

Developing an Industrial Microbial Colour System through Textile Printing

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Developing a Microbial Colour System for Industrial Textile Design and Manufacturing

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Microbial colourants offer a potential alternative to conventional synthetic textile colouration, but industrial adoption also requires systems through which colours can be selected, specified and reproduced. This paper presents the Colorifix Microbial Colour System (CMCS), an emerging architecture developed through practice-led doctoral research embedded within Colorifix, a microbial dyeing biotechnology startup. Using two validated microbial colourants on a selected 100% polyester fabric substrate, the research translates measured colour and application data into linked design-facing and production-facing documentation. The CMCS combines perceptual colour organisation, CIE L*a*b* measurement, substrate-specific physical standards and technical process information, drawing on sources such as Munsell, Pantone, Archroma and historical dye documentation. Its contribution is a microbial-colourant-specific information structure connecting colour appearance to validated application conditions. The paper presents the CMCS as a modular foundation rather than a complete industrial library; it can expand as further colourants, substrates and processes are validated.

Keywords: *microbial colourants; textile colour systems; textile printing; colour specification.*

1. Introduction

Microbial colourants are produced through fermentation rather than petrochemical synthesis or agricultural extraction and are being investigated as alternatives to conventional textile dyes (Cipolatti et al., 2019; Ren et al., 2017; Usman et al., 2017). Research has concentrated mainly on colourant production, optimisation and dyeing, with less attention to the systems needed to specify, communicate and apply microbial colours in textile design and manufacturing (Shirata et al., 2000; Usman et al., 2017; Venil et al., 2016, 2020). Industrial colouration depends on infrastructures that connect physical standards and colour measurement with formulation, substrate, processing and

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performance data (Choudhury, 2015). Existing biological colour databases support research and colourant discovery but do not provide the application-level or performance data required for industrial textile production (Meyer et al., 2022; Primetta et al., 2024; Sharma & Meyer, 2022). Designers and manufacturers therefore lack a shared means of determining which microbial colours are available, how they can be applied and reproduced, and what performance they offer. This paper treats that infrastructural gap as a barrier to specification and industrial adoption.

The paper proposes the Colorifix Microbial Colour System (CMCS) as a modular colour-specification and application architecture developed through practice-led research embedded within Colorifix, a microbial dyeing biotechnology startup. It asks: How can a microbial colour system translate validated microbial colourant behaviour into a specification and application infrastructure for industrial textile design and manufacturing?

The contribution is not a new colourant or universal model of colour organisation, but an architecture that adapts established functions - colour selection, measurement, substrate compatibility, process information and production translation - to emerging microbial colourants. Lab-scale magnetic flatbed screen-printing generated the empirical colour and application knowledge organised by the system. The paper focuses on the CMCS as a dual-audience framework linking design-facing selection with production-facing specification. The print-validation process is included only to explain eligibility for the CMCS; detailed proprietary formulations and process parameters fall outside the paper's scope and will be reported separately where appropriate. The CMCS is presented as an emerging prototype, not a complete operational library or technical printing protocol.

2. Context: Microbial colourants and textile colour-systems

Microbial colourants are coloured compounds biosynthesised by microorganisms, including bacteria, fungi and microalgae, through controlled cultivation processes (Usman et al., 2017; Venil et al., 2016, 2020). Their chromophores and application behaviour vary with organism, strain, metabolic pathway, cultivation conditions and downstream processing, affecting hue, strength, solubility, fibre affinity and fixation (ibid). Microbial origin therefore describes a production route rather than a single dye class: individual colourants must be differentiated by their chemical and application behaviour. For the purposes of the CMCS, industrial readiness was defined as a documented colourant–substrate–process–performance relationship covering substrate compatibility, formulation and fixation, reproducible colour and acceptable colour fastness (Choudhury, 2015; CIE, 2018). Existing colour systems do not supply this microbial-specific layer of application knowledge (Choudhury, 2015; Kramar & Kostic, 2022).

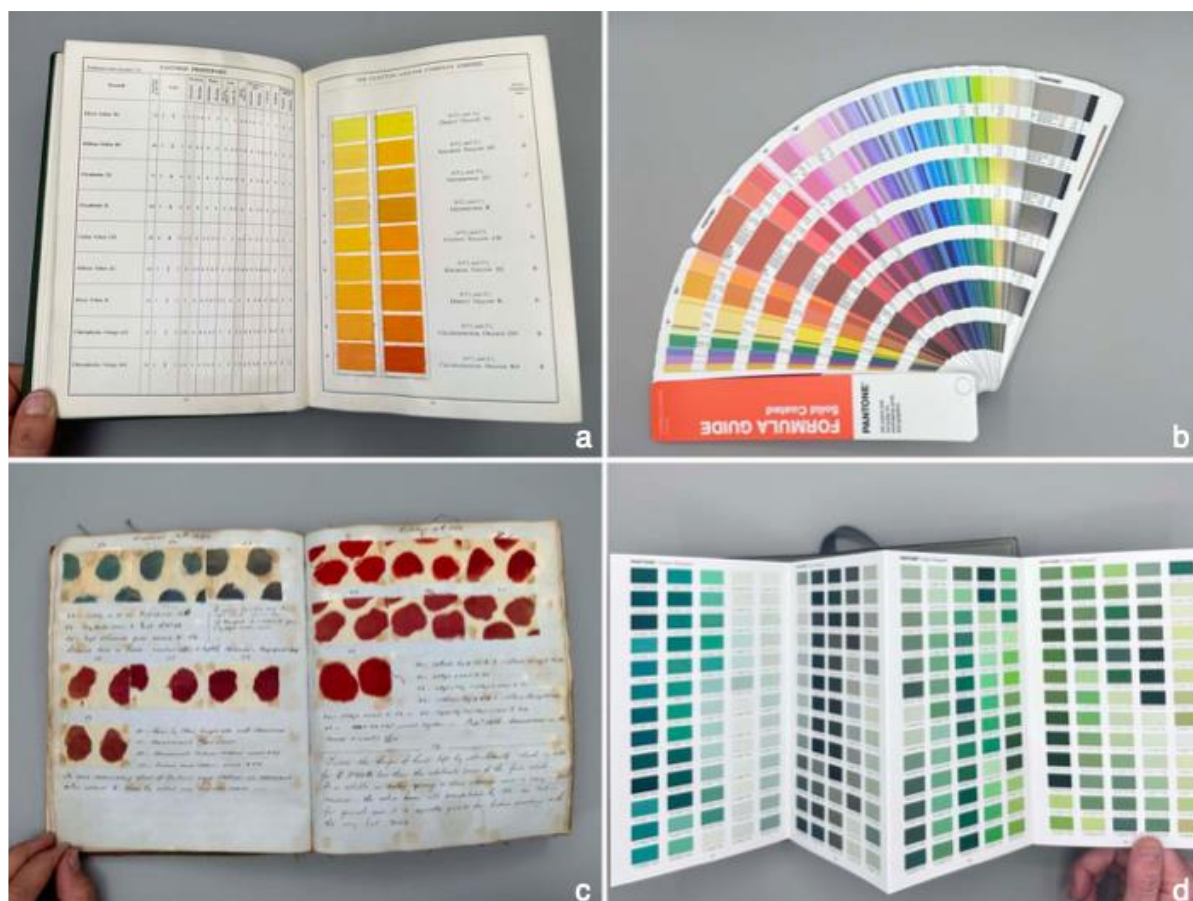


Figure 1. Historical and contemporary textile colour documentation: (a) dye supplier atlas; (b) Pantone coated paper fan; (c) archival grain book linking samples to formulations and process notes; and (d) Pantone cotton colour passport. The examples show the continuing relationship between physical standards, colour organisation and technical documentation. Supplier-specific textile systems such as the Archroma Colour Atlas are not shown in Figure 1 but provide a closer functional precedent for the CMCS because they connect physical colour standards with application-specific technical knowledge (Archroma, 2024). Photographs by the author; archival materials photographed at the Society of Dyers and Colourists.

Historical dye atlases and technical sample books show that textile colour systems have long depended on the co-location of physical samples and process information (Clayton Aniline, 1897; Smith, 1881). Archival dye documentation often links a colour sample directly to formulation, concentration, substrate and processing notes. Contemporary tools perform related functions in different ways. Pantone provides standardised physical references for colour communication across design and manufacturing, including textile-specific standards (Choudhury, 2015; Pantone, 2026). CIE $L^*a^*b^*$ provides an instrument-based framework for numerical colour measurement, comparison and tolerance control (Choudhury, 2015; CIE, 2018). Datacolor and X-Rite software support computerised colour matching, formulation and correction within textile workflows (DataColor, 2026; X-Rite, 2026). Supplier-specific systems such as the Archroma Colour Atlas link physical colour standards to formulation and production information (Archroma, 2024).

The CMCS does not seek to replace these systems. Instead, its architecture adapts and emulates their relevant functions to establish the basis for a microbial-specific colour infrastructure: one that links colour specification, instrumental measurement, perceptual organisation and application knowledge. Its value lies in connecting colour appearance to validated microbial application and performance knowledge.

Table 1. Relationship between CMCS and existing colour systems/tools.

System/tool	Main function	Why it is useful	Limitation for microbial colour	How CMCS uses or differs from it
CIE L*a*b* / Datacolor / X-Rite	Instrumental colour measurement and colour matching	Provides measurable colour values and ΔE -based comparison	Does not itself contain microbial application knowledge, substrate compatibility or process routes	CMCS uses L*a*b* as the technical backbone, but links it to microbial colourant, substrate, process and performance data
Munsell	Perceptual colour ordering by hue, value/lightness and chroma	Helps designers navigate colour relationships visually – and is the basis of many established colour systems	Not a textile production system and not linked to formulations or fastness	CMCS borrows perceptual organisation while retaining industrial L*a*b* measurement
Supplier-specific colour systems (e.g. Archroma Colour Atlas)	Supplier-specific textile colour libraries	Link physical colour standards to dye/application knowledge	Built around established commercial dye systems, not microbial colourants	CMCS adapts this supplier-system logic for biologically produced colourants; these systems provide its closest functional precedent
Pantone	Standardised colour communication across design and manufacture	Familiar to designers and brands; useful as a nearest visual reference	Not process-specific, not microbial-specific, and does not provide textile application recipes	Pantone may be used alongside the CMCS as a familiar visual reference or nearest match; the CMCS additionally links each colour to microbial-specific substrate, process and performance data.
Dye-agnostic colour systems / universal colour platforms e.g. Coloro	Colour communication and perceptual organisation through coded physical and digital standards	Useful for specifying colour across different colouration routes and could support hybrid transition periods where synthetic and microbial colourants are used alongside one another	Cannot integrate microbial colourants meaningfully until validated microbial colour data, substrate compatibility, process routes and performance information exist	The CMCS architecture organises the microbial-specific data and application knowledge generated through validation, which could allow microbial colourants to be incorporated into broader dye-agnostic systems in future.

* Sources: (Archroma, 2024; Choudhury, 2015; CIE, 2018; Coloro, 2026; DataColor, 2026; X-Rite, 2026; Fairchild, 2013; Munsell, 1912; Pantone, 2026)

Existing colour systems and tools therefore provide important precedents, but none of the systems reviewed supplies the microbial-specific substrate, application and performance data required for reproducible textile production. Munsell supports perceptual organisation by hue, value and chroma, while CIE L*a*b* supports instrument-based colour measurement and tolerance control; neither system encodes the formulation, substrate or performance information required for application-specific production (Choudhury, 2015; CIE, 2018; Fairchild, 2013; Munsell, 1912). Among the systems reviewed, supplier-specific colour libraries such as the Archroma Colour Atlas provide the closest functional precedent because they connect physical colour standards with formulation and production information (Archroma, 2024). However, these systems are structured around established commercial textile colourants and supplier application workflows rather than microbial colourants. Dye-agnostic systems such as Coloro may become relevant during a transitional period in which microbial and synthetic colourants are specified alongside one another; for example, a future workflow might allow a factory to specify a microbial Pink or Blue alongside a compatible synthetic disperse Green, provided each colour is linked to relevant substrate, process and performance data. The CMCS architecture therefore adapts relevant aspects of existing colour systems while specifying the missing microbial-specific layer: the connection between colour appearance, validated application knowledge and technical performance.

3. Methodology: Generating the evidence base for the CMCS through textile printing

3.1 Practice-led research context, scale and scope

The CMCS was developed through practice-led research embedded within Colorifix R&D facilities. Lab-scale magnetic flatbed screen-printing was used to generate structured knowledge of formulation, print quality and colour interaction. Printing is therefore the investigative route through which the CMCS evidence base was produced, rather than the principal subject of technical disclosure.

The evidence base comprised 91 discrete experiments. An experiment was defined as a planned study addressing a specific aspect of microbial colourant behaviour, not an individual fabric swatch. Each involved controlled preparation, printing, processing and evaluation, producing physical samples and quantitative and qualitative data on colourant strength, CIE L*a*b* colour, fastness and print behaviour. The technical work informed five CMCS design cycles and three design-led testing projects. The validation workflow and associated print-development processes were established within Colorifix R&D, while the CMCS was developed as a system architecture and an initial prototype comprising digital atlas designs, physical reference standards and technical documentation.

Two proprietary fermentation-derived colourants, referred to as Blue and Pink, were used as case studies on a selected 100% polyester fabric substrate. Their organism, strain, chromophore and downstream-processing identities are withheld. Both colourants met the technical requirements for inclusion and could be applied through a shared substrate, formulation and process route.

Yellow was also investigated as part of the original aim to establish a broader colour space, but process sensitivity prevented validation within the reported workflow. It was therefore excluded from the prototype. This exclusion illustrates the system's conditional logic: the CMCS represents only colourant–substrate–process relationships supported by documented performance evidence, while unresolved outcomes return to further R&D.

3.2 Print-validation framework and CMCS inclusion criteria

The three-stage print-validation framework was established as a repeatable Colorifix R&D workflow for progressing microbial colourants from initial screening to validated print protocols. Within this paper, it is presented specifically as the evidence pathway through which a colourant becomes eligible for representation within the CMCS architecture.

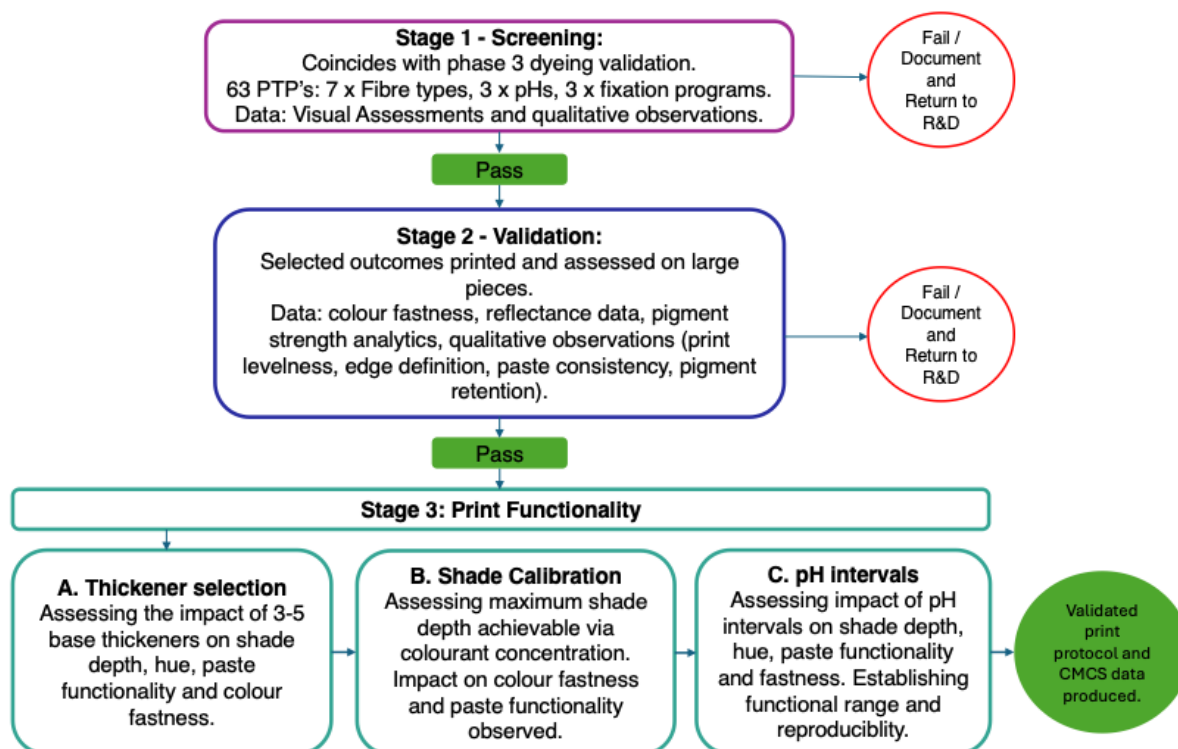


Figure 2. Print-validation pathway from screening to CMCS inclusion. Validated colourant–substrate–process relationships progress to print-protocol development and CMCS representation; unsuccessful outcomes are documented and returned to troubleshooting or further R&D.

As shown in Figure 2, CMCS inclusion is conditional rather than automatic. Only colourant–substrate–process relationships that meet the relevant technical requirements progress to representation within the system. Stage Three establishes print functionality through formulation selection, shade calibration and pH-dependent reproducibility testing. This prevents visually interesting but technically unsupported colours from being represented within the CMCS.

Table 2. Print-validation workflow used to generate CMCS data.

Validation stage	Validation question	Evidence collected	Role in CMCS development
Stage 1: Print screening	Which colourant–substrate–fixation–pH combinations show initial potential?	Screening on a multifibre test fabric containing seven fibre types, across 3 fixation programmes and 3 pH intervals (3, 7 & 11); visual assessment; qualitative observations	Identifies candidate colourant–substrate–process relationships for further validation
Stage 2: Print validation	Does the candidate colourant–substrate–process relationship meet the defined technical requirements?	Larger print trials on the selected single-fibre–composition substrate; instrumental colour and colourant-strength measurement; colour-fastness testing; qualitative assessment of paste and print performance.	Confirms whether a candidate relationship is technically viable and can progress into print-functionality testing
Stage 3: Print-functionality testing 3A: Thickener/formulation selection	Which thickener or formulation gives the most stable and effective print outcome?	Comparative thickener/formulation trials supported by instrumental colour measurement, fastness testing and qualitative evaluation of paste and print performance.	Identifies the formulation route needed for reproducible printing and determines whether a shared formulation can support multiple colourants
3B: Shade calibration	What is the usable shade range and maximum practical saturation?	Concentration and dilution trials supported by colour and colourant-strength measurement, fastness testing and qualitative print evaluation.	Defines pale, mid and dark calibration anchors and establishes the practical saturation limit for each colourant
3C: pH and reproducibility testing	What is the functional pH range and standard operating point?	pH interval and repeatability trials supported by instrumental colour measurement, including ΔE where relevant, colour fastness testing and qualitative stability assessment.	Establishes the operating range and preferred standard condition for reproducible production and colour mixing
Post-validation mixing and compatibility testing	Can validated colourants be mixed or overprinted within the same process route?	Controlled ratio mixing and overprinting trials supported by instrumental colour measurement, colour fastness testing and qualitative evaluation.	Populates the colour space between validated anchors and tests whether colourants can operate within a shared substrate- and process-specific system
Cross-stage failure documentation	What happens when a colourant or process route fails validation?	Documentation of unmet technical requirements (inadequate fixation, poor colour fastness, low colour strength, unstable paste behaviour, speckling, staining, pH incompatibility or process incompatibility).	Prevents unsupported colours from being represented within the CMCS architecture and provides feedback for troubleshooting or return to R&D

The print-validation framework produced the quantitative and qualitative evidence needed to determine whether a microbial colourant was suitable for representation within the CMCS architecture and how that representation should be structured.

Blue and Pink were evaluated on the selected 100% polyester fabric substrate using a shared proprietary print formulation and a controlled lab-scale magnetic flatbed workflow. Samples were dry-cured at 185°C for 8–10 minutes and assessed across pH 3–11, with pH 7 selected as the standard operating point. Evaluation combined instrumental colour and colourant-strength measurement, colour-fastness testing and qualitative assessment of paste and print behaviour.

3.3 Anchor-shade and controlled interval-mixing method

Stage Three established calibrated pale, mid and dark anchor shades for the validated Blue and Pink colourants; their measured colourant strengths are reported in Table 3. At each shade level, the corresponding Blue and Pink print pastes were prepared using the shared validated workflow and combined gravimetrically at Blue mass ratios of 1:0, 9:1, 8:1, 3:1, 1:1, 1:3 and 0:1. These ratios describe proportions of the finished print pastes rather than equalised colourant concentrations. The initial sequence of 1:0, 3:1, 1:1, 1:3 and 0:1 was expanded with 9:1 and 8:1 Blue-dominant intervals after preliminary trials showed compressed differentiation at the Blue end. The purpose of the mixing study was not to exhaustively map every possible mixture, but to test whether the colour space between validated microbial anchor colours could be populated through controlled, measured and logically ordered colour relationships. In industrial use, these measured relationships could support colour matching, strike-off development and production testing for specific target colours. The resulting colour relationships are reported in the following section.

4. Results: The Colorifix Microbial Colour System

4.1 Validated colour relationships

Table 3. Representative validation outcomes supporting inclusion in the initial CMCS prototype.

Evidence	Blue	Pink	Relevance to CMCS inclusion
Calibrated shade anchors	Approximately 85, 600 and 2450 mg/L	Approximately 400, 1350 and 4000 mg/L	Established measurable pale, mid and dark reference shades
pH and colour stability	Tested across pH 3–11; pH 7 selected as the standard operating point. ΔE relative to pH 7 ranged from 0.14–2.39 for the pale shade, 0.64–2.64 for the mid shade and 0.34–1.05 for the dark shade	Tested across pH 3–11; pH 7 selected as the standard operating point. ΔE remained below 1 for most comparisons, with marginal increases at pH 3–4	Established a shared controlled condition and demonstrated the need to specify pH for consistent colour reproduction
Technical performance	Definitive pH-validation samples achieved light fastness of 3.5–4.0, wash colour-change scores of 4.5–5.0, dry-rub scores of 4.0–5.0 and wet-rub scores of 3.5–5.0	The selected protocol achieved light fastness of at least 4, wash colour-change scores of at least 4.5, dry-rub scores of at least 4.5 and wet-rub scores of at least 3.5, with some staining exceptions at the dark shade	Confirmed that the selected shades met the principal technical-performance requirements for inclusion (≥ 3.5).
Identified boundaries	Surface staining and rub-fastness failures at higher colourant concentrations established the upper usable saturation limit	Optical saturation at approximately 4000 mg/L, together with declining surface performance at higher colourant strengths, established the upper usable saturation limit.	Prevented technically unsupported colours and shades from being represented in the prototype
Validation outcome	Included	Included	Formed the two anchor colourants of the initial polyester CMCS prototype

In this paper, reproducibility refers to the capacity to reproduce colour outcomes within the defined Colorifix laboratory workflow when colourant strength, formulation, substrate, pH and fixation route are controlled. It does not constitute an inter-laboratory or multi-site reproducibility study.

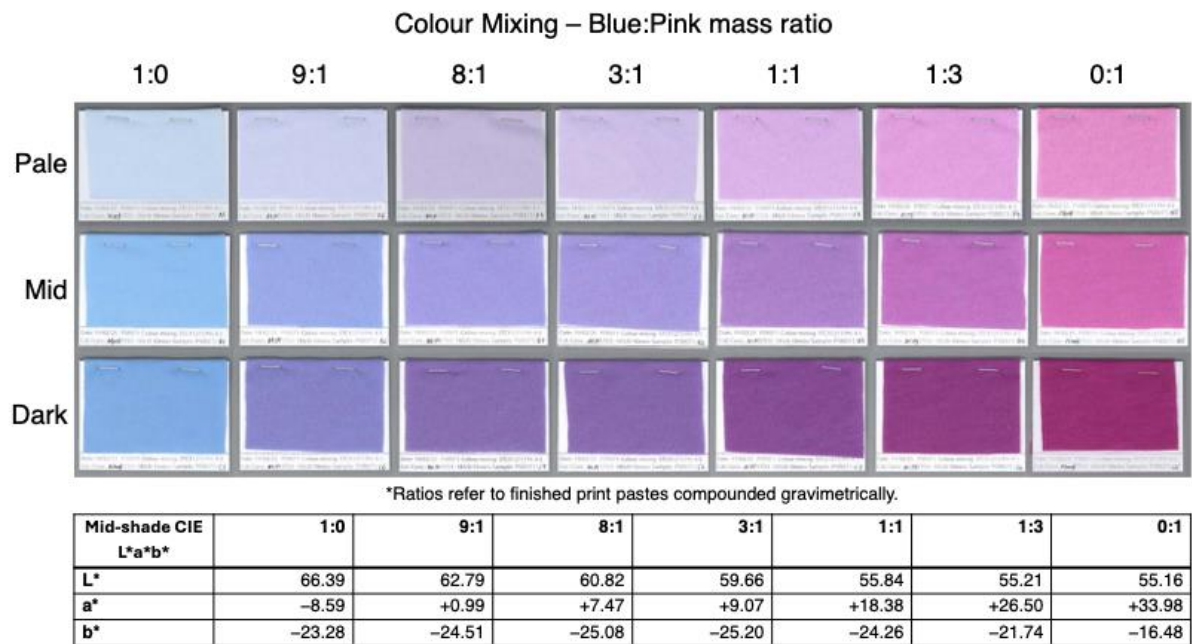


Figure 3. Blue:Pink interval-mixing sequences on the selected 100% polyester substrate at pale, mid and dark shade levels. Calibrated print pastes were combined gravimetrically at mass ratios of 1:0, 9:1, 8:1, 3:1, 1:1, 1:3 and 0:1. CIE L*a*b* values are shown for the mid-shade sequence.

As shown in Figure 3, the validated Blue and Pink colourants could be combined to produce an ordered and continuous progression through violet and purple across all three shade levels. Instrumental measurements confirmed the visual progression, while also showing that proportional paste ratios did not produce perceptually equal colour intervals. This non-linearity reflected the different lightness and chroma capacities of the two anchor colourants rather than instability or interference when they were combined. Introducing the additional 9:1 and 8:1 Blue-dominant ratios partially improved differentiation within the compressed Blue end of the sequence. The mixed pastes also retained stable print quality and broadly consistent technical performance. Across the wider dataset of 40 printed formulations, six individual fastness results fell below the minimum threshold of 3.5 - one wet-rub result and five nylon wash-staining assessments - all associated with high-strength Pink-dominant samples. Together, these results established a measured and technically supported range of intermediate colours for inclusion within the initial CMCS prototype.

4.2 CMCS architecture

The Colorifix Microbial Colour System is a modular architecture for translating empirical microbial colour data into a structured framework for design specification and production communication. It is designed for two professional audiences whose needs differ but must remain connected. Designers require clear, navigable information about available colours and the textile substrates for which each colour has been validated. Production specialists require the technical specifications and application information needed to reproduce them. The integrated architecture is designed to link these two audiences through shared information structures.

Colorifix Microbial Colour System (CMCS)

System Architecture

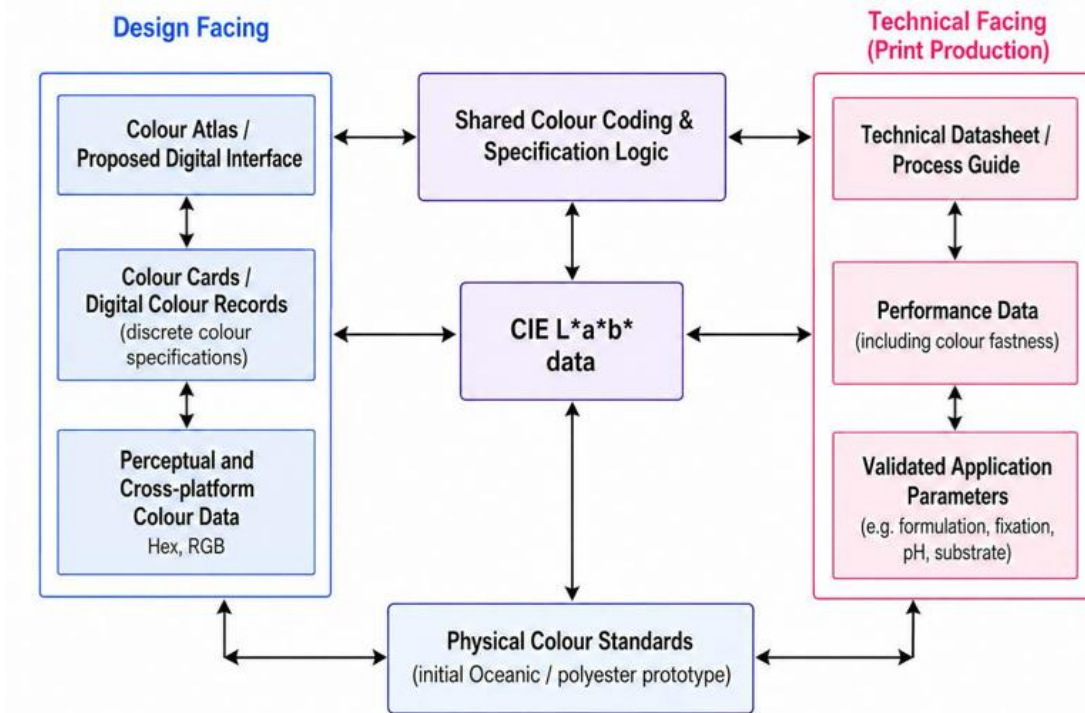


Figure 4. Architecture of the CMCS, linking design-facing colour navigation, shared coding, CIE L*a*b* data, substrate-specific physical standards and production-facing documentation. Double-headed arrows indicate traceability and interdependence. The digital interface and records are proposed; selected atlas pages, physical standards and the documentation logic were prototyped.

The proposed CMCS architecture comprises four main components:

- A perceptually organised colour atlas, developed through digital page layouts and selected prototype pages, designed to enable designers to browse available microbial colours by hue, lightness and chroma. This structure draws on Munsell-informed colour ordering while retaining CIE L*a*b* data as the industrial measurement backbone.
- Physical colour standards printed on validated substrates. These standards provide substrate-specific physical colour references that are more reliable than screen-based colour alone for both design and technical users.
- A production-facing documentation structure linking each colour to its validated application and performance data.
- A proposed digital architecture through which users can search and filter colours by visual, substrate, technical criteria and eco-credentials.

Together, these components define an integrated colour specification and application architecture intended to link visual selection to the information required for reproducible production.

As shown in Figure 4, these components do not operate as separate outputs. The shared CMCS code provides traceability between a design-facing colour selection, its physical standard, its measured colour data and the corresponding production-facing documentation. CIE L*a*b* data provide the

common measurement layer, while the physical standard retains the substrate-specific colour appearance that cannot be communicated reliably through digital colour alone. The atlas design and documentation logic were developed through the research, whereas the fully searchable digital interface remains proposed for future implementation.

4.3 Initial CMCS prototype implementation

In this paper, the initial CMCS prototype refers to a partial implementation of the architecture comprising digitally designed atlas pages, selected physical textile standards and linked technical documentation, populated with validated Blue and Pink colour data generated on the selected 100% polyester substrate. As shown in Figure 5, the prototype brought together selected design-facing atlas pages, physical textile standards and linked technical documentation. Shared coding connected each colour sample to measured colour and validated application data. The prototype was used to test the system's organisation and the proposed continuity between design- and production-facing information; it is not presented as a finished colour volume or digital tool. Its restricted colour range reflects the current extent of validated microbial colour on this substrate rather than the full potential gamut of microbial colouration.

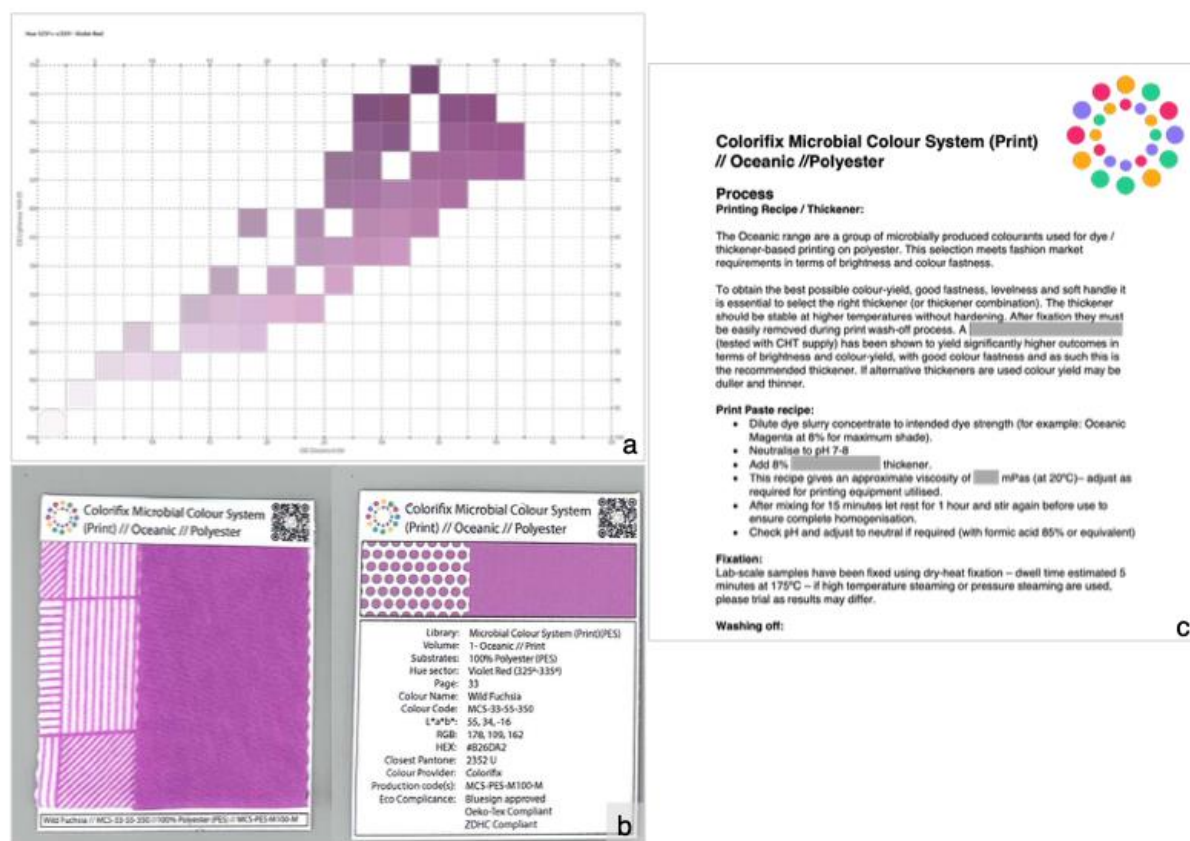


Figure 5. Selected components of the initial CMCS prototype: (a) design-facing atlas page organised by hue, lightness and chroma; (b) substrate-specific physical colour standard linking the textile sample to its CMCS code and measured values; and (c) associated technical datasheet. Proprietary formulation and processing details are partially redacted.

4.4 Colour specification, production translation and prototype scope

In a proposed CMCS use case, a designer selects a colour from the atlas using its physical textile standard and CMCS code. The same code links the production partner to the corresponding substrate, formulation, fixation and performance data. A strike-off can then be produced and compared with the physical standard and measured CIE $L^*a^*b^*$ values within an agreed ΔE tolerance before approval or adjustment.

The colour standards available within this workflow are drawn from the empirically validated Blue–Pink colour space shown in Figure 6. The plot defines the chromatic range represented within the initial CMCS prototype on the selected polyester substrate.

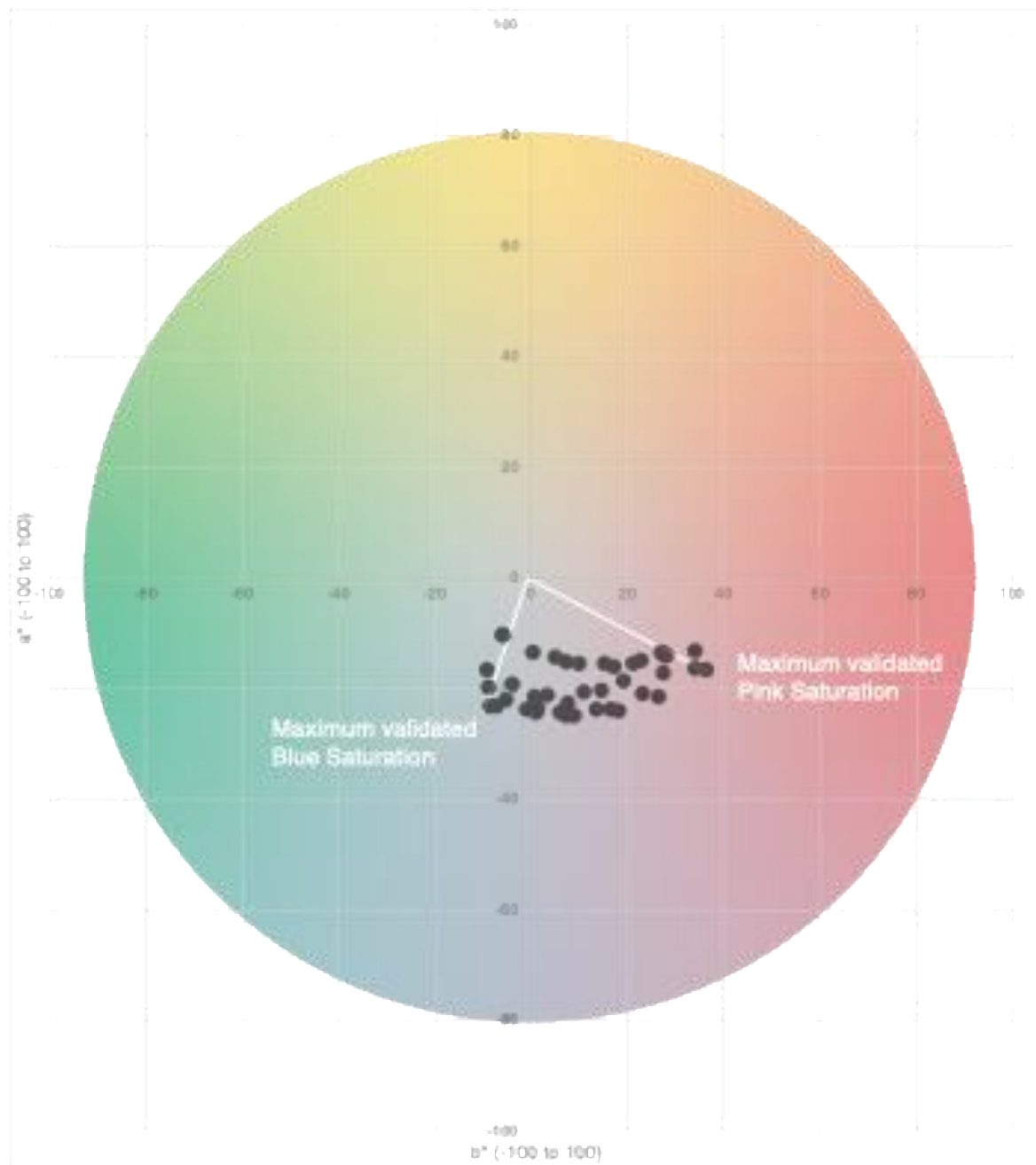


Figure 6. Two-dimensional CIE $L^*a^*b^*$ a^*-b^* plot of validated Blue, Pink and mixed colour samples on the selected 100% polyester substrate. Endpoints indicate maximum validated saturation. The plot represents the prototype's chromatic range; lightness variation and the wider potential microbial gamut are not shown.

The plot shows mixed samples bridging the Blue and Pink anchors within the negative b^* region, with greater extension towards positive a^* because Pink achieved higher chroma than Blue. Its asymmetry therefore records the measured capacities of the two colourants and the non-linear behaviour of their mixtures, rather than a geometrically uniform colour space.

The restricted colour range is a deliberate boundary of the prototype rather than simply a limitation. Existing synthetic dye systems can offer broad, highly populated colour libraries because they draw on more than 150 years of development in dye chemistry, formulation and industrial application (Barnett, 2007; Gordon & Gregory, 1983). By contrast, the prototype reflects the current state of the microbial colour technology and includes only colours supported by the validation evidence presented here. This produces a limited colour space but prevents unsupported colour claims. The modular architecture allows further colourants, substrates and process routes to be incorporated as they are validated. Continued development within Colorifix is already extending the validated colour range, showing how the workflows and architecture established through the research can support the ongoing population of the CMCS.

5. Discussion: Evaluation, positioning and future development

5.1 Evaluation through design-led testing and expert review

The CMCS architecture and prototype were reviewed through six expert interviews involving seven industry practitioners in November 2025, alongside internal Colorifix stakeholder review and three design-led textile-printing projects. Participants were selected to represent expertise across technical colouration and dyehouse operations, CMF and colour strategy, commercial development, digital colour management and brand-side production. Each interview combined a visual presentation of selected design-facing atlas pages, technical documentation, physical colour standards and the proposed digital architecture with structured prompts and open discussion. Responses were compared thematically, and refinements were implemented progressively across the interview sequence in four areas: technical documentation, design-facing navigation, physical reference standards and digital integration.

The design-led projects tested whether validated colour relationships could be translated from isolated swatches into composed and larger-format textile outcomes (Figure 7). They examined colour selection, combination and application rather than designer-to-manufacturer communication or full industrial implementation. Together, these activities informed refinements to the atlas organisation, coding structure and production-facing documentation.

Across the three projects, the physical standards and linked records supported the selection and recombination of validated colours in mixed and overprinted compositions. Larger-format trials demonstrated that the system could inform composed textile outcomes, while exposing refinements needed in atlas navigation and documentation rather than constituting full production validation.



Figure 7. Design-led testing during CMCS development: (a) printed samples combining colours within the validated Blue–Pink range; and (b) larger-format printed textile lengths. These projects informed system refinement but did not constitute full industrial implementation.

The recurring findings from the expert review and the resulting refinements to the CMCS are summarised in Table 4.

Table 4. Expert-review findings and resulting CMCS refinements.

Area reviewed	Expert-review finding	Resulting refinement
Technical documentation	The overall documentation structure aligned with established industry expectations, but production instructions and performance reporting required greater precision and transparency	Wash-off and fixation guidance was simplified; unvalidated additives were removed; neutralisation to pH 7 was standardised; full ISO 105 test codes and individual multifibre staining values were added; and shade strengths were expressed more clearly through stock-concentration percentages and depth-equivalent descriptions
Design-facing colour communication	Relationships between anchor colours, intermediate mixtures and modelled colours were not necessarily intuitive to non-technical design users	The atlas was revised to communicate colour relationships more clearly, using a more unified visual language while retaining explicit identification of validated and modelled shades
Physical colour standards	Physical textile standards were considered essential, but their opacity, durability, handling and compatibility with established industry formats required improvement	Standards were reformatted using double-thickness polyester, single-edge mounting and non-fluorescent adhesive; visual colour information was separated on the front from substrate, measurement and technical information on the reverse; and production and review dates were added
Digital architecture	Practical use would require nearest-match searching, substrate- and performance-based filtering, differentiated access for design and production users, and future visibility within existing digital workflows	These requirements were incorporated into the proposed digital architecture through ΔE -based nearest-match search, filtering, role-based access and provision for future integration with PLM and established colour-management systems

Overall, the expert review reinforced the CMCS's alignment with familiar textile colour-system conventions and indicated that the dual-audience architecture was relevant to connecting design-facing colour selection with production-facing specification.

5.2 Positioning within existing colour workflows

The CMCS is intended to operate alongside existing colour tools rather than replace them. Pantone may remain useful as a familiar design-facing reference, and nearest-match Pantone references could support communication between designers, brands and production partners. However, mapping a microbial colour to a Pantone reference would communicate only an approximate visual target. It would not provide the validated substrate, formulation, fixation and performance information required to reproduce that colour using a microbial colourant. The CMCS could therefore work alongside Pantone in the same way that design-facing colour references already work alongside supplier-specific textile colour systems.

CIE L*a*b* measurement and Datacolor or X-Rite workflows provide the technical means to measure, compare and control colour, but they do not themselves contain microbial-specific application knowledge. The closest functional precedents for the CMCS are therefore supplier-specific textile colour systems such as the Archroma Colour Atlas, which connect physical colour standards with colourant- and application-specific information. The CMCS adapts this supplier-system logic for microbial colourants, while also drawing on Munsell-informed perceptual organisation and established instrumental colour measurement. Its contribution lies not in replacing existing colour tools or proposing a new universal method of colour organisation, but in structuring validated

microbial colour, substrate, process and performance data to support colour selection and provide a pathway towards production through recognisable textile workflows.

5.3 Limitations and future development

The CMCS is best understood as an emerging infrastructure rather than a complete industrial colour system at this time. This research establishes its architecture and an initial prototype populated with validated Blue and Pink colour data generated on one selected 100% polyester fabric substrate. Further development into a functioning industry tool will require the validation of additional colourants and substrates, digital implementation, and continued investment in system population and maintenance.

The current stage of development has three main limitations. First, it is based on two validated microbial colourants, Blue and Pink, producing a colour space concentrated in blue, violet, purple and pink regions rather than a full spectrum. Yellow was investigated but could not be validated within the shared process route required for inclusion in the initial prototype. Second, the prototype is based on a single validated 100% polyester fabric substrate; future substrate-specific colour volumes will require additional testing through the same print-validation framework. Third, although the architecture has been evaluated through design-led practice, stakeholder review and expert feedback, it has not yet been implemented widely across the textile supply chain.

These limitations define the next stage of development of the underlying architecture. A microbial colour system should not represent colours that cannot be produced under validated and reproducible conditions. The modular architecture can expand as additional colourants, substrates and process routes are validated. Wider supply-chain testing will then be required to evaluate usability, specification accuracy, production translation and integration with tools such as Datacolor, X-Rite and product lifecycle management systems.

6. Conclusion

This paper has argued that microbial colour adoption depends on information infrastructure as well as material innovation. Successful fermentation does not alone make microbial colourants ready for industrial textile use; validated application knowledge and supporting infrastructure are also required.

The Colorifix Microbial Colour System begins to address this gap by defining an architecture through which validated knowledge of microbial colour behaviour can be translated into design- and production-facing information. Developed through practice-led textile-printing research, the CMCS demonstrates how validated colour and application knowledge can be organised to make microbial colour legible within industrial workflows.

The research establishes a foundational CMCS architecture and an initial prototype implementation rather than a complete operational system. The prototype is limited to two validated colourants, one 100% polyester fabric substrate and one primary process route. However, this clearly defined scope is also a strength: it contains only colours supported by empirical validation. As Colorifix validates additional microbial colourants and process routes, the architecture can be populated through future substrate- and process-specific colour volumes. In this way, the research positions textile practice as a method for generating and organising textile application knowledge, and colour-system design as an important enabling condition for the industrial adoption of microbial colouration.

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