, experimental couture and performative fashion, giving rise to new ways of thinking about the interaction between clothing, the body and technology [35].



a) **b)**

Figure 6. a) Issey Miyake Spring-Summer 1995 ready-to-wear collection in Paris [41]
b) Yoshiyuki Miyamae's Issey Miyake A/W 17 womenswear collection [42]

Issey Miyake is one of the most influential designers in the development of innovative and technological textile structures, particularly known for his use of thermoset and pleated materials. His work is based on the concept that fabric can be active and dynamic, rather than just a static form. Employing techniques like knitting and specific processing of materials [38, 39], he produces garments that change their shape, texture and drape in response to movement, heat and how they are worn [38, 39].

The most famous is the collection "Pleats Please", where the clothes are first produced in larger forms, then pleated by heat treatment, which creates an elastic and stable structure. Such clothes move with the body, fit the body and keep their shape. This vision combines fashion to materials engineering and promotes the concept of "living textiles" as adaptable systems. Such developments contribute considerably to the development of smart and functional textiles by Issey Miyake, where design and technology are combined into one entity [40].

Anouk Wipprecht is a Dutch designer who merges fashion with robotics and interactive technologies. Her creations are based on the use of biosensors, microcontrollers and robotic systems to develop clothing that reacts to the human body and its environment [43].

In her designs, clothing reacts to biometric data such as movement, proximity to other people, and physiological signals. These concepts are driven by biometric inputs, allowing garments to respond dynamically to the wearer and their surroundings. Famous projects such as the "Spider Dress" use sensors and mechanical elements that change the shape and behavior of the clothing in real time [44].

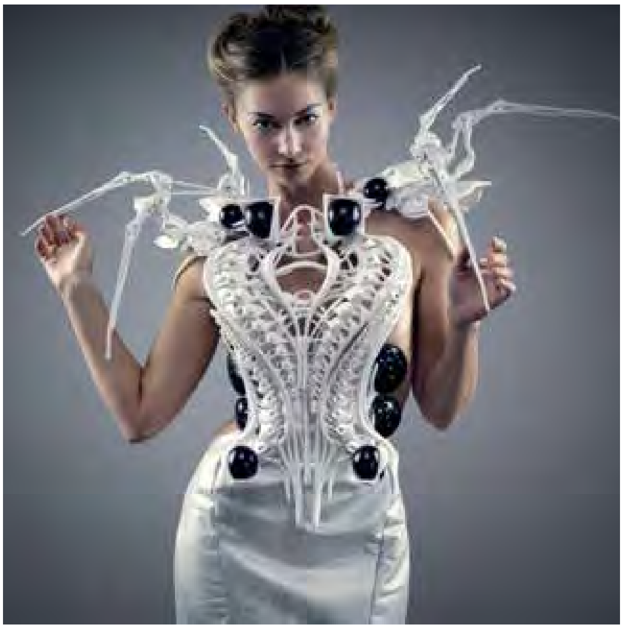
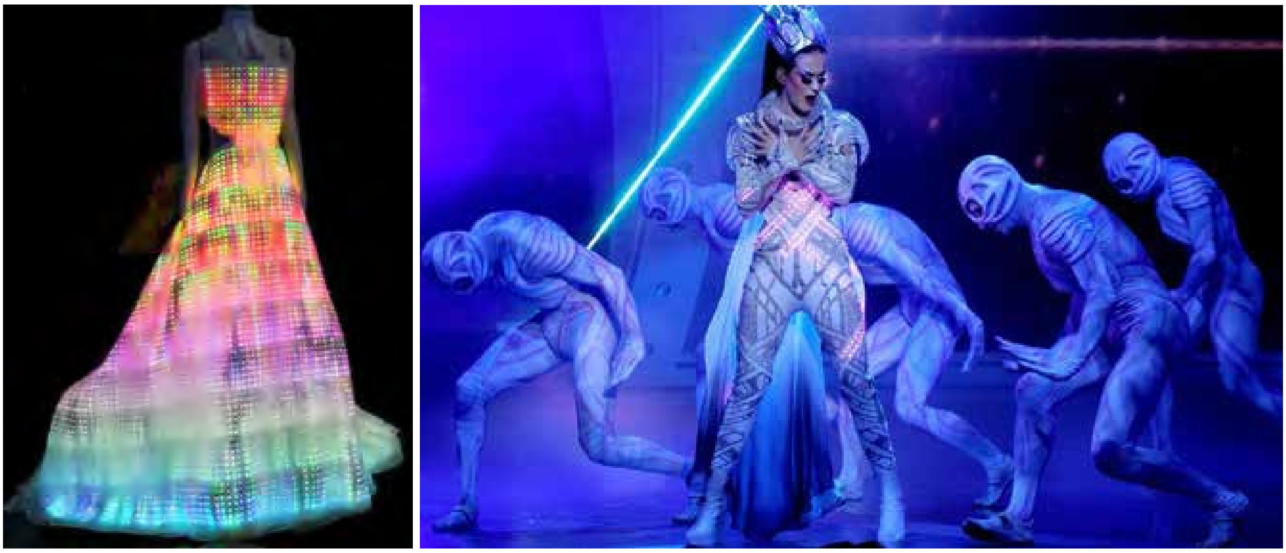


Figure 7. Anouk Wipprecht, The Spider Dress [46]

With solutions like these, Wipprecht transforms fashion into an interactive system that combines technology and human interaction, creating clothing that functions as a dynamic interface between the body and the environment [45].

CuteCircuit is a fashion technology company known for developing clothing with integrated LED systems and electronic components. Their ideas com-



a) b)

Figure 8. a) CuteCircuit (2008), The Galaxy Dress, Chicago [50] b) CuteCircuit. (2013). Katy Perry wears CuteCircuit on American Idol, [50]

bine fashion with digital technology, so clothes may give forth light, display text, and create all kinds of visual effects. They use microcontrollers and flexible LED parts to make the apparel interactive and able to communicate visually. It can change its appearance, show messages or light animations depending on the program or interaction with the user. In this way, fashion is transformed into a digital medium of expression, where clothing acting as a dynamic visual interface [47,48, 49].

Ralph Lauren is an American fashion designer and the founder of the eponymous brand. Smart clothing has been developed through the integration of wearable electronics and biometric sensors. One of the most popular items is the PoloTech Smart Shirt, which employs built-in sensors to track heart rate, respiration, physical activity level and general physical fitness. The data gathered is transmitted in real time to mobile devices, allowing the clothes to operate as a digital health and performance monitoring system. This concept combines fashion with sports technology and health monitoring, turning clothes into a useful instrument to analyze human activity [51]

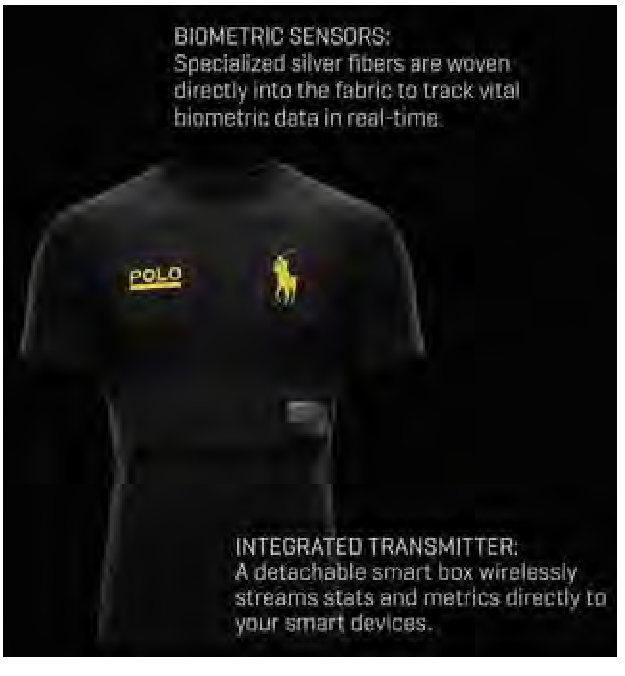


Figure 9. Ralph Lauren (2015), PoloTech Shirt [51]

4. CONCLUSION

Smart textiles are a major step forward in the textile and fashion industry, allowing the transition from traditional, static clothing to functional and interactive systems that interact with people and the environment. Their sensory, adaptive and communicative capabilities create new opportunities for application in fashion design, with clothing turning into an active medium that has not only aesthetic value, but also a technological and functional function.

In modern fashion, intelligent textiles support the development of innovative concepts combining technology, art and engineering, enabling the creation of dynamic and transformational designs. Through their application, personalization, interactivity and user experience are increased, which redefines the role of fashion in modern society.

It may be said in general that the smart textiles play a key role in the future development of the fashion sector. Their multidisciplinary nature and continuous technological progress indicate that they will become an important part of sustainable, functional and smart fashion solutions in the future.

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Primljeno/Received on: 06.05.2026.

Revidirano/ Revised on: 04.05.2026.

Prihvaćeno/Accepted on: 04.05.2026.