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# A Study on the Visual Expression and Graphic Design of Functional Textile Performance Data

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## Article

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## ABSTRACT

*The modern textile industry relies on engineering materials, from natural fibers like cotton and wool to advanced synthetics, to deliver specific functionalities. The performance characteristics of these materials, determined by factors including yarn properties, weaving or knitting structures, and finishing chemical operations, are critical to their value. However, the complex physicochemical data from laboratory tests is often poorly communicated, creating a barrier to transparency for consumers and designers. This communication gap is also prevalent for high-performance materials such as technical leather, where performance metrics are key. This research addresses this challenge by studying the visual expression and graphic design of performance data for textiles. It establishes a design methodology rooted in materials science principles and textile technology standards (ISO, AATCC), analyzing how data from textile testing machinery can be transformed into intuitive graphics. Through case studies on visualizing properties relevant to both synthetic and natural fibers, the paper develops and evaluates visual systems, including a novel “functional textile performance quad” (FTPQ) framework. The study argues that adopting a standardized, clear visual language would be a crucial step towards sustainable development in the textile industry. It enhances transparency, empowers informed product selection, and allows for the effective validation of high-performance, durable fiber products, providing actionable guidelines for the textile products and processing sector.*

## KEYWORDS

*functional textiles, data visualization, textile industry, sustainable development, natural fibers*

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## INTRODUCTION

The textile industry has undergone a significant transformation, evolving from a focus on aesthetics and basic durability to the engineering of high-performance materials known as functional textiles [1]. These textiles

are designed with specific functionalities to enhance the user's comfort, safety, and health [2]. Key categories include thermal regulating fabrics that manage body heat, moisture-wicking textiles that transport sweat away from the skin, ultraviolet (UV) protective clothing, and antibacterial fabrics [3]. The global market for functional textiles has seen consistent growth, driven by consumer demand in sportswear, protective workwear, medical textiles, and athleisure markets [4].

The value of a functional textile is intrinsically linked to its performance, which is measured and validated through a battery of standardized tests developed by organizations like the International Organization for Standardization (ISO) and the American Association of Textile Chemists and Colorists (AATCC) [5]. These tests yield quantitative data for metrics such as thermal resistance ( $R_{ct}$ ), water vapor resistance ( $R_{et}$ ), overall moisture management capacity (OMMC), and ultraviolet protection factor (UPF) [6]. While this data is fundamental to the material's integrity and marketing claims, its communication to the end-user and other stakeholders remains a significant challenge. Currently, performance data is often presented in dense technical specification sheets, lengthy paragraphs of text on product tags, or as abstract scores without context [7]. This lack of a clear, standardized, and intuitive communication method creates an "information-action gap," where stakeholders possess technical data but lack the interpretive clarity needed to act on it confidently [8]. For consumers, it makes comparing products difficult and fosters skepticism towards marketing claims [9]. For apparel designers, it complicates the material selection process [10]. For B2B transactions, it can obscure the true value proposition of an advanced material [11].

This paper argues that the principles of data visualization and graphic design offer a powerful solution to this problem. By translating complex numerical data into well-designed visual representations, the performance of functional textiles can be communicated with far greater clarity, efficiency, and impact. Effective information design can bridge the gap between technical lab results and user comprehension, much as nutritional labels have done for food products. To achieve this, the research explores and develops a systematic approach to the visual expression of functional textile performance data. This study begins by reviewing the theoretical foundations of data visualization and identifying key performance metrics for major functional textile categories. It then proposes a design methodology for creating visual systems that are accurate, clear, and comparable. The core of the work involves developing and analyzing a series of visual design case studies for thermal, moisture, and multi-functional textiles. Ultimately, the paper concludes by

synthesizing these findings into a set of guiding principles for the industry to adopt a more effective visual communication strategy, aiming to enhance transparency, empower consumer choice, and better communicate the value of textile innovation.

## **THEORETICAL FRAMEWORK**

To build a robust system for visualizing textile data, it is essential to integrate principles from two distinct but related fields: the science of data visualization and the technical standards of textile testing.

### **Principles of Effective Data Visualization**

The goal of data visualization is to provide clear, accurate, and efficient communication of information. Seminal works in this field have laid down fundamental principles. Edward Tufte advocates for “graphical excellence,” which involves communicating the greatest number of ideas in the shortest time with the least ink, and in the smallest space. He introduces the concept of the “data-ink ratio,” urging designers to remove any visual element that does not represent data, a concept he terms “chartjunk.”

Building on this, other researchers in information design and cognitive science have established further guidelines:

- **Accuracy and integrity:** The visual representation must not distort the underlying data. The scale, proportions, and labeling must be truthful. Using a non-zero baseline on a bar chart, for example, can be highly misleading.
- **Clarity and simplicity:** The design should be easy to understand. It should minimize cognitive load by avoiding unnecessary complexity, 3D effects, and excessive colors or fonts (“visual noise”). The message should be immediately apparent.
- **Comparability:** An effective design should make it easy for the viewer to compare different data points or different products. This is critical in a consumer context where choice is paramount. Consistency in visual language and structure across a product line or an entire industry is key.
- **Purposeful use of visual encodings:** Data is encoded into visual properties like length (bar charts), position (scatter plots), angle (pie charts), or color (heatmaps). The choice of encoding must be appropriate for the type of data (categorical, ordinal, quantitative) and the message being conveyed. For

example, length and position are perceived more accurately by the human eye than area or angle, making bar charts generally superior to pie charts for comparison.

- Context and annotation: Data rarely speaks for itself. It needs context. Labels, titles, units of measurement, and brief explanations are crucial. Good design integrates this text seamlessly without cluttering the visual.

### **Key Performance Metrics in Functional Textiles**

A visualization system must be built upon the specific data it intends to represent. For functional textiles, this means understanding the outputs of standardized tests.

#### *Thermal Comfort Properties*

Thermal comfort relates to the ability of a fabric to manage heat and moisture to keep the body in a stable state. The primary standard is ISO 11092, which uses a “sweating guarded hotplate” to mimic human skin. It yields two key metrics:

Thermal resistance ( $R_{ct}$ ): This measures the fabric’s ability to block heat transfer (insulation). It is measured in square meters Kelvin per watt ( $m^2K/W$ ). A higher  $R_{ct}$  value means better insulation, suitable for cold weather garments. This is sometimes converted into the “clo” unit, where 1 Clo = 0.155  $m^2K/W$ .

Water vapor resistance ( $R_{et}$ ): This measures the fabric’s resistance to allowing water vapor (sweat) to pass through (breathability). It is measured in Pascal square meters per watt ( $Pa \cdot m^2/W$ ). A lower  $R_{et}$  value means better breathability, essential for activewear.

A good visualization must represent these two opposing yet equally important metrics simultaneously.

#### *Moisture Management Properties*

This refers to the ability of a fabric to handle liquid sweat. The AATCC 195 standard uses a moisture management tester (MMT) to quantify this. The MMT provides a rich, multi-dimensional dataset, including:

- Wetting time: How quickly the top and bottom surfaces of the fabric absorb the test solution.
- Absorption rate: The average speed of moisture absorption.
- Spreading speed: How quickly moisture spreads across the top and bottom surfaces.
- One-way transport capability (R): A calculated value indicating how effectively moisture is moved from

the skin-facing side to the outer side. A higher value is better.

- OMMC: A single index combining the above parameters to give a holistic score.

Visualizing this requires a multi-dimensional approach to avoid oversimplifying the fabric's complex behavior.

### *UV Protection Properties*

UV-protective fabrics are tested according to standards like AATCC 183 or AS/NZS 4399:2020. The key metric is the UPF. The UPF rating indicates how much of the sun's UV radiation is blocked by the fabric. For example, a fabric with a UPF of 50 allows only 1/50 (2%) of the UV radiation to penetrate. The ratings are typically categorized for easy consumer understanding:

- Good protection: UPF 15-29
- Very good protection: UPF 30-49
- Excellent protection: UPF 50+

The visualization challenge here is not just displaying the number, but integrating it into a comprehensive system and potentially indicating performance under different conditions (e.g., wet vs. dry), as specified by advanced standards like UV STANDARD 801.

## **METHODOLOGY FOR VISUAL DESIGN**

The methodology adopted in this study is a constructive, design-based approach. It focuses on developing visual prototypes and conducting a heuristic evaluation based on established theoretical principles of information design, rather than collecting empirical data from users at this stage. This expert-based analysis allows for the refinement of designs prior to future empirical validation. The process is as follows:

- Data set formulation: For each case study, realistic yet hypothetical performance datasets for functional textiles are created. These datasets are based on plausible values derived from reviewing existing textile research and commercial product specifications. This ensures the design challenges are representative of real-world scenarios. This approach of using curated, hypothetical data was chosen intentionally to create clear and controlled scenarios that directly test the core design challenges (e.g., visualizing opposing metrics, integrating multi-dimensional data) without the additional confounding variables often present in raw industry datasets. While this methodology allows for a focused evaluation of the

visual design principles themselves, it is a precursor to testing the systems against the complexities of real-world data.

- Establishment of evaluation criteria: Based on the principles discussed in Section 2.1, a framework of evaluation criteria is established to analyze the effectiveness of each visual design. The core criteria are:
  - Informational accuracy: Does the visual truthfully represent the data and units?
  - Interpretive clarity: How quickly and easily can a non-expert user understand the primary benefit of the fabric? Is the good direction clear (e.g., higher is better, lower is better)?
  - Comparability: How effective is the system for comparing two or more products side-by-side?
  - Information density: How much information is conveyed in the available space without becoming cluttered?
  - Aesthetic and commercial viability: Is the design clean, professional, and suitable for application on product hangtags, websites, and technical sheets?
- Visual system design and iteration: For each dataset, several visual communication strategies are designed. This includes traditional charts (bar, line, etc.) and novel graphical systems. The designs are described in detail, focusing on the rationale behind the choice of chart type, color, typography, and iconography. This process is iterative, with initial designs being refined against the evaluation criteria.
- Analysis and synthesis: The designed visuals are then critically analyzed using the evaluation criteria. The strengths and weaknesses of each approach are discussed. This analysis forms the basis for synthesizing a set of best-practice guidelines for the visual communication of textile data. The analysis is structured into case studies, each focusing on a specific functionality to provide clear and actionable insights.

This methodology allows for a focused exploration of the design space, leading to the development of practical and theoretically-grounded solutions for the textile industry.

## RESULTS

This section presents the application of the design methodology to three distinct case studies: a single-function thermal regulating fabric, a single-function moisture-managing fabric, and a multi-functional fabric.

**Case Study 1: Thermal Comfort (Insulation vs. Breathability)**

Dataset:

Fabric A (winter base layer):  $R_{ct} = 0.08 m^2 K/W$  (high insulation);  $R_{et} = 8 Pa \cdot m^2/W$  (good breathability)

Fabric B (summer T-shirt):  $R_{ct} = 0.02 m^2 K/W$  (low insulation);  $R_{et} = 4 Pa \cdot m^2/W$  (excellent breathability)

Design Challenge: To visually represent two metrics where “high is good” for one ( $R_{ct}$ ) and “low is good” for the other ( $R_{et}$ ). This duality is a common source of confusion, as a simple bar chart would require the user to interpret opposite directions as positive attributes.

Design Solution: The Annotated Bidirectional Bar Chart

To solve this, we developed an annotated bidirectional bar chart. This design aligns both metrics on a shared “performance” axis, where moving away from the center always indicates better performance. For insulation ( $R_{ct}$ ), a higher value is better. To ensure visual comparability with the breathability score, the raw  $R_{ct}$  value is normalized to a proportional visual length, so its bar extends to the right. For breathability ( $R_{et}$ ), a lower value is better, so its performance is visualized by converting the value into a “breathability score” (e.g., based on established comfort bands) where higher is better, and the bar also extends to the right. The chart includes clear annotations, units, and qualitative labels (“high insulation,” “excellent breathability”) to aid interpretation. Figure 1 shows this system applied to the two sample fabrics.

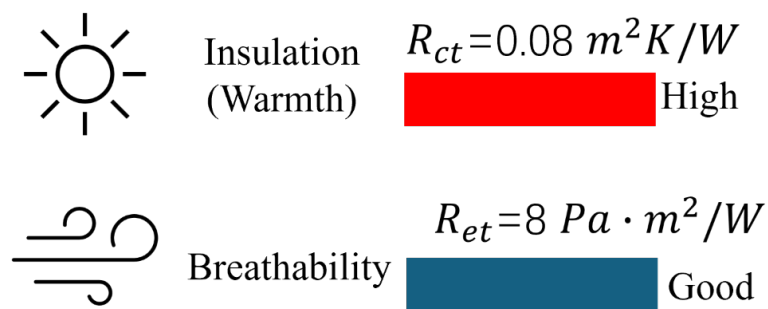


Figure 1. The Annotated Bidirectional Bar Chart for Thermal Comfort. The chart visually compares two fabrics. Fabric A (top, winter base layer) shows strong insulation and good breathability. Fabric B (bottom, summer T-shirt) shows minimal insulation but excellent breathability. For both metrics, a longer bar indicates better performance, making the comparison of their intended uses intuitive



### Case Study 2: Moisture Management

Dataset (based on AATCC 195):

Fabric C (advanced wicking fabric): Wetting time = 1 s; one-way transport (R) = 750%; spreading speed = 4.5 mm/s; OMMC = 0.85

Design challenge: Representing multiple related metrics without overwhelming the user. Plotting these raw data with different dimensions and scales directly on a radar chart would cause visual distortion due to the excessive numerical differences (for example, 750% vs 0.85), making it impossible to compare them clearly. To address this issue, we first normalize the data by converting each raw metric into a unified performance score from 0 to 100. Crucially, the benchmarks for this normalization are not arbitrary. They are derived from the performance rating scales specified in the AATCC 195 standard, combined with a review of published literature to establish values representative of “excellent” or Grade 5 performance in high-tech textiles. For example, the AATCC 195 standard grades wetting time, and a value of  $\leq 1$  second is considered excellent, which we set as our benchmark for a top score. This approach ensures the resulting scores are grounded in established industry criteria. The specific benchmarks and calculated scores are shown in Table 1. The OMMC provides a single score, but this can hide important nuances (e.g., a fabric might spread moisture fast but not move it away from the skin). The radar chart in Figure 2 plots these normalized performance scores, providing a holistic view of the fabric’s capabilities relative to established benchmarks. This approach enables a direct comparison of the performance strengths and weaknesses of the fabric in different dimensions such as “wetting time” and “unidirectional transfer capacity,” avoiding visual misguidance caused by differences in data scales. Thus, it successfully addresses the design challenge of presenting multiple related indicators without confusing the users.

Table 1. Data Normalization

Metric	Original value	Performance Interpretation	Performance Benchmark (Basis for Grade 5 / “Excellent” Score)	Calculation method	Performance score (0–100)
One-way Transport (R)	750%	The higher, the better.	800%	$(750 / 800) * 100$	94

Spreading Speed	4.5 mm/s	The higher, the better.	6 mm/s	$(4.5 / 6) * 100$	75
OMMC	0.85	The higher, the better.	1.0	$(0.85 / 1) * 100$	85
Wetting time	1 s	The lower, the better.	10 s (more than 10 seconds indicates poor performance)	$(1 - 1/10) * 100$	90

Note: Performance benchmarks are established based on the AATCC 195 standard’s grading criteria and a review of high-performance textile literature. Additionally, calculated scores are mathematically clamped between 0 and 100 to prevent negative values or distortion in the radar chart visualization.

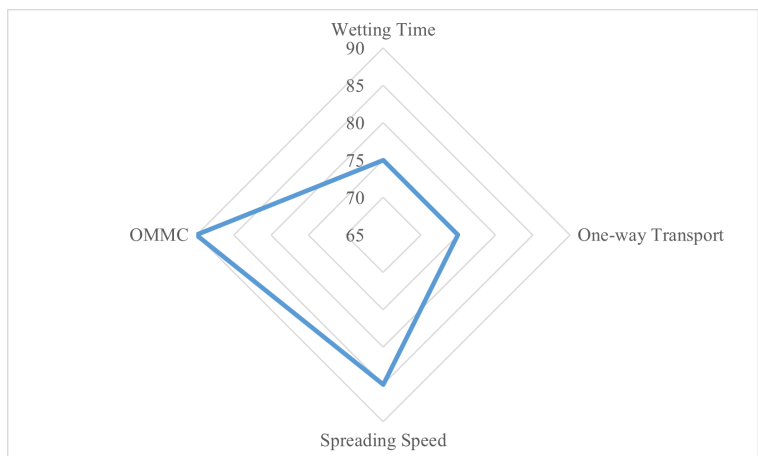


Figure 2. Moisture Management Profile

The normalized radar chart excels in information density, allowing for the simultaneous display of multiple performance aspects. This provides a holistic “performance signature” of a fabric. Its primary strength is in showing the balance of properties; for instance, it can reveal if a fabric is strong in one area but weak in another. However, its interpretive clarity can be lower for novice users compared to a bar chart, and direct comparability of a single metric (e.g., spreading speed) between two different radar charts can be less precise than comparing two bars side-by-side. The normalization process ensures informational accuracy relative to established benchmarks, but it does abstract the raw data.

### Case Study 3: The Multi-functional Fabric

Dataset: To validate the framework with complex, conflicting engineering constraints, we selected a high-performance soft shell fabric designed for alpine climbing. Unlike the previous single-function examples, this material must balance protection with physiology. The empirical data, obtained from accredited laboratory tests, are as follows:

Thermal (ISO 11092):  $R_{ct} = 0.058 m^2 K/W$  and  $R_{et} = 8.5 Pa \cdot m^2/W$ . The  $R_{et}$  value is slightly higher than the base layer in Case Study 1, reflecting the necessary trade-off to achieve wind resistance while maintaining sufficient breathability for high-output activities.

Moisture (AATCC 195): One-way transport (R) = 380%. This indicates effective sweat removal from the inner surface, a critical feature for preventing post-exercise chill in a soft shell.

Protection (AATCC 183): UPF 50+.

Durability (ASTM D4966): Abrasion Resistance > 35,000 cycles.

Design challenge: To create a holistic and scalable system that can represent multiple, unrelated functions without becoming a collection of disparate charts. Furthermore, it must visually reconcile the hidden mechanical properties (like abrasion resistance) with user-centric comfort metrics.

Design Solution: The Functional Textile Performance Quad (FTPQ)

To address this challenge, the FTPQ framework was applied. As shown in Figure 3, this dashboard organizes performance into four distinct quadrants: Thermal, Moisture, Protection, and Durability.

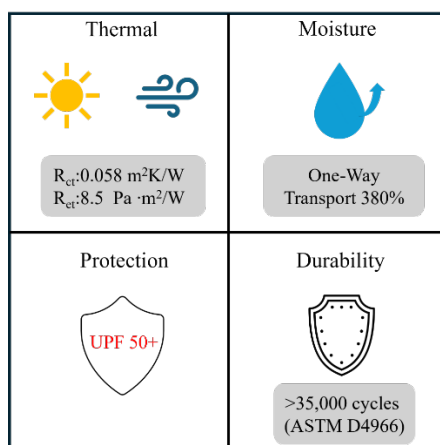


Figure 3. The FTPQ applied to Fabric D. The framework is organized into four distinct functional categories, with the “Durability” quadrant showing the fabric’s high abrasion resistance, a key mechanical property

Crucially, the design integrates quantitative engineering data directly into the visual structure to bridge the information gap:

Thermal quadrant: Displays the precise  $R_{ct}$  and  $R_{et}$  values, allowing technical users to assess the specific warmth-to-breathability ratio.

Moisture quadrant: Instead of a generic water icon, the one-way transport rate (380%) is prominently displayed, validating the fabric's dry-touch capability.

Durability quadrant: This section explicitly visualizes the mechanical failure point (>35,000 cycles). This addresses a common industry deficiency where longevity data is often omitted from consumer labels, providing verifiable evidence of the product's lifespan.

## DISCUSSION

The case studies demonstrate a clear progression from visualizing simple data pairs to complex, multi-functional profiles. The analysis reveals that moving beyond raw numbers towards structured, visually intuitive systems offers substantial benefits. The proposed designs—the annotated bidirectional bar chart, the radar chart, and the FTPQ system—are not merely aesthetic exercises; they are tools for cognitive efficiency. The primary implication of this research is the call for standardization in the visual communication of textile performance. The current ad hoc approach, where one brand uses a 1–5-star rating for breathability and another uses a proprietary “climate index,” creates confusion and undermines consumer trust. A standardized visual language, much like the universal symbols for recycling or care instructions, would create a level playing field and empower consumers to make informed choices based on performance, not just marketing rhetoric.

The FTPQ in particular offers a promising path towards such a standard. Its modular, dashboard-like design is both comprehensive and easy to scan. By consistently placing core functions (thermal, moisture, protection, durability) in the same location, it reduces the learning curve for consumers. Over time, shoppers could learn to read an FTPQ graphic as quickly as they read a nutrition label on a food package. This could fundamentally change how functional apparel is marketed and sold, shifting the focus from abstract claims (e.g., Stay dry and comfortable) to transparent, verifiable data that is communicated through a standardized visual language

(e.g., displaying UPF 50+ or 380% one-way transport within the FTPQ framework).

Furthermore, implementing such a system has benefits for other stakeholders. For apparel designers and product developers, having a clear visual summary of a fabric's properties would streamline the material selection process. They could quickly compare the performance profiles of dozens of fabric samples to find the optimal material for a specific garment's intended use. For textile manufacturers, a standardized visual system provides a powerful way to communicate the innovative value of their products to brands, justifying premium pricing with clear, easy-to-understand evidence. However, the successful implementation of such a system faces challenges. It requires industry-wide buy-in, from textile mills to apparel brands and retailers. There may be resistance from brands who prefer their own proprietary marketing systems. Therefore, adoption would likely need to be championed by industry associations like AATCC or by major, influential brands setting a new precedent. A significant limitation of this study is that the proposed designs, while grounded in established visualization theory, have not been empirically validated with a broad consumer audience. Therefore, claims regarding their intuitive nature are theoretical and serve as a hypothesis for future research, which is a crucial next step to confirm their real-world effectiveness.

## CONCLUSION

This study has investigated the critical but often overlooked area of visual communication for functional textile performance data. By synthesizing principles from data visualization and textile science, it has shown that the complex, multi-dimensional data generated from standardized tests can be transformed into clear, intuitive, and powerful graphic representations. The research established a design methodology and, through a series of case studies, developed and analyzed several visual models. The findings suggest that well-designed visuals, such as the proposed annotated bidirectional bar chart for thermal properties and the FTPQ for multi-functional fabrics, have the potential to significantly enhance the clarity and comparability of performance information. These proposed systems aim to solve key challenges, such as representing opposing metrics and displaying multi-dimensional data in a holistic yet accessible manner. The principal contribution of this paper is the proposal of a systematic and standardized approach to visualizing textile performance. Adopting such a framework would empower consumers, streamline the design process for professionals, and allow innovative textile manufacturers to more effectively communicate the value of their

products. While further research involving user testing is necessary to validate these designs, this study provides a strong theoretical and practical foundation for the textile industry to build a more transparent, data-driven, and user-centric communication standard.

#### *Author Contributions*

Lina Yang designed, collected and analyzed the data, and drafted the manuscript. Lina Yang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Lina Yang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

#### *Conflict of Interest*

The author declares no conflict of interest.

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Not applicable.

#### *Availability of Data and Materials*

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

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