From Loom to Light: Electronics in Textile Art and Design

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Article Info	ABSTRACT
	The integration of electronics into textiles has transformed traditional fabric design and art into a dynamic, interdisciplinary field that bridges engineering, material science, and creative practice. Electronic textiles, or e-textiles, have evolved significantly since early explorations with conductive threads in the late twentieth century, advancing through developments in weaving, printing, and fiber-level integration. Weaving techniques enable the incorporation of conductive yarns and circuits directly into fabric structures, while printing approaches facilitate scalable fabrication of conductive patterns, sensors, and responsive surfaces. These methods provide the structural and functional foundation for smart textiles, which are capable of sensing, actuating, and even adapting autonomously. Applications now extend across healthcare, sports, defense, and fashion, supported by innovations in energy harvesting, flexible storage, and adaptive computation within fibers. In the domain of textile art, artists are actively exploiting these technologies to expand aesthetic expression and interactivity. Works by practitioners such as Maggie Orth, LigoranoReese, and Victoria Manganiello highlight how electronics enable textiles to become dynamic, data-driven, or responsive artworks, merging craftsmanship with interactivity. Contemporary fashion innovators like CuteCircuit have further demonstrated how e-textiles blur the boundaries between art, design, and wearable technology. Beyond static functionality, the future of e-textile art points toward bio-adaptive, self-powered, and battery-free fabrics that integrate soft robotics, wireless communication, and AI-driven adaptability, offering unprecedented potential for sustainability, immersion, and embodied interaction. This review highlights the historical development, fabrication strategies, artistic applications, and emerging challenges of electronic textiles. By synthesizing insights across both technological innovation and creative exploration, it underscores how electronics in textiles are reshaping not only material design but also cultural and artistic practices, positioning smart e-textiles as critical to the future of design, wearable systems, and interactive art.

Introduction

The application of electronics in textile design has emerged as a transformative field, bridging traditional fabric production with advanced technological innovation. By embedding electronic components such as sensors, conductive fibers, and microcontrollers into textiles, designers are able to create functional fabrics that go beyond aesthetic value, enabling new forms of interaction and utility. These so-called "e-textiles" or "smart textiles" are increasingly used in areas such as wearable health monitoring, adaptive fashion, and responsive interior design. For instance, garments integrated with biosensors can track physiological parameters like heart rate or body temperature, while textiles with embedded light-emitting diodes (LEDs) or shape-memory alloys can dynamically alter color, pattern, or form. Such integration not only expands the creative possibilities within textile design but also addresses contemporary demands for multifunctionality, sustainability, and user-centered innovation. Consequently, electronics in textile design represents a critical intersection of art, science, and engineering, fostering the development of intelligent materials that redefine both fashion and functional applications.

The history of electronics in textile design can be traced back to the late 20th century, when advances in conductive materials and microelectronics began to inspire experimentation within fashion and textile industries. Early developments in the 1980s and 1990s primarily focused on incorporating conductive threads and fibers into fabrics to create basic circuits. These initial explorations were limited in scope, often confined to prototypes and artistic projects rather than mass-market applications. However, they laid the foundation for the concept of "smart textiles," where fabrics could serve not only as aesthetic surfaces but also as interactive mediums capable of sensing and responding to environmental or bodily changes.

The evolution of this field accelerated in the early 21st century with breakthroughs in nanotechnology, flexible electronics, and wearable computing. Conductive polymers, micro-sensors, and lightweight power sources made it possible to design textiles with advanced capabilities such as health monitoring, temperature regulation, and real-time data communication. Today, electronic textiles are used across diverse domains, including sports, healthcare, defense, and fashion, reflecting a shift from experimental designs to commercially viable products. The growing emphasis on sustainability has also influenced this evolution, with researchers exploring renewable energy integration, such as solar-powered fabrics, and recyclable electronic components. Overall, the progression of electronics in textile design demonstrates a continuous move from simple conductive fabrics toward complex, multifunctional systems that redefine the role of textiles in both everyday life and specialized applications.

The field is typically dated to the late 1990s and early 2000s, when researchers began integrating sensing, interconnects, and computation directly into garments. An early landmark was the Georgia Tech "Wearable Motherboard™/Smart Shirt," which embedded a textile bus to route physiological

data (an archetype for health-monitoring wearables) (Gopalsamy et al., 1999). Soon after, industry demonstrations such as Philips' Lumalive (2006) showcased flexible, fabric-integrated LED matrices for dynamic visuals, signaling commercial interest in expressive, light-emitting textiles.

In parallel, open, stitchable toolkits like Leah Buechley's LilyPad Arduino (mid-2000s) lowered barriers for designers to prototype soft circuits through sewable microcontrollers, sensors, and conductive thread, accelerating experimentation across design schools and labs (Buechley et al., 2008).

As the area matured, definitions and taxonomies emerged. ISO/TR 23383 (2020) formalized "smart textiles" as textiles that reversibly interact with their environment, distinguishing them from merely "functional" textiles and mapping generations from passive (sensing) to active (sensing + actuation) to very smart (sensing + actuation + adaptation). This standard also identified application domains and standardization needs—an important step toward common terminology across research and industry (Sajovic et al., 2023).

consumer products, platforms such as Google's Project Jacquard with Levi's demonstrated capacitive, touch-sensitive textiles coupled to removable electronics, a form factor designed for laundering and everyday use (Loke et al., 2021).

Contemporary research pushes capabilities down to the fiber level and toward system-scale robustness. MIT's "digital fiber" (2021) integrated addressable chips along a drawable fiber to sense, store data, and even run on-fiber machine-learning inference when stitched into garments—pointing to fabrics as information media, not just sensor substrates (Wang et al., 2025).

Recent studies also extend textile sensing modalities (e.g., large-area acoustic/pressure textiles for gesture and respiration monitoring), illustrating how fabric architectures can implement distributed sensing without heavy wiring (Hughes-Riley et al., 2018).

Meanwhile, reviews highlight rapid growth across materials and processes (conductive yarns, printed conductors, embroidered interconnects, and laminated modules) paired with applications in medicine, sport, defense, and interior environments (Rotzler et al., 2021).

A recurring barrier to deployment is durability, especially washability and mechanical fatigue. Historically, developers borrowed tests like ISO 6330 (domestic laundering), but a dedicated e-textiles washing durability method has now been issued: IEC 63203-204-1:2023 for leisurewear/sportswear e-textile systems. Together with ongoing methodological work, these standards are beginning to make performance claims more comparable across products and labs (Tadesse et al., 2025).

Sustainability is another active thread: recent reviews call for design-for-disassembly, recyclable conductive components, and alternatives to perfluorinated coatings, given the multi-material nature of e-textiles and their end-of-life challenges (Sajovic et al., 2023).

In sum, electronic textiles have evolved from proof-of-concept garments and expressive LED fabrics into increasingly integrated, standards-aware systems capable of multimodal sensing, actuation, and on-fabric computation. The near-term research agenda spans (i) fiber-scale integration and interconnect reliability, (ii) power and energy harvesting tailored to soft substrates, (iii) validated, standardized testing (especially laundering and wear), and (iv) sustainable materials and product architectures—directions that will determine whether smart textiles scale from niche applications to ubiquitous, everyday platforms (Tadesse et al., 2025).

Weaving Electronic Textiles

The integration of electronics into textiles via weaving techniques has gained increasing attention as a versatile and scalable approach to creating functional fabrics. Traditional weaving methods enable the incorporation of conductive yarns, metallic filaments, or coated fibers directly into textile structures, offering flexibility in placement, patterning, and routing of electronic functionality. However, this process can affect both electrical and mechanical properties of the resulting fabric—factors such as weave density, yarn orientation, and substrate structure influence conductivity, durability, and feel. Weaving allows real-time integration of components during fabrication, but achieving wrinkle-free and reliable textiles remains a challenge, demanding careful adaptation of conventional equipment and materials (Tseghai et al., 2020).

Practical applications and prototyping strategies illustrate the breadth of weaving in electronic textiles. For instance, Georgia Tech's "Weaving Integrated Circuits into Textiles" demonstrates a method of embedding small surface-mount devices (SMDs) along flexible plastic strips woven into the fabric weft, combining electronics and textiles at an architectural level. Similarly, Google's Project Jacquard embeds metallic-alloy conductive yarns into standard looms, creating touch-sensitive fabrics that can be processed by existing manufacturing infrastructure—without altering fabric aesthetics or feel. These examples underscore how weaving serves as both a fabrication pathway and a design enabler, enabling e-textile systems that are structurally sound, visually coherent, and compatible with mass-production (Zysset et al., 2010).

Printing Electronic Textiles

Printing techniques are revolutionizing how electronics are integrated into fabrics, enabling scalable, customizable, and robust production of e-textiles. Screen printing remains one of the most prominent methods due to its simplicity, high throughput, and cost efficiency. It works by pressing a viscous conductive paste—typically silver- or carbon-based—through a patterned mesh directly onto fabric substrates. This approach ensures good ink penetration and adhesion, especially with flexible wearable materials, and supports roll-to-roll manufacturing. For example, screen-printed silver tracks have been used to create textile-based patch antennas capable of reliable Bluetooth

communication, as well as flexible biosensors combining silver ink and graphene oxide for influenza detection. However, challenges such as fabric rigidity due to layer thickness and potential cracking under repeated deformation remain areas of focus (Karim et al., 2017; Ojstršek et al., 2021).

Inkjet printing, in contrast, offers much finer precision and thinner conductive layers, making it ideal for high-resolution and flexible applications. Recent innovations include using inkjet-printed organic nanoparticle pre-treatments on textiles to improve adhesion and reduce surface roughness. This enables direct inkjet deposition of reduced graphene oxide (rGO) inks, producing conductive tracks that are breathable, comfortable, and more environmentally friendly—resistance levels are dramatically lowered from ~10^6 Ω/sq to ~10^3 Ω/sq. Additional advances involve formulating composite inks—such as graphene-silver blends—that balance conductivity and cost, and can be printed onto pre-treated cotton substrates to yield durable e-textiles with sheet resistance ranging from ~0.08 to 4.74 Ω/sq depending on layering. Other printing approaches, like gravure, transfer, and film-release techniques, are also emerging; for instance, transfer printing of silver nanowire conductive inks has demonstrated lightweight, flexible conductive fabrics with sheet resistance as low as 3 Ω/sq . Meanwhile, novel copper-complex inks that fully penetrate knitted fabrics and serve as seeds for electroless plating show promise for robust, stretchable, and durable e-textile circuits (Farraj et al., 2023; Karim et al., 2017; Onggar et al., 2020).

Smart Electronic Textiles

Smart electronic textiles—often termed smart textiles or e-textiles—are fabrics that actively sense, respond, and interact with their environment. These textiles integrate electronic components such as sensors, actuators, interconnects, power sources, and computing units at multiple scales, including fiber, yarn, fabric, coatings, or embellishments. They are capable of detecting stimuli like temperature, light, pressure, moisture, or pH, and can translate this into visual, thermal, mechanical, or electrical responses—forming dynamic, biomimetic systems. Functionally, smart textiles are categorized by their level of interactivity: passive textiles only sense environmental changes, active ones sense and react, while intelligent or very smart textiles go further by sensing, acting, and adapting autonomously.

Applications of smart e-textiles span multiple domains. In healthcare, they deliver continuous monitoring of vital signs such as heart rate, respiration, and movement, enabling early detection of medical conditions and facilitating remote care. In sports and occupational safety, they track biomechanical performance to prevent injuries and optimize training. Meanwhile, military and first responders benefit from real-time status monitoring, environmental sensing, and situational awareness via smart garments. Fashion and design also embrace e-textiles, enabling interactive garments, displayable fabrics, or responsive aesthetics. Emerging innovations even include battery-

free, IC-less smart textile systems that wirelessly harvest energy via electromagnetic coupling, eliminating rigid electronics from the textile structure altogether (Ruckdashel et al., 2022).

At the material level, conductive fibers and yarns form the backbone of most smart textile architectures. These are created by blending or coating traditional fibers (e.g., cotton, polyester, nylon) with conductive materials such as silver nanoparticles, carbon nanotubes, or conductive polymers like PEDOT:PSS. Such fibers enable seamless electrical conductivity within fabrics without significantly altering their flexibility or comfort. Recent work has demonstrated the feasibility of weaving and knitting conductive yarns into standard textile processes, producing fabrics that can host sensors, antennas, and circuits directly in their structure. These advances are essential for developing garments that are lightweight, washable, and durable while retaining their sensing capabilities (Zohoori et al., 2017).

Another critical element is energy harvesting and storage, which addresses one of the most persistent challenges of smart textiles: powering electronic functions without bulky batteries. Researchers are investigating textiles that integrate flexible photovoltaic cells, triboelectric nanogenerators (which generate energy from motion), and piezoelectric fibers that convert mechanical stress into electricity. For example, hybrid energy-harvesting fabrics can collect both solar energy and biomechanical energy during wear, providing a continuous energy supply to embedded sensors. Complementary innovations in flexible supercapacitors and fiber-based batteries are making on-fabric energy storage increasingly feasible, opening the path to fully self-sustaining wearable systems (Zhang et al., 2020).

Finally, adaptive and intelligent textile systems represent the frontier of smart e-textile research. These involve not only sensing and actuation but also real-time data processing and decision-making, often through integration with artificial intelligence. MIT's recent development of "digital fibers" that can store data, sense, and even perform machine learning inference when woven into a garment illustrates this paradigm shift. Such fabrics can recognize complex activity patterns or environmental changes without requiring separate computing modules, effectively transforming garments into self-aware systems. These adaptive capabilities open possibilities for responsive clothing that adjusts insulation, alerts wearers of hazards, or personalizes user interaction—merging fashion with functionality at an unprecedented level.

Electronic Textile Designing art

Artists today are transforming textiles into dynamic, responsive artworks by integrating electronics—creating pieces that move, illuminate, or interact with the environment. Maggie Orth, a foundational figure in the e-textiles realm, has crafted works like *Electric Plaid*, which harnesses conductive yarns, thermochromic ink, and embedded electronics to produce color-changing patterns within woven fabrics. Another compelling example includes the "fiber-optic data tapestries" by LigoranoReese, which embed fiber-optic threads into tapestries to visualize live

data—such as Twitter streams or flight patterns—as evolving light patterns across the textile. These practitioners push beyond traditional textiles by using light, motion, and electronics as expressive media in their art.

In gallery and performance contexts, electronics in textiles become extensions of narrative and interaction. As showcased in the "Pretty Smart Textiles" exhibition, wearable artworks like Nicky Assmann's musical-circuit dress, Evelyn Lebis's clear LED dress, and Meg Grant's "Apology Helmet"—which verbalizes a programmed apology—illustrate how e-textiles can blend wearable form with storytelling, sound, and emotion. On another front, composer-artist Nicola Woodham employs soft circuitry embedded in wearable garments—like her "Buffer e-textile jacket"—to control sound in live performance through touch and movement, using fabric-based sensors tied to microcontrollers. These examples underscore a convergence of tactile textile craft with electronics and programming, enabling multidimensional, interactive art experiences.

How artists using electronics in textile art

Artists across the globe are harnessing electronics to transform textiles into dynamic storytelling media—moving beyond static craftsmanship to interactive, conceptual art. For example, Maggie Orth, a pioneering technologist and artist, has created numerous works integrating conductive yarns, thermochromic inks, LEDs, and e-ink displays. Her portfolio includes pieces like *Electric Plaid*, dynamic color-changing fabrics, wearable musical instruments, and interactive garments such as the *Firefly Dress*, *Musical Jacket*, and *Fuzzy Apparatus*—all of which embody the fusion of textiles and electronics into expressive, responsive art. Likewise, the artist duo LigoranoReese developed "fiber optic data tapestries"—electronic weavings that visualize real-time data feeds, such as Twitter or flight information, in luminous patterns across the textile surface.
Beyond these innovators, other artists are exploring personal and social dimensions through interactive fabrics. Victoria Manganiello, for instance, intertwines cloth and computation in her installation *COMPUTER 1.0,* where dark liquid flows through woven tubes, controlled by Arduino microcontrollers to briefly form woven patterns like twill or houndstooth before dispersing—a poetic reference to early computational looms. Similarly, CuteCircuit, led by Francesca Rossi and Ryan Genz, pushes fashion into the digital era with garments like the *Hug Shirt*—a Bluetooth-enabled wearable that simulates the sensation of a hug—and the *Galaxy Dress*, featuring 24,000 LEDs forming the world's largest wearable LED display .

The future of electronics in textile art

As electronic textiles evolve, the realm of textile art is poised to embrace "bio-adaptive and ephemeral materials" that respond intuitively to human presence and environmental stimuli. Materials designer Scarlett Yang, for example, is pioneering lab-grown hydrogel composites that shift their texture and rigidity based on ambient humidity—grown from algae-dyed silk protein, these pieces exist at the intersection of biotechnology and artistry, pointing toward textiles that evolve and even degrade gracefully over time. Such creations underscore a shift from static art objects to *living fabric installations*—works that dialogue with space, time, and materiality, introducing temporality, fragility, and sustainability into textile art.

In addition, the next generation of smart textile art promises battery-free interactivity by leveraging wireless sensing and energy harvesting directly from the human body or nearby fields. Researchers in China have already developed electronic fibers that function without rigid components or batteries—activated via the wearer's touch and ambient electromagnetic energy to emit light or control devices—suggesting dramatic freedom in wearable art production. Likewise, entirely soft-logic garments like the pneumatic nylon jacket designed by Rice University display how soft robotics can drive integrated movement in textile forms, independent of traditional electronics. These breakthroughs herald a future of textile art that is self-powered, sensorially responsive, and deeply embodied—able to dynamically unfold movement, light, or transformation without visible wiring or power sources.

Conclusion

The convergence of electronics and textiles represents a transformative moment in both design and artistic practice. What began as experimental applications of conductive threads and simple circuits has grown into a field that now encompasses woven and printed electronic fabrics, fiber-level computing, and fully integrated smart systems. These advances have enabled textiles to move beyond their traditional roles as functional and decorative materials, becoming interactive, responsive, and even adaptive media. From healthcare monitoring and wearable interfaces to expressive art installations and interactive garments, electronic textiles illustrate the profound potential of merging material innovation with digital technology.

In the context of art, electronic textiles expand the expressive vocabulary of textile practitioners by enabling works that change color, emit light, respond to touch, or visualize data. Artists and designers are increasingly embracing these technologies not only to enhance aesthetics but also to engage audiences in new forms of sensory and participatory experience. As sustainability, durability, and washability challenges are addressed through advances in materials science and standardization, electronic textiles will continue to mature as both a functional technology and an artistic medium.

Ultimately, electronic textiles exemplify the interdisciplinary collaboration between engineering, design, and art. Their evolution reflects a growing cultural interest in interactive, embodied, and adaptive forms of creativity. Looking forward, the integration of energy harvesting, artificial intelligence, and biodegradable conductive materials will shape the next generation of smart textiles—garments and artworks that are self-sustaining, environmentally conscious, and deeply interactive. In doing so, electronic textiles not only redefine the future of design and wearable systems but also reimagine the possibilities of textile art in the digital age.

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Conflict of interest

The author declare no conflict of interest.

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