PROJECT 43 — LABRADOR

Multifunctional Structural Colour E-Textiles with Integrated Energy Harvesting

A Collaboration Whitepaper

This document is not a funding request.

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Note: *This is the most technically complex proposal in the Project 43 series. Three independently unproven technologies are proposed for integration. The integration risk is multiplicative—and likely worse than multiplicative, because the three functions share a single substrate and their failure modes are correlated. A staged development pathway with quantitative gate criteria is proposed in Section 5.*

1. Executive Summary

The global textile colorant market is valued at approximately £5.5 billion. Textile dyeing remains one of the most polluting industrial processes on Earth, consuming 93 billion cubic metres of water annually and generating 20% of global industrial water pollution. Structural colour—colour produced without chemical dyes—eliminates dye-related water pollution from the colouring step itself. It does not eliminate pollution from fibre production, finishing, polymer synthesis, carbon nanotube (CNT) production, or polyvinylidene fluoride (PVDF) processing, each of which carries its own environmental footprint. A full lifecycle comparison between structural colour production and conventional dyeing has not been conducted and would be required before any net environmental benefit can be claimed.

This whitepaper proposes a convergent textile technology combining three functions in a single fibre or yarn: permanent, wash-durable structural colour via Bøggild-architecture polymer coatings; electronic conductivity via CNT or conductive polymer yarn substrates; and autonomous energy harvesting via integrated piezoelectric elements.

Each of these three technologies is independently unproven at the specifications defined in Section 5.2 (Table 1). The probability that all three work simultaneously is, at best, the product of three independent success probabilities—and likely worse, because failure in one function may directly cause failure in another. A staged development pathway with quantitative pass/fail criteria is proposed to manage this risk.

2. Context and Problem Statement

Global fibre production exceeds 124 million tonnes per year. The only prior commercial structural colour fibre, Morphotex (Teijin, 61 polyester/nylon layers), was discontinued in 2011 due to cost and a limited colour palette. This is a directly relevant precedent: the proposed system is structurally more complex than Morphotex and faces the same commercial viability challenge.

In June 2025, Sparxell launched the first commercial structural colour textile ink using cellulose nanoparticles. This is a printed surface pigment, not a fibre-level structural colour—a fundamentally different approach.

No prior art combining structural colour with electronic textile functionality was identified in a search conducted during January–February 2026. Absence of found prior art is not proof of non-existence; a systematic prior-art review by a specialist in either field may reveal related work not captured by the search strategy used.

Reactive epoxy copolymer approaches to wash durability are supported by academic work: P(t-BA-co-GMA) cross-linked photonic crystals on flat polyester showed colorfastness results reported by the authors as “good” (Soochow University), though the original publication does not provide a quantitative colorfastness rating against a standard scale such as ISO 105 grey scale. That work used flat substrates rather than curved fibre surfaces—a geometry that introduces different coating uniformity and adhesion challenges.

3. Analysis: What May Be Novel

A prior-art search was conducted during January–February 2026. Three aspects were identified as potentially novel. Novelty, however, is not evidence of feasibility—each aspect is flagged as novel precisely because it has not been demonstrated, and the absence of prior work may reflect genuine technical barriers rather than unexplored opportunity.

3.1 Low-Δn Multilayer Fibres via Thermal Drawing

Thermal drawing of polymer optical fibres is established, but all prior work identified uses high-Δn materials (PC/PMMA, As_2Se_3/PES). Low-Δn materials (Δn = 0.008–0.1) face a fundamental trade-off: at low Δn, the materials are chemically similar, which is good for viscosity matching during thermal drawing but means the layer boundaries may be diffuse—potentially reducing the optical contrast that creates the photonic effect.

The minimum Δn required to produce visually perceptible structural colour in a multilayer fibre geometry has not been experimentally determined and would need to be established in the first development phase. For reference, Morphotex used nylon/polyester (Δn of approximately 0.1); lower Δn values would require proportionally more layers to achieve equivalent reflectance, increasing manufacturing complexity.

3.2 Block Copolymer Coating on CNT Conductive Yarns

No prior art combining structural colour with e-textile conductivity was found in the search described above (with the caveat noted in Section 2). Block copolymer (BCP) self-assembly on flat substrates is well-characterised, but on the curved surface of a yarn (diameter 10–100 μm), curvature introduces confinement effects that alter BCP lamellar orientation and spacing. Published literature on BCP behaviour on curved substrates shows significant deviation from flat-substrate performance.

3.3 Structural Colour with Piezoelectric Energy Harvesting

Integration of structural colour and piezoelectric energy harvesting in a single yarn has no prior art (subject to the same search limitations noted above). PVDF nanofibre generators doped with $BaTiO_3$ or LiCl are reported to produce piezoelectric output under mechanical deformation. The specific power figure cited requires essential context: deformation frequency, amplitude, and fibre area must all be defined before the output can be related to any wearable system power requirement.

Typical body-motion energy harvesting from textiles produces on the order of 1–10 μW/cm², with actual output depending on motion type, frequency, and harvester geometry. This power level is potentially sufficient for low-duty-cycle sensor wakeup—for example, a sub-μW wake-up receiver triggered once per minute—but not for continuous sensor operation. No specific target sensor, duty cycle, or power budget has been defined for this proposal. Defining a target application with a quantified power budget (sensor type, sampling rate, transmission interval, sleep current) is a prerequisite for evaluating whether piezoelectric integration adds meaningful functionality. This work has not yet been done.

3.4 Integration: Competing Demands

The three functions place competing demands on a single fibre structure. The photonic function requires uniform multilayer stacking with low defect density. The conductive function requires uniform CNT distribution within the yarn core with minimal interference from the polymer coating. The piezoelectric function requires PVDF crystallisation in the β-phase with good mechanical coupling to fibre deformation.

These requirements may conflict. BCP coating solvents may infiltrate the CNT bundle, disrupting electrical percolation pathways. PVDF processing temperatures may affect BCP layer integrity. The photonic function's requirement for optical uniformity may be incompatible with the mechanical deformation needed for piezoelectric output. No analysis of how these requirements co-exist in a single structure has been conducted. This is the central unproven integration claim—the risks are correlated, not independent.

4. Target Applications

All applications described here are conditional on the staged development pathway (Section 5) producing positive results at each quantitatively defined gate.

Sustainable fashion textiles. Permanent structural colour replacing chemical dyes, reducing dye-related water pollution from the colouring step. The net lifecycle environmental benefit remains to be demonstrated.

Self-powered wearable electronics. Conductive structural colour yarns with piezoelectric energy harvesting for autonomous low-duty-cycle sensors. This application is viable only if the third development phase demonstrates power output sufficient for a defined sensor application under realistic conditions.

Military and emergency services. Dual-purpose garments combining decorative structural colour with short-wave infrared (SWIR) detectability.

Marine and extreme-environment textiles. Superhydrophobic structural colour with self-healing capability for harsh operating conditions.

5. Known Risks and Staged Development Pathway

5.1 Multiplicative and Correlated Integration Risk

[HYPOTHESIS] Three unproven technologies are combined in a single fibre. The failure probability is not simply the product of three independent success probabilities. The three functions share a single substrate, and failure modes are correlated: BCP coating defects may simultaneously degrade optical performance, infiltrate the CNT bundle to reduce conductivity, and compromise the mechanical coupling needed for piezoelectric output. The actual joint failure probability is likely higher than any independent-product model implies.

No fallback position exists for the fully integrated three-function system. Partial integration (structural colour alone, or structural colour plus conductivity without the piezoelectric function) remains viable if the first development phase succeeds—the staged pathway explicitly provides for these reduced-scope outcomes.

5.2 Staged Development with Quantitative Gate Criteria

To manage this correlated risk, the following phased approach is proposed. Each gate has defined pass/fail criteria. The thresholds below represent initial proposed values that should be refined by domain experts during project planning.

Table 1: Phase Gate Criteria

Phase	Objective	Gate Criteria	Kill Criterion
1: Structural Colour Only	Demonstrate BCP multilayer coating on flat textile substrates, then on individual curved fibres (radius 5–50 μm). Validate wash durability.	**Peak reflectance:** ≥30% at target wavelength (microspectrophotometry). **Minimum Δn:** ≥0.02 (initial target based on Morphotex precedent, subject to revision). **Wash durability:** ≥50 cycles to ISO 6330:2012 (60°C, 30 min), no visually detectable speckle-pattern delamination; ΔE < 3.0.	If structural colour cannot be achieved on curved fibres with ΔE < 3.0 after 50 wash cycles, Phases 2 and 3 are cancelled.
2: Integration with Conductive Yarns	Apply structural colour coating to CNT conductive yarns. Measure conductivity impact.	**Sheet resistance increase:** ≤20% relative to uncoated CNT yarn (four-point probe). **Structural colour:** Reflectance maintained within ΔE < 3.0 of Phase 1 result.	If sheet resistance increase exceeds 50%, Phase 2 is abandoned. 20–50%: proceed with documented trade-off analysis.
3: Piezoelectric Integration	Integrate PVDF piezoelectric elements. Characterise power output under defined body-motion conditions.	**Power output:** ≥1 μW/cm² at 2 Hz sinusoidal deformation (simulating walking gait) across 10 kΩ resistive load. **Target application:** Wake-up signal for sub-μW wake-up receiver at ≤1-minute intervals; ≥50 nJ per event. **Preservation:** Structural colour and conductivity within prior phase thresholds.	If power output under walking-gait simulation is <0.1 μW/cm², piezoelectric integration is abandoned.

5.3 Morphotex Cost Precedent

Morphotex (61-layer PVD fibre) was discontinued due to cost and limited palette. This proposal involves thermal drawing plus BCP coating plus CNT yarn fabrication plus PVDF integration—a manufacturing chain that is structurally more expensive than Morphotex. The cost trajectory is steeper, not shallower. No cost modelling has been conducted for the proposed system.

The proposal must demonstrate a credible path to cost parity with conventional dyed textiles or identify a specific premium market segment willing to pay significantly above commodity price. In this context, “credible” means a bottom-up cost estimate based on materials, processing steps, yield assumptions, and scale projections, benchmarked against the target market price point. The existence and size of a premium market for structural colour textiles has not been validated—this is an assumption, not a finding.

5.4 Wash Durability

BCP coatings on curved CNT yarn surfaces face repeated hydrothermal stress during washing. CNT yarns have low surface energy, making them difficult to wet and coat uniformly. Coating delamination after washing is the most likely first failure point.

Unlike chemical dyes (which fade gradually and uniformly), photonic structural colour degrades catastrophically. Structural colour is a threshold phenomenon—partial delamination does not produce “faded” colour but instead produces patchy total colour loss, a binary on/off speckle pattern with no graceful degradation path. A consumer garment that develops random bright and dark patches after a small number of washes is commercially unviable. This makes the wash durability requirement absolute rather than graduated: the product either passes at commercially relevant cycle counts (50–100+) or it fails completely as a consumer product.

5.5 Regulatory Compliance

If BCP coatings shed microparticles during washing (as all textile coatings do to some degree), EU regulations restricting synthetic polymer microparticles will likely apply. The specific regulatory instrument should be confirmed by a regulatory specialist; the general regulatory direction is established. Bio-derived BCP alternatives may be required for EU market compliance, adding a materials development requirement.

5.6 Collaboration Sustainability Risk

The proposed system requires simultaneous expertise in at least five domains: block copolymer chemistry, carbon nanotube yarn fabrication, piezoelectric materials, photonics, and textile engineering. No single research group is likely to possess all five competencies. A multi-partner programme of this complexity carries sustainability risk: if one domain partner withdraws or is unable to deliver, the programme may stall. A collaboration agreement should define intellectual property ownership, publication rights, and contingency arrangements for partner withdrawal before technical work begins.

6. Open Questions Requiring Collaboration

Coating uniformity on curved substrates. Can BCP self-assembly produce uniform multilayer coatings on the curved surface of individual fibres or yarns? Curvature effects on lamellar orientation may prevent adequate layer count.

Wash durability. What is the achievable wash durability? The minimum commercially viable target is 50 wash cycles to ISO 6330:2012 (60°C, 30 minutes). The 25-cycle threshold in the standard represents a test minimum, not a commercial acceptability threshold—consumer garments typically require 50–100+ cycles before visible degradation. Structural colour degradation is catastrophic: partial coating delamination produces binary on/off colour loss rather than gradual fading, creating a visually objectionable speckle pattern. The Soochow University epoxy-based work was on flat polyester, not curved CNT yarn—adhesion on curved, low-surface-energy CNT substrates is an open question.

Cross-function interference. Does the structural colour coating degrade the electrical conductivity of CNT yarns or affect the piezoelectric output of PVDF fibres? The BCP coating process (solvent-based or melt-based) may infiltrate the CNT bundle, disrupting percolation pathways.

Cost per metre. What is the achievable cost per metre? For fashion textiles, structural colour should not add more than 2–5× to the cost of conventional dyeing (approximately £0.10–£0.50 per metre for commodity fabrics). Morphotex failed at lower manufacturing complexity than this proposal. No cost modelling has been conducted for the proposed system. A bottom-up cost estimate covering BCP synthesis, CNT yarn, PVDF integration, coating process, and quality control would be needed before any commercial viability assessment.

Microparticle shedding. Do the structural colour coatings shed microparticles during washing? If so, EU regulations on synthetic polymer microparticles may apply. The specific regulation number should be confirmed by a regulatory specialist; the general regulatory trajectory towards microparticle restriction in the EU is well established.

7. Invitation to Collaborate

This whitepaper is issued as an open invitation to research collaboration. Project 43—Labrador is not seeking funding at this stage. The project seeks expertise across the following domains: textile engineering and fibre science; block copolymer chemistry (particularly BCP self-assembly on curved substrates); e-textile and conductive yarn development (particularly CNT yarn characterisation); piezoelectric energy harvesting (particularly PVDF nanofibre systems); wash durability testing to ISO 6330, AATCC, and Martindale standards at commercially relevant cycle counts; sustainable materials chemistry (bio-derived polymers for regulatory compliance); and cost modelling for novel textile manufacturing processes.

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8. Source Documents

8.1 Internal Project Documents

Project Labradorite: Commercial Applications of Synthetic Labradorescence (Deep Research Report, Feb 2026) *[PL1]*

Strategic Evaluation and Commercial Roadmap for Project Labradorite (Technical Analysis, 2026) *[PL3]*

Critical Evaluation and Strategic Enhancement of Project Labradorite (External Review, 2026) *[Res1]*

Improvements to Project Labradorite (Enhancement Brief, 2026) *[PL2]*

8.2 External References

Morphotex—Teijin Ltd (2003–2011). 61-layer structural colour fibre. Discontinued due to cost.

Sparxell GmbH (June 2025)—First commercial structural colour textile ink (cellulose nanoparticles).

Soochow University—P(t-BA-co-GMA) cross-linked photonic crystals on polyester. Colorfastness reported by authors as “good” (quantitative rating not provided in the cited work).

ISO 6330:2012—Textiles: Domestic washing and drying procedures for textile testing.

EU regulatory framework on synthetic polymer microparticles—General regulatory direction established; specific instrument number to be confirmed by regulatory specialist.

Appendix A: Document Metadata

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Appendix B: Glossary

Term / Abbreviation	Definition
BCP	Block copolymer. A polymer composed of two or more chemically distinct blocks that self-assemble into periodic nanostructures.
$BaTiO_3$	Barium titanate. A piezoelectric ceramic used as a dopant in PVDF nanofibre generators.
CNT	Carbon nanotube. A cylindrical carbon nanostructure used as a conductive yarn substrate.
ΔE	Delta E. A metric for colour difference; values below 3.0 are generally imperceptible to the human eye.
Δn	Delta n. Refractive index contrast between two materials in a multilayer optical structure.
E-textile	Electronic textile. A fabric with integrated electronic functionality such as sensing or conductivity.
ISO 6330:2012	International standard for domestic washing and drying procedures for textile testing.
LiCl	Lithium chloride. A salt used as a dopant in piezoelectric PVDF systems.
Morphotex	A 61-layer structural colour fibre produced by Teijin Ltd (2003–2011), discontinued due to cost.
P(t-BA-co-GMA)	Poly(tert-butyl acrylate-co-glycidyl methacrylate). An epoxy copolymer used in cross-linked photonic crystals.
PC/PMMA	Polycarbonate / polymethyl methacrylate. A high-Δn material pair used in polymer optical fibres.
PVDF	Polyvinylidene fluoride. A piezoelectric polymer used for energy harvesting applications.
PVD	Physical vapour deposition. A thin-film coating process.
Structural colour	Colour produced by the physical microstructure of a surface (photonic effects) rather than by chemical pigments or dyes.
SWIR	Short-wave infrared. Electromagnetic radiation in the wavelength range approximately 1.4–3 μm.
β-phase PVDF	The electroactive crystalline phase of PVDF responsible for its piezoelectric properties.

Appendix C: Methodology and Transparency Statement

Author Context and Expertise

This work is grounded in 30 years of multi-sector experience in Systems Engineering. The analytical framework reflects professional history, focusing on practical application.

Digital Methodology and Accessibility

In the spirit of transparency, I utilised a suite of Generative AI tools—specifically Claude, Google Gemini, and ChatGPT—to assist in the production of this paper. These tools were employed as “force multipliers” for data synthesis and editorial accessibility. As a writer with dyslexia, I leverage these models as assistive technology to refine grammar and streamline sentence structure.

Verification and Integrity

While AI assisted in processing data, the intellectual oversight is entirely human. I performed manual validation of all citations and accept full responsibility for the accuracy and originality of the final output.

Appendix D: Raw Author Notes

No raw author notes are appended to this version. Source material for this whitepaper is drawn from the Project 43 (Labrador) research portfolio, comprising four internal documents (PL1, PL2, PL3, Res1) and external references cited in Section 8.

Appendix E: Change Log

Version	Date	Description
1.0	25 February 2026	Publication-ready formatted edition. All content integrated, structured per collaboration whitepaper format, and reviewed against quality gate criteria.