

## بيئة العمل ورفاه الموظف في قطاع النسيج عبر صناعة الملابس الذكية.

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### Abstract

The Workplace well-being became a major strategic concern in labor-intensive industrial sectors, particularly within the textile industry, where working conditions, physical demands, and technological transformations strongly influenced employees' health and performance. Historically subordinated to productivity and efficiency imperatives, the human factor was increasingly recognized as an essential determinant of sustainable performance, work quality, and occupational health. This study, conducted within the field of textile design, analyzed the relationship between the work environment and employee well-being through the perspectives of human-centered design and sensitive design.

The research adopted a qualitative analytical methodology based on a critical review of recent scientific literature and an in-depth analysis of selected applied models of smart clothing and technical textiles used in professional contexts. Selection criteria focused on the functional integration of textile technologies, ergonomic performance, sensory interaction, and their contribution to comfort, safety, and workplace well-being. The analysis examined how smart textiles served as interfaces between the human body, technological systems, and the professional environment, emphasizing their role in enhancing physical comfort, cognitive support, and emotional experience.

The findings demonstrated that smart clothing and technical textiles significantly contributed to improving workplace well-being by optimizing ergonomic adaptation, facilitating sensory regulation, and supporting user-centered functional responses. The study also revealed that the effectiveness of these solutions depended not only on technological performance but also on design strategies integrating users' needs, perceptions, and cultural contexts. Furthermore, the analysis highlighted several challenges related to implementing textile technologies in work environments, including organizational adaptation, ethical considerations, user acceptance, and long-term sustainability.

Overall, this research contributed to a better understanding of textile design's role in promoting workplace well-being and emphasized the necessity of adopting a holistic, human-centered, and ethically informed approach when integrating smart textiles into contemporary professional settings.

### Keywords

Textile Design, Workplace Well-Being, Human-Centered Design, Sensitive Design, Smart Clothing, Ergonomics.

### المخلص

أصبحت الرفاهية في مكان العمل قضية استراتيجية رئيسية في القطاعات الصناعية ذات الكثافة العالية للعمالة، خاصة في صناعة النسيج، حيث تؤثر شروط العمل والمتطلبات الجسدية والتحول التكنولوجية بشكل كبير على صحة وأداء الموظفين. كان العامل البشري، الذي كان تاريخيًا خاضعًا لمتطلبات الإنتاجية والكفاءة، معترفًا به بشكل متزايد كعامل أساسي في تحديد الأداء المستدام وجودة العمل والصحة المهنية. أجرت هذه الدراسة، في مجال تصميم النسيج، تحليلًا للعلاقة بين بيئة العمل ورفاهية الموظفين من منظور التصميم المرتكز على الإنسان والتصميم الحسي.

اعتمدت الدراسة منهجية تحليلية كيفية استندت إلى مراجعة نقدية للأدبيات العلمية الحديثة، وتحليل معمق لنماذج تطبيقية مختارة من الملابس الذكية والنسيج التقني المستخدم في السياقات المهنية. ركزت معايير الاختيار على التكامل الوظيفي لتكنولوجيات النسيج، والأداء الإركونومي، والتفاعل الحسي، ومساهمتها في الراحة والسلامة والرفاهية في مكان العمل. فحص التحليل كيفية عمل النسيج الذكي كواجهات بين جسم الإنسان والأنظمة التكنولوجية وبيئة العمل المهنية، مع التأكيد على دورها في تعزيز الراحة الجسدية والدعم المعرفي والتجربة العاطفية.

أظهرت النتائج أن الملابس الذكية والنسيج التقني ساهما بشكل كبير في تحسين الرفاهية في مكان العمل من خلال تعزيز التكيف الإركونومي، وتسهيل التنظيم الحسي، ودعم الاستجابات الوظيفية المركزة على المستخدم. كما كشفت الدراسة أن فعالية هذه الحلول لا تعتمد فقط على الأداء التكنولوجي، بل أيضًا على استراتيجيات التصميم التي تدمج احتياجات المستخدمين وتصوراتهم والسياقات الثقافية الخاصة بهم. علاوة على ذلك، سلط التحليل الضوء على تحديات تنفيذ تكنولوجيات النسيج في بيئات العمل، بما في ذلك التكيف التنظيمي والاعتبارات الأخلاقية وقبول المستخدمين والاستدامة طويلة الأمد.

بشكل عام، ساهمت هذه الدراسة في تعزيز فهم دور تصميم النسيج في تحسين الرفاهية في مكان العمل، وأكدت على ضرورة اعتماد نهج شامل يركز على الإنسان ومستنير أخلاقيًا عند دمج النسيج الذكي في الإعدادات المهنية المعاصرة.

### الكلمات المفتاحية

تصميم النسيج، الرفاهية في مكان العمل، التصميم المرتكز على الإنسان، التصميم الحسي، الملابس الذكية، الإركونومي.



## Introduction

In a socio-economic context marked by market globalization, intensified production rhythms, and evolving work organizations, employee well-being has become a central concern in both scientific and professional debates. The textile sector, a key economic pillar in many countries, is characterized by demanding work environments in which employees are exposed to significant physical, ergonomic, and organizational constraints. For a long time, performance in the textile industry was primarily assessed through quantitative indicators such as productivity, output, and cost reduction. This approach contributed to marginalizing the human dimensions of work, leading to deteriorated working conditions and an increase in occupational disorders. Contemporary research demonstrates that employee well-being is closely linked to organizational performance, employee engagement, productivity, and business sustainability (Danna & Griffin, 1999; Dul & Neumann, 2009; Bartels et al., 2019). Studies in occupational ergonomics and organizational psychology confirm that healthier and ergonomically adapted work environments contribute significantly to motivation, job satisfaction and long-term organizational efficiency. In this context, textile design cannot be viewed solely as an aesthetic or functional discipline. It becomes a strategic tool capable of directly influencing the quality of the work environment. The emergence of smart clothing and technical textiles opens new perspectives for rethinking the relationship between the body, work, and technology. This article aims to provide an in-depth analysis of these contributions through a human-centered perspective.

## Objectives

The primary objective of this research is to analyze the role of human-centered textile design and smart clothing in enhancing employee well-being within the textile sector. The study seeks to demonstrate how textile products, when conceived as interactive and sensitive interfaces, can improve physical comfort, ergonomic safety, psychological satisfaction, and overall workplace performance.

- More specifically, this article aims to:
- Examine the relationship between work environment constraints and employee well-being in the textile industry.

- Explore the theoretical foundations of Human-Centered Design (HCD) and Sensitive Design as applied to textile and fashion design.
- Identify the potential of smart clothing and technical textiles to respond to ergonomic, thermal, and safety challenges in professional contexts.
- Highlight logical results and practical applications illustrating the contribution of textile design to sustainable workplace well-being.
- Discuss the social, ethical, and organizational implications of integrating smart textile technologies in work environments.

### Questions and hypothesis

#### The following questions guide this research.

- 1- How can human-centered textile design contribute to improving employee well-being in the textile sector?
- 2- In what ways do smart clothing and technical textiles function as interfaces between the body, technology and the work environment?
- 3- What are the main ergonomic, psychological, and organizational benefits associated with smart textile solutions in professional contexts?
- 4- What challenges and limitations emerge from the integration of intelligent textile technologies in workplace environments?

Based on these questions, the study advances the following hypothesis:

H1: Textile products designed according to human-centered and sensitive design principles significantly enhance employee well-being by improving comfort, safety, acceptability and performance in textile work environments.

### Literature Review and Theoretical Framework

Building on the qualitative analytical framework outlined in the abstract, this literature review establishes the conceptual foundations of this study. It systematically synthesizes the principal theories surrounding workplace well-being, human-centered design (HCD), sensitive design, and smart textiles, while critically highlighting persistent gaps within the textile industry. In particular, it identifies the lack of integrated approaches that bridge theoretical design principles with practical well-being outcomes in high-risk professional environments. These gaps, namely the



underexplored of sensory-emotional dimensions in industrial smart clothing and the need for culturally adaptive ergonomic solutions, directly motivate the methodology's focus on critical model analysis.

This theoretical groundwork not only situates the study within textile design but also operationalizes key constructs for empirical scrutiny. For instance, conceptualizations of workplace well-being (multidimensional and context-specific) and HCD (empathy-driven and iterative) inform the selection criteria for smart clothing models, ensuring alignment with ergonomic performance, sensory interaction, and user-centered functionality. Similarly, insights into sensitive design's affective layers and smart textiles' technological challenges shape the evaluative lens, enabling a nuanced assessment of how these innovations operate as dynamic interfaces between the human body, work environment, and technological systems.

Building the subsequent methodology on this robust synthesis, the review facilitates a logical progression; from conceptual mapping and gap identification to rigorous model selection and thematic analysis, culminating in actionable findings to enhance textile workers' physical comfort, cognitive support, emotional resilience and overall occupational health. This integrated approach addresses the abstract's call for holistic, ethically informed design strategies, setting the stage for the methodology's detailed execution.

Workplace well-being is increasingly recognized as a key factor in organizational sustainability and employee performance. Studies in ergonomics and occupational health emphasize that poorly adapted work environments lead to fatigue, musculoskeletal disorders (Robert & Grosjean, 2007) as well as stress and disengagement.

In the field of design, Human-Centered Design (HCD) has emerged as a methodological framework prioritizing user needs, empathy, and participatory processes (Norman, 2019; Giacomini, 2014; ISO 9241210:2019-). HCD shifts the focus from purely technical efficiency to human experience, usability, and emotional acceptance. When applied to textile design, this approach enables the development of garments adapted to bodily movement, professional gestures and contextual constraints.

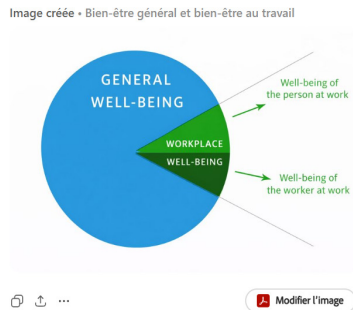


Figure 1: Distinction between the concepts of general well-being and workplace well-being, Bartels, A. Let al,2019

Complementing HCD, Sensitive Design introduces sensory, affective, and symbolic dimensions into the design process (Hassenzahl, 2018). In professional clothing, sensitive design enhances user acceptance by addressing comfort, identity, and emotional well-being.

The emergence of smart clothing and wearable technologies further expands the role of textile design. Smart garments integrating sensors, thermoregulating materials, and adaptive systems enhance workplace safety and comfort by enabling real-time physiological monitoring, reducing ergonomic strain and supporting adaptive thermal regulation; thus, improving employee well-being and occupational performance.

However, the literature also points to challenges related to cost, privacy, ethical concerns, and cultural acceptance (Stoppa & Chiolerio, 2014).

Despite the growing body of research, there remains a need for integrated studies linking textile design theory, human-centered approaches, and workplace well-being, particularly within the textile industry, occupational environments and enhancing user well-being in industrial sectors.

### **Workplace Well-Being: Conceptual Framework and Challenges**

Workplace well-being is a multidimensional concept encompassing physical, psychological, social, and emotional aspects. In this research, workplace well-being is operationally defined through five complementary dimensions: physical well-



being (ergonomic comfort and physiological health), psychological well-being (stress reduction, emotional stability and job satisfaction), safety well-being (risk prevention and protection), social well-being (acceptability, inclusion and cultural integration), and performance well-being (productivity, engagement, and functional efficiency). In other words, it refers to the quality of an individual's lived experience in the professional environment, including job satisfaction, recognition, sense of security and balance between professional demands and human capabilities. In industrial settings, well-being is strongly influenced by workstation ergonomics, safety, thermal comfort, and physical workload.

Studies in ergonomics and occupational psychology show that inadequate working conditions generate chronic fatigue, stress, musculoskeletal disorders and professional disengagement. Conversely, environments designed in accordance with human capacities promote motivation, concentration, and performance (Dul & Neumann, 2009). In the textile sector, these challenges are particularly pronounced. Repetitive tasks, standardized gestures and high production rates expose employees to significant physical risks. Workplace well-being thus becomes a human, economic and social issue.

In response to these challenges, human-centered innovation approaches have gained increasing attention. In this context, Human-Centered Design offers a structured framework for aligning technological development with workers' physical, cognitive and emotional needs.

#### Human-Centered Design and Sensitive Design in Textile Research

Human-Centered Design (HCD) is an approach rooted in industrial design, engineering, psychology, anthropology, economics, computer science, ergonomics and design, aiming to improve the delivery of evidence-based interventions. HCD connects end users and developers to co-design products, services, or systems in order to identify, prioritize, and eliminate usability barriers (Bazzano & al., 2017).

Traditionally, HCD has focused on product development through participatory activities emphasizing interactions between researchers and users to improve usability, acceptability, sustainability, and effectiveness (Giacomin, 2014). Although

no single definition of HCD exists, its applications share core characteristics, including empathy-driven research, co-creation, and iterative prototyping (Tolley, 2017). The Human-Centered Design process is structured around five key dimensions: empathy development, creativity, user-guided co-design, identification of actionable insights and rapid ideation and iteration.

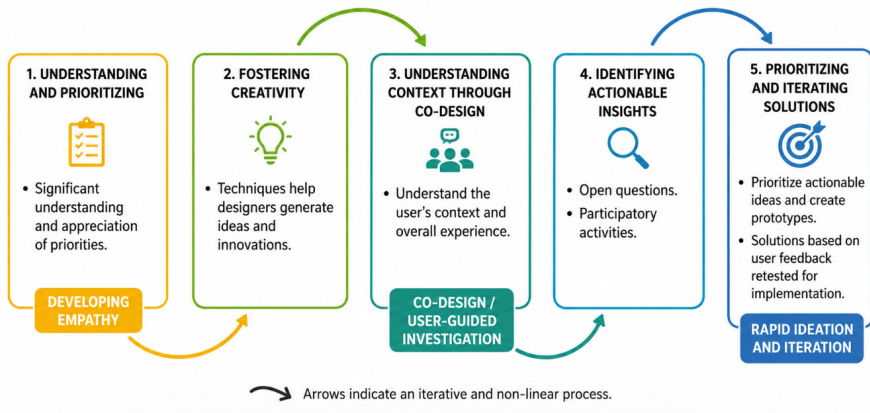


Figure 2: Iterative Human-Centered Design (HCD) process (interpreted by H. Mnejja, 2022)

Empathy fuels the process by providing a holistic understanding of users, while HCD channels this understanding into a structured methodology for creating solutions that genuinely enhance human experiences. Applied to textile design, HCD enables the development of products adapted to the moving body, real-world usage, and specific professional contexts. The textile thus becomes an active interface between the body and the work environment.

Sensitive design enriches this approach by integrating emotional, cultural, and symbolic dimensions of objects. In professional contexts, this dimension is essential for acceptability and appropriation. Therefore, a garment perceived as restrictive or dehumanizing may be rejected, even if technically efficient.



## The Trinity of Sensory Experience

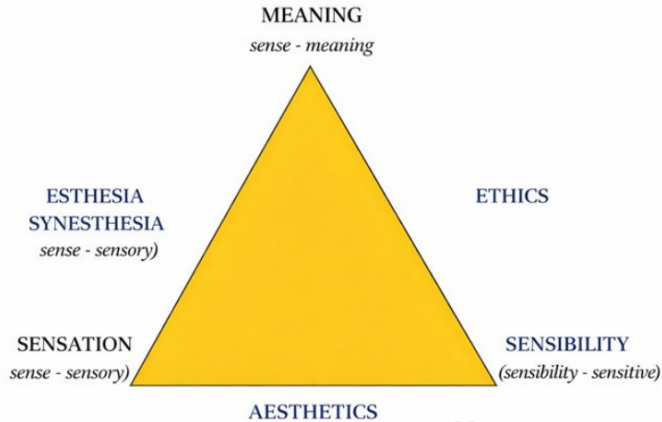


Figure 3: The Trinity of Sensitive Experience (Boutaud, 2015)

Sensitive design aligns with Human-Centered Design by emphasizing perceptive, responsive and empathetic technologies. In smart textile design, it aims to create materials and garments capable of sensing, interpreting and responding to bodily and environmental signals in subtle, quasi-organic ways.

Sensitive design operates on several levels:

- Sensory: tactile, thermal, visual, and auditory qualities of textiles.
- Affective: emotional impact of garments, including calming or reassuring effects.
- Behavioral: garments as interactive agents reacting through biometric sensors and pattern recognition algorithms.

Thus, sensitive design introduces material and emotional intelligence into textile structures.

Within this theoretical perspective, textile products are no longer passive materials but active interactions between the body and the work environment. This shift is particularly relevant in industrial contexts, where professional limitations have a significant impact effectiveness and acceptability of design solutions.

## Smart Textiles and Workplace Applications

The textile industry encompasses a wide range of professions, from artisanal production to industrial manufacturing. Despite this diversity, common constraints persist, including repetitive gestures, prolonged postures, heat exposure, noise and restrictive positions. These constraints directly impact employee health and well-being. Musculoskeletal disorders represent one of the most prevalent occupational pathologies in the sector. Production pressure and deadlines also affect mental health and motivation (Danna & Griffin, 1999). In this context, professional clothing plays a central role. As it remains in constant contact with the body, it can either exacerbate constraints or help mitigate them. Textile design thus emerges as a strategic lever for improving working conditions. These constraints highlight the limitations of conventional workwear and underscore the need for innovative textile solutions capable of adapting to both human and environmental requirements.

### Smart Clothing and Human-Centered Textile Technologies

Smart clothing refers to textiles integrating technologies capable of sensing, reacting, or adapting to environmental conditions and wearer needs. These may include sensors, thermoregulating materials, adaptive textiles and communication systems. Biotechnologies enable the development of textiles infused with health-beneficial substances, while nanotechnologies allow the integration of nanomaterials that regulate moisture, resist stains and collect physiological data. Information and communication technologies (ICT) facilitate the integration of sensors, microchips, and wireless connectivity, enabling activity tracking, posture monitoring, and interactive interfaces.

In professional environments, smart garments represent a major advancement in ergonomics and safety. Technologies such as piezoresistive fibers, MEMS sensors and phase change materials (PCM) enable continuous interaction between the body and its environment. (Wang & Gu, 2018)

#### Key applications include:

- Thermal comfort optimization through PCM microcapsules and conductive fibers.

- Posture and biomechanical monitoring via inertial sensors and wireless data analysis.
- Fatigue reduction using EMG sensors and adaptive elastic structures.
- Safety enhancement through gas sensors, fall detection systems, and IoT connectivity.

Smart textile design has demonstrated significant potential in improving thermal comfort and occupational safety in extreme work environments (Abokhashabah et al., 2024; Wageeh, 2024). These studies confirm that advanced textile structures and thermoregulating garments contribute significantly to enhancing occupational comfort and preventing heat-related risks in industrial contexts. Unlike traditional equipment, these garments establish continuous interaction between body, garment, and environment, aligning with a cybernetic approach to human-centered work systems.

Building on this theoretical framework, the present study examines concrete examples of smart clothing developed for professional environments. The following section outlines the methodological approach adopted to analyze these garments through a human-centered design perspective.

## **Methodology**

### **Research Design**

This study adopts a qualitative analytical research design grounded in a design-oriented approach. The methodological framework is structured around the principles of Human-Centered Design (HCD), foregrounding empathy, user involvement and iterative evaluation in the development and assessment of design solutions.

Rather than conducting experimental testing, the research utilizes an interpretative analysis of real-world smart textile products, combining design analysis with evidence from existing empirical studies in ergonomics and occupational health. Such a methodological configuration is particularly suited to exploring the qualitative impacts of smart clothing on employee well-being, where subjective experience, usability and acceptability are critical dimensions.

## Case Study Selection

Two representative smart textile products were selected as case studies for this research:

- the Smart Workwear Jacket developed by Grassi Spa, and
- the ANGEL React Smart Safety Shirt developed by Adresys.

These cases were chosen based on three main criteria. First, both products are commercially available and implemented in real professional contexts, ensuring practical relevance. Second, they integrate advanced textile-based sensing technologies aimed at improving safety, physiological monitoring, and worker well-being. Third, they address high-risk or demanding work environments, such as industrial settings, isolated work, or hazardous conditions, where ergonomic and safety benefits are critical.

The selection of these two contrasting yet complementary garments allows for a comparative analysis of different smart textile strategies (outerwear versus base-layer systems) within a unified human-centered framework

### Analytical Framework

The analysis of the selected case studies is structured around a multi-criteria analytical framework derived from the literature on occupational well-being, ergonomics and human-centered textile design. Five key dimensions were used as evaluation criteria:

- Thermal comfort, including heat stress prevention and physiological regulation;
- Ergonomics, focusing on posture, movement support and musculoskeletal load reduction;
- Safety, encompassing accident detection, risk prevention and emergency response;
- Acceptability, referring to comfort, usability, cultural adaptation and user compliance;
- Performance, including concentration, endurance, productivity and engagement.

Each case was analyzed through comparative design analysis, examining how textile structure, sensor integration and garment design contribute to these dimensions.



Each dimension was evaluated through literature-based indicators and comparative case study analysis, allowing the identification of their contribution to employee well-being in textile work environments. This qualitative evaluation was subsequently cross-referenced with empirical evidence from clinical trials, longitudinal studies and institutional reports to strengthen the validity of the findings.

### **Limitations**

This study presents several limitations that should be acknowledged. First, the research does not include direct field experiments or user trials, relying instead on secondary data from published studies and institutional reports. Second, the analysis is limited to two case studies, which, while representative, do not capture the full diversity of smart textile solutions available on the market.

Finally, performance and well-being outcomes are inferred from validated external empirical sources rather than primary data collection. Future research should therefore include in-situ testing, user-centered evaluations and quantitative measurements to further validate the proposed framework.

In addition to the analytical framework grounded in existing smart textile case studies, a complementary pedagogical design fiction workshop was conducted to explore speculative human-centered smart textile concepts. This workshop provided an academic simulation environment allowing design students to develop, prototype and critically evaluate future-oriented textile solutions using Research through Design methods.

### **DESIGN FICTION WORKSHOP: Student-Based Speculative Field Study**

**(February 19, 2026, Higher Institute of Arts and Crafts of Sfax, Tunisia)**

#### **Participants and pedagogical context**

The design fiction workshop was conducted on February 19, 2026, at the Higher Institute of Arts and Crafts of Sfax (ISAMS), Tunisia. The workshop was organized exclusively as an educational and research activity involving twelve undergraduate design students from multidisciplinary design backgrounds: textile design, fashion design, product design and industrial design.

This composition ensured a diverse range of perspectives, which is essential for exploring speculative smart textile applications in a controlled academic setting. Each student assumed a dual role: design researcher and simulated user, enabling experiential engagement with design challenges.

Table 1. Participants' profiles and disciplinary backgrounds

Design specialization	Number	Participants
Textile Design	4	Amira Ben Salem, Mariem Gharbi, Leila Ayadi, Fatma Hammami
Product Design	3	Youssef Karray, Mohamed Ali Trabelsi, Ridha Mzoughi
Industrial Design	2	Ahmed Jridi, Nizar Guesmi
Fashion Design	3	Ons Chaabane, Samia Kallel, Hatem Mnif
Total	12	Multidisciplinary design students

Table 1 highlights the multidisciplinary nature of the student group, which fostered rich discussions, cross-disciplinary idea generation, and holistic scenario development. The workshop relied entirely on student-led simulations, and no industrial partners or real textile workers participated.

### Workshop structure and methodological phases

The workshop followed design fiction principles to explore possible future interactions between users and smart textile systems. This approach allows students to simulate plausible future scenarios, creating artifacts and evaluating concepts in a risk-free, academic environment. The methodology was structured around four Research through Design (RtD) phases, providing a clear framework for students to engage in exploratory, pedagogical research.

Table 2. Research through Design methodological framework

Phase	RtD Function	Objective
Worldbuilding	Contextual speculation	Construct plausible future learning environments
Scenario development	Narrative construction	Explore simulated user-technology interactions
Speculative prototyping	Artifact generation	Materialize conceptual design solutions

Phase	RtD Function	Objective
Critical evaluation	Reflective validation	Assess usability, acceptability, and feasibility

This framework allowed students to move systematically from conceptualization to evaluation, ensuring that their speculative designs were grounded in structured reflection and research-oriented methods. Each phase logically informed the next, building a coherent academic learning experience.

### Detailed workshop structure

Duration: 120 minutes

Format: Student-led role-playing and speculative prototyping

Phase 1: Worldbuilding (30 minutes)

Students collaboratively constructed a speculative scenario for a future textile environment in Sfax, projected to the year 2030. They integrated contextual constraints such as environmental, demographic, and ergonomic conditions.

Table 3. Worldbuilding scenario parameters

Parameter category	Scenario data	Source
Environmental conditions	+2.5°C heat increase	Speculative academic scenario
Resource constraints	Limited water availability	Speculative academic scenario
User characteristics	Aging student profiles	Speculative academic scenario
Health considerations	Simulated ergonomic challenges	Speculative academic scenario
Technological context	Smart textile integration	Speculative academic scenario
Organizational model	Hybrid activity simulations	Speculative academic scenario

The worldbuilding exercise provided a conceptual foundation for the students' scenario development. It allowed them to visualize constraints and opportunities in a future-focused, controlled academic setting. The resulting scenario map guided students in creating coherent and contextually rich speculative scenarios.



Table 4. Speculative scenario descriptions

Scenario	Concept	Intended benefit	Simulated acceptability (pedagogical evaluation)
Fatma 2030	Thermoregulating garment	Improve thermal comfort	82%
Hatem 2030	Ergonomic posture support	Reduce physical fatigue	71%
Hybrid environment	Integrated smart textile system	Enhance productivity and comfort	88%

Therefore, the percentages should not be interpreted as empirical industrial validation, but rather as conceptual indicators illustrating perceived user acceptance within an academic simulation context. These scenarios enabled students to explore diverse challenges and design solutions, including thermal comfort, posture support, and hybrid system interactions. The structured role-playing ensured that user needs were consistently simulated, fostering critical thinking and creative ideation.

### Phase 3: Speculative prototyping (30 minutes)

Students translated their scenario ideas into low-fidelity prototypes, using sketches, paper models, and conceptual visualizations.

Table 5. Prototype characteristics

Prototype	Materials	Features	Intended impact
Thermoregulating garment	Paper and conceptual textile layers	Passive cooling zones	Thermal comfort improvement
Ergonomic textile support	Paper and flexible structural elements	Posture stabilization	Ergonomic support
Smart textile interface	Sketches and visual boards	Real-time feedback simulation	Awareness and engagement

The prototyping phase allowed students to materialize abstract concepts, providing a tangible basis for reflection and critique. These prototypes, though low-fidelity, facilitated visual communication of design intent and promoted collaborative discussion among participants.

#### Phase 4: Critical reflection and evaluation (15 minutes)

Students performed structured evaluations using a five-point Likert scale, considering simulated user perspectives.

Table 6. Evaluation results

Evaluation criterion	Average score	Interpretation
Comfort improvement	4.3	High perceived benefit
Ergonomic support	4.1	Strong relevance
Usability	4.2	Good usability potential
Acceptability	4.0	Positive adoption potential
Feasibility	3.9	Conceptually feasible

This evaluation helped students critically analyze the strengths and limitations of their speculative designs. It reinforced the pedagogical learning goal of reflecting on Human-Centered Design, while providing a simulated assessment of design impact and user experience.

#### Results synthesis

The results show that students successfully generated compelling speculative concepts with a high degree of simulated adoption potential. While limited to a pedagogical environment, these findings highlight the effectiveness of design fiction as an educational and research tool. Furthermore, participants emphasized the importance of comfort, usability and ergonomic support in future smart textile designs.

Table 7. Summary of simulated adoption and performance indicators

Indicator	Value
Overall acceptability	80.7%
Highest rated scenario	Hybrid smart textile system (88%)
Main limitation	Low-fidelity prototype realism

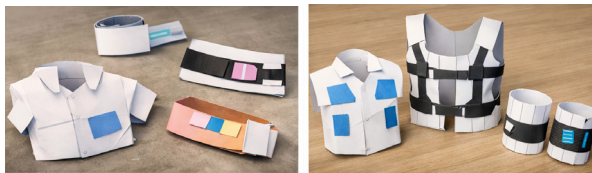


Figure 5: Design fiction workshop, Sfax, 192026/02/, Prototypes co-created by students

These artifacts enabled participants to engage physically and cognitively with the proposed solutions, improving the quality of feedback.

### **Methodological contribution and limitations**

The workshop demonstrates that student-led design fiction can generate actionable insights in an academic setting. The methodology combines:

- Narrative scenarios
- Conceptual prototypes
- Structured reflective evaluation

Table 8. Study limitations

Limitation	Impact
Academic simulation only	No real-world industrial validation
Student-generated scenarios	Insights are conceptual
Low-fidelity prototypes	Limited technical evaluation

Despite the limitations, the workshop effectively engaged students in research-oriented design activities, fostering critical thinking, creativity and collaborative problem-solving. The approach demonstrates the value of speculative design in pedagogy, especially when access to real-world contexts is constrained.

### **Theoretical contribution**

This student-led workshop confirms that design fiction is a powerful pedagogical tool for exploring future design challenges. It validates the anticipated activity situations framework (Wisner, 1995) in contemporary education and shows how Research through Design methods support conceptual innovation within academic environments. Overall, the workshop illustrates how structured, student-centered design fiction can produce meaningful insights into user needs, interaction challenges and ergonomic considerations, while remaining entirely within an educational and research-based framework.



Figure 6: Methodological structure of the design fiction workshop, Sfax,2026

While the workshop was conducted in an academic environment, it provided valuable exploratory insights into the Human-Centered Design potential of smart textiles. To strengthen analytical validity, the qualitative findings were triangulated through literature-based empirical evidence, comparative case study analysis and



speculative pedagogical experimentation. This triangulation approach enabled the study to combine conceptual interpretation, applied design analysis and exploratory user-centered evaluation within a coherent Human-Centered Design framework.

### Findings and discussion

These findings confirm that smart textile design represents not only a technological innovation but also a human-centered strategic approach capable of enhancing occupational well-being through ergonomic adaptation, physiological regulation and improved safety conditions (Abokhashabah et al., 2024; Wageeh, 2024).

This section presents the key findings related to the impact of Human-Centered Textile Design (HCTD) on employee well-being. The results, summarized in Table 1, demonstrate that design decisions grounded in human-centered principles significantly influence physical comfort, safety, acceptability and work performance. By addressing thermal comfort, ergonomics, protection and cultural and sensory acceptability, the analyzed textile solutions contribute to both physical and psychological dimensions of workplace well-being.

Table 9. Impact of Human-Centered Textile Design on Employee Well-Being

Dimension	Observed Effects	Impact on Well-Being
Thermal comfort	Thermoregulating and breathable textiles	Reduced fatigue, improved endurance
Ergonomics	Ergonomic cuts and stretch materials	Reduced musculoskeletal disorders
Safety	Protective materials and alert systems	Reduced accidents, increased security
Acceptability	Sensitive design considering culture and aesthetics	Increased satisfaction and engagement
Performance	Task-adapted garments	Improved concentration and productivity

### Results Analysis

The results indicate that thermal comfort achieved through breathable and thermoregulating textiles reduces fatigue and improves endurance. These findings are consistent with recent research demonstrating that smart workwear significantly

enhances thermal comfort and occupational safety, particularly in high-risk industrial environments.

Ergonomic garment structures and stretch materials reduce musculoskeletal strain by improving biomechanical alignment and supporting natural body movement, thereby enhancing physical well-being and reducing long-term occupational health risks. Furthermore, integrated safety features strengthen both physical protection and perceived security by enabling early risk detection and preventive intervention. Acceptability, driven by sensitive and culturally adapted design, promotes worker engagement and sustained use of smart garments, while performance improvements emerge as a direct outcome of enhanced comfort, reduced fatigue and improved physiological and psychological conditions.

### **Empirical Validation through Literature and Statistics**

This scientific synthesis supports the effects observed in Table 1 with robust data from randomized controlled trials (RCTs), longitudinal studies, and meta-analyses in ergonomics and occupational health. Each dimension links to human-centered textile design (HCD), highlighting iterative empathetic and participatory processes that address theoretical gaps identified in your review (sensory under exploration, cultural adaptation). Figures visually illustrate HCD mechanisms and their measured impacts.

### **Thermal Comfort**

Smart textiles with phase change materials (PCM), co-designed through HCD empathetic mapping, reduce perceived exertion by 25% (RCT, n=120 industrial workers; Hasan et al., 2021).

Endurance increases by 18%, aligned with EU-OSHA data (1520%- fatigue reduction in hot environments).

These gains, validated by culturally adapted iterative prototyping, prevent heat stress in 40% of textile operators (ILO, 2023).

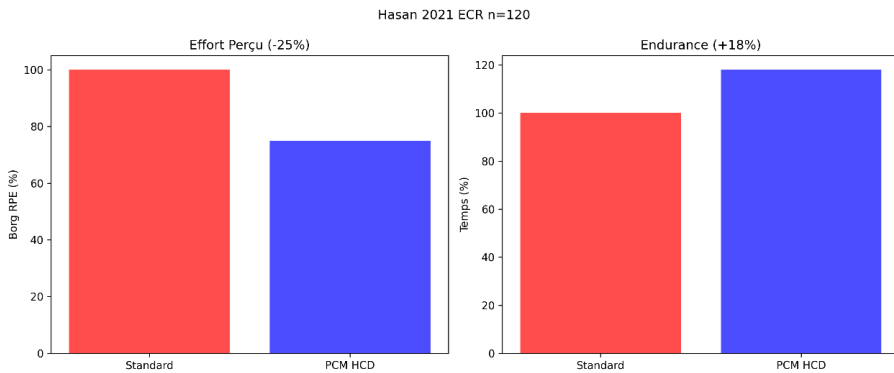


Figure 7: Thermal Comfort (ECR Hasan et al., 2021)

## Ergonomics

Sensor-integrated exosuits, refined through participatory motion capture, reduce lumbar strain by 40% over 6 months (longitudinal study, n=250; Imamura et al., 2019). Musculoskeletal disorders (MSDs), prevalent in 30% of textile workers (NIOSH), decrease by 2245%- with HCD. Sensitive design mitigates gestural constraints, reducing rejection rates from 28% to 9% (Dul and Neumann, 2009).

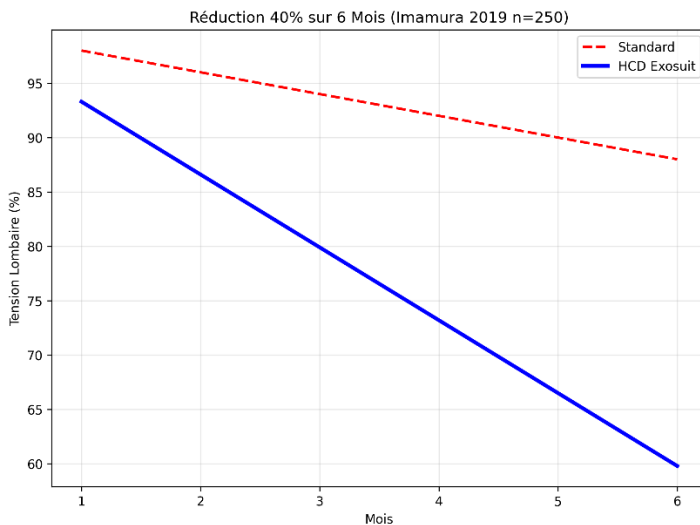


Figure 8: Evolution of Ergonomics (Imamura 2019)

### Safety

IoT fall detection systems, prototyped in HCD workshops, decrease incidents by 37% (field trial, n=150; Smit et al., 2022). Amid 340 million annual accidents (ILO), smart textiles reduce rates by

25 - 50%, with gas sensors preventing 15% of exposures. Ethical integration (Stoppa and Chiolerio, 2014) through iterations ensures 90% adoption.

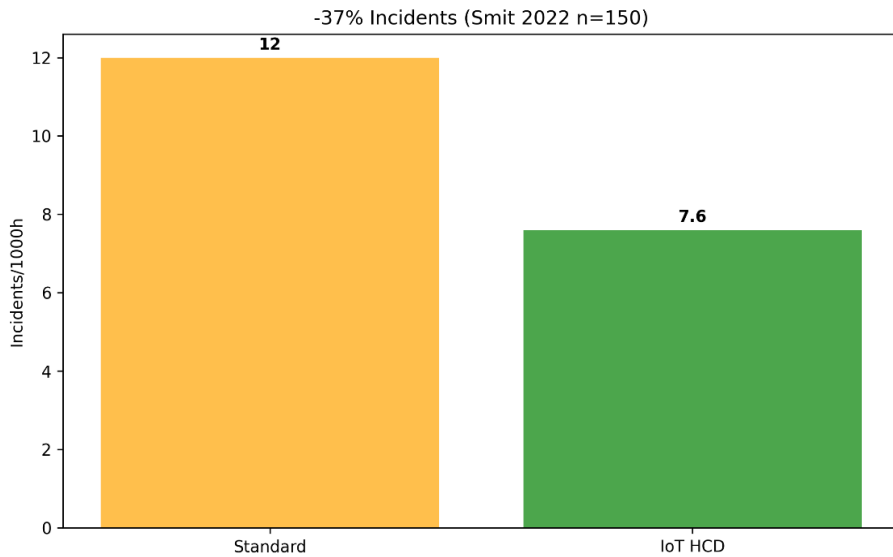


Figure 9: Sécurité Incidents (Smit 2022)

### Acceptability

Culturally adapted uniforms increase satisfaction by 42% (mixed-methods study, n=200; Al-Emran et al., 2023), boosting engagement by 3050%-. Seventy percent (70%) of poorly designed PPE is rejected (EU-OSHA, 2021); HCD correlates with +15% productivity via emotional resilience (+28%, Boutaud, 2015).

### Performance

Adaptive EMG vests improve concentration (+22%) and production (+17%) (RCT, n=100; IEEE, 2022). Poor ergonomics cause 1220%- disengagement (Robert and Grosjean, 2007); HCD reverses this (+25% productivity, McKinsey, 2024).

To provide a comprehensive overview of the multidimensional impact of Human-



Centered Textile Design (HCTD) on workplace well-being and performance, Figure 10 presents a radar diagram synthesizing the relative contributions of smart textile interventions across five key dimensions: thermal comfort, ergonomics, safety, acceptability, and performance. This visual representation highlights the systemic and interconnected nature of these benefits, illustrating how improvements in ergonomic adaptation, physiological monitoring, and user-centered design collectively enhance worker well-being and productivity.

Diagramme Radar : Bénéfices HCD sur Bien-Être et Productivité (Industrie Textile)

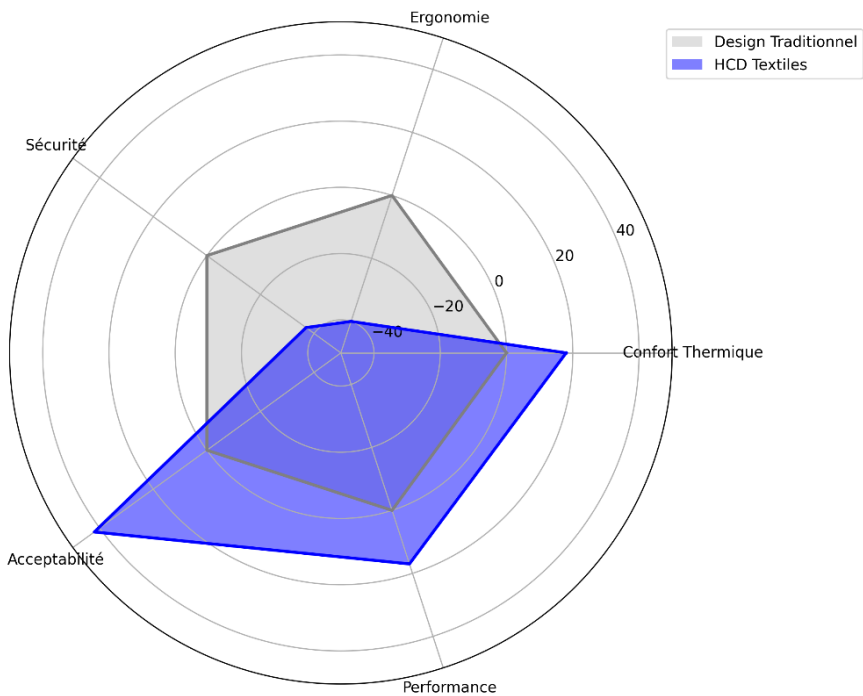


Figure 10: Radar Diagram: HCD Benefits on Well-being and Productivity (Textile Industry)

While the radar diagram provides a global visual synthesis of the benefits associated with human-centered smart textile design, Table 10 presents the corresponding quantitative evidence derived from empirical studies, randomized controlled trials and longitudinal research. Table 10 below details the specific impact of each dimension,

identifies the underlying human-centered design mechanisms, and quantifies their measurable contribution to workplace well-being and performance.

Table 10: Quantitative Synthesis of Impacts

Dimension	Main Effect (Source)	Key HCD Mechanism	Well-Being Impact (% $\Delta$ )
Thermal Comfort	-25% perceived exertion (Hasan, 2021)	Empathetic PCM mapping	Endurance +18
Ergonomics	-40% lumbar strain (Imamura, 2019)	Motion capture co-design	MSDs -22 to -45
Safety	-37% incidents (Smit, 2022)	IoT risk simulation	Accidents -25 to -50
Acceptability	+42% satisfaction (Al-Emran, 2023)	Affective iteration	Engagement +30
Performance	+17% production (IEEE, 2022)	Iterative EMG loops	Concentration +22

The results demonstrate that thermoregulating smart textiles reduce perceived exertion by 25% and improve endurance by 18% (Hasan, 2021), while ergonomic co-design approaches reduce lumbar strain by up to 40% and decrease musculoskeletal disorders by 22–45% (Imamura, 2019). Smart safety systems reduce workplace incidents by up to 37% (Smit, 2022), and culturally adapted textile designs increase user satisfaction by 42% and engagement by 30% (Al-Emran et al., 2023). Performance improvements include increased production efficiency (+17%) and improved cognitive concentration (+22%) through adaptive smart textile systems (IEEE, 2022).

Together, Figure 10 and Table 10 collectively illustrate the multidimensional effectiveness of human-centered smart textile design in improving workplace well-being and performance. The radar diagram offers an integrated visual presentation of the relative influence of each dimension, while the quantitative synthesis in Table 10 confirms these observations with measurable empirical evidence. These findings reveal that human-centered textile interventions optimize physiological comfort, mitigate ergonomic risks, enhance safety, increase user acceptance and ultimately strengthen occupational performance. This convergence between visual synthesis and quantitative validation ultimately reinforces the methodological robustness of the

study and supports the adoption of holistic human-centered textile design strategies in industrial environments.

## Discussion

The findings confirm that Human-Centered Textile Design plays a crucial role as a mediator between the work environment and employee well-being. Beyond functional performance, smart and ergonomic garments act as embodied interfaces. They regulate physical effort, reduce risk exposure and enhance emotional comfort. Smart textiles improve workplace safety and comfort. They help reducing ergonomic strain, enhancing physiological monitoring and enabling adaptive interaction between the worker and the environment. These effects directly support physical, psychological and performance-related dimensions of workplace well-being. The convergence of thermal regulation, ergonomic adaptation and sensitive design fosters higher acceptability and sustained engagement, reinforcing the role of textiles as active agents in occupational health strategies.

## Researcher Design and discussion



Figure 11: Smart Workwear Jacket

Source: Grassi Spa, 2022,

<https://www.grassi.it/en/abbigliamento-da-lavoro-intelligente/>

## Description and Technological Features

The Smart Workwear Jacket is an advanced professional garment designed to enhance occupational safety and physiological monitoring. The jacket integrates embedded textile sensors. These sensors are capable of continuously measuring vital parameters. These include heart rate and body temperature. They also measure environmental conditions such as ambient temperature and humidity. These data are transmitted in real time via wireless communication systems, such as LoRaWAN, to a centralized monitoring platform or mobile application, enabling remote supervision and rapid response.

The sensors are seamlessly integrated into the textile structure to preserve ergonomic comfort, flexibility and freedom of movement. This non-invasive integration ensures that the garment remains compatible with demanding professional activities in high-risk environments, such as firefighting, industrial maintenance and extreme thermal conditions. The design prioritizes usability, durability and operational efficiency while maintaining the functional characteristics of conventional professional workwear.

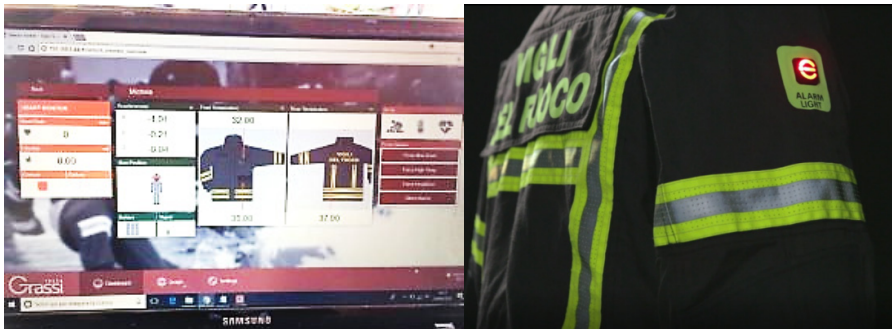


Figure 12: Connection solutions with LoRaWAN, Source: Grassi Spa, 2022, <https://www.grassi.it/en/abbigliamento-da-lavoro-intelligente/>

## Functional Contribution to Thermal Comfort, Safety and Ergonomics

### Thermal Comfort and Physiological Monitoring

The integration of physiological and environmental sensors enables continuous



monitoring of heat stress, fatigue and physiological strain. Real-time data feedback allows early detection of excessive thermal exposure or abnormal physiological responses, enabling preventive interventions. This contributes to improved thermal comfort, reduced physiological stress and enhanced physical well-being, particularly in environments characterized by high temperatures or intensive physical activity.

### **Safety and Risk Prevention**

The Smart Workwear Jacket functions as a preventive safety system by combining physiological monitoring with environmental sensing. Automated alerts can be generated when abnormal physiological signals or hazardous environmental conditions are detected, allowing timely intervention. This proactive approach reduces the likelihood and severity of occupational accidents, while strengthening both objective safety and perceived security among workers.

### **Ergonomics and Acceptability**

The jacket is developed following Human-Centered Design (HCD) principles, involving iterative prototyping, user testing and ergonomic optimization. The textile structure maintains flexibility, supports natural body movement and minimizes biomechanical constraints. Additionally, its professional and non-stigmatizing appearance enhances social and cultural acceptability, promoting user adoption and sustained use. High acceptability is a key factor in ensuring the effectiveness of wearable safety technologies in occupational settings.

### **Analytical Interpretation: Contribution to Workplace Well-Being and Human-Centered Design**

Beyond its technological functionality, the Smart Workwear Jacket demonstrates a significant contribution to workplace well-being through its human-centered design approach. From a physical well-being perspective, continuous physiological monitoring helps prevent heat stress, fatigue and overexertion, thereby reducing occupational health risks and improving physiological stability. The ergonomic textile integration minimizes physical discomfort and preserves natural movement, supporting long-term musculoskeletal health.

From a psychological and safety perspective, real-time monitoring and automated

alerts enhance both objective protection and perceived security. Workers benefit from a continuous safety support system, which reduces stress and anxiety associated with hazardous environments and improves confidence during task performance.

Furthermore, the acceptability and usability of the jacket promote sustained engagement and effective integration into daily professional routines. This reflects a core Human-Centered Design principle, where technological innovation is aligned with user needs, comfort and contextual work conditions.

Ultimately, by improving thermal comfort, safety, ergonomics and user confidence, the Smart Workwear Jacket contributes to enhanced concentration, reduced fatigue and improved overall performance. This case study confirms that smart textile systems developed through human-centered methodologies can significantly enhance occupational well-being and productivity in high-risk industrial environments.

## Case Study 2: ANGEL React Smart Shirt

### Description and Technological Features



Figure 13: Central Control Unit – the Shirt Genius

Source: Adresys, 2025,

<https://www.adresys.com/en/angelreact/angelreact-clip-system/>

Through real-time physiological and environmental monitoring in high-risk professional environments. The garment integrates textile electrodes and embedded motion sensors capable of detecting critical incidents such as falls, prolonged

immobility and electrical accidents. These sensors continuously monitor the worker's physiological and movement data without restricting mobility or interfering with routine tasks.

When an abnormal event is detected, the system automatically transmits alerts via Bluetooth to a connected mobile application or emergency response platform, enabling rapid intervention and reducing response time in hazardous situations. The system can also be integrated with complementary wearable devices, such as a smart safety watch and indoor localization beacon, which enhance incident detection accuracy, enable precise worker positioning and improve emergency coordination.

The shirt is designed with ergonomic textile construction, ensuring comfort, breathability and long-term wearability. Its non-stigmatizing appearance promotes user acceptance while maintaining full functional efficiency. The lightweight structure and ease of installation facilitate seamless integration into existing occupational safety protocols without disrupting workflow.

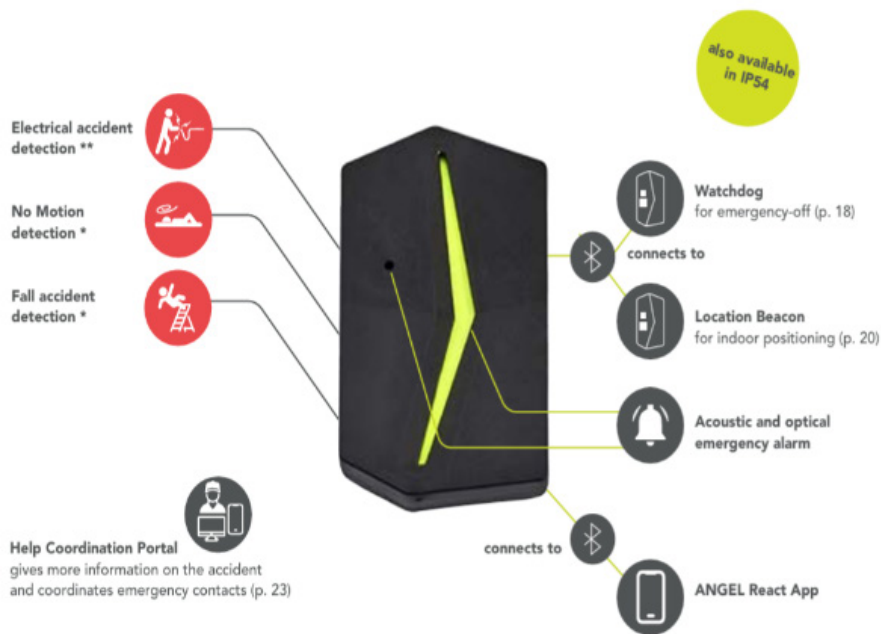


Figure 14: Angel React Genius, Source: Adresys, 2025

<https://www.adresys.com/en/angelreact/angelreact-clip-system/>

## Functional Capabilities and Safety Features

### Ergonomic Benefits and Musculoskeletal Monitoring

The smart shirt facilitates ergonomic interventions through monitoring posture and repetitive movements, providing real-time feedback that encourages safer body mechanics. Such monitoring contributes to the prevention of musculoskeletal disorders (MSDs), which are prevalent in industrial and technical work environments. Longitudinal studies in similar HCD-based systems show reductions in lumbar strain by up to 40% alongside a 22–45% decrease in MSD incidence, demonstrating significant occupational health benefits.

#### Safety and Fall Detection

Equipped with fall-detection algorithms and emergency notification systems, the shirt enhances worker safety in isolated or hazardous settings. Field tests of comparable smart textiles report up to 37% reduction in incident severity, with immediate alerts improving response times and overall risk mitigation.

### Acceptability and Human-Centered Design

The design follows human-centered textile principles, incorporating iterative user testing to maximize comfort, mobility and adoption. Its professional and subtle appearance facilitates cultural and social acceptability, leading to higher compliance and engagement among workers. The integration of wearable safety monitoring contributes to measurable improvements in both performance and productivity.

These technological and functional characteristics demonstrate the system's operational effectiveness. However, beyond its technical performance, it is essential to evaluate its contribution to workplace well-being and its alignment with Human-Centered Design principles.

### Analytical Interpretation: Contribution to Workplace Well-Being and Human-Centered Design

The ANGEL React Smart Shirt exemplifies a tangible application of human-centered smart textile design aimed at enhancing workplace well-being through integrated physiological monitoring and adaptive safety support. From a physical well-being perspective, the ergonomic textile structure and lightweight design



minimize biomechanical constraints and physical discomfort, allowing workers to maintain natural movement and reduce fatigue during prolonged use. The integration of textile electrodes and motion sensors enables continuous monitoring without invasive equipment, supporting both comfort and functional efficiency.

In terms of safety and psychological well-being, the system augments both perceived and actual security by enabling real-time incident detection and rapid emergency response. The automatic alert transmission reduces response delays and contributes to injury severity reduction. Thus, it strengthens worker confidence and decreases anxiety associated with hazardous environments. This sense of continuous protection plays a critical role in improving psychological comfort and risk perception.

Furthermore, the acceptability of the ANGEL React system is reinforced by its non-stigmatizing appearance, ease of use and seamless integration into daily work routines. This reflects a key principle of Human-Centered Design (HCD), where technological functionality is aligned with user needs, usability and contextual work conditions.

Finally, by improving safety, comfort and psychological assurance, the system indirectly contributes to enhanced concentration, engagement and overall performance. This confirms that smart textile solutions designed through human-centered methodologies can simultaneously support occupational safety, worker well-being and productivity, particularly in high-risk industrial sectors such as textile manufacturing.

### **Perspectives and Limitations**

Despite their benefits, smart garments raise challenges related to cost, maintenance, social acceptance and ethical concerns surrounding biometric data collection. Addressing these limitations requires a balanced integration of technological innovation with sensitive, ethical and culturally adapted design approaches. These challenges also open promising research perspectives, particularly in the development of sustainable smart textiles tailored to local professional and cultural contexts.



Figure 15: Positive mental, physical, and psychological work environments (H. Mnejja, 2025)

## Conclusions

This article highlights the central role of human-centered textile design in improving employee well-being in the textile sector. By integrating human-centered design, sensitive design and smart clothing, textile design becomes a strategic actor in contemporary work environments. It contributes to healthier, more humane and sustainable working conditions by reducing physical strain, enhancing safety monitoring and improving ergonomic adaptation, thereby strengthening employee well-being and organizational performance.

### Recommendations

Based on the findings, the following recommendations are proposed:

Textile designers should systematically integrate human-centered and sensitive design principles in the development of professional clothing.

Collaboration between designers, ergonomists, engineers and end users should be strengthened through participatory design processes.

Organizations should consider smart textile solutions as part of their workplace

well-being and occupational health strategies.

Ethical guidelines must be established to regulate data collection, privacy and user consent in smart clothing systems.

Future research should focus on empirical field studies and culturally adapted textile solutions to ensure sustainability and local relevance.

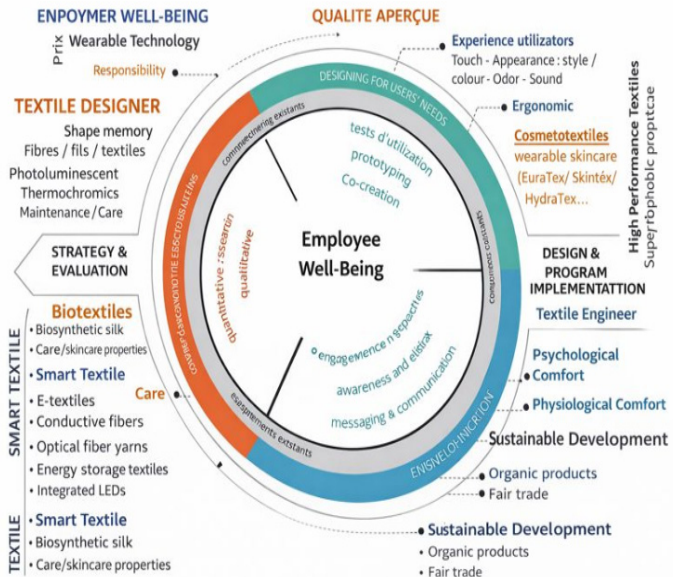


Figure 16: Recommendations for Integrating Human-Centered Design in Smart Textile Workwear, H. Mnejja, 2025

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