RETHINKING THE LIFESPAN OF TEXTILES: A FRAMEWORK FOR SUSTAINABLE MATERIAL DESIGN BASED ON ENHANCED MULTIMODAL ATTRIBUTES.

Delia Dumitrescu*[a], Erin Lewis[a], Riikka Talman[a]

a The Swedish School of Textiles, University of Borås, Sweden
* delia.dumitrescu@hb.se

DOI: 10.63442/RDPD9400

KEYWORDS | MATERIAL DESIGN, RESPONSIVENESS, PRODUCT AESTHETICS, SUSTAINABILITY

ABSTRACT | Sustainable design thinking challenges perspectives on approaches to material development that are considerate of resources from the natural environment. This involves limiting energy consumption and re-purposing materials' use, qualities, and functions for an extended life span. Using a practice-based research methodology, this research proposes an alternative framework for sustainable textiles with a strong emphasis on designing a material's expressive qualities related to its extended use values: co-creation and wear. The experimental practice looks at the interplay between a material's inherent properties and its craftmanship, as well as aesthetic and expressive values which could extend the duration of use. The research takes a bottom-up approach to sustainable design thinking and exemplifies the design of diverse material strategies through a curated library of responsive textile expressions. The responsive textile samples developed in this research illustrate rich ways of responding and adapting to user actions and their environmental surroundings. The textiles' extended multimodal attributes suggest an alternative framework to design for prolonged lifespan, and exemplify materials that enhance daily life by conserving energy and allowing for customization and location-specific applications.

1. Introduction: A Role of Material Design in the Development of Sustainable Design Thinking

Materials, serving as raw matter for the design of products and spaces, represent our physical interface to the surrounding man-made world, from body to architecture. Similar to the ubiquitous role of technology in our lives, the function of proximate materiality can be termed by using Verbeek's (2004, p.200) descriptions as both pragmatic and hermeneutic. The notions he introduced imply dual values: as a mediator of people's presence and actions in the world, and as a mediator of how reality is presented to us when informing our experiences of the surrounding world. Like technology, the presence of materials is essential in shaping our interactions with artifacts and influencing our daily activities and behavior in the world.

From the perspective of the designer's practice, the value of materials encompasses a range of dimensions from technological development to craftsmanship and artistic expression. Moreover, exposed to use and user's actions, the material transcends the disciplinary borders of the design profession, moving towards the methodology of other disciplines–social sciences. In the context of sustainability, Corbin (2018) refers to the fluid roles materials can play in communicating and connecting diverse knowledge domains across disciplines: art, science, engineering, and social sciences. Designing for sustainability is a dynamic concept that initiates in the technical and product-centric perspective and evolves by integrating the synergy of social and ecological systems (Ceschin and Gaziulusoy, 2016). Thus, seen bottom-up from and outside the design practice, the place of materials in influencing a systemic approach towards sustainable design thinking tackles different aspects of technology, function, expression, human behavior, and empathy for nature.

2. Designing for Extended Lifespan

2.1 Reflections on Product Aesthetics

The enormous amount of resources employed to develop, design, produce, and commercialize products that support and enrich our lives accentuate the importance of looking at the surrounding materiality through the perspective of designing and producing for longevity rather than obsolescence and waste. The length of the life span and obsolescence of the textile products we use depends on the interlace of material qualities, for example, intrinsic raw properties and technologies, as well as immaterial qualities such as aesthetics and emotional values. Design decisions play an important role in influencing the shape and use of objects that surround us. The basic principles for circular design proposed by the Ellen McArthur Foundation (2024) refer to three categories of placeholders: eliminate: focusing on the appropriate material choice with consciousness to the environment; regenerate: using the bio-based material properties to reintegrate them in nature, and third element refers to circulate: keeping the materials in use at their highest value by expanding their life span to the maximum through emotional durability. Moreover, referring to causes of product obsolescence, Packard (c.f. Burns., 2016, p. 42) describes products as being influenced by three fundamental criteria that link to emotional durability: function, quality, and desirability. Even minor technological improvements of newly realized products open the curiosity of use, transforming the existing objects into obsolete ones. As a result, the fast-paced wear of products generates an obsolescence of quality. Referring to the emotional value of products, Packard introduces the term "psychological obsolescence," which refers to the outdated expressions or styles of products that also influence their desirability.

The need for designing for an extended lifespan rather than obsolescence has opened questions regarding the forming of alternative sustainable systems of thinking applied to material design and innovation. This approach views design not only as a problem-solving process but as an innovative approach. It encompasses new territories of understanding for design through expressive dimensions, methods, tools, and skills, as well as behaviours, use, values, alternative consumption and a systemic thinking (Harper,2018; Manzini, 2009))To some people there is no such thing as a sustainable material, rather it is the use of a material that introduces a sustainable advantage (Thackara, 1997) and it connects to the designer's choices to design for an extended life span. As he describes:

> "Design for sustainability means fostering innovation – not just in products and services, but in work methods, behaviors, and in business processes. This takes designers into uncharted territory; they need new tools, skills, and understanding." (Thackara,1997, p.14)

Hence, there is a need for new ways to approach sustainability as Thakara emphasizes, not just a problem-solving process but from an innovative perspective, that opens new territories of understanding for the practice of design.

The importance of changing perspective by designing for durability and longevity is a strategy pioneered and promoted by the Eternally Yours foundation (van Hinte, 1997). The foundation addresses the importance of designing for an extended "'psychological life span': the time products are able to be perceived and used as worthy objects" (van Hinte, 1997, p.19). Preoccupied with the extended length of the lifetime of products through use and dignified ageing, Hofland (van Hinte, 1997) makes the distinction of two stages to consider in durable design: First, cherishable objects as being cared for and appreciated, and second having a nostalgic value to the user. He emphasizes that nowadays, due to the continuous development of technologies, product development focuses on adding new functions, a development strategy that swiftly transforms products into obsolete objects without ever reaching the cherishable stage. Inspired by the ideology introduced by the Eternally Yours, Materially Yours (Karana, et al, 2017) proposes an alternative framework for sustainable material design with a prolonged life span. In the vision proposed by the researchers, undesired aesthetic qualities such as imperfection become desired in the material design. In addition, the framework proposes new processes that imply the use of more democratic tools and open for the experiential engagement of the designer in the making, together with proposing more open relations between materiality and functionality of objects in daily life.

Another complementary perspective regarding the longevity of use as a response to aesthetic obsolescence is introduced by Chapman (2005). One of the design strategies he proposed in Emotional Durable design refers to the importance of designing complex objects. In his vision, the multiple layers of narratives embedded in objects open for the user's continuous curiosity of discovery. From this, it is understood that complex aesthetic experiences embedded in the design of objects extend the time of discovery and generate new temporal dimensions in relation to use.

Further addressing the temporal dimension of products, Harper (2018) analyzes the role of time expression when designing sustainable products. Reflecting on the expression of time embedded in the character of the artifact, Harper suggests viewing the aesthetics of objects as 'containers of time' can be a method of building durable relationships between users and objects, thereby increasing the importance of the aesthetic dimension in designing sustainable artifacts. The notion of time in product design links the user to the aesthetic dimension of objects as an expression of the quality of craftsmanship, expression of use, and wear, and through the prolonged aesthetic discovery embedded in the design.

2.2 Rethinking Life-Span in Textiles

In the field of textiles, the life span of textile products is relatively short. The rhythm of use, which combines slow and fast paces, depends on the symbolic relation created between the wearer and the garment as a matter of clothing or fashion, as defined by Fletcher and Tham (2004). The durability of the material and expression do not always align, causing a shortening of the life span of textile products (Goldsworthy et al., 2018).

Thus, mass production and the shortening length of life of materials for garments and interiors have created an assiduous search for alternative systems of thinking, starting from the design of material properties to craftsmanship, production, consumption, and end-of-life disassembly and recycling of textile products (Fletcher, 2014; Bigolin et al., 2022). Niinimaki and Lassi (2011) open the discussion on the need for a systemic change in the textile and fashion business to become sustainable. The proposed change is inclusive, based on real needs and values that demand more engagement from the consumer. This can be understood as an active value creator in the material design chain. Thus, in the framework recommended by Niinimaki and Lassi, new strategies for design should be founded on and include values such as use, emotion, culture, society, and customization.

In the field of responsive and innovative materials, sustainable design thinking introduces alternative perspectives on how to tackle material development in a way considerate to the resources of the natural environment by limiting energy consumption and re-purposing material use and function for a prolonged life span. In this context, textile systems capable of responding and adapting to their environmental surroundings could offer sustainable alternatives to daily living that source and preserve energy, are more locally obtained, and offer multiple possibilities for customization and location-specific applications. Thus, designing textiles with changeability of expression can be a way of extending an emotional bond between a textile object and the user, as well as “a way of creating the potential for durability and aesthetic sustainability” (Harper, 2018, p.85).

Exemplary works in the textile research field introduce alternative perspectives on textile products' lifespan by placing the design of the material changeability in focus and envisioning alternative scenarios of use. The design of temporal textiles expressions with irreversible colour changes, which are created by plant dyes on textiles without the use of mordants, is investigated by Worbin (2013). Signs of ageing, use, and degradation transform the quality of wear as a value rather than a criterion of obsolescence, thus expanding the life span of garments. By exploring the richness of the color palettes achieved by different plant mixtures and by analyzing the perceived transformability of colours on yarns and fabrics, the project proposes an alternative way of using and perceiving changeable colours on textiles. Compared to conventional views, which look at colour durability as a desired quality of textiles, irreversible colour expressions are those that fade and evolve over time due to exposure to natural light and use. The collection of garments that emerge from Worbin’s research is designed from the initial stages of the process with the intention to evolve over time. It aims to change preconceptions on the performance of colour and textiles in use by generating acceptance to natural transformability over time.

Keune (2017) proposes another view on the design of transformable textile expressions and use. The transformability of textiles is designed by embedding seeds as active natural materials into woven textile structures. The temporality of the textile expression is dependent on the agency of the raw material used with a specific temporal frame to grow, mature, and decay. The user’s involvement and autoethnographic approach become part of the transformation process, ensuring the maintenance of the textile pieces through the management of necessary nutrients for supporting plant growth and appropriate exposure to light sources. The temporality and life span of textile transformation and use determine the transformation of the interiors and their daily experience, which depend on the properties of plants grown in the textile structures and natural seasons.

Sustainable design thinking challenges perspectives on how to approach material development in a way that is considerate of the resources of the natural environment and influence a prolonged use. This may be by conserving energy and re-purposing materials, qualities, and functions for an extended life span. As the research examples demonstrate, alternative uses and life spans that can be generated by the responsive expressions of the emerging bio-based raw materials (Karana, et al., 2017), natural dyes (Worbin, 2013) and active natural materials, for example, seeds (Keune, 2017). Using a similar research methodology based on material exploration, this research aims to start with a bottom-up process to expand the material palette of responsive material systems using the agency of the natural environment and user’s actions. Furthermore, the research aims to speculate on diverse design strategies for an extended life span of responsive textiles. This is based on the creation of expressive ways of responding and adapting to user actions and their environmental surroundings.

3. An Experimental Approach

3.1 Method

In order to address the challenges of designing for alternative textile/material life span, the research presented in this paper uses an experimental research methodology (Bang and Eriksen, 2014) and explores the design of responsive textile material systems through the lens of textile design methods. Material prototyping was used here as a method to give a tangible dimension to the ideas contained in the research program and to speculate on the possible scenarios that these materials can inspire. The research began with near-field design at the structural level of textiles using techniques of weaving and knitting. This approach enabled an experiential understanding of the capabilities of the raw material and allowed for speculation on possible scenarios for sustainable making and use of textiles.

Experiments are formed around two primary placeholders: First, extending the material expressive dimension by exploring the intrinsic value of the raw material agency and the appropriateness of craftmanship; and second, speculating on the use dimension by exploring the value of aesthetic discovery embedded in the material design through co-creation and natural phenomena. The prolonged longevity of a material's use is a quintessential dimension for the decisions taken in each sample in the making and design and is informed by the aesthetics of material transformation and use. In the creation of textile samples, we combined reactive yarns (UV rays, PH with conventional textile raw material yarns (wool, cotton, and paper) to explore their relation to the agency of natural phenomena (i.e. UV rays) and how they affect the expression of textiles.

As a result, a material library is developed to present alternative perspectives on sustainable transformative textiles that change their expressions due to environmental stimuli rather than using energy-driven electronics. The material library illustrates different design methods that explore material responsiveness in relationship with the variation of expression as valuable dimensions for proposing alternative life spans. The experiments presented explore methods for designing the expressions of textile materials to vary over their lifespans through changes in colour and light emission in structural textiles triggered by natural phenomena or user's action. In doing so, ambient energies and considerations of use are incorporated into the design process.

The experiments investigate two types of lifespans: one involved gradual, irreversible colour changes created using the varying properties of fibres, and the other involved reversible colour changes created using UV-responsive yarns that change colour from white to another colour when exposed to UV rays and then back again when no longer exposed to them.

3.2 Exploring the Influence of Natural Phenomena on Textile Expressions Over Time

Designing with Nature: Experiment 1

Gradual, irreversible changes were explored using woven fabrics that had been dyed by taking advantage of fibre properties and using naturally occurring dyestuffs such as organic matter and minerals in the seawater (Talman, 2018). Thus, Jacquard-woven fabrics were exposed to these dyestuffs for varying lengths of time in order to explore the range of colours created. The materials used were selected based on differences in susceptibility to various types of dyestuff and expected lifespans when used in fabrics, and included cellulose-based cotton and paper, protein-based wool, and petroleum-based polyester yarns. These materials absorbed different pigment particles, leading to them reacting differently when exposed to the same dyestuff or environmental conditions.

The influence of exposure to ambient stimuli on the expression of textiles was explored by placing samples of Jacquard-woven fabrics made using wool, paper, polyester, and cotton yarns out environment. One set of samples submerged in the Baltic Sea. Later, the samples were reproduced in the lab using similar water conditions to test if we could replicate their change (Fig. 1). The samples were exposed to various agents such as minerals, soil, and water, as well as fluctuations in temperature for two months, after which inspection showed that the fabrics had developed a specific colour scheme depending on the environment they had been placed in. The samples that had been submerged in iron-rich water had taken on a range of stronger shades of brown orange and light yellow towards green shades, with the wool yarn also being dyed towards dark brown. The overall surface design of the textile has been altered due to the occurrence in the foreground of the dominant triangular shapes as repeated patterns (Fig. 1). Activated by the conditions in the water, the triangles were capturing the colour in an uneven way that enhanced the depth of the final surface expression.

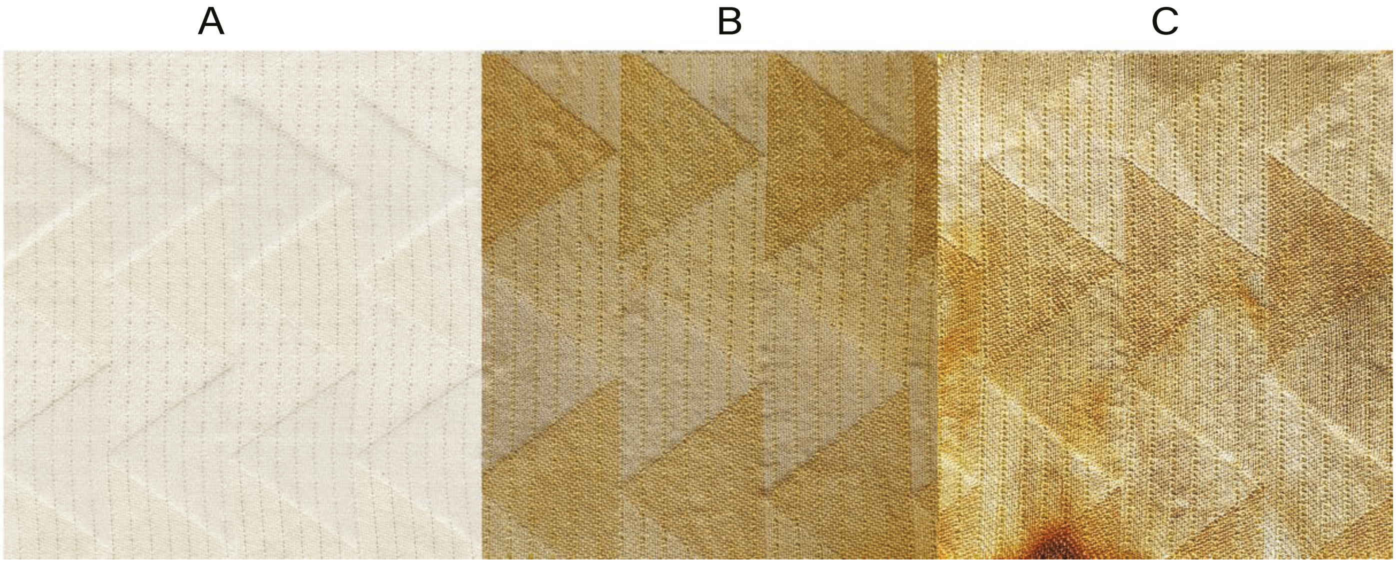

Figure 1. The transformation of the textile design into various color schemes after the exposure to changing water conditions that are rich in iron similar to the iron-rich areas of the Baltic Sea.

Co-designing with Nature: Experiment 2

In the second experiment, colour changes brought about by long-time exposure to natural conditions were explored by placing plain wool/cotton and paper/cotton textile samples along with patterned, Jacquard-woven samples made in wool, paper, polyester, and cotton in closed jars together with different kinds of food waste for a period of several years. At the time of writing, the experiment was on its eighth year and still ongoing. Four of the jars were prepared with plain wool/cotton and paper/cotton textile samples at the bottom and vegetable peels, lingonberries, a banana, and an orange, respectively, were placed on top of the textile samples, and two of the jars had patterned, Jacquard-woven textile samples made of wool, paper, polyester, and cotton yarn placed at the bottom and vegetable peels and coffee grounds, respectively, on top of the samples. The samples were photo-documented after three years, and again after seven years without removing them from the jars (Fig. 2). After three years, the foodstuff had dyed the fabrics in varying shades ranging from red (Fig. 2, row 6: the jar with lingonberries) and orange (Fig. 2, row 2: the jar with vegetable peels) to brown (Fig. 2, row 1: the jar with coffee grounds). The textile samples placed together with the banana and the orange displayed the smallest change (Fig. 2, rows 4 and 5, respectively). After seven years, the colours of all textile samples had faded and were tinted in shades of brown (Fig. 2, column 4). In all samples, the wool yarn had acquired the most colour. It should be noted that there was practically no mould in the jars, which was likely due to the jars having been thoroughly disinfected prior to being prepared.

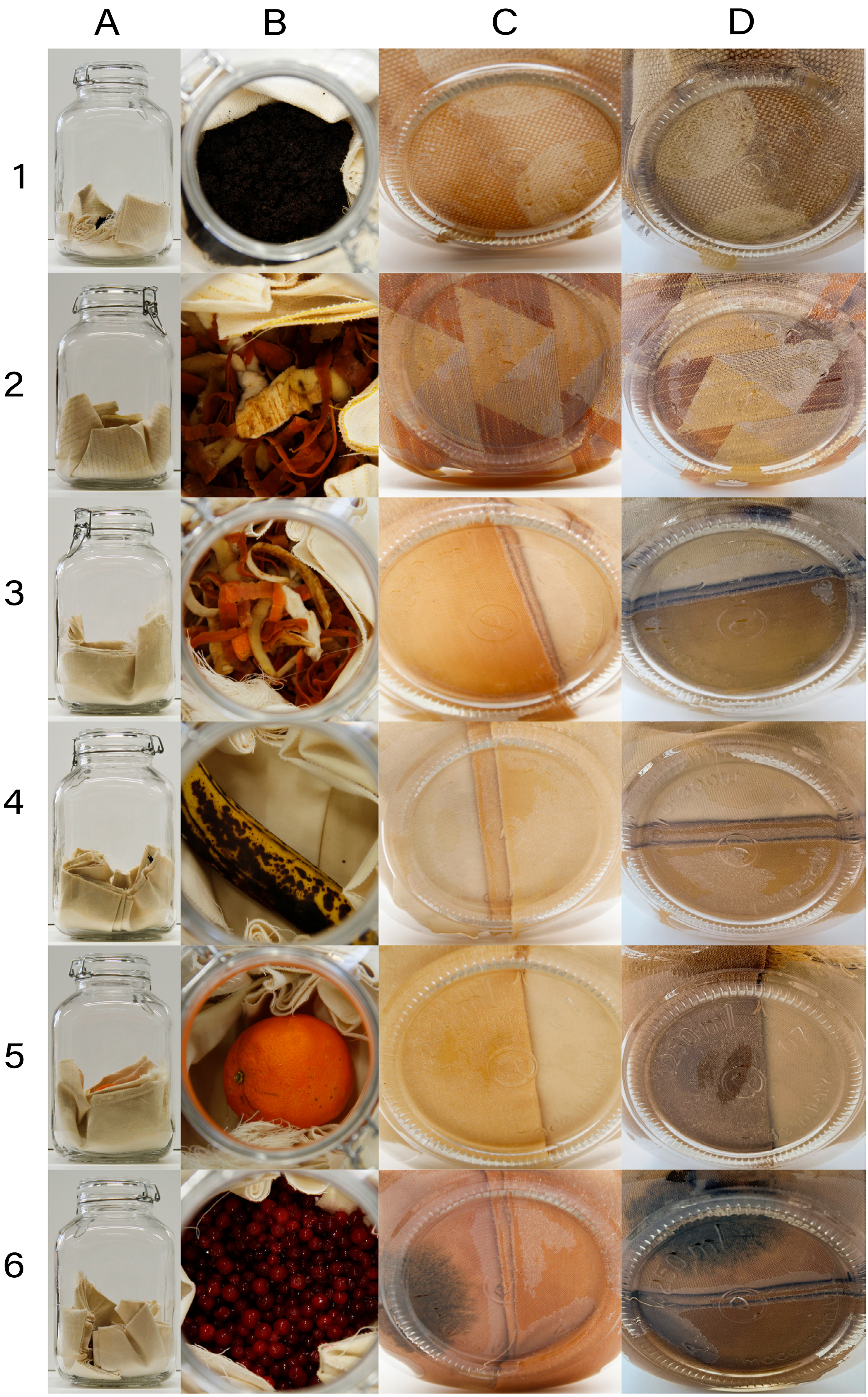

Figure 2. Experiments showing the variation in color on textiles after exposure using fruits and food waste.

3.3 Exploring Recurring Changes Over Time in Response to Ambient Stimuli

Extending the Aesthetic Discovery with Responsive Materials: From Mono-Changes to Multimodal Changes

Mono-Changes: Experiment 3

Short-term, recurring changes were explored using UV-reactive, colour-changing, and light-emitting yarns, which react to the ambient energy of sunlight and therefore change their expressions in outdoor contexts depending on UV intensity. Using yarns in which the colour changes were reversible allowed the creation of textiles that had different expressions in daytime or nighttime, and the UV-reactive, colour-changing yarns changed colour from white to another colour when exposed to UV light, and then back to white again when no longer exposed to light. The light-emitting yarns recharged when placed outdoors, even when not exposed to direct sunlight, and emitted a yellowish glow that was visible in the dark and which lasted for several hours. The UV-reactive colour-changing yarns were made of polyester and had different lengths of life. The photochromic pigments used in colour-changing yarns have a relatively low lightfastness, meaning that over time the dynamic effect decreases and the yarns cease to react to UV stimuli. More durable alternatives based on natural hackmanite crystals exist but are not yet commercially available in yarn form. The photoluminescent pigments used in the light-emitting yarns are harmless to the environment and have exceptionally long lives, as their light-emitting properties either do not deteriorate over time at all or do so to a lesser extent.

The textile samples used in the Experiments 3 were created using Dubied hand-knitting machines and computerized ARM handlooms. The knitted samples explored the effect of UV-reactive colour-changing yarns (Fig 3). Delicate lines of different colors occur in the knitted as exposed to the UV value of daylight. The colour effect is stronger in direct sunlight. When activated, lines of different colours enhance the three-dimensional expression of the knitted shape.

Figure 3. Emerging color changes patterns in knitted structures.

The second series of experiments were woven on a computerised ARM loom. Experiments 4 explored gradient colour effects created by varying the proportion of materials used, as well as weft-warp thread ratio (Fig. 4) in order to create a smooth gradient colour effect that went from relatively low to relatively high light intensity.

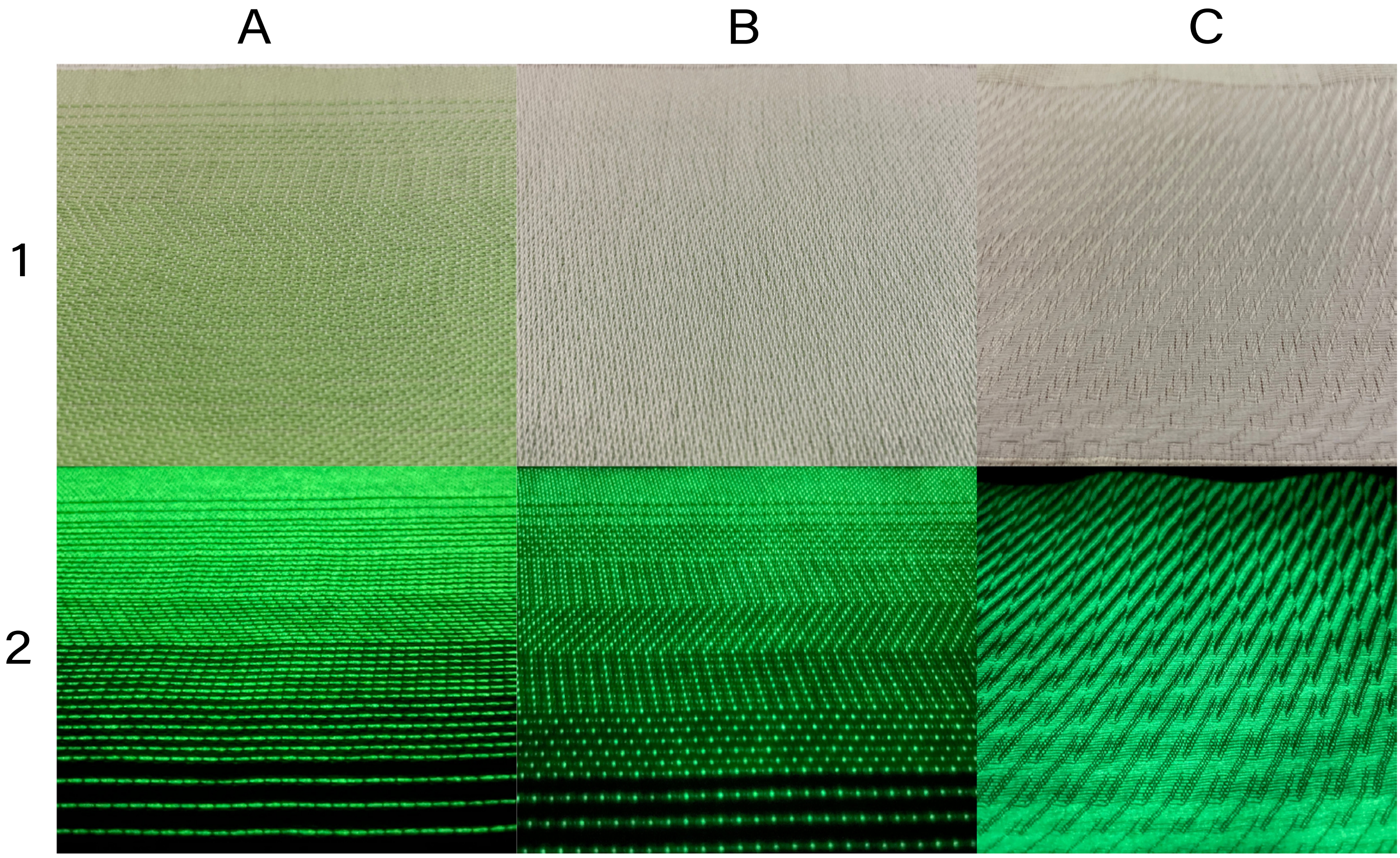

Figure 4. Emerging expressions of the UV-graded patterns in different woven structures.

Dual Changes: Experiment 4

Experiment 4 explored different methods of enhancing the light intensity of the light-emitting yarn and making less prominent the line pattern it created in its inactive state. White paper yarn reflected some light, enhanced the glow effect, and slightly diffused the lines of light created by the light-emitting yarn (Fig. 5, column 1, row 1). Two reflective yarns were also tested, but the intensity of the light emitted by the light-emitting yarn was not strong enough to activate them, therefore they appeared to be black in the dark, which enhanced the contrast in the striped pattern (Fig. 5, column 1, row 2). Reflective yarns could, however, be used to make the fabric visible in the dark when struck by strong light, such as the headlights of cars. To enhance the intensity of the emitted light and disrupt the pattern of the textile, two polyester Lurex bands with metallic coating were used, one of which was a matte gold colour and the other a shiny silver (Fig. 5, column 3, row 1). These gave a subtle shine and texture at close range but were not visible from a distance (Fig. 5, column 3, row 2). An attempt to change the colour of the yellowish glow of the textile sample was made by placing light-emitting yarn between two layers of the transparent, red plastic band; this did not change the colour of the glow, however, and the only effect produced was the glow becoming dimmer due to the red plastic band blocking the light emitted by the light-emitting yarn (Fig. 5, column 3, row 2). In addition, water-soluble polyvinyl alcohol (PVA) and heat-dissolving thermoplastic copolyamide (coPA) yarns were used as auxiliary materials to enable layers of materials in the woven textile samples to be separated from one another. Both PVA and coPA yarns and their residual waste products are harmless to the environment.

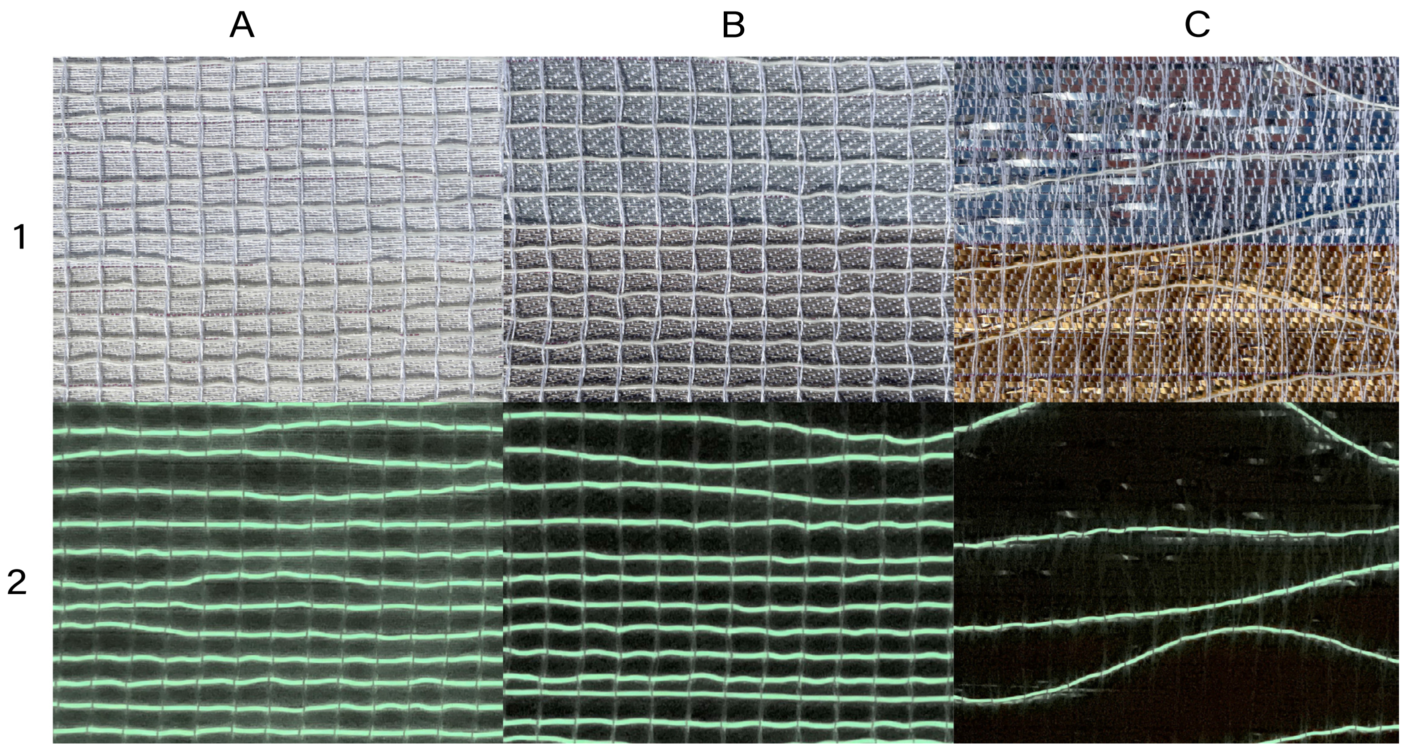

Figure 5. Details of the material layers in the structural design woven design that are seen in the daylight and night time.

Multi-Modal Changes: Experiment 5

Experiment 5 (Fig. 6) is focused on the development of multi-modal expressions that are triggered by the appearance and intensity of UV light. The sample is a mono-material textile based on polyester yarns with different charging capabilities. The background material is knitted with heat-reactive yarns. When exposed to heat, the yarns shrink irreversibly and can keep the desired shape. An origami structure was transferred by pleating the material to demonstrate how three-dimensional shaping can be applied to the material after production. The sample is knitted in an industrial process using an inverse plating technique to apply a repeated pattern on a mesh structure.

The plated pattern is designed with three UV-reactive yarns: two color-changing and one light-emitting. During the daytime, the color-changing yarns transform from white to pink and purple, following a repeated geometric pattern (Fig. 6, B). The quality and the position of the UV light influence the intensity, gradation, and occurrence of the colored pattern on the textile surface and form. The light-emitting yarns are charged during the day and become visible when dark. The creases of the surface influence the difference in intensity of the light pattern (Fig. 6, C). The pattern activates a part of the shape, providing a new expression to the initial form. The sample aims to demonstrate how multi-modal expressions can be embedded in structural design, extending by design the curiosity of surface exploration. The rhythm of change in the pattern of the surface design has a seasonal quality that depends on the intensity of the UV light in the environment. A rainy day can trigger discrete changes in pattern, while in the summer, the color design appears with full intensity. The way the textiles are positioned by the user in relation to the window and the length of exposure determine the color changes and the accuracy of the light-emitting pattern. Changes can also be triggered by the user when using a UV lamp. In this case, the changes appear and disappear at a fast pace compared to the activation given by the natural light.

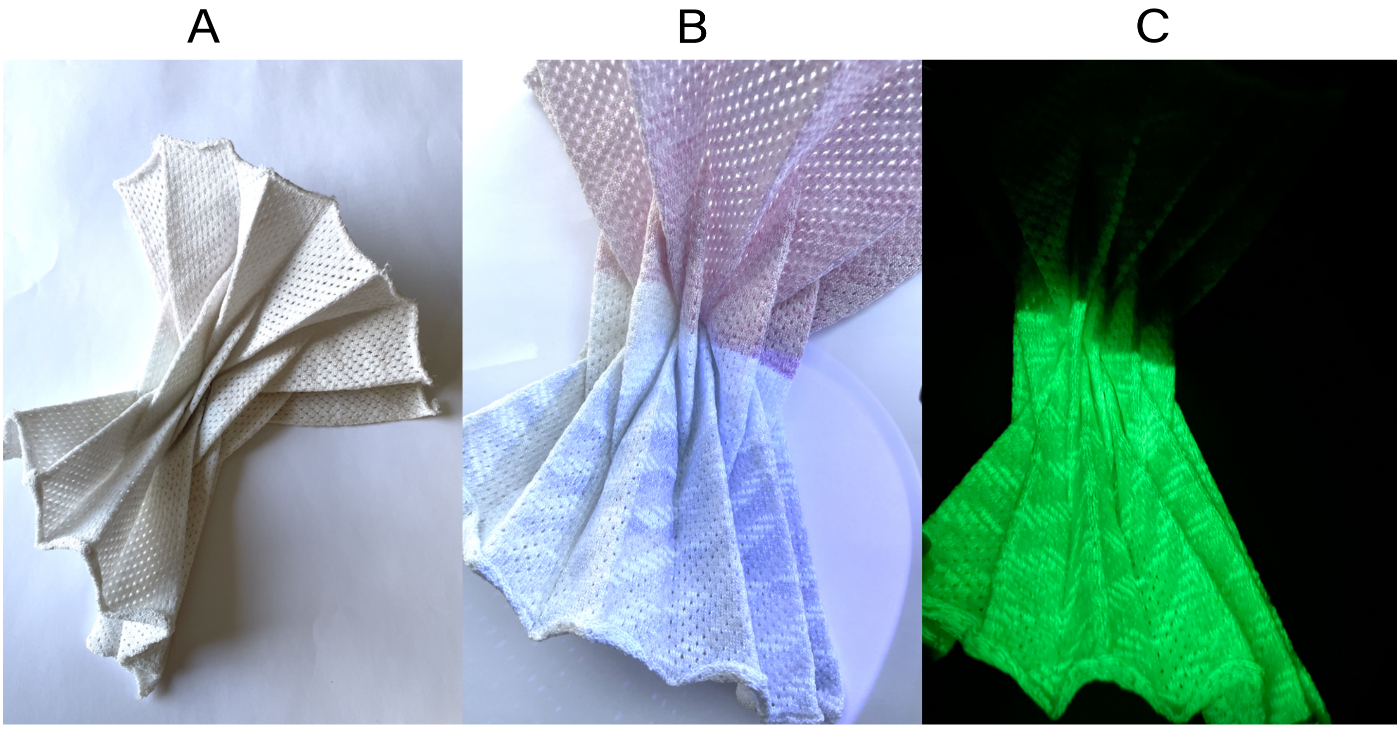

Figure 6. The changeability of textile patterns when exposed to UV light under different lighting conditions.

3.4 Summarizing the Experiments

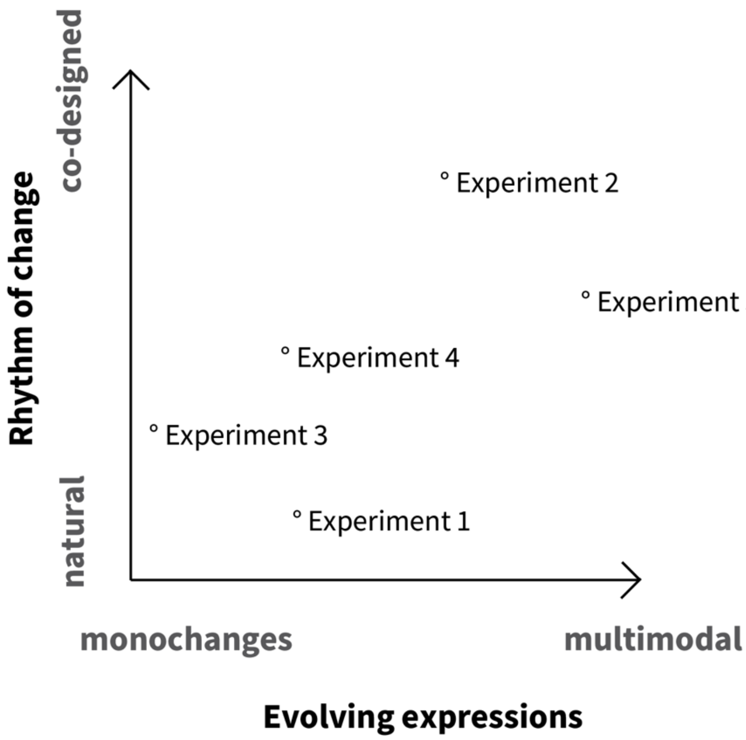

Figure 7. A graphical representation of the experiments structured according to the rhythm of change related to the evolving expressions of textile structures.

A graphical representation (Fig. 7) is proposed as a framework for the experiments to give structure to the material library. The samples are positioned according to rhythms of transformation and the variation of expressions each material embeds. The evolving expressions in each sample depend on the property of the yarns used and how the structure is designed to exhibit changes. The changes in expression can vary from dual expressions to multi-modal expressions, and the changes may be permanent or reversible. The rhythm of transformation can depend on activation triggered by natural phenomena like the exposure to UV light from the surrounding environment (as in Experiment 3) or the conditions of water such as the presence of bacteria, minerals and the variation of PH values (as in Experiments 1 and 2). Human actions also influence the rhythm of change by manipulating the material surface (as in Experiment 4), varying the material placement in the environment (as in Experiment 5), or by using the agency of the environment to co-design (as in Experiment 2) in the textile using natural or artificial triggers for change.

4. Discussion: Expanding Sustainable Material Systems

For years, material innovation in the field of textiles has been linked to smart textiles as computational materials, which are activated by electrical power. Integrated into daily living, smart textiles aimed to hide complex technology in products using the familiar interface of textiles. However, in recent years, the material paradigm shifted from digital to bio-based materials. Recent research demonstrates that transformation and responsiveness in textile materials can be achieved using bio-based matter to trigger changes through using the agency of the natural environment (Worbin, 2013; Keune, 2017; Talman, 2018). Users can be co-designers to enhance the material expressiveness by surface manipulation and wear (Karana, et al., 2017). To complement this, the textile's extended multimodal attributes presented in this research suggest an alternative responsive material system to design for a prolonged lifespan.

Using experimental research methods, the research illustrates how textile methodology and materiality can be tackled to support sustainability from a bottom-up perspective. The sample library provided by this research extends the research in sustainable, innovative textile systems by exploring the role of material expressiveness. The material library developed exemplifies alternatives to the experience of daily living that both source and preserve energy and offer multiple possibilities for customization and location-specific applications. The context of use for these textiles spans from body to space. Some of the material choices, wool and cotton linen, indicate that some textile samples are more appropriate for use in clothing, such as in the case of Experiments 1, 2 and 3. The material choices in Experiments 4, and 5, which are based on the use of man-made responsive yarns and multimodal expressions, suggest the interior as a context of use. Further, material science collaborations with design fields can innovate on bio-based smart yarns that have properties and expressions like the man-made yarns that were used in this research. This aligns with a vision of sustainable smart materials that can bring a gentler imprint to the environment and can be used in products for daily living that capture and maintain our interest over extended periods of time. A holistic approach can be further developed to combine the properties of the raw materials, their sustainability, and the emotional aspects that counter the obsolescence of expression.

Generally, in the design field, the lifespan of textiles has been discussed from a material durability perspective. In contrast, in this research, we aim to open new dialogues towards the role of design methodology and aesthetics in sustainable product development by suggesting complementary perspectives and strategies. These include the perspective of emotional durability and the strategy of generating more sustainable behaviors through understanding and direct interaction with textile materials and products. The materials proposed relate through their design of natural and man-made fibers and are used to speculate how multi-modal textile expressions can be designed, and how alternative rhythms of use can be created. Complementary to the method of Fletcher and Tham (2004), here, the rhythm of nature as an agent for change is integrated into the textile expression relating to the user's actions and mediates how reality can be presented to us when linking our daily experiences through textiles to the pace of nature. As a result, the graphical illustration proposed by this research aims to structure and characterize the materials developed. The illustration can be used as a framework by others to further develop new material ideas, for example, how responsive textiles as design materials can act as a mediator of people's presence and actions in specific geographic locations or environmental conditions.

The framework developed in this research can also be integrated in the sustainable model proposed by Ceschin & Gaziulusoy (2016) to add the textile/material perspective at the product development level. By relating in this way frameworks of different domains, cross-disciplinary approaches can be further created to expand the material domain to a systemic level. Furthermore, the strategies proposed can be integrated into the design of a broader systemic thinking model for sustainability where the product design level can be enriched, for example, by projecting the concept of emotional durability within new visions. These new visions could start at the material level and generate more personalized object interactions, services, and social innovation that expand on user understanding within its social context.

References

Bang, A. L., & Eriksen, M. A. (2014). Experiments all the way in programmatic design research. *Artifact: Journal of Design Practice, 3*(2), 4-1. https://doi.org/10.14434/artifact.v3i2.3976

Bigolin, R., Blomgren, E., Lidström, A., Malmgren de Oliveira, S., & Thornquist, C. (2022). Material inventories and garment ontologies: Advancing upcycling methods in fashion practice. *Sustainability, 14*(5), 2906, 1–22. https://doi.org/10.3390/su14052906

Burns, B. (2016). Re-evaluating obsolescence and planning for it. In T. Cooper (Ed.), *Longer lasting products* (pp. 39–60). New York: Routledge.

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design Studies, 47*, 118–163. https://doi.org/10.1016/j.destud.2016.09.002

Chapman, J. (2005). *Emotionally durable design: Objects, experiences and empathy*. London: Taylor and Francis Group.

Corbin, L. (2018). Foreword. In S. Solanki, *Why materials matter: Responsible design for a better world* (pp. 6–7). New York: Prestel Publishing.

Ellen MacArthur Foundation. (n.d.). Circular economy introduction. Retrieved February 21, 2024, from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Fletcher, K. (2014). *Sustainable fashion and textiles: Design journeys* (2nd ed.). New York: Routledge. https://doi.org/10.4324/9781315857930

Goldsworthy, K., Earley, R., & Politowicz, K. (2018). Circular speeds: A review of fast & slow sustainable design approaches for fashion & textile applications. *Journal of Textile Design Research and Practice, 6*(1), 42–65. https://doi.org/10.1080/20511787.2018.1467197

Harper, K. (2017). *Aesthetic sustainability: Product design and sustainable usage*. New York: Routledge. https://doi.org/10.4324/9781315190419

Karana, E., Giaccardi, E., & Rognoli, V. (2017). Materially yours. In J. Chapman (Ed.), *Routledge handbook of sustainable product design* (pp. 206–221). New York: Routledge. https://doi.org/10.4324/9781315693309-18

Keune, S. (2017). Co-designing with plants: Degrading as an overlooked potential for interior aesthetics based on textile structures. *The Design Journal, 20*(sup1), S4742–S4744. https://doi.org/10.1080/14606925.2017.1352977

Manzini, E. (2009). New design knowledge. *Design Studies, 30*(1), 4–12. https://doi.org/10.1016/j.destud.2008.10.001

Niinimäki, K., & Hassi, L. (2011). Emerging design strategies in sustainable production and consumption of textiles and clothing. *Journal of Cleaner Production, 19*(16), 1876–1883. https://doi.org/10.1016/j.jclepro.2011.04.020

Talman, R. (2018). Designing for multiple expressions: Questioning permanence as a sign of quality in textiles. *Journal of Textile Design Research and Practice, 6*(2), 201–221. https://doi.org/10.1080/20511787.2018.1514697

Thakara, J. (1997). Preface. In E. van Hinte (Ed.), *Eternally yours: Visions of product endurance* (pp. 13–15). Rotterdam: 010 Publishers.

Verbeek, P. P. (2004). Material morality. In E. van Hinte (Ed.), *Eternally yours: Time in design: Product, value, sustenance* (pp. 198–213). Rotterdam: 010 Publishers.

Worbin, L. (2013). Irreversible color expression Åland. Retrieved February 21, 2024, from https://researchoutlet.se/publications/irreversible-color-expressions-aland-2013-report-no-1

About the Authors:

Delia Dumitrescu is a professor of textile design and head of the Smart Textiles Design Lab. Her cross-disciplinary research focuses on developing smart material design methods and aesthetics using industrial textile manufacturing and digital technology for diverse applications, e.g., body and interiors.

Erin Lewis is a senior lecturer in textile interaction design. Her research explores smart textile design methods and tools and the use of AI to enhance design creativity. At the material level, she specifically engages with the electromagnetic expressive domain through techniques of industrial weaving and knitting.

Riikka Talman is a senior lecturer in textile design. Using advanced methods for knitting and weaving, her research focuses on the development of alternative design methods for sustainable textile having the material's changeability in expression as the main area of investigation.

Acknowledgements: This research is part of the cross-disciplinary project: Nordic network on smart light-conversion textiles beyond electric circuits (Beyond e-Textiles**)** funded by NordForsk.

P/REFERENCES OF DESIGN

This contribution was presented at Cumulus Budapest 2024: P/References of Design conference, hosted by the Moholy-Nagy University of Art and Design Budapest, Hungary between May 15-17, 2024.

Conference Website
cumulusbudapest2024.mome.hu

Conference Tracks
Centres and Peripheries
Converging Bodies of Knowledge
Redefining Data Boundaries
Bridging Design and Economics
Speculative Perspectives
The Power of Immersion
The Future of Well-being
Taming Entropy: Systems Design for Climate and Change
Ways of Living Together
Cumulus PhD Network

Full Conference Proceedings
https://cumulusbudapest2024.mome.hu/proceedings

ISBN Volume 1: 978-952-7549-02-5 (PDF)
ISBN Volume 2: 978-952-7549-03-2 (PDF)

DOI Volume 1: https://doi.org/10.63442/IZUP8898
DOI Volume 2: https://doi.org/10.63442/TADX4016

Conference Organisers
Moholy-Nagy University of Art and Design Budapest (MOME)
mome.hu
Cumulus Association
cumulusassociation.org