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Entangled in the design of a relational materiality: Beyond smart textiles

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ENTANGLED IN THE DESIGN OF A RELATIONAL MATERIALITY: BEYOND SMART TEXTILES

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ABSTRACT

Nowadays, ethics and care for the environment have shifted paradigms in smart textile design towards responsible energy use and preservation of natural resources. In this research, we aim to relate material science and engineering to textile and interaction design in discovering a vibrant responsive materiality triggered by ultraviolet (UV) energy. The research addresses a bottom-up approach entangling scientific development in material science, textile craftsmanship, and design to the understanding of human use and the capacities for change of this natural phenomena. Compared to a conventional textile design process where material and form composition connect in a final expression, this research positions designers and scientists as enablers of material relations. The artefacts, therefore, exhibit multiple states and forms, transforming dynamically through use and sensitivity to natural phenomena. The selected textile artefacts are seen as relational; they open for different conversations and materialize entanglements of materials, techniques, methods, and research methodologies that relate experimental research to human-centered and more-than-human approaches.

INTRODUCTION

The experimental research work presented in the exhibition is part of the Beyond e-Textiles research program, which is unfolding the relationship between textile materiality and UV energy. The program (Redström, 2017) intends to develop a novel category of smart textiles that bypasses the need for electrical circuits and transforms solar energy into useful action.

Shaped by human invention, textiles have always served as fundamental materials for living, conveying essential functions such as clothing and shelter. The creation of textiles is deeply intertwined with human innovation

and craftsmanship, based on daily necessities and locally available resources (Nimkulrat & Groth, 2024). The human capacity to adjust to change moderated the use of materials, and in doing so fostered a deeper connection to the local environment using materials as a mediator. By understanding the characteristics of ecosystems through plants, animals, and weather patterns, humans could conceive of innovative textile functions that aligned with the attributes of the surrounding natural environment (Gordon, 2011).

DESIGNING A RESPONSIVE MATERIALITY

Once defined by static materials, textiles have gained extended functional and expressive possibilities through the adaptability of smart materials – such as electroluminescent elements, electrochromic dyes, and metals composing embedded electrical circuits and coursing with computational data. This allowed for complementing the diverse textile design elements of colours, patterns, and shapes of conventional textile qualities with additional sensing capabilities of the body and environments. As part of wearables or responsive interiors, smart textiles offered a familiar face to complex technology and opened for multi-sensorial material expressivity. In this context, the designer's utilized their knowledge of traditional textile techniques and opened to new forms of craftsmanship that involve embedding advanced electronic functionalities and aesthetic expressions within textile structures (Kettley, 2016).

Nowadays, ethics and care for the environment have shifted paradigms in material design and innovation. The focus on designing with concern for a responsible future opens new research trajectories for smart textiles, such as reduced and renewable energy use, longevity of use, and circularity. Moreover, material research seeks out alternative approaches that address cross- and transdisciplinary perspectives that involve a holistic view of the role of the material, its agency, and its relationality to other systems, for example natural phenomena, the environment, and living organisms (Wakkary, 2021).

At the scale of architecture, Lumen by Sabin (2020) presents a transdisciplinary research perspective on designing multisensorial spaces, connecting fields such as biology, materials science, mathematics, and engineering in material fabrication. The knitted structures shield sunlight and adapt to its changes throughout the day by changing colour and emitting its own light. The installation is an example of environmentally adaptive architecture design that

connects humans to the near environment through the design of responsive textile materiality.

Complementary to this, Keune (2021) uses the first-person perspective for a better understanding of cycles in nature through plant growth and other living organisms in textiles in interior/outdoor living conditions. The rich experiences generated by this research describe principles of cohabitation between humans and other organisms through textiles by continuously following seasonal changes. The project demonstrates the value of a bottom-up understanding of materials and nature to dissolve hierarchies between human and non-human entities within a shared environment. Furthermore, the project *Becoming Solar* (Mackey et al., 2023) introduces an alternative relation to solar energy and exemplifies how decentering the human perspective in the design process opens for a better understanding and persistent awareness of a natural resource and its phenomena. Experiencing the nuanced design values of solar energy from a first-person perspective raises new questions about the thoughtful use of solar energy in daily life through electronic artefacts and the environmentally conscious choices designers can integrate into the creative process.

Compared to the perspectives presented in these exemplary works, this research aims to further expand textile methodology by looking into the relational properties of materials responding to UV energy. This is demonstrated through a selection of textile artefacts where solar energy is not treated as a natural resource but as a design agent.

RESEARCH METHODS: RELATIONAL BETWEEN DISCIPLINES

In this example of material-driven experimental research (Zhou et. al., 2023), we aim to relate material science to textile design and interaction design through the discovery of vibrant materiality – bridging developments in material science, textile craftsmanship, artistic research, and design. The entanglement of these disciplines aims to contribute to the development of relational materiality and an experimental system (Schwab, 2013) where the end design and functionality opens for more democratic structures, and in doing so, relates diverse agencies in the material development and the design process. Here, the aesthetic and functional decisions of the designer are complemented by the agency of the material, acts of use, and agency of the natural environment. Unlike conventional design processes where materials and form composition result in a static final expression, here, designers and scientists enable relationships among materials, allowing textile artefacts to continually transform through use and natural phenomena. We engage these concepts cross-disciplinarily through advanced material developments for new yarns, exploring textile crafting and design

methods for novel textile structures, through experimental construction techniques with concern for aesthetics, and formal and temporal qualities of shape-morphing 3D textiles.

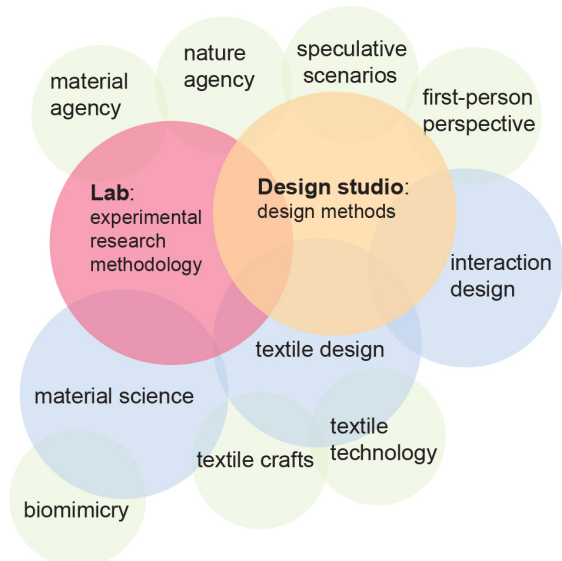


Fig. 1 Entangled disciplines, research methods and research laboratories

ENTANGLED MATERIALS RELATIONS: MATERIAL, METHODS, ARTEFACTS

A collection of explorative textile artefacts was created as “a cabinet of curiosities” to illustrate how responsive textiles can be designed when ultra-violet radiation (UV) from the sun as an agent for change, rather than relying on electrical energy commonly used in smart textile designs. The textile artefacts show variations in materials, techniques, and research methodologies that can relate human-centered to more-than-human design methodologies (Giaccardi et al., 2024). The artefacts open for different dialogues regarding textile responsive materiality. The curated collection has an experimental character and allows the public to physically interact with it. The artefacts open the public’s curiosity about the omnipresence of UV energy and its agential qualities combined with agencies of textile materials that, as a result, open to differing temporalities, and suggest acts of use. For example, textile artefacts alter shape, colour, and luminosity, among other properties when exposed to UV energy, in ways that are reminiscent of smart textiles. Many of these transformations are reversible, while others follow a linear, irreversible change (e.g. fading colours or the appearance of pattern).

Examples of reversible transformations include textile designs with UV-reactive properties, such as colour-changing, light-emitting, and self-cleaning effects, and constructions featuring developed yarns that can reversibly change shape in response to UV energy exposure. In contrast, the temporal colour shifts of natural dyes influenced by UV energy and the

transformations of new PLA yarns illustrate irreversible change. The coexistence of both reversible and linear transformations means that the artefacts' appearance and overall aesthetics are in a continuous state of flux. Furthermore, these textile transformations unfold across different scales of temporality, creating a dynamic interplay of diverse, sometimes intersecting qualities, further enriching the exploration of material agencies and change in the pieces.

The exhibition pieces are based on interdisciplinary research that draws from physics, crafting, materials engineering, and textile design. By integrating methodologies from these different fields and exploring textile construction at multiple hierarchical levels, we can rethink, materialize, and ultimately bring new textile concepts to life, along with their evolving aesthetics. We propose three categories in this “cabinet of curiosities” based on the role UV energy plays as a design agent: choreographing movements, devaluating/enhancing colours and exposing natural cycles.

EXHIBITION CATEGORIES

CHOREOGRAPHING MOVEMENTS: DESIGNING WITH NUANCED SHAPE CHANGES USING UV ENERGY AS AGENT FOR CHANGE

Project team at Aalto University: Zhara Madani, Mithila Mohan, Pedro Silva, Maija Vaara and Jaana Vapaavuori

Showcasing: Three textile artefacts and a video material.

From material: From a materials science perspective, new combinations of materials needed to be developed to create active yarns and textile coatings capable of responding to their environment. Guided by green chemistry principles, a low-melting-point polyamide composed mostly of bio-sourced monomers was developed. Lowering of the melting point allowed both melt-blending bio-based fillers, such as starch, as well as extruding the textile filaments as a significantly lower temperature than for commercial polyamides (nylons), thus reducing the energy required during the processing. To embed the potential for light responsiveness, photothermal fillers were developed, allowing the conversion of light of different colours into a macroscopic motion of twist-coiled yarns. The small-scale custom-built twister-coiler device was developed alongside the polymer synthesis, thus highlighting the interplay of practice-led crafting and materials science approaches (Baniyadi, 2023).

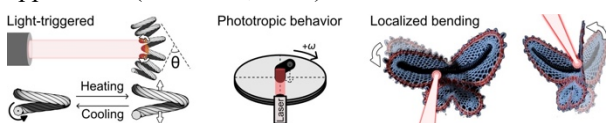


Fig. 2 The reversible twist-coiled yarn triggered by UV energy allows for localized bend and release

To design: As illustrated schematically in Figure 2, any coiled structures undergoing local asymmetric deformation behaves similarly: uniform triggering causes contraction or expansion, whereas partial triggering results in bending. This discovery lays the groundwork for a completely electronics-free method for creating simplified actuating textiles and environmental adaptation. As a showcase of this, we created prototypes exhibiting phototropic behaviour, inspired by the daily choreography of sunflowers tracking the sun -a striking strategy for the plant to optimize the sunlight capture (fig. 3).

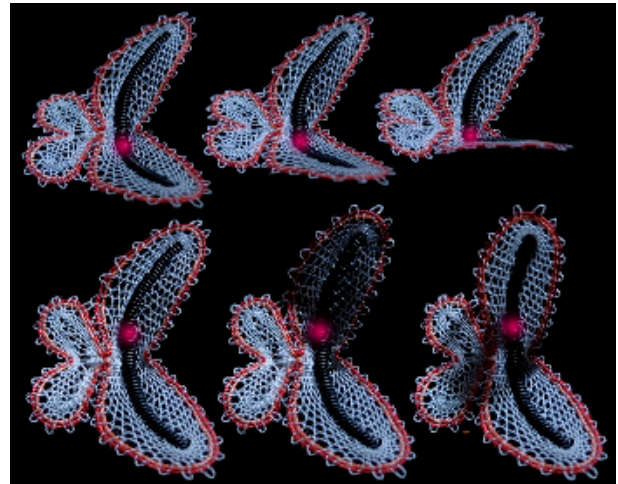


Fig. 3 A crocheted butterfly where the reversible twist-coiled yarn triggered by UV energy allows for localized bend and release

Furthermore, the “sunshade” prototypes (fig. 4) tap into multilayer weaving embedding different expressions into the textile – on one hand, the curling movements can be responses to light or heat, whereas absence of the light causes the fabrics to glow, indicating the presence of the fabric in the dark. Hence, the expression of the textile changing as a response to the illumination conditions reveals an interplay between physical shape-morphing and the visual expression of the yarns.

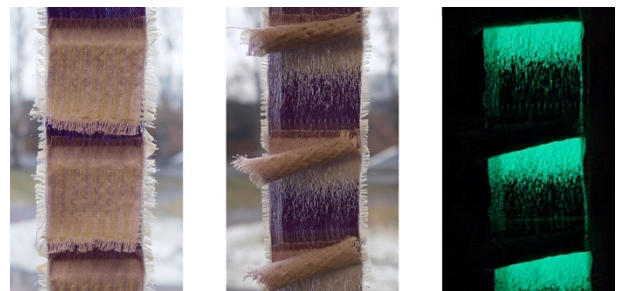


Fig. 4 Double-woven textile with reversible twist-coiled yarns triggered by UV energy. Cut top layer lifts and releases when triggered. The textile exhibits additional expressions through UV-charged yarns when viewed in darkened conditions.

The developed material formulations were further explored through textile prototypes, guided by both the yarns' ability to convert environmental signals into actuation and the techniques of traditional bobbin lace making and multilayer fabric weaving. As shown in the prototype examples (fig.5), the active yarns are seamlessly integrated into textiles – providing a way for imparting light-driven macroscopic motions.

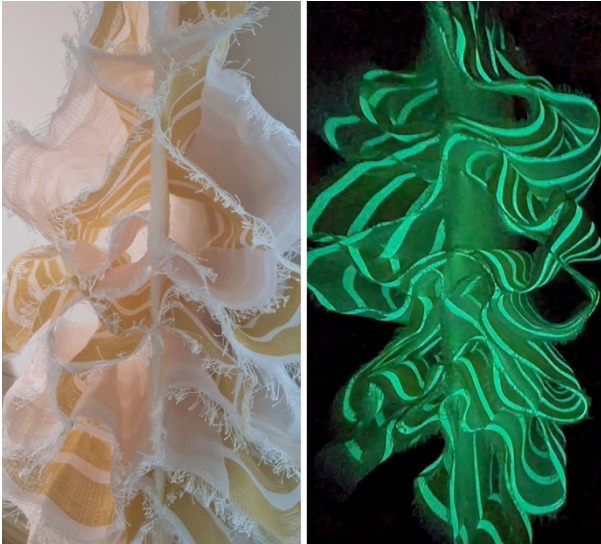


Fig. 5 Multi-layered woven textile gathers and releases using reversible twist-coiled yarns triggered by UV energy. The textile exhibits additional expressions through UV-charged yarns when viewed in darkened conditions.

The way people would interact with the prototype would then also depend on the current environmental conditions. These prototypes depict a world where textiles are not just passive entities, but active accomplices responding to environmental stimuli, paving the way for adaptive, shape-changing systems.

DEVALUATING/ENHANCING COLOURS: DESIGNING TEXTILES WITH NATURAL DYES USING UV ENERGY AS AGENT FOR SLOW COLOUR-CHANGE

Project team at VIA University College: Anne Louise Bang, Malene Harsaae, Inger Marie Ladekarl and Lena Kramer Pedersen

Showcasing: curated categories of textile samples and a systematic colour library.

From material: Natural dyes from food waste sources from the local canteen were used to dye and print in multiple layers on textiles, in a way that would allow the consumer to re-dye and/or re-print the products to achieve alternative aesthetics through their own intervention. Through this experimentation, a scenario was speculated where the dyeing and printing of textiles would consist of fully biodegradable dyes, binders, and auxiliaries throughout the production and use phases of a textile product's life cycle.



Fig. 6 Prepared food waste materials and dye baths for print and dye processes. Fig. 7 Sample collection of colours.

To design: In this exploration, the dominant perception of a “perfect product” is challenged. A “perfect product” can be defined as the state of the product at the time of purchase. For textile products which tend to change over time due to washing and wearing, the perfect product is difficult to maintain.

This perception, combined with industry standards concerning colour fastness and aesthetic stability, suggests clothing products quickly diminish in value. In this research, the interaction between solar energy and acts of wear, time, and exposure are explored in efforts to reframe the discourse around longevity and stability of expressions of textiles and clothing.

The speculative scenario projects a future where the original state of a product at the point of purchase does not define the best and only version of the product, rather the product will change throughout consumer intervention, exposure to environmental conditions such as UV energy, and the slow passage of time. Consumers participate in creating variations of aesthetic expressions (Harsaae et al., 2023).

Questioning the ways in which such a scenario can come to light, first, thickened colour and multilayered analogue print techniques were explored. Secondly, the ease and accessibility of re-dyeing and printing in home environments with household food waste is in the planning phase. This phase's aim is to explore how to communicate with consumers new understandings of product value and to encourage them to engage in the process of re-designing their products and to challenge the expectation of aesthetical devaluation of the product.

EXPOSING NATURAL CYCLES: DESIGNING MULTIMODAL INTERACTIVE TEXTILES USING UV ENERGY AS AGENT FOR IMMEDIATE COLOUR CHANGE

Project team: Delia Dumitrescu, Hanna Landin, Erin Lewis, Kristian Rödby and Linda Worbin

Showcasing: Three textile artefacts and illustrative photo documentation with changes and interactions.

From material: Hackmanite-coated textiles are another category of responsive materials developed in this research project. The raw mineral changes colour with UV energy, offering simple, visual gradual changes to natural phenomena.

The exact shade depends on the active material – here, hackmanite shifts from white to purple, with the colour’s intensity deepening as the fabric absorbs more UV energy (Lawryniewicz et.al, 2024). What makes hackmanite-based dyes unique from other colour-changing dyes is their non-toxic composition and impressive durability, ensuring they remain a safe and reliable choice over time.

This project involved parallel teams at the material level developing methods to apply hackmanites on textiles. Due to the long time required for the readiness of the technology, on the design side, colour-changing properties were explored using already existing materials.

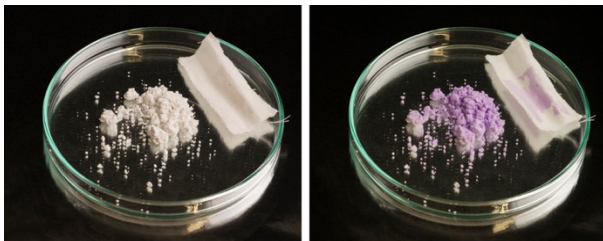


Fig. 8 Colour change of hackmanite powder and textile sample with hackmanite print activated by five-minute exposure to UV. Left: Powder and sample before UV exposure. Right: Powder and sample exhibiting colour change after 5-minute exposure to UV.

To design: Despite the invisibility of UV energy to the human eye, it is omnipresent, active, variable, and traceable. In this selection of textile artefacts, material agencies of textiles and solar energy intertwine and overlap. Three distinct knitted textile artefacts exhibit multiple congruent and reversible colour changes in response to UV energy and its variabilities. The temporality of the changes in the material is gradual and overlapping, as solar energy transitions slowly throughout the day. In doing so, the textile’s responsive colour change captures fluctuations in light intensity, cloud cover, and seasonal changes. From a designer’s perspective, one can facilitate conditions where UV energy and textile materials interact in open-ended, evolving ways. This also reinforces the awareness of the

passage of time and the co-existence of natural processes by being intentional with design choices.

The use of solar energy as an agent for change is to acknowledge phenomena itself as an agential material, thus a co-designer that can inform how these textile artefacts behave, appear, and interact with their surroundings. The motivation for this research track has been threefold: first, to explore the ways in which solar energy could trigger changes in textile materials; second, how textile materials integrate with natural rhythms of our lived environments; and third, whether these material entanglements could cultivate deeper awareness and connectedness with the phenomena that shape our environment.

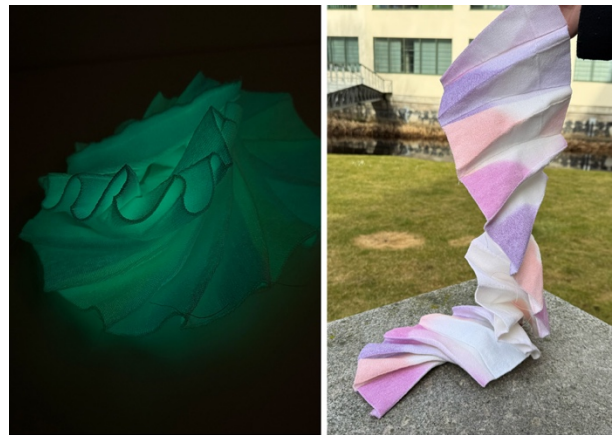


Fig. 9-11: Knitted origami textile (rosette shape) with UV-responsive and illuminating yarns viewed in darkness (9) and in daylight (10-11). Fig. 10 The folds of the origami structure have a blocking effect which causes areas of the textile to remain in its original white state.



Fig. 12-14: Tubular knitted textiles demonstrating different effects of UV responsive and illuminating yarns.

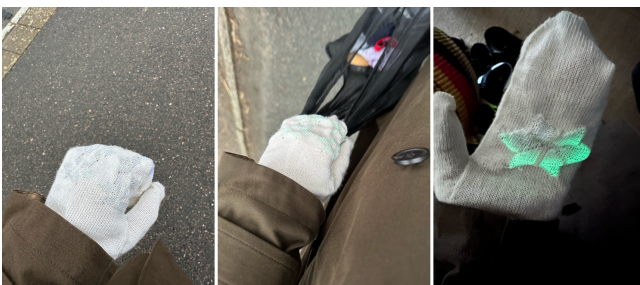


Fig. 15 taken at 15:27, fig. 16 at 16:08 and fig 17 at 16:12 with sunset at 17:30. Fig 15-17 First person perspectives of knitted mittens with UV-responsive yarns on one side and illuminating yarn on the other side. When upper side exposed, the pattern changes colour from light green to white/purple. When other side is charged with UV exposure it glows in darkness.

USE-CASE REFLECTION: CATCHING STARS

Looking for something that is defined by the cycle of the day and that is brought with you that you do not actively have to decide to look at but anyway would notice now and then, mittens were chosen to be knitted with UV-reactive colour-changing yarn on the top of the hand, and light emitting yarn on the bottom (palm) (see fig. 15-17).

The mittens are light green when not activated by UV radiation, white when semi-activated and light purple in full activation. In Sweden in February, they never turn

purple, just white mid-day. I realize after some days of wearing that the UV is usually not strong enough when I get to work or leave work, and it crosses my mind how many hours that we actually are spending indoors every day. I also realize that I with these mittens start to question my perception of light. They make me aware of another time scale since they indicate the time to the sunrise or sunset in another way than I can judge with my eyes. It is like discovering another cycle that is going on, that I have not been able to relate to earlier. We discuss how the different textile pieces have made us aware of time and direction in another way. Direction since the pieces are clearly affected with their colour changes from the top, even if the sun would light it up from the side. Clearly something that we cannot see is deciding, defining and designing the momentary look of the pieces.

Round-shaped transparent pieces (fig. 12-14) were knitted with UV-reactive yarn in order to further explore the relations of materials, expressional possibilities and first-person perspectives also through transparency and 3-dimensionality. If being exposed to UV radiation the pieces are reacting with colour changes on the top part and emits light in darkness on the bottom part.

At work nothing happens indoors. The windows of the building are blocking the UV radiation. The pieces are therefore brought to a house with older windows. It is noted that their shape works well as textile pieces not reminding of traditional textile interior objects such as curtains etc. Hence, they work well as an investigative tool of the cycle of the day, slowly changing its colour from yellow to orange. At sunset their emission of light starts to be visible as well. They are perceived as calm objects. People around me suggests they should move in permanently. When re-visited a month later it is clear how the season have changed, not just that the UV-radiation is prolonged hour-wise during the day but also that the UV-level has increased. They point out a certain cycle of the day, as well as of the year, addressing a usually non-visible phenomena of nature.

CONCLUDING REMARKS

According to Nathanson (2021), the sun's agency was important in ancient architecture to communicate nature's rhythm to humans. Building elements were designed to cast engineered shadows and gather natural light in located shapes at the equinox in Mayan culture; it was a way to highlight the seasonal changes and link to religious rituals, and work in agriculture. Similarly, in this exhibition we treat solar energy as a design agent for textiles. Through choreographing movements, devaluing/enhancing colours, and exposing natural cycles, the exhibited artefacts open for diverse relations, communicating the rhythm of light. The design is not completed by the designer, rather it is intentionally open-ended, responding to the context of use and

actions around it. Sharing a similar cross-disciplinary approach regarding the use of experimental research methodology as Lumen (Sabin, 2020) or as Zhou et al., (2023) the aim here was to discover new relations and directions of work through the research program and to expand the limits of a unique field by relating to many. Hence, the focus in the Beyond e-Textile research program is to expand on the textile methodology and exemplify what working with solar energy means. The perspective of the sun as a source of energy was an initial point in the material development, which is comparable to the research approach in the project *Becoming Solar* (Mackey et al. 2023). When transferring the responsive materials developed in the project from the science lab to the design, we changed perspective to understand the agency of solar energy as co-designers for textiles.

The sample and artefact library developed by this cross-disciplinary research gave us a different understanding of how natural properties can be mimicked by designed materials, and how we co-design with natural phenomena by using UV energy. By designing speculative scenarios with these changing materials, we could develop different nuanced perspectives on responsive and sustainable futures. For example, compared to the hard movement of mechanical motors, we discovered through our research ways to express soft actuation in textiles and to reflect on how kinetically empathic thinking (Miyoshi, 2020) could enrich the artefact design as a method to speculate on alternative futures for soft robotics and prosthetics. The slow changes and versatility of the natural colour dyes produced by the effect of UV energy on wear can influence ways of thinking about textile use and product sustainability by discussing the emotional durability of garments and textile life span. Subsequently, the invisible spectrum of UV energy present in natural light can materialize by the direct changes in artefacts' colours due to the use of sustainable hackmanite coating. The continuous and reversible colour change opens for the curiosity for exploring the qualities of an artefact; it suggests discrete dialogues with the surrounding environment, which provide awareness to radiation exposure, weather conditions, and environmental changes. This awareness may lead to a change of behaviour.

Designing unique material qualities and applying design thinking through cross-disciplinary research – grounded in a bottom-up approach that connects materials, humans, and nature – opens new possibilities for inclusive research methodologies and alternative ways of thinking and designing for thoughtful, everyday living.

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