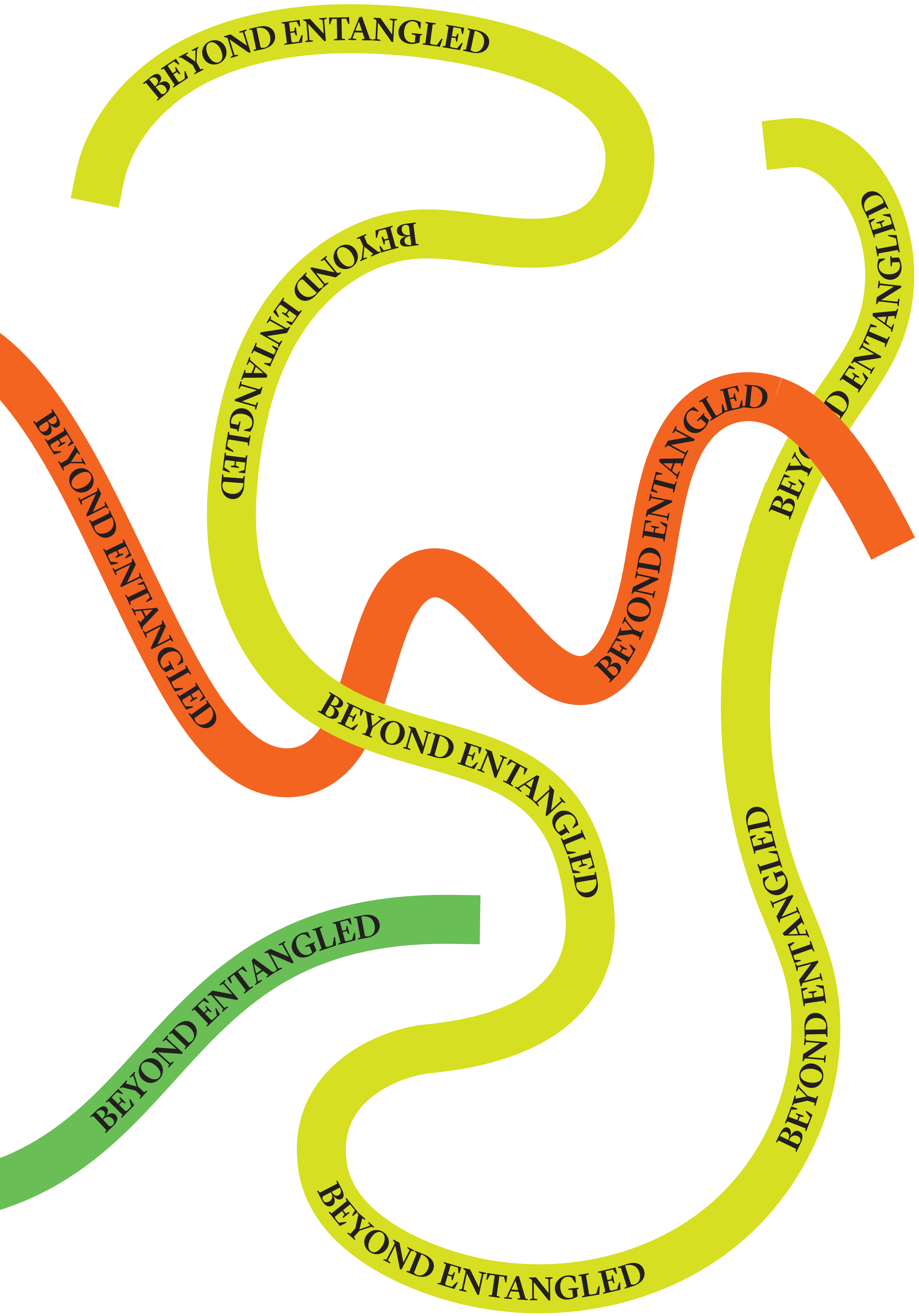
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A collection of research stories from the Beyond e-Textiles project 2021-2025

Nordic Network on Smart Light-Conversion Textiles Beyond Electric Circuits, 2021-2025. (Nordic Programme for Interdisciplinary Research – NordForsk / ID: 103894)

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BEYOND ENTANGLED

A collection of research stories
from the Beyond e-Textiles project
2021-2025

BEYOND ENTANGLED IN TEXTILE THINKING

It is with great pleasure that we present a collection of research stories from the Beyond e-Textiles project. This project was first and foremost crafted to foster interdisciplinary collaboration, e.g., material science, engineering, design, and fine arts throughout Nordic countries around a defined subject area - the development of novel responsive yarns, textile craftsmanship and design methods. This book collects snapshots from the joint explorations of the partners, Aalto University, University of Borås, University of Turku, Iceland University of the Arts and VIA University College, on this vast domain. These case studies were guided by collaborative biannual workshops, which deepened our understanding of each other's disciplinary expertise and aimed to refine the concrete research tasks of our open-ended inquiries. With this publication we document different ways of working together, showing creative ways of finding trust and courage to conduct projects that often crossed many different knowledge domains and sometimes seemingly contradictory aims. It is our hope and concern that our experiences will contribute and inspire future interdisciplinary research. After all, holistic, multi-sectorial knowledge is needed to drive radical systemic changes, essential in fostering the transition to more sustainable societies and ways of living.

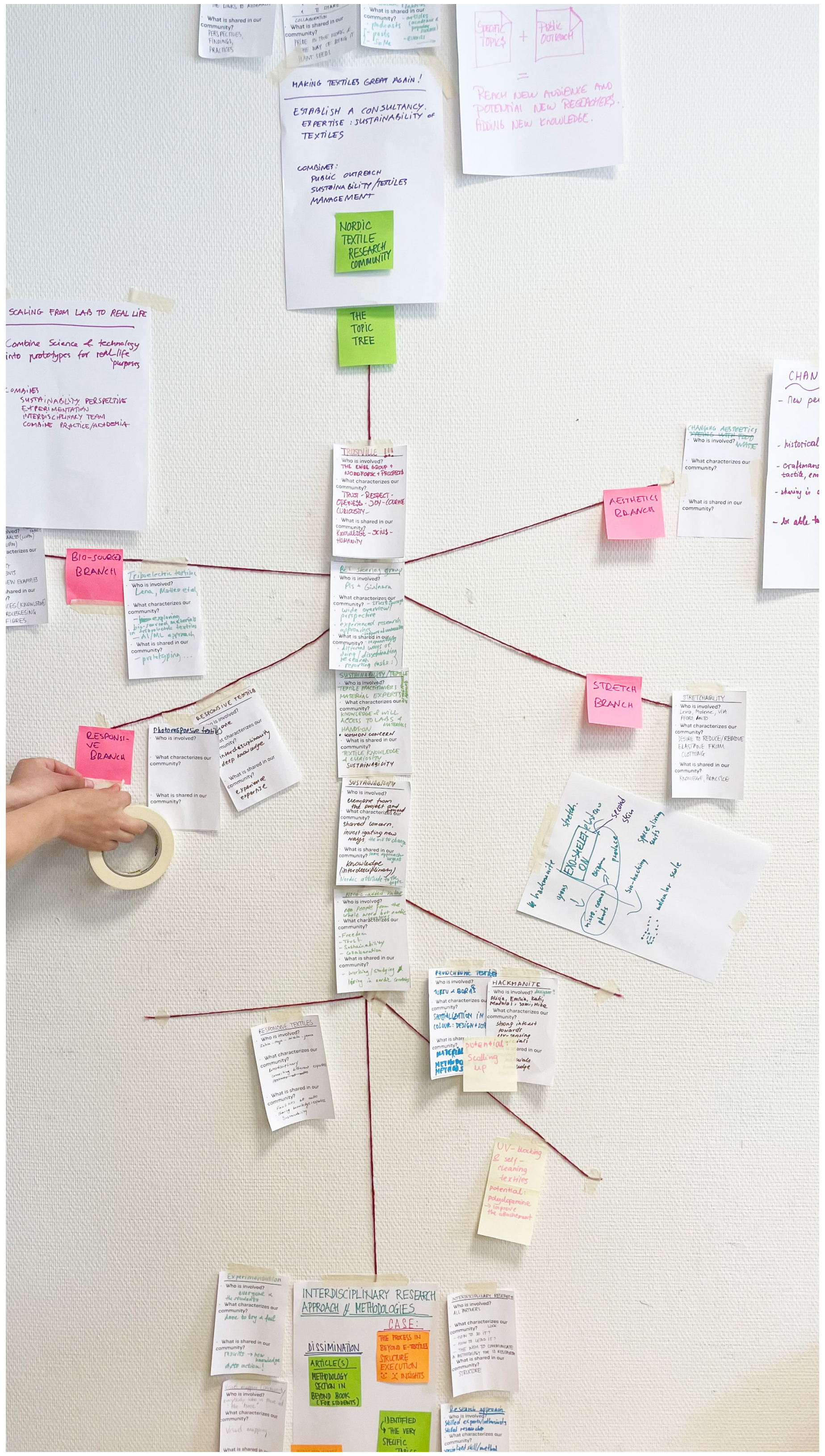
Compared to conventional textile design methods where material qualities and form composition define the final expression, this research positions designers and scientists as enablers of material relations. The research artefacts, therefore, exhibit multiple expressive states and transformative forms determined by use and sensitivity to natural phenomena. Even though we often intentionally didn't target production or application, the research findings and created prototypes provide new openings for paths that would warrant a research project of their own. The research findings include healthcare applications, new aesthetic norms of use and wear, and ideas for interior textiles that can alter their shape and function relying on energy harvested from their immediate environment.

Together with the published articles and numerous exhibitions, both physical and digital, this collection of cases represents the project's legacy. The presented works showcase the formation of deep interdisciplinary links between participating researchers and mixing methodologies typical for the diverse participating domains. We see the case book as a rich material library and as a foundation for cross-disciplinary training where design and science meet to generate more sustainable material practices together, based on a better understanding of natural phenomena as agent for change. Moreover, a meaningful learning was that textile craftsmanship such as weaving, knitting, bobbin lace, dyeing and printing was a crucial factor to fully understand the character and potential of different light stimuli, ranging from UV to near-IR, as well as temperature as change agents on textiles. Other learnings, too numerous and occasionally too personal to list here, will hopefully reveal themselves to you, while reading.

NordForsk enabled this research through the funding to *Nordic network on smart light-conversion textiles beyond electric circuits*, 2021-2025, project ID: 103894. The work will continue with NorTex, 2025-2026, which allows us to further explore the journey towards a *Nordic Center of Future Textiles*, project ID: 202996. For this support we are truly grateful.

Happy reading, on behalf of the Beyond e-Textiles research team,

Jaana Vapaavuori, Anne Louise Bang, Delia Dumitrescu, Ragna Bjarnadóttir and Kati Miettunen.



EDITOR'S NOTE:
The contributing researchers come from very different academic fields of science, art and design. In order to stay true to each institutions' academic writing tradition, the style of citations and references will vary from case to case.

CONTENTS

ENTANGLED EXHIBITION

Entangled was a series of exhibitions that offered a glimpse into the interdisciplinary process behind the research project Beyond e-Textiles. Rather than showcasing finished products, the exhibition highlighted prototypes-in-progress, novel textiles, and materials that responded to environmental stimuli such as light, heat, and humidity. It opened space for reimagining the role of textiles as active elements in their environments, capable of reacting by changing shape, color, or other qualities. This interdisciplinary project combined expertise from physics, design, engineering, and craft to explore sustainable textile practices and experimental material development.

More than just a display of prototypes and artefacts, Entangled fostered dialogue, curiosity, iteration, and discovery, inviting feedback that carried the project forward. By presenting work in progress, the series facilitated interdisciplinary idea generation and enabled the dissemination of project outcomes across diverse communities, institutions, professional events, and public spaces.

Through these exhibitions, audiences gained insight into how collaboration across different fields shaped the creative and technical experimentation vital to the project. Additionally, the spaces where Entangled was exhibited encouraged discussion between different communities, further enabling the project to grow.

GENERAL INFO

Involved partners: Aalto University, University of Turku, VIA University College, University of Borås, Iceland University of the Arts
Researchers: All participants in the BET project
Date of project: June 2023 – May 2025 and online from April 2024

PROJECT OUTLINES

Entangled was designed as a prototype exhibition of the Beyond e-Textiles project, showcasing the prototypes developed by the project's cooperating partners. The idea behind Entangled emerged from understanding how different practices and ways of knowing from various disciplines can inform and integrate into each other. In other words, this exhibition series showed how craft, design, and material science become entangled within the project's evolving ecology.

Entangled was first exhibited at Aalto University's School of Chemical Engineering in June 2023, followed by installations at Oodi, Helsinki Central Library, and the Textiles Intersections conference at Loughborough University in London (UK) in September 2023. The exhibition later traveled to the Iceland University of the Arts in November 2023. The concept was further developed and presented at the Designs for a Cooler Planet festival at Aalto University in September 2024.

The Entangled exhibition continued its journey to Turku, evolving under the title Interlaced for an exhibition at the University of Turku in October 2024. The last installation, titled Beyond Entangled, was featured as part of the SCALES in Textiles conference at Aalto University in April 2025, marking the final event of the Beyond e-Textiles project. In May 2025, Beyond Entangled was also showcased at Turku City Library, bringing the project into a broader public setting. The virtual version of the exhibition was launched on the Aalto Virtual Exhibitions platform in April 2024.

PROJECT PURPOSE

The exhibition project was undertaken with several key objectives in mind. Firstly, it aimed to visually present the ongoing research work and the prototypes produced within the project, offering a tangible representation of the theoretical and practical advancements achieved. By showcasing these prototypes, the BET-team intended to disseminate information about its' scope, objectives, and progress to a broader audience, fostering greater awareness and understanding of the innovative efforts being pursued.

Additionally, the exhibitions attracted audiences from various disciplines, encouraging interdisciplinary engagement and collaboration. This approach was designed to foster a diverse and continuing exchange of ideas, insights, and perspectives that could enrich the project's outcomes and spur innovation. By inviting participation from a wide range of fields, the evolving exhibition endeavored to create a platform for meaningful dialogue and interaction among experts, practitioners, and the public.

Moreover, the exhibitions made it possible to obtain feedback about the produced prototypes and test ideas. By gathering input from diverse audiences, the team could refine and evolve its' methodologies and research directions, ensuring that the ongoing work was both comprehensive and relevant. This feedback loop was essential for adapting the project to the needs and expectations of its varied stakeholders, ultimately enhancing its impact and success.

METHODOLOGY

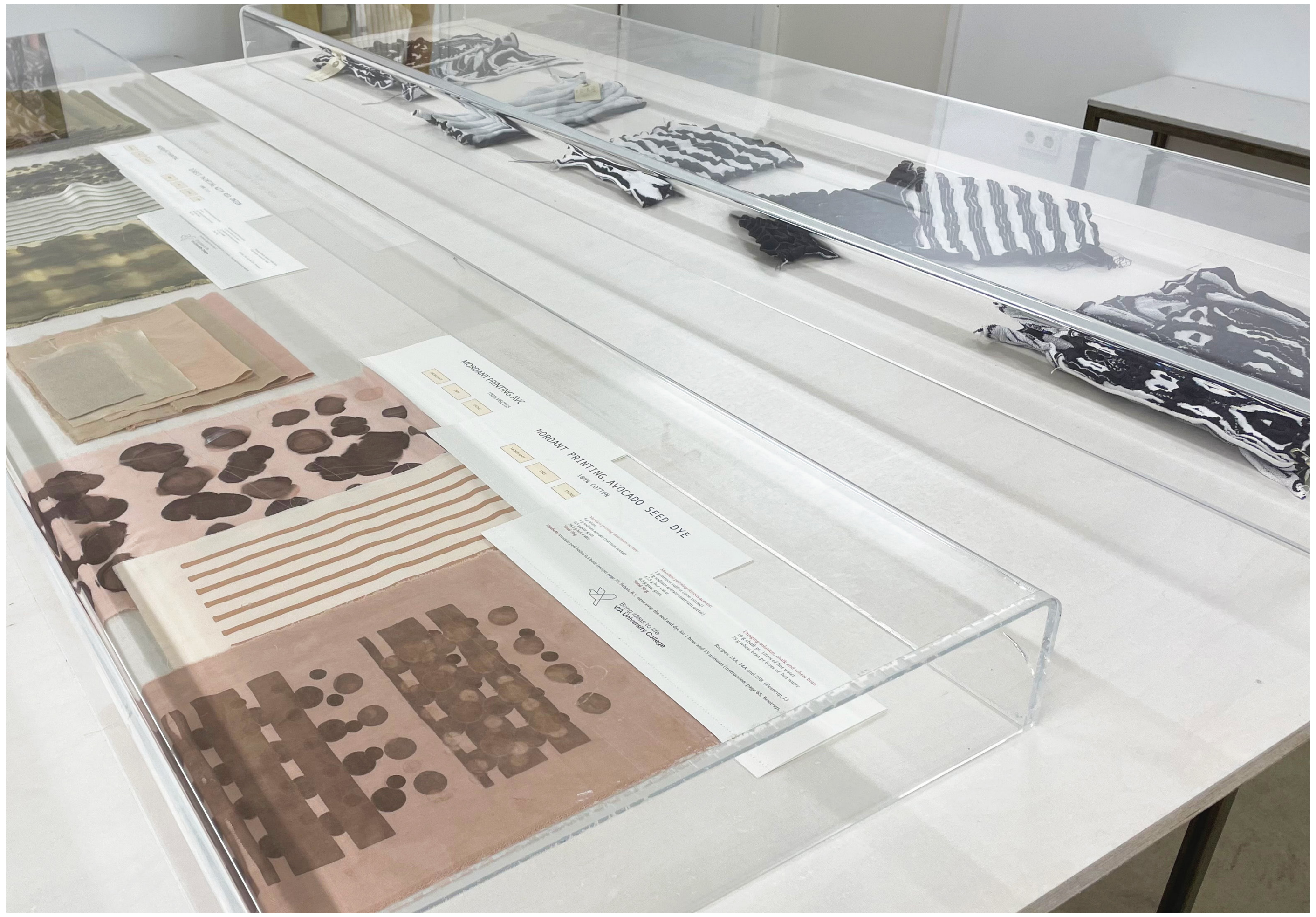
The exhibitions were curated with a guiding idea of showcasing the intersection of art and science through textiles. Collaborative efforts from various academic institutions enabled a rich collection that visualized ongoing research themes. Each partner contributed exhibits reflecting their unique area of expertise, ranging from physics and materials science to design and craftsmanship. This interdisciplinary approach used a methodology that interconnected materials engineering with creative design principles.
The displayed artefacts were curated as prototypes demonstrating responsive textile functionalities using UV-reactive and heat-responsive properties. Concepts such as reversible and irreversible changes were highlighted to offer diverse aesthetic interactions and sustainability narratives. The exhibitions were organized to invite engagement and feedback, creating a dialogue between researchers, artists, and the public. Additionally, the exhibits were tailored for each unique space, adapting to different layouts and audiences.

FINDINGS

The Entangled exhibition revealed invaluable insights into collaboration across varied scientific and artistic disciplines. It successfully demonstrated the potential of textiles as dynamic materials responsive to environmental stimuli, such as heat and light. The complex interplay of reversible and irreversible transformations in textile aesthetics was highlighted, prompting discussions on sustainable material innovations. Collaboration among partners showcased the power of interdisciplinary efforts in advancing textile functionalities while addressing sustainability. Moreover, the exhibition drew attention to Nordic cooperation in promoting holistic approaches to technology-integrated textiles. Feedback from visitors reinforced the importance of balancing innovative design with environmental responsibility, challenging perceptions of conventional textiles. The engagement facilitated future research opportunities while strengthening the relationship between academia and industry within sustainable practice.



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CHALLENGES

One significant challenge was integrating extensive research from diverse disciplines into a cohesive exhibition narrative. The partners worked together to present sophisticated scientific themes alongside artistic interpretations, blending various methodologies and outputs from different research areas. Bringing the exhibition to multiple locations involved transporting delicate artifacts and redesigning layouts to suit each unique space. Ensuring the concepts resonated with local audiences at each venue, while remaining faithful to the overarching themes, called for thoughtful planning.

OPPORTUNITIES

Future steps could involve deepening collaborations among existing partners and engaging external entities to expand the reach and impact of future showcases. Bringing Entangled to additional events across the Nordics, Europe, and beyond would facilitate wider dissemination. Moreover, the exhibition's virtual version could be further developed to enhance accessibility and broaden audience reach.

NOVELTY

Entangled introduced an unprecedented level of interdisciplinarity, merging materials science with speculative design and crafting practices. This innovative approach deviated from traditional e-textiles exhibitions, by showcasing functional textiles without embedded electronics. By debuting at the building of Aalto University School of Chemical Engineering, the exhibition set a precedent for integrating design and scientific research in academic venues, encouraging future multidisciplinary collaborations.

SUSTAINABILITY

Sustainability was central to the Entangled exhibition's ethos, reflected in the development of responsive textile prototypes that minimized traditional electronic integrations. This prioritization fosters better practice advancements by reducing dependency on energy-intensive components. The research behind the samples emphasized sustainable material practices and the exhibition's reuse of artefacts across multiple venues underscores its commitment to resource-efficient practices. Additionally, the team prioritised the use of responsible materials in the exhibition designs, like paper, wood and reusable glass/plexi covers.

SUMMARY

Entangled was, and still is through the digital platform, a groundbreaking exhibition showcasing responsive textile prototypes developed through interdisciplinary collaboration among five Nordic institutions. Integrating materials science, artistic design, and sustainable practices, it visualizes innovative textile functionalities without traditional electronics. Through exhibitions across various venues, it engaged audiences in dialogues about aesthetics and environmental responsibility. Entangled has sparked future research and collaboration opportunities in sustainability-oriented textile advancements.

REFERENCES

1. Mohan, M., Dumitrescu, D., Talman, R., Bang, A. L., Harsaae, M., Ladekarl, I. M., Kramer Pedersen, L., Bull Nielsen, T., Ege, A., Lawrynowicz, A., Miettunen, K., Nizamov, R., Vapaavuori, J., Koskelo, L., Vaara, M., Santos Silva, P., & Madani, Z. (2023). Textile Intersections exhibition. Exhibition, Loughborough University. [https://research.aalto.fi/en/publications/textile-intersections-exhibition-3]. Featured at [https://www.linkedin.com/feed/update/urn:li:share:7110594530508218368/].
2. Vapaavuori, J., Madani, Z., Santos Silva, P., Mohan, M., Vaara, M., Iannacchero, M., Koskelo, L., & Launonen, G. (2024). Entangled – Reimagining textile functionalities / Designs for a Cooler Planet. Exhibition, Aalto University & Helsinki Design Week. [https://research.aalto.fi/en/publications/entangled-reimagining-textile-functionalities-designs-for-a-coole]. Featured at [https://www.aalto.fi/en/events/entangled-reimagining-textile-functionalities] and [https://www.linkedin.com/feed/update/urn:li:activity:7245775912682606592/].

Also featured at:

https://virtualexhibitions.aalto.fi/en/virtual-exhibitions/entangled

https://www.aalto.fi/en/events/beyond-e-textiles-entangled

https://www.utu.fi/en/news/press-release/new-ecological-smart-textiles-on-show-at-exhibition

https://www.aalto.fi/sites/default/files/2025-04/SCALES-in-Textiles-Conference-Book_0.pdf

https://www.utu.fi/en/news/events/beyond-entangled-exhibition-and-public-lecture

LEARNING THROUGH TEXTILES

Throughout the Beyond e-Textiles project, there was a focus on the significance of establishing dialogues across professions using physical prototypes as prompts. Given the framework of the project, where the involved partners developed and explored in parallel, the prototypes have been developed through a mimicking approach. The mimicking consisted of identifying and sourcing for existing yarns that could exemplify the yarns that the project was expected to develop and then exploring these existing yarns with knitting machines, weaving looms and other textile making machines, tools and techniques to illustrate potential outcomes and uses. This part of the process focused on creating tangible samples that enabled interdisciplinary discussions in relation to aesthetics and tactility as well as further development of technical properties and functionality.

All image credits: VIA Team

GENERAL INFO

Involved partners: VIA University College, Aalto University, Borås University, Iceland University of the Arts, Turku University
Researchers: Lena Kramer Pedersen, Malene Harsaae, Anne Louise Bang
Date of project: 2021-2022

PROJECT OUTLINES

When different disciplines meet and must work cross-functionally in larger projects, intelligibility and mutual understanding are at the core. In the Beyond e-Textiles project, with researchers coming from material engineering, physics, chemical engineering, fashion and textile design and art, there was a great diversity of professional languages and research traditions. The group experienced the inadequacy of words when researchers from different disciplines and research fields discussed the project objectives and the initial experiments of the project.

The main research objective of the Beyond e-Textiles project was to develop fibres and design textile products that could harvest and immediately apply energy from sources such as UV light and heat, without using wires and electronics. Consequently, the process focused on developing fibres and textile products with specific properties for this purpose. The group discussed targeting different functionalities including self-cleaning, heating or cooling effects.

This way of working, where prototypes and materials can serve as knowledge providers between disciplines, can be resembled with Schön's notion of reflection through and on action (Schön, 1983). It can be demonstrated in the following example where a knitted textile was developed to mimic a desired effect of contraction and retraction.

METHODOLOGY

One of the aims of the Beyond e-Textiles project was to develop a yarn that would work as a heat sensitive actuator that could expand and contract, reacting to temperature. The scientists were able to work on a molecular level, adding catalysts to the basis material, which were extruded into a monofilament that contained the functionality of an actuator. In this process, the team realised that the dialogue across disciplines was very difficult, as the scientists had little knowledge about textile construction and preferred properties and aesthetics in relation to use, and the designers were not familiar with physics and chemistry on a molecular level.

Having a yarn in mind that could enable a fabric to expand and contract to support regulation of body heat, the first thread developed by the scientists was relatively thick and stiff considering using it for garment textiles. Reflecting on this, the design team developed a series of knitted textiles that could contract (but not expand again), to showcase possible functionalities and aesthetics. Even if these textiles did not have the reversible functionality of expanding and contracting yarns, simulating a one way effect of a non-existing fibre communicated potential functionality and aesthetics of textiles made with expanding and contracting yarns. The team experienced that this way of materializing knowledge enabled the researchers to deepen the interdisciplinary dialogue about the development of the yarn.

Fig 1. In this sample, only the white yarn reacts to heat by contracting. This creates an uneven surface texture and changes the fit of the garment.

FINDINGS

This research demonstrates that dialogue based on visual and tactile sensing opens an operational space for interdisciplinary groups where it is possible to discuss matters that are beneficial for progressing a research project beyond the boundaries of the individual professional areas of expertise.

In this case, the prototypes mimicking the potential use, including considerations about aesthetics and functionality of a not yet developed yarn, served as a catalyst for dialogue and knowledge transfer between partners from different professional fields. Concretely, this resulted in a change of basis material from nylon to starch. Additionally, it demonstrated what yarn thickness and flexibility means for knitted textiles. In the end, it provided a "safe space" for scientists and designers to ask the necessary questions in the process of driving an exploratory development process.

Thus, this mimicking of non-existing materials supported the Beyond e-Textiles project in driving the collaboration as well as the development process forward. The findings emphasize the significance of using physical prompts and prototypes to illustrate future potential possibilities. Prompts and prototypes also minimize the risks of misunderstandings and misinterpretations that may appear in a solely word-based dialogue. Different professions have different skill sets and expertise, and words may have different meanings and interpretations depending on profession.

CHALLENGES

The prototypes mimicking potential outcomes paved the way for relevant and valuable professional dialogue and enabled the researchers to establish a common ground for development in the Beyond e-Textiles project. However, profession specific terminology is still an inherent part of the way in which disciplines communicate and as these terminologies are often subjected to other disciplines' interpretation in interdisciplinary development processes, there is a risk of misinterpretations, and thereby a continuous challenge of establishing an operational dialogue.

OPPORTUNITIES

Further refining the use of mimicking through prototypes, with the purpose of establishing a dialogue between different disciplines in a very early stage of a given research project, will definitely support the in-depth development of novel materials. It gives an opportunity to discover misunderstandings, challenges, and inherent potential at an early stage of the research process. From a sustainability perspective, it gives an opportunity to consider use-cycles and material recycling already in the development phase.

NOVELTY

This project shows that knowledge in the form of an early, physical prototype can provide information, drive dialogue and foster knowledge experienced through tactile and visual sensing. This materializing was a necessary tool in the interdisciplinary Beyond e-Textiles research project between science, design and art. Textile crafting proved to be a relevant entrance point to facilitate and support dialogue through the senses about properties related to functional and aesthetic values.

SUSTAINABILITY

The dialogue through prototypes enabled the researchers from science and design to relatively early in the process detect that a new yarn for garment textiles should be based on starch instead of nylon in order to meet desired functional and aesthetic properties. This paved the way for collaborating with Ioncell® on implementing functionality into sustainable cellulose yarns made from textile waste, pulp and/or old newspapers.

Additionally, the prototypes supported the researchers in their discussions about relevance, which is a highly important topic to discuss when developing novel yarns and textiles. In this case for example, the development work with heat sensitive textile actuators initiated a discussion about stretchability. In fashion, the desire for stretchability contributes to a harmful impact on the environment as the stretchability is often obtained by using elastane together with other fibres. Elastane is extremely difficult to separate from other fibers in recycling processes and for sustainability reasons it should be avoided as much as possible. This initial discussion inspired a separate project focusing on achieving streatchability without the use of elastane (see case 10, *Stretchability*).

SUMMARY

The importance of prototyping at a very early stage to ensure common ground for dialogue between researchers from different disciplines is clear, as prototypes and materials can serve as knowledge providers between disciplines. This was demonstrated with an example where a knitted textile was developed to mimic the desired effect of contraction and retraction, within a project aiming to develop a yarn actuator for a reversible heating and cooling function resulting in the contraction and retraction of the yarn itself. Such prototyping influenced the choice of materials early on as well as discussions about relevance.

REFERENCES

1. Schön, D. (1983). The Reflective Practitioner. How Professionals Think in Action. London: Ashgate.

SCENARIO BUILDING AS DIALOGUE TOOL

By spring 2022, the Beyond e-Textiles project had been running for a year, and the deeply interdisciplinary composition of professions together with the exploratory open approach meant that it was difficult to reach mutual understanding and establish a sense of community between the participants. The project partners therefore agreed that there was a need to define some interim goals and decide on the path to reach them. Thus, the *Scenario Building as Dialogue Tool* project would explore how each partner institution could navigate in a way that was relevant to the involved researchers, and with the intention of uniting across partners at identified common places. For this purpose, the third biannual workshop of the Beyond e-Textile research group included a brainstorming session aimed at creating spaces for informal yet project relevant and constructive dialogues, a hands-on dialogue tool that could foster a sense of community, create a map of goals to pursue and identify paths to follow.

All image credits: VIA Team

GENERAL INFO

Involved partners: VIA University College, Aalto University, Borås University, Iceland University of the Arts, University of Turku
Researchers: Malene Harsaae, Anne Louise Bang
Date of project: May 2022

PROJECT OUTLINES

After the first project year, several researchers expressed frustration and/or insecurity about to which extent they were working according to the expectations of the project and actual deliverables. The science partners were absorbed in developing yarn, but still far from delivering yarn enough for the designers to experiment with for developing knitted and woven textiles. The design partners were occupied with investigating existing responsive materials to mimic and showcase effects and explore the properties of responsive yarns to contribute to the idea generation of the yarn development. To deal with the frustration and anxiety, the whole team spent a full workshop day creating future scenarios, developing scenario crosses that sparked discussions looking for insights that might bring all the reasearchers forward.

As preparation, the researchers from VIA University College introduced the group to the concept of megatrends, counter trends and scenario crosses as tools for identifying different types of future scenarios (e.g. utopic and dystopic scenarios). At the workshop these identified trends and megatrends were used as a starting point for the scenario building and mapping of goals.

PROJECT PURPOSE

The collaboration between the partners in the project was challenged by different presuppositions and traditions towards research, approaches, language and culture. Therefore, the aim of working with scenario building was to create mutual understanding, allowing each partner to continue working with an open and exploratory mindset, deeply rooted in professional practice and at the same time, highly focused on the interdisciplinary collaboration.

Working with speculative prototyping and scenarios are basic methods for project framing and idea development in the field of design, while the science partners in general are more trained in and comfortable with lab experiments. This juxtaposition became evident as speculative design was chosen as the starting point for a discussion in an online team meeting prior to the biannual workshop. The team realized that intuition and exploratory experiments did not resonate well with the approaches generally employed by the scientists in the project. This kick-started a crucial dialogue about which practice of interdisciplinary collaboration the team wanted to employ. Perhaps a hands-on experience of working with speculative design through scenario building could contribute to creating a common platform for future discussions, experimentation and collaboration.

METHODOLOGY

The Danish team, that was facilitating the workshop, drew on speculative design theory (Dunne & Raby, 2013) and future prescriptive scenarios (Margolin, 2007; Voros, 2022) to foster rich dialogues. Prior to the on-site workshop, there was an online workshop where the project partners were introduced to the concept of megatrends and identified a number of these to serve as a foundation for the on-site scenario workshop. The participants were divided into three groups across disciplines and competencies.

Each group was asked to:

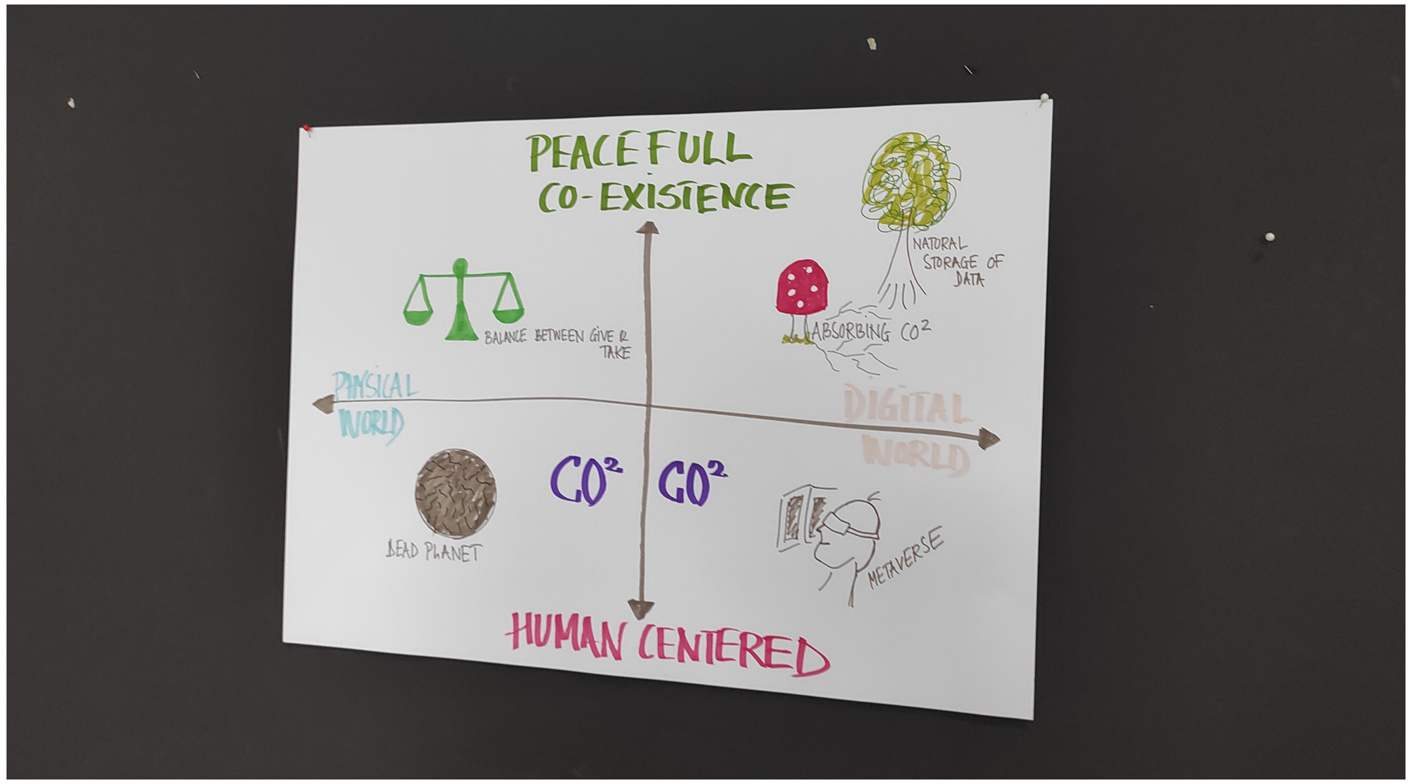
1. Identify and select two megatrends and their counter trends.
2. Create four scenarios using the scenario cross approach.
3. Formulate a hunch.
4. Visualize the hunch in 2D/3D sketches.

The three groups worked autonomously, and the exercise fostered fruitful discussions and revealed several interesting aspects and perspectives to dive into and explore. Based on the group presentations of the scenarios, the emerging subjects were discussed from all angles and then clustered in themes before giving them headlines that all the attending researchers found relevant and could relate to their profession. Each partner indicated the areas they wished to pursue, meaning that the same area would be explored from different perspectives and with different approaches.

FINDINGS

The findings from the workshop led to both intangible and tangible findings. The exercise contributed to a shared understanding between the researchers and perhaps more importantly, the team experienced that the workshop created deep and varied dialogues between researchers in a way that had not been achieved before the workshop. In a diverse group including both young and experienced researchers from different fields, the scenario workshop served as a "safe space" where everyone, including more quiet participants, was encouraged to speak up. Also, clustering the various perspectives, themes, and subjects that emerged from the exercised contributed to identifying specific and concrete areas of interest and establishing concrete objectives for further exploration.

The scenario building approach thus proved its relevance and effectiveness in establishing a space that enabled dialogues. At the same time, the method also functioned as a catalyst for identifying research areas contributing to formulating concrete research questions that fitted into the overall goals of the Beyond e-Textiles project.



In the long run, it also turned out that the scenario work led to the formation of several communities of practice within and across professions (see Case 5, *Communities of Practice*).

NOVELTY

The scenario building workshop significantly pushed the project forward. The workshop contributed to creating a "safe space" among the researchers by fostering open dialogues where profession or seniority were indifferent, thus enabling truly interdisciplinary collaboration. The identification of the areas of interest for exploration and experimentation similarly contributed to frame the research processes at all the partner universities and established a mutual understanding across professions and of the methodologies of the related research processes. The identified goals also pointed towards different areas of sustainability, supporting the researcher's effort in promoting an overall sustainable perspective.

SUMMARY

One year into the Beyond e-Textiles project, the partners were frustrated with expectations and how to reach the overall project objectives. The partners also experienced that there was a lack of common understanding. Therefore, it was decided to dedicate an on-site scenario building workshop to help manage this. The workshop resulted in a series of shared goals to work with and paths to follow.

The scenario building workshop significantly pushed the project forward. It created a "safe space" for the participants by fostering open dialogues between all partners and through it, the whole team of researchers together identified areas of research potential and interest, which led to the formation of several communities of practice within and across professions.

REFERENCES

1. Dunne, A. & Raby, F. (2013). Speculative everything; design, fiction, and social dreaming. MIT Press
2. Margolin, V. (2007) Design, the Future and the Human Spirit. Design Issues: Volume 23, Number 3
3. Voros, J. (2022) A primer on Futures Studies, foresight and the use of scenarios. Last updated 2022-03-08.First published in prospect, the Foresight Bulletin, No. 6, December 2001, Swinburne University of Technology, Melbourne, Australia.

THE TEXTILE THING FROM THE FUTURE

During the sixth biannual workshop of the BET research group, all participants took part in a workshop titled *The Textile Thing from the Future*. The workshop was prepared and facilitated by the Icelandic team. The workshop's aim was to bring together group members from different fields within textiles, design and engineering and come up with future scenarios and objects taking inspiration from the research projects being carried out by the whole group.

GENERAL INFO

Involved partners: Aalto University, VIA University College, the University of Turku, the University of Borås and Iceland University of the Arts
Researchers: Thomas Pausz and Ragna Bjarnadóttir
Date of project: November 2023

TECHNICAL TERMS

"The Thing from the Future": An award winning game, designed by Situation Lab, that challenges players to collaboratively and competitively describe objects from a range of alternative futures. Each group is given four cards, one from each of the following categories:

ARC: Outlines the type of future world that the "thing" comes from, and how far away it is from today. There are four types of Arc, each an umbrella for countless possible scenarios; Growth, Collapse, Discipline and Transformation.
TERRAIN: The thematic context or location where this object could be found in that future.
OBJECT: The focus for the imagination: a specific cultural artifact that reveals something about how this future is different from today. For the sake of the game being played in relation to the Beyond e-Textiles workshop, these object cards were swapped out with specific cards such as: Embodied e-Textiles, Vanishing Textiles, Everlasting Textiles, Musical Textiles and more.
MOOD: Suggests how it might feel to experience this thing from the future.

PROJECT OUTLINES

Some of the research projects within the BET project are based on very specific textile materials, even threads or coatings that, of course, do not excist yet. It can be very valuable for researchers to foresee an end purpose or product which the textile could be used for or as, but when dealing with a completely new textile it can be hard to imagine that purpose. Speculative design games can be a great catalyst to spark brainstorming and enhance open imagination, intuition and collaborative creativity.

When people from different disciplines are in groups together it brings very different persceptives. Some may have worked for a long time on a certain textile material while others have never heard of it, but together they need to come up with a creative scenario and object made from this material.

METHODOLOGY

The researchers were split into groups of 4-5 people and each group was given four cards to work with. The groups were given 30 minutes to discuss their future scenarios, settings, feelings and objects and then all the groups presented what they came up with.

For example, one group got the cards "Grow – A generation" (ARC), "Reykjavik" (TERRAIN), "Embodied e-Textiles" (OBJECT) and "Serenity" (MOOD). So, they had to come up with a scenario for an embodied e-Textile object that would provide a feeling of serenity for someone in Reykjavik, Iceland, one generation into the future.

FINDINGS

The different groups came up with future objects such as (from the example above) an embodied textile suit that both protects from outside elements but also signals emotions so that people arorund the wearer can react in empathy, a liquid garment poured from a bottle, heirloom garments with some sort of embedded visible storytelling and a textile passport that links to a textile family tree.

The game sparked some very thought provoking and lively conversations and the presentations from each group sparked even more, where all participants had a chance to reflect on each group's objects and scenarios.

CHALLENGES

"The Thing from the Future" game is a great way to spark conversation and get the ball rolling but it has a very open format and endless possibilities, so the imagined objects and scenarios tended to be extreme in nature and seem not feasible at all. This is of course the aim of the game but it can make it hard to apply the brainstorming directly into an ongoing research project.

OPPORTUNITIES

For this specific workshop, the OBJECT cards were swapped out with specific textile objects related to the Beyond e-Textiles project. In the same way, cards from the other three categories, ARC, TERRAIN and MOOD, could be either pre-selected; for example to only give positive results (only work with positive moods or desirable societal structures), or swapped out completely for cards defined and/or made up by a facilitator, to give a more specific frame or context for players to brainstorm within.

NOVELTY

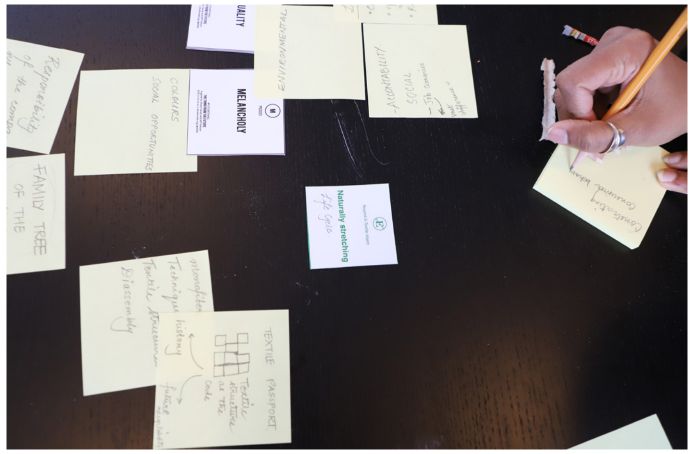
Playing "The Textile Thing from the Future" game proved to be a great way for researchers from different fields, institutions and geographical backgrounds to take part in creative brain storming together, reflecting on some imaginative and far reaching possibilities for the textiles being researched within the project. While not necessarily providing ideas for any concrete objects or applications, it was a great facilitator and ice-breaker for group members to get to know each other and get familiar with each other's thinking processes, background and knowledge.

SUSTAINABILITY

Topics such as sustainability, product life-cycle, fast-fashion, new bio-materials, recycling and social responsibility came up in most sessions that the groups played, demonstrating clearly the inherent values, focus and aim of the researchers to support a more sustainable textile industry. Some ideas were more applicable today, for example a textile-passport enabling recycling facilities to identify fibers in any given textile, while others were reaching far into the future, for example garments made from regenerated textiles that could be worn in a world where the sea level has risen so much that human beings live submerged in water.

SUMMARY

The future scenario building game "The Textile Thing from the Future" sparked a lot of lively discussions on the specific research objects of the Beyond e-Textiles project, but also on topics regarding sustainability and the use of different textile materials for different possible planetary futures. It was also a great catalyst and ice-breaker for people from different coutries and professional backgrounds to get to know each other through creative brainstorming. These discussion topics of possible objects and futures continued to come up in group member's conversations throughout the whole three day duration of the workshop held in Reykjavik in November 2023 and even onwards.



REFERENCES

1. S. Candy, J. Watson, The Thing from the Future, (Print-and-Play Edition), Situation Lab (2015) https://www.researchgate.net/publication/364677670_The_Thing_From_The_Future_Print-and-Play_Edition

COMMUNITIES OF PRACTICE

"Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."
(Wenger-Trayner & Wenger-Trayner, 2015).

During the Beyond e-Textiles project, several communities of practice (CoP) were formed through regular interactions blended with interests in and passion for combining different fields of practice to foster a green transition. Some communities materialized randomly by means of unexpected findings, some were a direct outcome of the scenario building workshop (see case 3, *Scenario Building as Dialogue Tool*), and others were intentionally established.

In the spring of 2024 at the seventh biannual workshop, held at VIA University, the hosting team facilitated a workshop dedicated to identifying the CoPs that had emerged through the inherently interdisciplinary process over the project period and to identify which drivers had been decisive in forming the CoPs.

All image credits: VIA Team

GENERAL INFO

Involved partners: VIA University College, Aalto University, Borås University, Iceland University of the Arts, University of Turku
Researchers: Malene Harsaae, Anne Louise Bang
Date of project: June 2024

Special thanks for developing and facilitating the workshop: Martin Storkholm Nielsen & Klaus True Greve, VIA University College, Denmark

PROJECT OUTLINES

The Beyond e-Textiles project was organised around biweekly online sessions and biannual on-site workshops. This structure provided a significant element for establishing different CoPs. It strengthened the initial intentional CoPs and the structure also enabled the emergence of new and unexpected CoPs. From an early stage of the project, different CoPs started forming around the development of prototypes. In combination with hands-on workshops and exploratory experiments, the prototypes played a pivotal role in generating discussions and building bridges between different research fields and their methodologies.

PROJECT PURPOSE

Seeing the need to create a common overview of the results towards the end of the Beyond e-Textiles project, the VIA University team held a workshop with the intent to map out the CoPs that had emerged and to identify the drivers that had been decisive in forming them.

The interdisciplinary collaboration between researchers had worked exceptionally well within the project's overall structure so the intention of this workshop was therefore to transfer knowledge about collaboration across disciplines to the benefit of future projects and networks comprising multiple stakeholders and research fields.

In the Beyond e-Textiles project, the concept of CoP was used methodologically and retrospectively to analyse how the cross-disciplinary team had worked and what had been achieved in relation to the collaborative aspects. For the VIA research team to participate on an equal footing with the other research teams, two external experts were invited to facilitate the workshop.

METHODOLOGY

The arc of the CoP workshop consisted of three approaches representing the PAST by looking at relationships, the PRESENT by identifying the states of different parts of the project, and the FUTURE by planning the next actions. The workshop was kicked off with a presentation of the concept of communities of practice together with an introduction to the four phases constituting the actual workshop:

1. Alignment - what did we experience,
2. Relationships –mapping the different CoPs,
3. States – identifying potentials,
4. Actions – looking for themes, overlaps, connections and common denominators with a specific focus on dissemination.

Through the workshop, the team moved from reflection on individual experiences, to smaller group discussions, before finalizing with a shared clustering of the extensive resume of findings.

The first phase kickstarted with an individual reflection exercise where all researchers noted key experiences and take aways from the project on post-its that were then clustered on a shared matrix, reflecting on their connection to subject vs. personal relations and formalized vs. non-formalized experiences.

The second phase centred on mapping the CoPs by identifying project-related past relationships in small groups. The groups determined who was involved, the characteristics of the community and the knowledge sharing within the community. Finally, the groups labelled the identified CoPs.

In the third phase, the whole group clustered the identified CoPs, looking for themes, overlaps, connections, common denominators etc. The clustering spontaneously developed into the shape of a tree. Constituted by the CoPs, the trunk represented the core elements of the project. The larger or smaller topics that had emerged during the project were visualised as branches and twigs. Hence the exercise resulted in what was coined fittingly as, "The Topic Tree".

In the fourth and final phase the whole group used the uncovered topics to discuss potentials for new collaborations. The discussion highlighted considerations, obstacles, resources, and realistic next steps. Furthermore, categories of dissemination were identified as an initial plan for action.

FINDINGS

The workshop revealed several communities of practice that were created in the Beyond e-Textiles project across the different professions and research fields. The dialogue revealed that the significant focus on developing prototypes, exploratory experiments and the biannual workshops had been a catalyst for many of the non-formalized CoPs.

The Topic Tree that emerged from the workshop turned out to provide a productive way to visualise the many topics that constituted the project. In this way it served to identify multiple spaces of opportunity and supported the overview and reflection on a highly complex project with multiple findings and outcomes addressing the fields of material science, design and art.

In the Beyond e-Textiles project, the communities of practice workshop emphasized the importance of collaborative experimentation and knowledge transfer between different research fields (see for example case 13, *Machine Learning Triboelectric PLA*). Even though it was not intentional from the project's start, researchers noticed in hindsight that the exploratory approach within the project supported the transformation of non-formal CoPs into more formalised and acknowledged collaborations.

OPPORTUNITIES

In relation to interdisciplinary projects, there is potential in digging deeper into the understanding of the drivers that promote the establishment of CoPs. In the Beyond e-Textiles project, the CoPs have not only contributed to unexpected findings but also created new networks between researchers and across disciplines and countries.

NOVELTY

The workshop and the resulting development of The Topic Tree pushed the dissemination process forward as the workshop identified more CoPs than expected and the Topic Tree that emerged created and served as a structural overview of the CoPs, thus contributing to the determination of which cases to concentrate on in relation to the dissemination of the project.

It turned out to be beneficial to the workshop and its outcome to invite external experts to facilitate the workshop, as they were not as absorbed in the project and were therefore able to pose challenging questions and spur critical reflection.

SUSTAINABILITY

The communities of practice workshop highlighted two perspectives of sustainability. One perspective covers the potential of the Beyond e-Textiles research project to affect sustainability in society in general. Through the workshop, the BET team discovered that they had nurtured and allowed several CoPs to emerge and in hindsight, the participants could see that these communities played a significant role in the way sustainability was embraced in technical and designerly efforts.

Another perspective embraces the viability of the Beyond e-Textiles project itself. The project included two PhD students and a larger group with different levels of experience within academic research. During the project several smaller working groups (CoPs) were formed across disciplines and research experience. These CoPs supported and sustained the project and established safe spaces for the PhD students, experienced researchers and less experienced researchers. At the end of the project, it is noteworthy that the CoPs allowed for the maturing of the interdisciplinary network within the group and that they also empowered each researcher.

SUMMARY

The communities of practice workshop addressed past, present and future by looking at relationships formed within the Beyond e-Textiles group (past), identifying the states of different parts of the project (present), and planning actions (future). It provided an overview and clarification into the mechanisms that nurtured the interdisciplinary collaboration. The Topic Tree that emerged from the workshop contributed to organizing and structuring the many identified communities of practice. The exercise provided a strong foundation for the dissemination of the Beyond e-Textiles project. Furthermore, it paved the way for future actions, including the successful application for the NorTex project: *Towards Nordic Center of Future Textiles – fostering network expansion and conceptualizing interdisciplinary methodology.*

REFERENCES

1. Wenger-Trayner, E. and Wenger-Trayner, B. (2015) Introduction to Communities of Practice, a brief overview of the concept and its uses. https://www.wenger-trayner.com/introduction-to-communities-of-practice/ [Accessed, May 2025)].

UV-SENSING TEXTILES FOR SUN PROTECTION

Excessive sun exposure is the main cause of melanoma, the most severe form of skin cancer [1]. Yet most people don't realize when they're at risk. As suggested by WHO, many cases of sunburn and related diseases could be prevented if people had better ways to monitor their ultraviolet (UV) exposure and take protective measures [2,3].

Current solutions for monitoring sunburn risk include the commonly utilized UV index (UVI) metrics, which are intended to enable real-time tracking of UV radiation levels in outdoor environments. However, this metric provides only general values for an entire geographic area rather than accurate information about individual exposure. More importantly, UV radiation levels vary significantly throughout the day and by location, highlighting the importance of continuous, personalized monitoring [4].

To address this challenge, this research explored UV-monitoring sensors attached to commonly worn garments. This approach utilized photochromic minerals - materials that change color when exposed to UV light, acting as a visual warning system. When applied to fabric surfaces, these materials transform ordinary clothing into convenient UV-sensing tools. These color-changing fabrics provide a simple and intuitive way to alert wearers when they need to seek shade or apply sunscreen—potentially saving lives through early intervention [4,5].

Figure 1. Photochromic mineral, hackmanite, before (top) and after (bottom) UV exposure. Author: Sami Vuori, UTU

GENERAL INFO

Involved partners: University of Turku (Finland), VIA College University in Herning (Denmark), University of Borås (Sweden)

Researchers: Alicja Lawrynowicz, Sami Vuori, Emilia Palo, Mathias Winther, Inger Marie Ladekarl, Marjan Kooroshnia, Mika Lastusaari, Kati Miettunen

PROJECT PURPOSE

This project aimed to develop and evaluate UV-sensing textiles by integrating photochromic materials into everyday fabrics. The primary purpose was to create functional clothing that helps people monitor and avoid harmful UV exposure through an intuitive visual indicator system. Reading UVI values on common forecast websites could be inaccurate considering individual circumstances. UV-sensing materials provide a constant, visible reminder when sunlight intensity reaches potentially harmful levels, as their color change responds directly to real-time UV intensity.

These textiles are targeted toward populations at heightened risk of UV overexposure, including outdoor workers, athletes, and children, who frequently spend extended periods in the sun without adequate awareness of accumulating UV exposure. Moreover, such UV-sensing garments could be beneficial for users who are concerned about potential health effects of sunscreen and prefer to minimize its use. Precise UV-sensing would serve this group effectively, allowing them to limit sunscreen application or implement other protective measures (such as seeking shade or wearing additional clothing) only when needed.

Beyond the primary health protection purpose, creative applications in fashion design were also explored in this research. Since hackmanite can be synthesized in different colors, such color-changing coatings could offer aesthetic versatility alongside its functional properties [6].

PROJECT METHODOLOGY

For this project, hackmanite was selected as the primary photochromic material due to its unique properties. This specialized mineral reacts strongly to UV light, changing from white to purple upon exposure, with the intensity of color proportional to the UV dose received. Importantly, the color response of hackmanite correlates closely with the erythemal spectrum (the measure of how different UV wavelengths affect human skin), making it an excellent natural UVI indicator [7].

The application process involved two distinct methods. Initially, the research team employed a doctor-blade coating technique, a precise laboratory method for creating uniform thin films. This approach allowed the team to carefully control coating thickness and composition during early testing phases [4]. As the project progressed toward practical applications, a successfull conventional screen-printing method was adapted for applying the hackmanite-loaded paste. This transition to screen printing proved advantageous, enabling the creation of larger, more complex designs while significantly improving the potential for commercial-scale production.

FINDINGS

Testing demonstrated that hackmanite-coated textiles respond rapidly to UV exposure, changing from white to deep purple in just 15 seconds and reversing completely within 50 minutes under white light. The fabric maintained consistent color saturation through at least 20 color-change cycles, outperforming, for example, spiropyran-based dyes, which degraded after only 10 cycles. The coating withstood 5 washing cycles and 500 flex cycles before showing surface damage, confirming it's suitability for wearable applications.

Importantly, the hackmanite-coated fabric detected UVI values below 3—the threshold at which sun protection is first recommended—and remained responsive up to UVI [7], the level at which strong preventive measures are recommended [4,7]. To ensure accurate reading, Prof. Lastusaari's team developed the Sensoglow mobile app that interprets the color changes of the coating and provides UVI readings with protection recommendations. These results indicate that hackmanite-coated textiles offer a practical solution for monitoring UV exposure, particularly in high-UV regions.

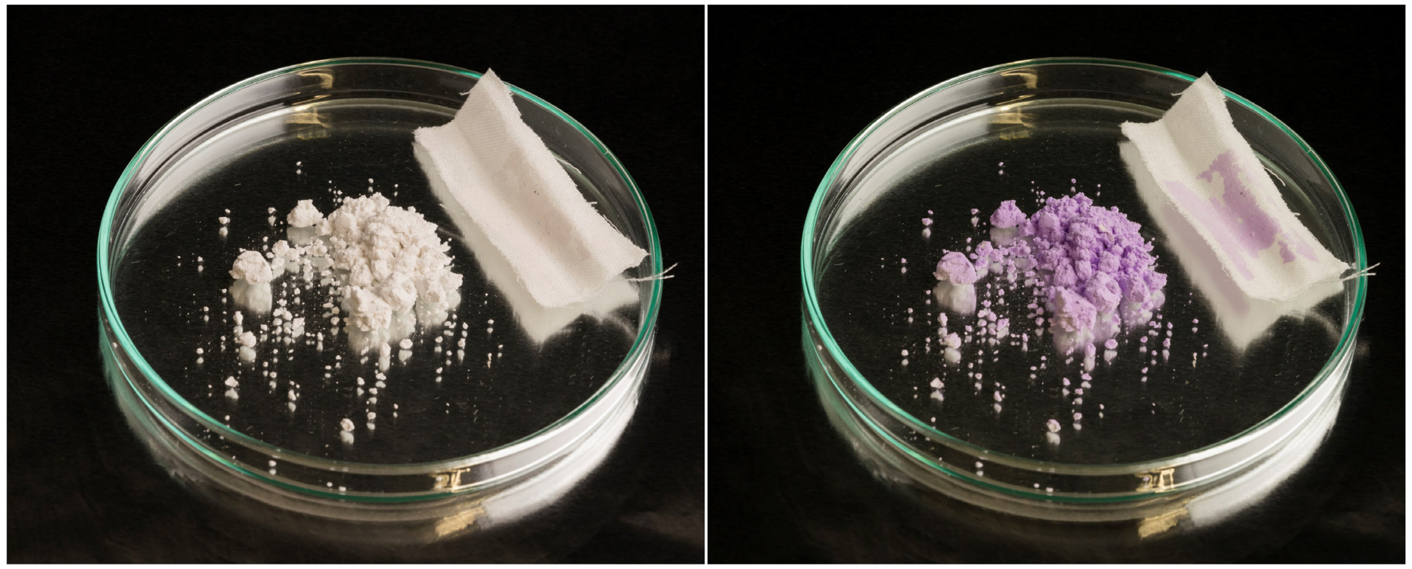


Figure 2. Hackmanite powder and a hackmanite-coated cotton sample, colorless (left) and colored under UV light (right). Author: Mikael Nyberg, UTU.

Figure 3. Hackmanite-loaded coating applied on an ordinary cotton T-shirt. Partial coloration changes under UV light. Author: Mikael Nyberg, UTU.

CHALLENGES

During the project, two significant challenges were encountered.

Technical challenges: Initially, scaling up production proved difficult as only small quantities of the coating paste could be manufactured in research conditions. This limitation was overcome through collaboration with the teams from VIA College University and the University of Borås. The cross-disciplinary teams adapted the formula using commercially available binders and standard screen-printing processes, successfully transitioning the lab-scale coating method toward industrial techniques.

Material challenges: The more persistent challenge related to the intrinsic photochemical properties of hackmanite. While color change is triggered under UV light, a simultaneous return to the original state is caused by exposure to green light, which is a component of natural sunlight. This competing process can reduce visibility of the color change in direct sunlight, potentially limiting the effectiveness of hackmanite as a visual indicator [4,7]. The current solution being developed focuses on a selective filtering system that allows UV light to reach the hackmanite while temporarily blocking visible light. Through this approach, full color change could be achieved before the filter is removed, after which the hackmanite could gradually return to its original state, ready for the next use.

SUSTAINABILITY

The sustainability of the hackmanite-based UV sensing system was evaluated across multiple dimensions. Synthetic hackmanite, which is chemically identical to the natural mineral form, was determined to be safe for skin contact in textile applications. Microsize particles (with a size of > 120 µm) were deliberately selected for the coating formulation rather than nanoparticles, thereby avoiding potential health concerns that are sometimes associated with nanoparticles.

The recyclability of the material has not been tested yet; however, its reusability has been confirmed through extensive coloration testing through multiple UV and X radiation exposures [8]. Thus, it could be assumed that the hackmanite powder maintains its photochromic properties even when subjected to standard mechanical recycling. This characteristic suggests that the functional component of the coating might potentially be recovered and reused without significant degradation of color-changing performance. While both the hackmanite and the textile fibres could be in a good condition for reuse, separating them efficiently may be the more challenging part of the recycling.

SUMMARY

The UV-triggered color-changing properties of materials like hackmanite are demonstrated to provide an effective solution for long-lasting and accurate UV-monitoring. Through this research, ordinary garments can be transformed into powerful UV-monitoring tools using affordable and straightforward coating methods. The hackmanite-coated textiles were shown to detect UVI from below 3 to at least 7, covering the range where protective measures become increasingly important. While challenges related to the concurrent response of the material to visible light were identified, potential solutions through selective filtering are being developed. With further development, these color-changing textiles could contribute substantially to preventing sunburn and reducing the risks associated with excessive sun exposure. Such solutions are needed to ultimately help address the public health challenge of melanoma and other UV-related skin conditions.

REFERENCES

1. K. Merin, M. Shaji, R. Kameswaran, A Review on Sun Exposure and Skin Diseases, Indian J. Dermatol. 67 (2022) 625. https://doi.org/10.4103/ijd.ijd_1092_20.
2. A.W. Schmalwieser, J. Gröbner, M. Blumthaler, B. Klotz, H. De Backer, D. Bolsée, R. Werner, D. Tomsic, L. Metelka, P. Eriksen, N. Jepsen, M. Aun, A. Heikkilä, T. Duprat, H. Sandmann, T. Weiss, A. Bais, Z. Toth, A.-M. Siani, L. Vaccaro, H. Diémoz, D. Grifoni, G. Zipoli, G. Lorenzetto, B.H. Petkov, A.G. Di Sarra, F. Massen, C. Yousif, A.A. Aculinin, P. Den Outer, T. Svendby, A. Dahlback, B. Johnsen, J. Biszczuk-Jakubowska, J. Krzyscin, D. Henriques, N. Chubarova, P. Kolarž, Z. Mijatovic, D. Groselj, A. Pribullova, J.R.M. Gonzales, J. Bilbao, J.M.V. Guerrero, A. Serrano, S. Andersson, L. Vuilleumier, A. Webb, J. O'Hagan, UV Index monitoring in Europe, Photochem. Photobiol. Sci. 16 (2017) 1349–1370. https://doi.org/10.1039/c7pp00178a.
3. E. Rehfuess, Global solar UV index: a practical guide, World Health Organization, Geneva, Switzerland, 2002.
4. A. Lawrynowicz, S. Vuori, E. Palo, M. Winther, M. Lastusaari, K. Miettunen, Transforming fabrics into UV-sensing wearables: A photochromic hackmanite coating for repeatable detection, Chem. Eng. J. 494 (2024) 153069. https://doi.org/10.1016/j.cej.2024.153069.
5. W. Fang, E. Sairanen, S. Vuori, M. Rissanen, I. Norrbo, M. Lastusaari, H. Sixta, UV-Sensing Cellulose Fibers Manufactured by Direct Incorporation of Photochromic Minerals, ACS Sustain. Chem. Eng. 9 (2021) 16338–16346. https://doi.org/10.1021/acssuschemeng.1c05938.
6. H.C. Byron, C. Swain, P. Paturi, P. Colinet, R. Rullan, V. Halava, T. Le Bahers, M. Lastusaari, Highly Tuneable Photochromic Sodalites for Dosimetry, Security Marking and Imaging, Adv. Funct. Mater. (2023) 2303398. https://doi.org/10.1002/adfm.202303398.
7. I. Norrbo, A. Curutchet, A. Kuusisto, J. Mäkelä, P. Laukkanen, P. Paturi, T. Laihinen, J. Sinkkonen, E. Wetterskog, F. Mamedov, T. Le Bahers, M. Lastusaari, Solar UV index and UV dose determination with photochromic hackmanites: from the assessment of the fundamental properties to the device, Mater. Horiz. 5 (2018) 569–576. https://doi.org/10.1039/C8MH00308D.
8. S. Vuori, P. Colinet, J.-P. Lehtiö, A. Lemiere, I. Norrbo, M. Granström, J. Konu, G. Ågren, P. Laukkanen, L. Petit, A.J. Airaksinen, L. Van Goethem, T. Le Bahers, M. Lastusaari, Reusable radiochromic hackmanite with gamma exposure memory, Mater. Horiz. 9 (2022) 2773–2784. https://doi.org/10.1039/D2MH00593J.

HEAT-RESPONSIVE ARTIFICIAL MUSCLES IN TEXTILES

The project focused on developing smart textiles that function without electricity by leveraging stimuli-responsive materials. The aim was to integrate materials with shape memory and artificial muscle properties into textile applications, particularly using methods like bobbin lace prototyping. The project explored how textiles can react to environmental stimuli such as light without the need for traditional e-textile electrical power. By demonstrating movement in a textile structure through photoresponsivity, the project aimed to show potential advancements in textile technology, merging traditional techniques with modern stimuli-responsive materials. An example used is a bobbin lace butterfly whose wings can be independently controlled using a laser, showcasing the smart textile's functionalities.

GENERAL INFO

Involved partner: Aalto University
Researchers: Zahra Madani, Pedro Silva, Maija Vaara, Mithila Mohan, Jaana Vapaavuori
Date of publication: July 2024

TECHNICAL TERMS

Stimuli-responsive materials: Materials that can change their properties, shape, or behavior in response to specific triggers from their environment, such as temperature, light, electricity, or pH.
Photoresponsivity: The ability of a material to respond to light. When exposed to light, such materials may change color, shape, or conduct electricity.
Shape memory materials: Smart materials that can "remember" their original shape. After being bent or deformed, they can return to their original form when exposed to the right stimulus, such as heat.
Actuation: The process by which a material or device produces movement or a mechanical response when triggered by an external signal, such as electricity, heat, or pressure.

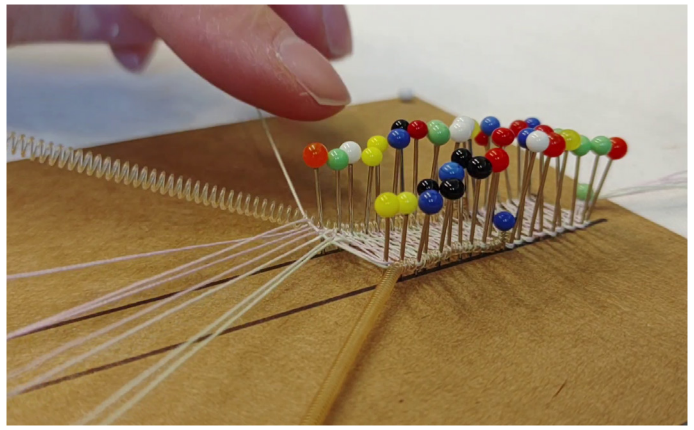
PROJECT OUTLINES

The project's purpose was to advance smart textile technology by developing non-electrical, stimuli-responsive materials that challenge traditional paradigms. Smart textiles are typically associated with e-textiles; however, this project seeks sustainable solutions that address ecological concerns. By creating textiles that can react to environmental stimuli such as light, without electricity, the approach aims to minimize reliance on energy sources and reduce environmental impact.

Nylon and other petroleum-based materials face sustainability challenges due to their high melting points and reliance on fossil fuels. This project aims to find sustainable alternatives by lowering the melting point and creating yarns that are not fully petroleum-based. Ultimately, it seeks solutions that can contribute to innovations in smart textiles without compromising environmental sustainability.

METHODOLOGY

The project involved the development of artificial muscles using nylon yarns with shape memory properties, which were then integrated into bobbin lace designs. The nylon yarns were twisted and coiled and subsequently heat treated to create stable spring shapes that mimic muscle actuation upon heating. Bobbin lace was used to prototype structures due to its flexibility in accommodating multiple yarn directions. This method allows for small batches when experimenting with new materials and incorporates movable structures that can be controlled using a laser to affect the material's contraction or expansion. A butterfly design was chosen to illustrate these properties, where specific points on the wings could be activated by light to demonstrate the movement and responsiveness of the textile muscles.



FINDINGS

The project revealed that textiles, such as nylon yarns with shape memory, can react to environmental stimuli like light without the need for electrical power. This further confirmed that shape memory materials could act as artificial muscles within textile structures and could be manipulated to contract or expand based on heat treatment. The bobbin lace technique demonstrated effective integration with stimuli-responsive materials, allowing for independent control of the textile structure's movement. However, initial trials with materials such as linen proved less effective due to their stiffness, highlighting the importance of material selection for achieving the desired actuation. The findings suggest promising advancements in creating energy-independent smart textiles, expanding the potential uses and applications of such materials.

CHALLENGES

Several challenges emerged during the project, chiefly related to material limitations and environmental concerns. The activation temperature for nylon-based artificial muscles, around 70-90°C, is relatively high, hindering practical wide-scale application. Additionally, nylon's oil-based nature poses ecological concerns, prompting a need for alternative materials. Furthermore, achieving effective movement in textile structures required suitable material choices, as demonstrated when linen failed to provide sufficient flexibility for the intended butterfly design. These challenges underscored the need for lower-melting point polymers and more sustainable materials that could maintain desirable properties while reducing environmental impact. The project thus highlighted a gap in material science that warrants further exploration to overcome these challenges while achieving sustainability goals.

OPPORTUNITIES

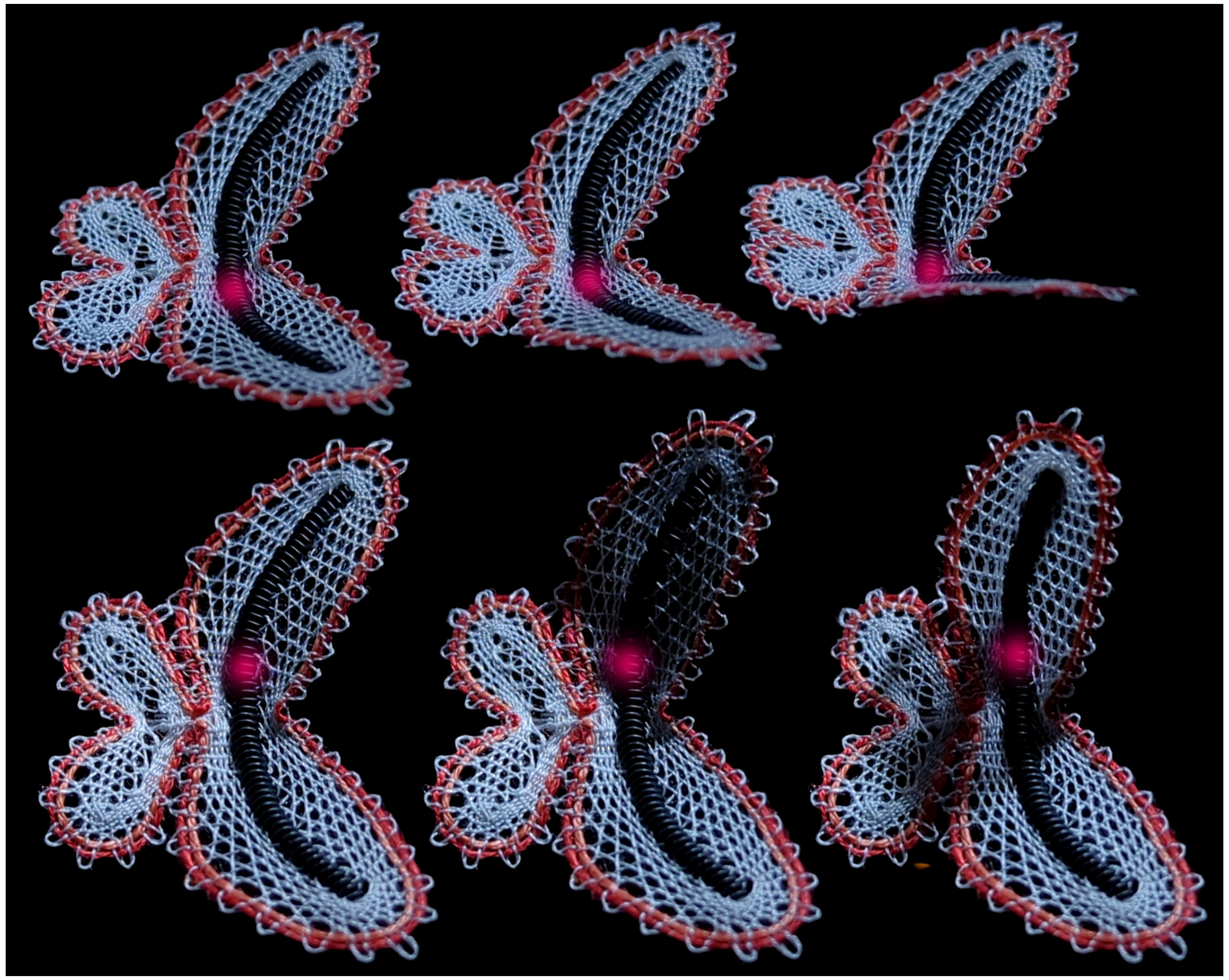
Future exploration could focus on improving materials with lower activation temperatures and developing polymers that are both sustainable and efficient. There is also potential in refining bobbin lace techniques for larger-scale textile applications and researching bio-based alternatives to further reduce ecological impact. Additionally, exploring more practical applications in soft robotics and other industries using smart textiles can extend the project's reach.

NOVELTY

The project introduced a novel approach by merging traditional textile techniques with modern stimuli-responsive materials, creating smart textiles without relying on electricity. This deviation from the typical e-textile approach underscored the potential for using shape memory materials in textile innovations and expanded the definition of smart textiles beyond electrical stimuli-activated systems.

SUSTAINABILITY

The project reflects sustainability by aiming to reduce reliance on petroleum-based materials, which are



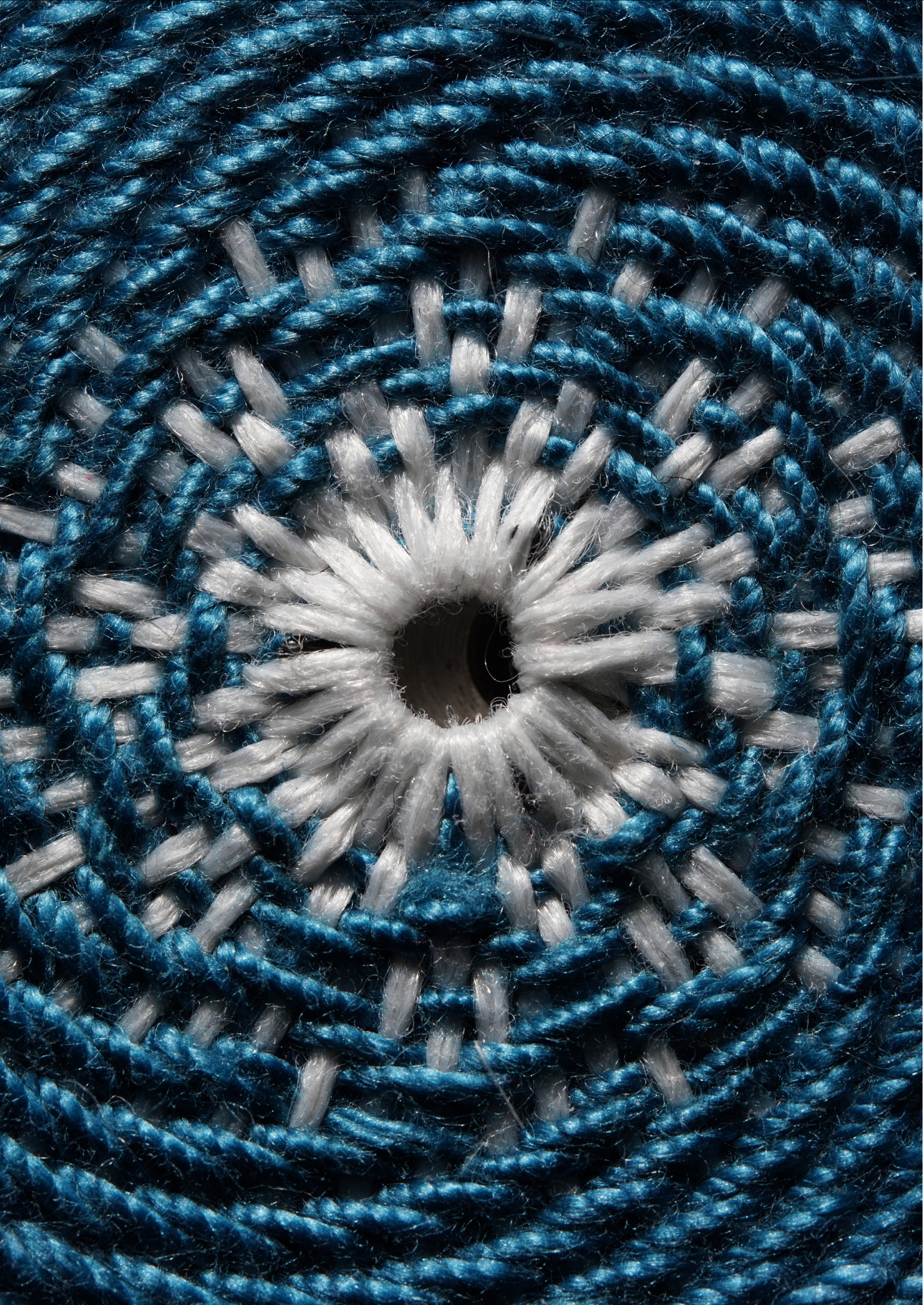
environmentally taxing due to their production processes and difficulty in recycling. It explores the use of lower melting point materials as a solution to high-energy consumption during production. However, the sustainability of these new materials themselves remains to be validated, as does the ability to scale production in an eco-friendly manner. On the positive side, the concept of creating stimuli-responsive textiles without electricity offers a pathway to reduce energy dependency and optimize resource use. Nonetheless, the transition to fully sustainable materials requires further research, and while the project steps toward ecological consideration, it must address challenges in material disposal and lifecycle management.

SUMMARY

The project revolutionizes smart textile development by integrating shape memory materials into textiles for non-electrical responsiveness. Through bobbin lace techniques, nylon yarns were adapted to mimic muscle actuation, enabling controlled movement via light stimuli. Challenges include high activation temperatures and sustainability concerns. Future research could offer eco-friendly materials and practical applications, marking a significant advancement in non-electrical smart textiles.

REFERENCES

1. Madani, Z., Silva, P. E., Baniasadi, H., Vaara, M., Das, S., Arias, J. C., Seppälä, J., Sun, Z., & Vapaavuori, J. (2024). LightμDriven Multidirectional Bending in Artificial Muscles. Advanced Materials, 36, 38, 2405917.
2. Baniasadi, H., Madani, Z., Mohan, M., Vaara, M., Lipponen, S., Vapaavuori, J., & Seppala, J. V. (2023). Heat-induced actuator fibers: starch-containing biopolyamide composites for functional textiles. ACS Applied Materials & Interfaces, 15(41), 48584-48600.



FROM 2D to 3D DESIGNS ON ACTIVE FABRICS

A fabric that moves on its own could completely change how we look at textiles. A shirt loosening for comfort on a hot day, or curtains closing to let the sunlight enter a room, are just two of many possibilities.

Behind this idea are liquid crystal elastomers (LCEs), advanced materials that can be programmed to deform in specific ways when exposed to light, heat, or humidity. By taking advantage of these properties, researchers have demonstrated how thin films of LCEs can transform into complex shapes like saddles and cones. Inspired by these examples, this project aimed to achieve similar precise deformation control using only yarn-based material by crafting circular woven fabrics using two types of yarns, passive and active, without any additional processing. Active yarns shrink when heated, while passive yarns counteract the movement. This invites scientist, designer, and innovator to explore the boundaries of material science when powered by textile craft knowledge.

GENERAL INFO

Involved partner: Aalto University
Researchers: Pedro Santos Silva, Mithila Mohan, Maija Vaara & Jaana Vapaavuori
Date of publication: January 2023

TECHNICAL TERMS

Active yarns: Threads that change their shape upon a stimulus.
Passive yarns: threads that do not change their shape upon a stimulus.
LCE: Liquid crystalline elastomer
Azimuthal direction: Going around the center
Radial direction: Going outward from the center
Warp: Vertical threds held in tension on a loom
Weft: Horizontal threads interlacing the warp.
Float: In weaving, when threads skip over others without interlacing.

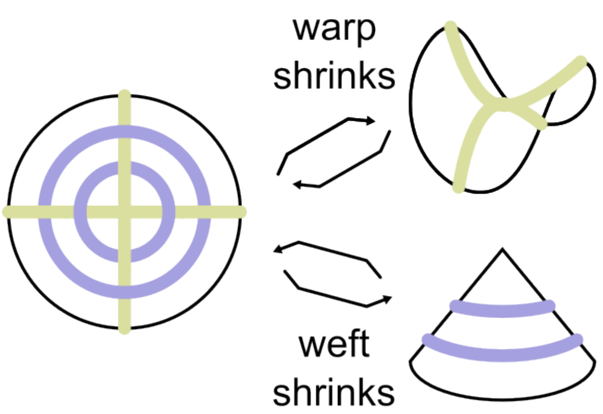
PROJECT PURPOSE

New materials promise to transform how people interact with textiles [1]. In this project, researchers created 3D-actuating fabrics capable of changing their shape in response to external stimuli, like heat, by combining the knowledge of materials science with traditional craft and textile design.

The textile sector has long refined traditional materials, where form stability is a critical requirement for many products. Form is achieved by keeping the yarns' shape as unaltered as possible – passive. However, emerging material solutions propose to introduce new functionalities in fabrics, such as adaptability and responsiveness. Therefore, the BET team tried to understand how trigger-responsive yarns – active yarns – can be integrated into current textile manufacturing and product design.

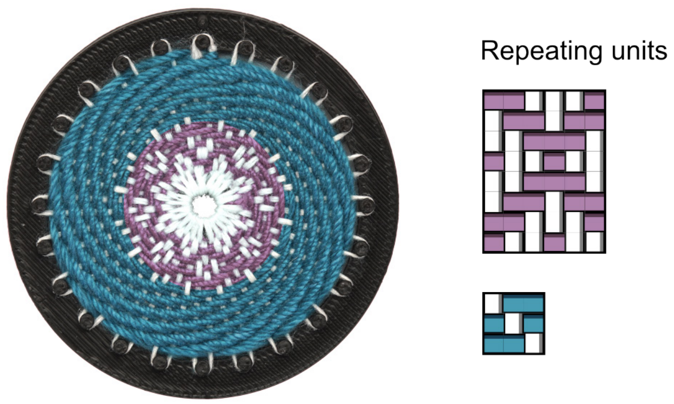
PROJECT METHODOLOGY

Complex deformations in LCE thin films arise when the director field, which describes how soft matter is organized at the molecular level, varies spatially within the material. For example, when the director field in a thin film is oriented from the center of a circle to its border, the film contracts into a saddle-like shape upon activation. In contrast, if the director field is perpendicular to the radial direction, the film undergoes a conical deformation when actuated.



Instead of relying on programming the material, the groundbreaking idea of the research team was to achieve similar results in textiles by embedding actuating yarns into circular weaves to see if they could reshape themselves upon triggering. In circular weaving, which is done on a circular loom, the warp is arranged radially, and the weft is in the azimuthal direction.

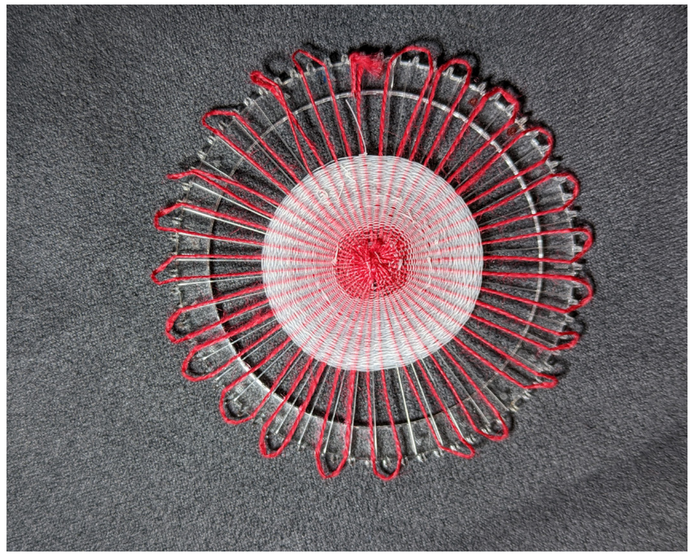
The first step was to design an application to simulate the circular interlacing pattern of both sets based on yarn thickness, the number of warp threads, and the repetition pattern. Next, the team designed and built a custom circular loom. They set the warp by knotting a thread to the frame, stretching it to a pin on the opposite side, sliding it behind the pin to secure it, and then continuing this process by placing the thread in the adjacent position to the knot. The pattern was repeated until the warp was fully arranged. The weft thread was inserted by starting at the center of the loom and weaving over and under the warp in a repeating pattern.

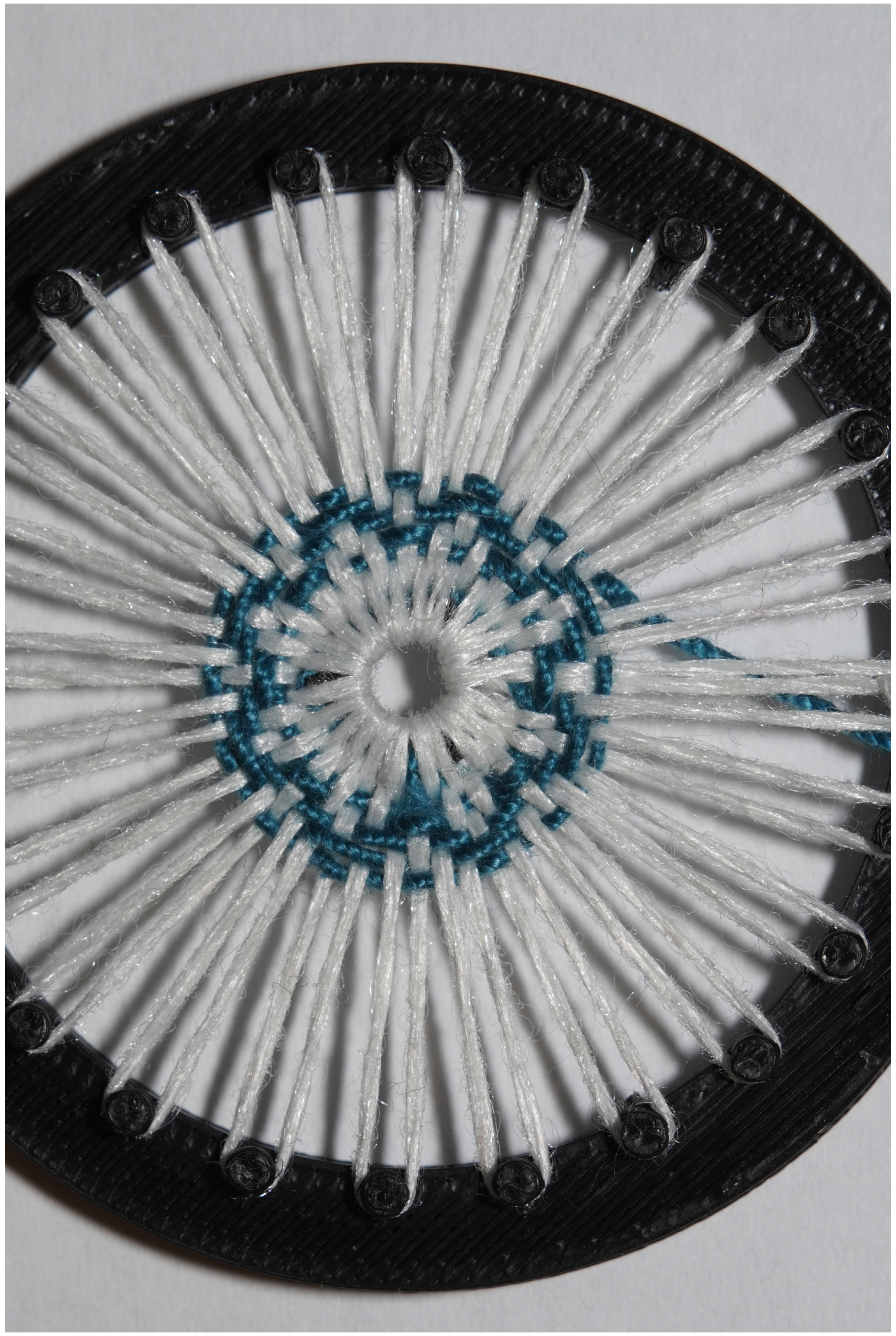


FINDINGS

Once assembled, different samples were gently heated to trigger the contraction of the active yarn. Besides the LCE yarn, other active materials were also tested, like elastane (pre-stretched) and Pemotex® (one-way activation only). Remarkably, the fabrics transformed into the intended shapes, conical or saddle-like shapes, upon activation. Upon cooling, the fabric settled back into a flat disc.

The research team observed reliable and reversible transformations through repeated heating and cooling cycles.





CHALLENGES

Some challenges were identified when using circular weaving. The density of the warp and weft is not constant, as it happens in the traditional weaving technique. This means that, in the beginning, the density of warp yarns is too high, causing the center to have only warp threads. Also, with the radius, the density of warp becomes too low, so the stability of the fabric might become compromised.

SUSTAINABILITY

From a sustainability standpoint, shape programmability has the potential to extend a textile's lifespan if it can be made to respond to different functional needs over time. While its real impact is still far from industrial validation, the initial experiments suggest that these multi-material fabrics can be designed to adopt complex changes upon a given stimulus.

SUMMARY

The BET team challenged the assumption that woven fabrics must remain two-dimensional and static. The main principle is to direct yarn contraction using the interplay between passive and active yarns.

Important principles when weaving passive and active yarns together:

1. the interlacing frequency impacts the actuation behavior, determining how much active yarns can change their shape;
2. an uneven float distribution of active yarns leads to the curling of the fabric, as the imbalance creates a bending force.

This project showcased the possibility of creating cone- and saddle-like structures, which paves the way for more advanced shape-shifting designs.

REFERENCES

1. Silva, P. E., Lin, X., Vaara, M., Mohan, M., Vapaavuori, J., & Terentjev, E. M. (2023). Active textile fabrics from weaving liquid crystalline elastomer filaments. Advanced Materials, 35(14), 2210689.

EXPERIMENTAL DEVELOPMENT OF THERMALLY RESPONSIVE WOVEN TEXTILES

Imagine a fabric that moves and reshapes itself without any embedded electronics, reacting solely to changes in temperature. Thermally responsive textiles redefine the role of fabrics, transforming them from passive materials into dynamic, functional components in everyday life, from wearable technology to adaptive interiors. This project explores the integration of thermally responsive coil actuators into textiles through weaving. Through systematic experimentation on weave structures and actuator placement, the project investigated how these textiles deform and move under thermal stimuli.

Through a series of woven explorations and prototypes, forming a base of three case studies, the project offers a framework for designing kinetic textiles that respond to temperature changes. It proposes new possibilities for responsive fabrics, materials that can morph, adapt, and interact with their environment in unique ways.

GENERAL INFO

Involved partner: Aalto University
Researchers: Mithila Mohan, Maija Vaara, Zahra Madani, Jaana Vapaavuori
Date of project: Autumn 2022 - ongoing

TECHNICAL TERMS

Coil actuator: A mechanism that can be integrated into fabrics to enable movement, such as bending or stretching, making the material "responsive" to external stimuli like heat or electricity.
Float length: In weaving, a float refers to a yarn strand that skips over other threads without interlacing. The float length is the distance that a yarn travels before it is interwoven again. Longer floats can make the fabric smoother or shinier but may reduce its durability.
Spacer fabrics: Three-dimensional textiles consisting of two outer fabric layers connected by a middle layer of yarns or filaments, thus creating a "space" between the layers.
Kinetic textiles: Fabrics that can move or change shape in response to external factors like heat, light, or pressure.
Shape memory actuators: Components made from special materials that "remember" a predefined shape. When exposed to specific triggers, such as heat or electricity, they return to that shape.
Warp & Weft: The warp consists of the vertical threads that are held stationary on a loom while weaving. They form the backbone of the fabric. The weft refers to the horizontal threads that are woven over and under the warp threads.

PROJECT OUTLINES

This project involved the experimental development of thermally responsive woven textiles by integrating coiled shape memory actuators, yarns that contract when exposed to heat, into fabric structures. The focus was on understanding how woven parameters, particularly float length and actuator placement, influence the movement and deformation of textiles under thermal stimuli.

Three case studies were conducted. Case Study I explored how actuators behave when woven into fabrics using weave structures with varying float lengths. It was found that longer floats gave the actuators more freedom to contract, resulting in greater deformation of the fabric. The study helped identify an optimal float length; beyond this point, instead of producing movement within the textile, the actuators began to escape the woven structure. The case showcased fabrics with different deformation effects, ranging from wrinkling in the fabric to curling movements depending on the float length.

Case Study II explored how the placement and orientation of these actuators within the single-layered fabric (e.g., edges, alternating sides) affected the type and direction of movement, such as curling and wave-like motion.

Case Study III integrated the actuators within double and multi-layered fabrics, allowing movement to occur internally, leading to pleating, opening, and tubular formations.

The prototypes were woven using semi-mechanized looms, allowing manual insertion of coiled actuators. Cotton was selected as the passive yarn for stability, flexibility, and mono-material recyclability of the ground fabric. The study emphasized a material-led, practice-based approach that combined textile design and material experimentation to enable kinetic textile behavior with changing temperature.

PROJECT PURPOSE

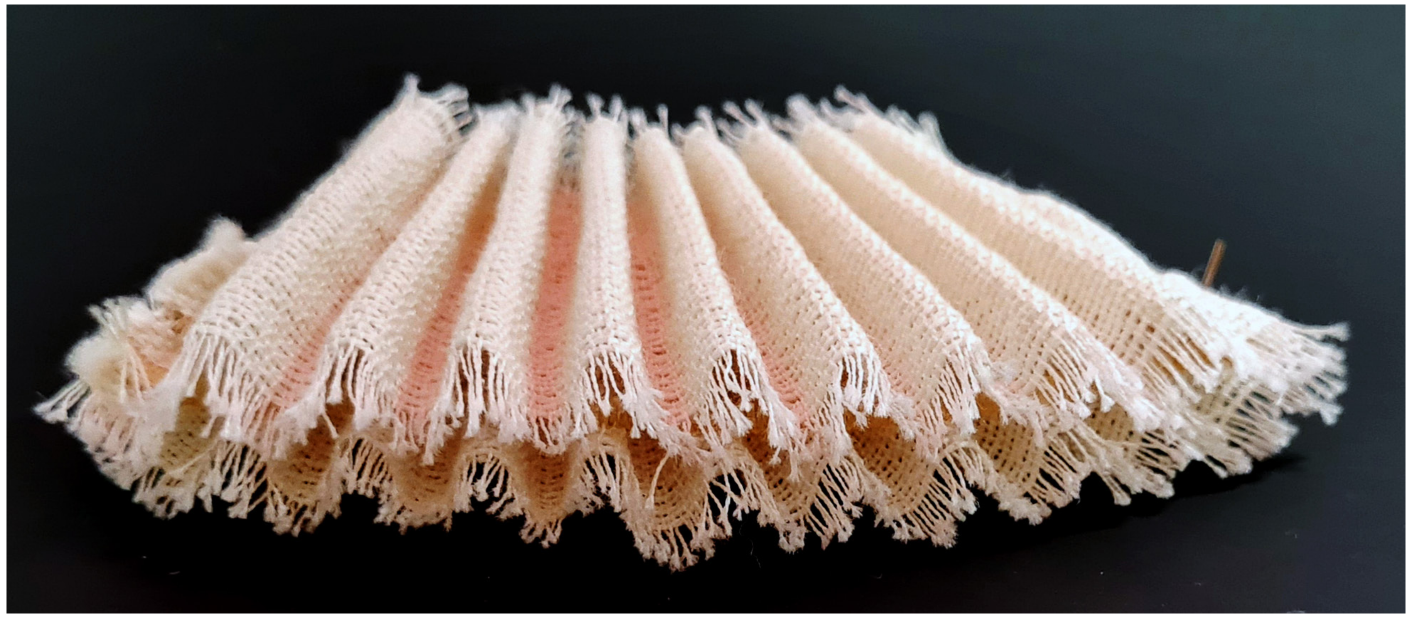
The project explored how thermally responsive elements, such as nylon or novel bio-based coil actuators developed within the Beyond e-Textiles project, can be embedded into woven fabrics to create textiles that deform and move in response to temperature. This research was motivated by the need for kinetic and adaptive textile systems that can shift shape without relying on electronic components or external mechanical inputs. The intent was to shift the paradigm of textiles from static materials to dynamic surfaces capable of interaction and transformation.

A key focus was on understanding the material and structural parameters that enable movement. This involved examining how active elements, such as actuators, interact with passive yarns like cotton, and how different weave structures can support or limit deformation. By investigating these parameters, the project aimed to develop a design methodology for responsive textiles that can inform future work by researchers and designers in the field. Possible applications include reconfigurable smart interiors, where textiles adapt to temperature fluctuations through controlled movement.

METHODOLOGY

The study employed an experimental approach through three structured case studies to investigate thermally responsive woven textiles. Coil actuators, which respond to heat, were manually integrated as weft alongside passive cotton yarns (which formed the ground weave of the fabric). Prototypes from Case I were woven using a Dobby CAD loom, whereas prototypes for Case II and III were woven using a TC2 digital Jacquard loom. TC2 allowed for weaving more complex double- and multilayered structures. Both looms are semi-mechanized where the wefts can be inserted manually, allowing for easy integration of the actuators.

In Case Study I, variations in float length were tested to assess their influence on actuation. Case Study II explored how the placement and orientation of floats affected fabric movement. Case Study III introduced actuators into double- and multilayered fabrics, enabling more complex deformations such as pleating or tubular structures. Across all studies, yarn and weave parameters were systematically adjusted and documented before, during, and after thermal exposure.



The semi-mechanized looms allowed precise control over the warp through digitally programmed shafts, while the weft was inserted manually using a shuttle. Due to their form, the coil actuators could not be used in industrial or fully mechanised looms and had to be carefully hand-inserted during weaving. This iterative, hands-on process allowed for fine-tuning the interaction between structure and material behavior.

FINDINGS

The project found that both float length and actuator placement significantly influence fabric deformation. Short float lengths produced minor wrinkling, while longer floats enabled visible curling and 3D shape transformation. The curling occurred inward toward the side where the actuators were on the face of the fabric, confirming directional response.

In single-layer fabrics, strategic placement of actuators, either on one edge or alternately on the face and back of the fabric, produced specific movement patterns like curling or wave motion. Double-layered textiles allowed hidden actuators to create volume changes, pleats, or tubular structures when heated. Whereas integration of actuators in multilayered fabric allowed for the realization of spacer fabrics that opened during actuation.

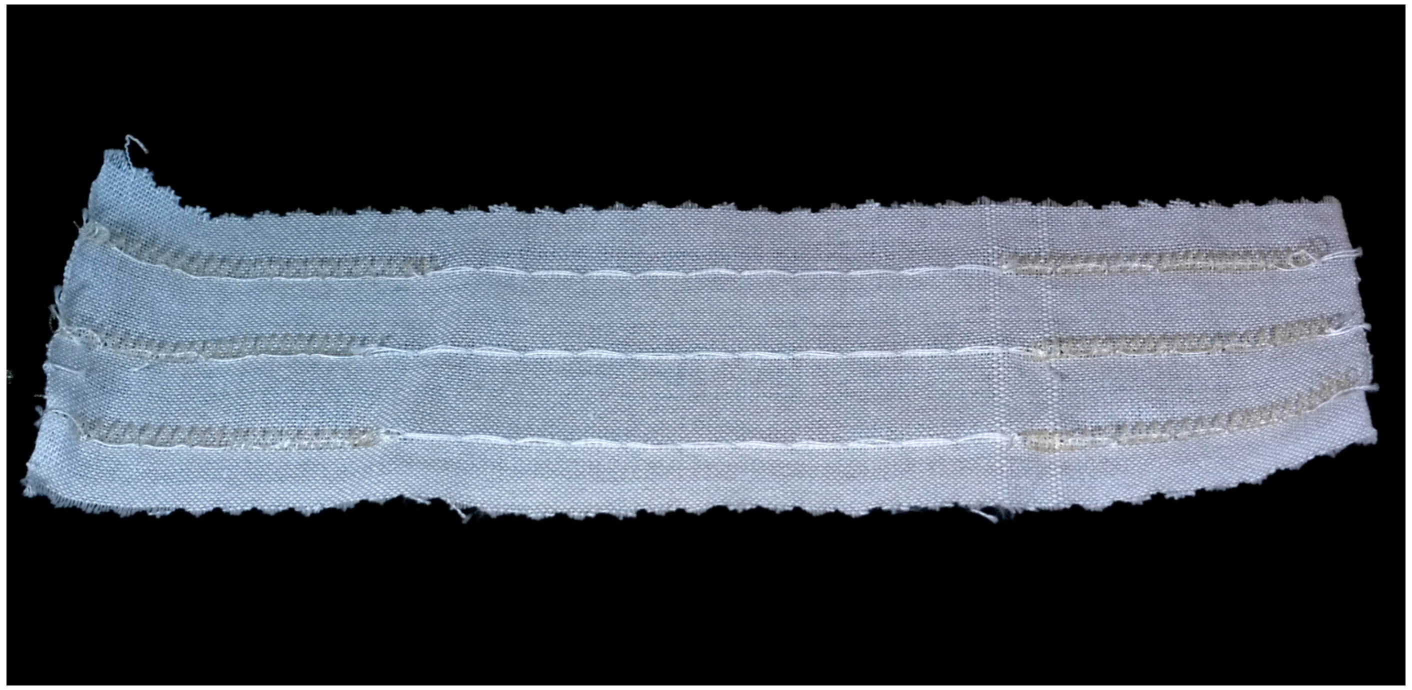
The fabric did not always return to its original state post-actuation, depending on the rigidity and arrangement of the passive yarns. Overall, longer floats and directional placement were key for meaningful actuation. The success of double- and multi-layer integration also showed potential for more complex, programmable textile behavior.

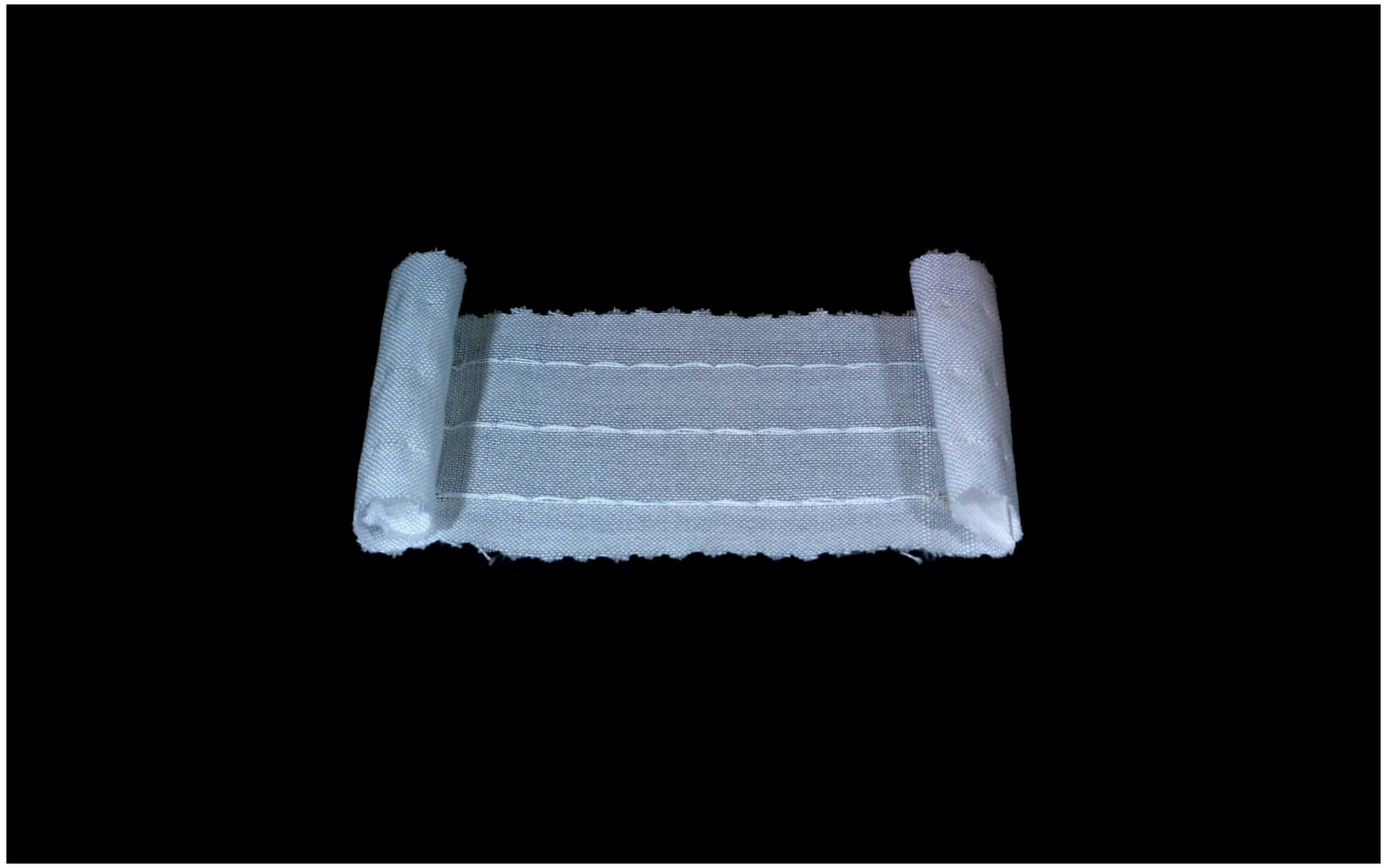
CHALLENGES

The coil actuators had to be hand-inserted, which limited the scalability of the process. The actuation temperatures for the coils varied across batches, typically ranging from 40°C to 60°C. While material scientists within the project worked to lower this threshold, inconsistencies remained. Some actuators activated at lower temperatures, while others required more heat, and in some cases, higher temperatures caused the coils to burn. These variations made it difficult to define reliable performance parameters and highlighted the need for further study into material stability and consistency.

Another issue was the reversibility of the fabric's movement. Many samples failed to fully return to their original form after cooling, raising concerns about material fatigue and long-term reusability. Passive yarn choice proved crucial here, as some rigid yarns inhibited recovery.

Weaving complexity also posed a challenge. Combining multiple weft systems and controlling floating yarns required manual skill and technical knowledge, especially on semi-mechanized looms. Designing for both flexibility and structural integrity required careful balancing of weave density and yarn behavior. Lastly, integration into real-world applications demands further material testing and environmental durability studies, especially for wearable or architectural uses.





OPPORTUNITIES

Future research could aim to advance the development of bio-based coil actuators with reduced actuation temperatures and more reliable, repeatable cycles of activation and recovery, in close collaboration with material scientists. Further exploration of multilayered weaving techniques may allow for more complex movements and reliable shape recovery. The multilayered fabric structure enables the integration of active components that respond to multiple environmental stimuli, such as temperature, proximity, and light. For example, combining thermal responsiveness with UV-triggered color change or movement could expand the possibilities for creating multifunctional textiles. These advances would open opportunities for smart materials that adapt to various environmental stimuli, supporting use cases ranging from dynamic interior fabrics and responsive garments to responsive textile sensors.

NOVELTY

This project pushed textile thinking and design into the realm of responsive systems by embedding actuators directly within the woven structure. Unlike post-processing methods, where actuators are attached to existing fabrics, the actuation was built within the fabric itself, making movement an integral part of the material. This approach introduced a novel, material-led method for creating shape-changing textiles with precise control over structure and behavior, opening new possibilities for designing textiles that interact dynamically with their environment.

SUMMARY

This project explored the integration of thermally responsive coil actuators into woven textiles to create shape-changing fabrics. Through three experimental case studies, it investigates how float length, actuator placement, and weave structure influence fabric movement. The exploration of weave structures played a key role in enabling programmable deformation through material and structural interaction. The findings shift the perception of textiles from passive surfaces to active systems, offering new directions for kinetic textile design and highlighting the potential of textiles as responsive elements within our environments.

REFERENCES

1. Vapaavuori, J., Madani, Z., Santos Silva, P., Mohan, M., Vaara, M., Iannacchero, M., Koskelo, L., & Launonen, G. (2024). Entangled – Reimagining textile functionalities / Designs for a Cooler Planet. Exhibition, Aalto University & Helsinki Design Week. [https://research.aalto.fi/en/publications/entangled-reimagining-textile-functionalities-designs-for-a-coole]. Featured at [https://www.aalto.fi/en/events/entangled-reimagining-textile-functionalities] and [https://www.linkedin.com/feed/update/urn:li:activity:7245775912682606592/].
2. Mohan, M., Dumitrescu, D., Talman, R., Bang, A. L., Harsaae, M., Ladekarl, I. M., Kramer Pedersen, L., Bull Nielsen, T., Ege, A., Lawrynowicz, A., Miettunen, K., Nizamov, R., Vapaavuori, J., Koskelo, L., Vaara, M., Santos Silva, P., & Madani, Z. (2023). Textile Intersections exhibition. Exhibition, Loughborough University. [https://research.aalto.fi/en/publications/textile-intersections-exhibition-3]. Featured at [https://www.linkedin.com/feed/update/urn:li:share:7110594530508218368/].
3. Mohan, M. (2022). DIALOGUES - Creating New Textile Futures @ Dipoli. Exhibition, Aalto University. [https://research.aalto.fi/en/publications/dialogues-creating-new-textile-futures-dipoli-15]. Featured at [https://www.instagram.com/p/Cn6146lNqZe/].
4. Mohan, M. (2022). DIALOGUES - Creating New Textile Futures. Exhibition, New York Textile Month. [https://research.aalto.fi/en/publications/dialogues-creating-new-textile-futures-3]. Featured at [https://www.instagram.com/p/CkQTR7qDouv/] and [https://www.instagram.com/p/Ck-ofRIt748/].

STRETCHABILITY

The Stretchability project explored the challenges related to the wide use of elastane, a synthetic fiber extensively used in the fashion industry, often superfluously. The project initially emerged from a scenario building workshop – see case 3, *Scenario Building as Dialogue Tool* – where the question "What if elastane were suddenly banned, or it's accessibility significantly reduced?" emerged from one of the scenarios.

The research team explored ways to gain stretchability and comfort in textile fabrics, using sustainable alternatives from elastane, both in regards of materials and material structure, while simultaneously investigating and mapping out the history and prevalence of elastane in garment manufacturing and the fashion industry.

All image credits: VIA Team

GENERAL INFO

Involved partner: VIA University College Denmark
Researchers: Lena Kramer Pedersen, Malene Harsaae, Tina Cecilie Bull
Date of project: 2023

TECHNICAL TERMS

Comfort: in clothing refers to its ability to allow freedom of movement, provide a good fit and usability, look visually appealing when worn, and function well psychologically in everyday life, encompassing both emotional and practical aspects.
Elastane: is a synthetic monofiber that creates stretch when blended with textile materials. Elastane is a fossil based polyether-polyurea copolymer invented in 1958 by chemist Joseph Shivers at DuPont's Benger Laboratory in USA.

PROJECT OUTLINES

Since elastane (also known as Lycra and spandex) was invented in 1958 the fiber has been increasingly implemented in clothing, even in products with no need for the stretchability elastane provides. Elastane is a synthetic man-made fiber deriving from fossil resources and is often mixed with other fibers, both natural and synthetic. It is currently both difficult and complex to separate elastane from these mixed fibers, making the proper recycling of post-consumer waste containing elastane a difficult and almost insurmountable task, which is an obstacle to the reuse and recycling of all the mixed textile materials. Consequently, products containing elastane predominantly end up being burned at their end of use. Furthermore, the production process of the material itself is environmentally damaging and products containing elastane shed microplastic during the washing process. Essentially, elastane provides comfort and flexibility but comes with huge environmental costs.

PROJECT PURPOSE

Elastane is widely used in performance clothes for functional purposes but consumer requests for comfort and appearance have led to an increased use of elastane in many fashion products where stretchability is not as necessary for the functionality of the garment. However, stretchability in products enables more body shapes to use the same fit, thus lowering complexity in the production phase.

Despite the undeniable stretchability, softness and enhanced freedom of movement that elastane brings to clothing, the widespread, often unnecessary use presents a significant problem due to its considerable environmental impact.

Therefore, the *Stretchability* project's primary aim was to explore and identify concrete, viable alternatives (material or structure substitutes) to elastane in fabric production, ultimately paving the way for a decrease in the utilization of this environmentally burdensome material and challenging the industry's habitual, often superfluous reliance on it. Reducing the amount of elastane is an important contribution to the green transition of the fashion industry.

METHODOLOGY

The project's methodology involved a double approach, combining tangible material exploration with desk research. The team started with research into existing fibers and yarns to explore available possibilities. This was followed with practical hands-on experiments into elastane alternatives and the development of physical prototypes. The team created material samples at the fabric level, showcasing various weaving and knitting techniques designed to achieve stretch without the use of elastane.

While developing samples and prototypes, the research team built and visualised a timeline tracing some of the highlights in the evolution and widespread adoption of elastane within garment manufacturing and the fashion industry. The primary intention of this historical investigation was not to serve as a definitive outcome in itself, but rather to provide a framework and context for the broader project. By understanding the historical drivers behind elastane's popularity, including factors related to comfort and aesthetic preferences, the project could better address the underlying needs that elastane currently fulfils. Initially added for comfort of movement, elastane's comfort properties now drive sizing rationalization and consumer expectation for adaptable, easy-to-wear clothing across garment types, complicating the search for alternatives.

FINDINGS

The project's investigations yielded confirmation of a significant premise: achieving considerable stretchability in textiles is indeed possible without relying on elastane. Through the strategic application of diverse knitting and weaving constructions and techniques, materials can be engineered to offer a comparable degree of elasticity. While this fundamental capability was not a groundbreaking revelation as such, particularly within the realm of knitwear, the project's most impactful discovery lay in its contribution to the broader field of fiber development.

The research served as a valuable source of insight for developers of new textile fibres. By highlighting the feasibility of elastane-free stretch, the project provided important knowledge regarding the properties and construction methods that warrant focus when developing innovative and, importantly, more environmentally conscious fiber alternatives. In essence, it offered inspiration and practical direction for future material advancements.

The very speculative nature of this project, particularly the "what if elastane were suddenly banned..." scenario, became a guiding principle for bridging the gap between design considerations and the physical and chemical aspects of textile innovation. Ultimately, the project successfully cultivated a heightened awareness surrounding the possibilities of working beyond the conventional reliance on elastane.

CHALLENGES

Despite the promising progress in identifying elastane alternatives, the team encountered several significant hurdles as it moved from conceptualization to practical application. One key challenge lies in adapting the developed alternatives for use in finer and lighter materials. The initial prototyping phase predominantly utilized more robust fabrics, leaving the applicability of these solutions for delicate items like sportswear and

underwear largely unexplored. Creating substitutes that offer the necessary stretch and recovery in significantly thinner and lighter textiles, often requiring finer yarns, presented a considerable technical obstacle.

Furthermore, the potential step of scaling up production for industrial purposes revealed another layer of complexity, as many companies rely heavily on their existing supplier networks. If these manufacturers lack the specific techniques or technological infrastructure required to support the production of novel elastane alternatives, the translation of successful prototypes into commercially viable products would become a major impediment. This is a common bottleneck in the journey from innovation to widespread adoption within the fashion industry.

Consumer expectations, habits and demands are not easily changed. The comfort of stretchability is a preference shared by a majority of consumers and a property expected in many clothing products as consumers have become increasingly accustomed to the product performance provided by including elastane. However, it is worth noting that if regulatory bodies, such as the EU, were to prohibit elastane in specific product categories, consumers would naturally adapt to the available, elastane-free alternatives. This suggests that while a shift in consumer mindset

is important, external factors could also play a significant role in driving the transition towards a less elastane-dependent fashion industry.

OPPORTUNITIES

Future exploration points towards two key directions to achieve comparable comfort without elastane: Developing environmentally friendly and recyclable alternative fibers that replicate elastane's stretch and investigating innovative garment construction methods to reduce or eliminate its necessity. These "fiber level" and "product level" approaches offer distinct pathways to significantly decrease elastane reliance.

Furthermore, shifting consumers' and producers' mindsets towards new material properties and design aesthetics will be crucial for a successful transition towards a more sustainable fashion industry.

NOVELTY

Instead of achieving a breakthrough replacement alternative to elastane, which was the initial goal, the project's purpose deviated towards understanding alternative stretch and comfort mechanisms and highlighting the remaining challenges in matching elastane's established performance. This recalibration of expectations became a significant outcome.

While not a complete overnight fix, the project underscores the urgent need to move beyond elastane. It

lays the groundwork for future innovation and emphasizes that a greener fashion future requires both clever science and consumers to embrace new materials and aesthetics for real change.

The resulting prototypes and research findings were incorporated into an exhibition and communicated to project partners within the 'Beyond e-Textiles' initiative. This helped raise awareness of elastane's environmental impact and the need for more sustainable alternatives to the partners who did not necessarily have a background in the clothing and fashion industry.

SUSTAINABILITY

Addressing elastane use may promote greater product durability, as elastane can compromise garment longevity. Furthermore, it is derived from fossil fuel and it's manufacturing process is environmentally damaging. Successful implementation of alternatives could lead to a reduction in microplastic shedding from clothing and facilitate the creation of circular systems where more garments effectively can be recycled and repurposed into new fibers – thus contributing to the green transition in fashion industry.

SUMMARY

The *Stretchability* project explored the possibilities of reducing elastane use within the fashion industry through novel materials and construction techniques as potential alternatives. The research successfully demonstrated the technical feasibility of creating stretchability without resorting to elastane and highlighted challenges in industrial scaling and consumer comfort expectations. The project also brought to light the critical need for ongoing research into sustainable elastane replacements and a shift in industry practices and consumer mindsets to reach a more environmentally conscious fashion industry and widespread adoption.

This project illuminated clear next steps: the development of truly sustainable, recyclable stretch fibers and innovative garment designs that minimize or eliminate the need for elastan.

REFERENCES

1. Fisher, Geoff (2021) https://www.fiberjournal.com/elastane-materials-expand-with-responsible-stretch/

FUNCTIONALISED IONCELL FIBERS

Oftentimes, imparting functionality – such as thermal regulation or light-to-heat conversion – into cellulosic textiles, compromises other qualities of these textiles, like easy recyclability. For the Functionalised Ioncell fibers project, the aim was to find bio-sourced functional molecules that could be directly integrated as a part of the Ioncell spinning process, thereby adding functionality to the fibers without introducing extra process steps. As demonstrated by small-scale textile samples, thermally regulating and slightly hydrophobic regenerated cellulose textiles were developed using a spinning process with significant sustainability advantages compared to conventional lyocell and viscose processes.

GENERAL INFO

Involved partners: Aalto University, VIA University College
Researchers: Zahra Madani, Pedro Silva, Maija Vaara, Marike Langhans, Jaana Vapaavuori, Lena Kramer Pedersen
Date of publication: April 2025

TECHNICAL TERMS

Hydrophobic: A surface or substance that repels water.
Hydrophobizing agent: A chemical compound applied to a material to impart water-repellent properties. It modifies the surface chemistry (often by adding non-polar groups) to reduce water absorption.
Regenerated cellulose fibers: Fibers produced by chemically processing natural cellulose (from wood pulp or cotton linters) into a soluble form and then regenerating it back into insoluble cellulose fibers.
Phase change particles: Micro- or nano-sized materials that absorb and release heat during a phase transition (e.g., solid -> liquid). In textiles and coatings, they are used for thermal regulation by storing and releasing latent heat.
Ionic liquids: Salts that are liquid at relatively low temperatures (often below 100 °C). They consist entirely of ions and are notable for their low volatility, high thermal stability and ability to dissolve a wide range of substances, including cellulose.
Solvent: A liquid capable of dissolving other substances (solutes) to form a homogeneous mixture (solution).
Supramolecular forces: The weak forces that hold molecules together without forming chemical bonds. These forces are important because they let molecules organize themselves into larger structures, like in self-assembling materials or biological systems.

PROJECT OUTLINES

Photothermal and thermoregulating textiles are important in modern clothing technology due to their ability to enhance comfort and energy efficiency. Photothermal textiles convert sunlight into heat, providing warmth in cold environments without the need for additional energy sources, making them ideal for outdoor activities and cold-weather clothing. Thermoregulation textiles, on the other hand, adapt to temperature changes by absorbing, storing, and releasing heat, thereby helping to maintain a stable body temperature. Overall, these advanced textiles contribute to sustainable and adaptable solutions for thermal management in clothing without the need to implement electrical circuits or power sources, thus preserving the textile-like quality and making garments easier to recycle.

METHODOLOGY

The team of researchers incorporated photothermal molecules for photothermal textile and phase change particles for thermoregulating fabric, into manufactured cellulosic fiber using the Ioncell spinning technology. This process utilizes ionic liquids as an innovative and environmentally friendly solvent for cellulose, with the additional advantages of also being recyclable and non-flammable. The resulting regenerated Ioncell cellulose fibers are soft, strong even when wet, and highly durable, making them directly suitable as a raw material for fabric manufacturing.

FINDINGS

The team discovered that photothermal textiles can achieve a temperature increase of approximately +8°C when exposed to a solar simulator compared to pure cellulosic textiles. In their investigation into thermoregulating textiles, the researchers identified a bio-sourced fatty acid that could be incorporated into Ioncell fibers to impart thermoregulation. Thanks to the supramolecular forces binding these thermoregulating particles into the cellulose matrix, the thermal storage function could be activated 100 times without losing its performance.

CHALLENGES

To advance towards commercialization, the temperature range at which the thermoregulating textile operates needs to be adjusted to better align with temperatures commonly encountered in outdoor environments. Regarding the photothermal textile, photothermal molecules were partially washed away during the process, reducing the functional material content in the final textiles. This aspect requires optimization to prevent significant material loss during production.

OPPORTUNITIES

As a next step, larger-scale fabric prototypes could be developed. For both the photothermal effect and thermoregulation, the architecture of the fabric will also play a role which could be explored by creating a textile prototype library that includes various amounts of functionalized and standard cellulosic yarns.

NOVELTY

The researchers' process demonstrated that these types of functional textiles can be made from purely bio-sourced raw materials. Additionally, a bio-sourced hydrophobizing agent was introduced to facilitate moisture management in these textiles. This overall enhancement is expected to improve the recyclability of the textiles at the end of their lifecycle as compared to textiles utilizing additional energy sources.

SUSTAINABILITY

The project reflected on sustainability by addressing both the benefits and challenges of integrating advanced functionalities into textiles. By utilizing bio-sourced molecules in combination with the Ioncell spinning method, it advanced clothing technology that enhances thermal comfort without relying on electrical energy sources. The Ioncell process itself is particularly sustainable, utilizing recyclable and non-flammable ionic liquids as solvents, thereby minimizing environmental impact compared to conventional lyocell and viscose processes. Additionally, the project aimed to enhance recyclability, a common issue when adding functional capabilities to textiles.

However, challenges remain, such as optimizing material loss during production of photothermal textiles and adjusting temperature ranges for thermoregulating textiles to better suit outdoor conditions. Future improvements could further enhance the sustainability of these textiles by refining their lifecycle and recycling potential.

SUMMARY

The *Functionalised Ioncell Fibers* project explored how thermal functionality can be imparted into regenerated cellulose fibers using the Ioncell spinning method where bio-sourced photothermal, phase-change, and hydrophobizing molecules were integrated into textile fibers. These fibers were directly used to develop simple textile prototypes which demonstrated that the designed functionality can be successfully implemented at the textile level.

REFERENCES

1. Madani, Z., Baniasadi, H., Silva, P. E. S., Vaara, M., Langhans, M., Schlapp-Hackl, I., Evenäs, L., Hummel, M., & Vapaavuori, J. (2025). Multifunctional thermoregulating and water repellent cellulosic textile. Green Chemistry, 27(22), 6482-6492. https://doi.org/10.1039/d5gc00943j. [https://research.aalto.fi/en/publications/multifunctional-thermoregulating-and-water-repellent-cellulosic-t].

BEYOND STAINS – SELF-CLEANING COTTON

We all know the struggle with cotton clothing - spill your coffee and you're rushing to the washing machine. Cotton fabrics, while comfortable and breathable, readily absorb stains and require frequent washing – a process that consumes significant water and energy resources. Recent advances in materials science have led to the development of self-cleaning coatings that enhance the surface properties of cotton without compromising its inherent softness and comfort. Particularly promising are metal oxide coatings such as titanium dioxide (TiO) and zinc oxide (ZnO), which offer cost-effective fabrication and excellent photocatalytic self-cleaning capabilities [1]. These materials utilize light-activated mechanisms to decompose organic contaminants without requiring water or detergents, potentially reducing the environmental footprint of textile maintenance substantially. This feature is especially promising for outdoor garments, which are often challenging to wash properly using conventional methods. Outdoor applications benefit from constant sunlight exposure, creating ideal conditions for effective self-cleaning action.

Figure 1. Time-series comparison showing the discoloration of dyes on a ZnO-coated cotton sample under simulated sun at intervals of 0, 1, 2, 4, 22, and 48 hours. Each photograph displays a brownish coffee stain in the top left corner and a blue MB stain on the right.

GENERAL INFO

Involved partner: University of Turku
Researchers: Alicja Lawrynowicz, Emilia Palo, Rustem Nizamov, Mikael Nyberg, Kati Miettunen
Date of publication: December 2023

TECHNICAL TERMS

ZnO: Zinc oxide
TiO: Titanium dioxide
MB: Methylene Blue
SEM: Scanning Electron Microscope
ROS: Reactive oxygen species

PROJECT PURPOSE

This research project aimed to develop a self-cleaning cotton fabric using ZnO as a photocatalytic agent. When exposed to sunlight, these ZnO particles facilitate the breakdown of organic pollutants, bacteria, and stains on the fabric surface through photocatalysis. Here, the main objective was to create a low-maintenance textile with enhanced sustainability characteristics through reduced washing requirements.

Figure 2. SEM image of beautiful flower-like ZnO crystal structures grown on a cotton substrate. This crystal morphology has been shown to provide optimal self-cleaning performance. Author: Alicja Lawrynowicz, UTU.

PROJECT METHODOLOGY

What is known from Material Science:

ZnO is a semiconductor that efficiently absorbs ultraviolet radiation. This material possesses several advantageous properties that make it ideal for textile applications: biocompatibility, biodegradability, high photostability, and low toxicity [2–4]. ZnO effectively absorbs light in both the UV-A and UV-B regions, providing UV-blocking functionality in addition to its photocatalytic properties [1].

Generally, the photocatalytic mechanism operates when ZnO absorbs photons with energy exceeding its bandgap, generating electron-hole pairs. These charge carriers interact with ambient oxygen and water molecules to produce reactive oxygen species (ROS), including hydroxyl radicals and superoxide ions. These ROS subsequently oxidize organic compounds, breaking them down into harmless substances such as carbon dioxide and water [5].

For this study, a microwave-assisted hydrothermal method was employed to grow ZnO crystals directly on cotton fabrics. This in-situ growth technique ensured strong adhesion between the photocatalytic material and the textile substrate while maintaining energy efficiency during fabrication. The project specifically investigated the relationship between ZnO crystal morphology and photocatalytic efficiency to identify optimal structures for self-cleaning applications in textiles.

FINDINGS

To evaluate self-cleaning performance, organic stains, including blue dye and black coffee, were applied to the treated fabrics and placed for 48 hours under simulated sunlight. The most effective in self-cleaning samples demonstrated 73 % degradation of MB dye within one hour of sun exposure – a rate twice as fast as comparable studies in the literature. This study also confirmed that ZnO-coated cotton provided exceptional UV protection, blocking as much as 99.93 % of UV-B radiation. These results confirm that the simplified fabrication protocol produces cotton with excellent self-cleaning and UV-blocking properties, validating the effectiveness of this research approach [1].

CHALLENGES

Despite the promising results, several challenges remain in the development of practical self-cleaning textiles. The primary limitation involves light intensity requirements. Laboratory tests utilized calibrated solar simulators providing full-spectrum illumination at standardized intensities, which may not be replicated in typical usage scenarios. The photocatalytic efficiency would likely decrease under ambient lighting conditions, especially in regions with limited sunlight or during indoor use. Additionally, comprehensive evaluation requires durability testing through multiple wash cycles to determine the mechanical stability of the coating and its long-term photocatalytic performance. Optimizing the ZnO particle size, distribution, and adhesion to maintain functionality throughout the garment lifecycle represents an ongoing research challenge.

SUSTAINABILITY

Self-cleaning cotton with ZnO photocatalytic coatings offers significant environmental benefits through reduced washing frequency, potentially decreasing water consumption, energy usage, and detergent release into wastewater systems. The self-cleaning features may also extend fabric lifespan by preventing fiber degradation due to intense washing. However, a critical environmental consideration is the potential release of nanoparticles during laundering. If ZnO (or any) particles detach from the fabric and enter aquatic ecosystems, they could pose ecotoxicological risks. Current research focuses on developing stronger binding mechanisms between metal oxides and textile fibers to minimize particle leaching while maintaining photocatalytic effectiveness. Life cycle assessment studies are needed to quantify the net environmental impact of this solution compared to conventional cotton processing and maintenance.

Figure 3. Cotton fabric stained with coffee and Methylene Blue (MB) dyes. These dyes were used to evaluate the self-cleaning properties of ZnO-coated samples. Author: Mikael Nyberg, UTU.

SUMMARY

Light-driven self-cleaning features represent a promising advancement for textiles. Fabrics enhanced with photocatalytic properties effectively break down organic stains and eliminate odours without conventional washing, simply by harnessing energy from sunlight to trigger cleaning reactions. Since fabrication techniques continue to improve, such materials have the potential to transform the environmental footprint of clothing care by reducing water consumption, energy use, and chemical detergent release. Moreover, certain materials, like ZnO, provide valuable UV protection for wearers, which was also obtained in this project. These photocatalytic fabrics appear particularly well-suited for outdoor applications, where garments are naturally exposed to sunlight.

REFERENCES

1. A. Lawrynowicz, E. Palo, R. Nizamov, K. Miettunen, Self-cleaning and UV-blocking cotton – Fabricating effective ZnO structures for photocatalysis, J. Photochem. Photobiol. Chem. 450 (2024) 115420. https://doi.org/10.1016/j.jphotochem.2023.115420.
2. V. Batra, I. Kaur, D. Pathania, Sonu, V. Chaudhary, Efficient dye degradation strategies using green synthesized ZnO-based nanoplatforms: A review, Appl. Surf. Sci. Adv. 11 (2022) 100314. https://doi.org/10.1016/j.apsadv.2022.100314.
3. J. Wojnarowicz, T. Chudoba, W. Lojkowski, A Review of Microwave Synthesis of Zinc Oxide Nanomaterials: Reactants, Process Parameters and Morphologies, Nanomaterials 10 (2020) 1086. https://doi.org/10.3390/nano10061086.
4. A. Kołodziejczak-Radzimska, T. Jesionowski, Zinc Oxide—From Synthesis to Application: A Review, Materials 7 (2014) 2833–2881. https://doi.org/10.3390/ma7042833.
5. E. Pakdel, J. Wang, S. Kashi, L. Sun, X. Wang, Advances in photocatalytic self-cleaning, superhydrophobic and electromagnetic interference shielding textile treatments, Adv. Colloid Interface Sci. 277 (2020) 102116. https://doi.org/10.1016/j.cis.2020.102116.

MACHINE LEARNING TRIBOELECTRIC PLA

This project explored the possibility of harvesting static electricity from a textile surface to use it as an alternative energy source. The friction that occurs when two surfaces are rubbed against each other creates static electricity, also called the triboelectric effect. The cross disciplinary research team used machine learning to create a method that can predict the optimal knitted surface when it comes to the tribo effect. The overall aim was to understand the triboelectric effect on different types of surface structures and to exploit machine learning methods to determine the optimal combination of the initial parameters of the fabric to maximize the charge harvested.

This was done by touching/rubbing together two surfaces that are connected in a circuit, using copper tape/wires and measuring the different charges harvested. The textile surface is knitted and represents a surface typically used in the commercial market.

Images. All images are by Maija Vaara / Aalto University.

GENERAL INFO

Involved partners: VIA University College, Aalto University
Researchers: Lena Kramer Pedersen, Matteo Iannacchero
Date of project: 2023 and ongoing

TECHNICAL TERMS

Interlock knit: A double jersey knit construction often used in jogging sweaters, dresses, leggings and T-shirts.
Polylactic Acid: Also called PLA, is a bio-based polyester, commonly made from materials such as sugar cane, corn starch or sugar beet.
Yarn count/Ne: Refers to the thickness of the yarn. Also referred to as Number English. It is the number of yard hanks (1 hank = 840 yards) in one pound of yarn. The yarn used was Ne21 = 17.640 yards/pound.
Knitting gague: The number of knitting needles per inch on a knitting machine. Tested gagues were 5, 8 and 12.
Stitch length: The length of the yarn from which the knitted loops are formed. Tested stitch lengths were 9.7, 10.0, 10.5, 11.0 & 12.8 mm.
Thread count: Refers to how many single yarns (2ply in this case) are combined as one yarn into the yarn feeder. The tested thread count was 2,4 and 8.

PROJECT OUTLINES

The quest for sustainable energy solutions has made triboelectricity an increasingly promising frontier. Triboelectric nanogenerators (TENGs) harness the electric charge generated by friction, offering a novel approach to converting mechanical energy into electrical energy.

The rise of wearable technology has prompted the use of triboelectricity as a potential power source. By embedding TENGs into clothing and accessories, a steady energy supply could be ensured, minimizing the need for frequent battery replacements. Made from eco-friendly and abundant materials, triboelectric generators could offer a sustainable way to generate power, supporting global efforts to reduce environmental impact and promote green technology.

METHODOLOGY

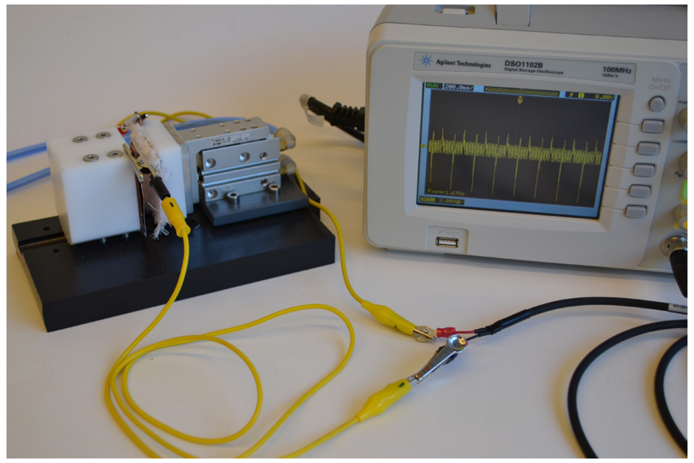
In the beginning, the team had a selection of different types of materials and knitted structures which were tested by hand, selecting the ones looking promising and developing the technology to standardize the testing. The machine-learning algorithm then suggested new combinations to try with the aim of maximizing the charge generated, so that new samples were created and tested using a tapping device connected to a logic analyzer.

The study was divided into 3 steps:

1. Investigated the triboelectric effect of a knitted surface. In this context, different knitting constructions were made, each with different surfaces. The tactility of the surfaces ranged from being completely smooth to being napped. This step helped to identify the main variables to be optimized via machine-learning: the gauge, the stitch length and the area of the sample.
2. Investigated the material's impact on the triboelectric effect. The team made knitting samples in PLA, pure mercerized cotton, pure wool, pure polyester and paper yarn (pure cellulose). PLA seemed to respond quite well in the initial testing so further matchings were tested.
3. Trained an algorithm to predict which knitting technicalities would give the best triboelectric effect.

FINDINGS

1. After testing the triboelectric effect, the results showed that the knitting construction interlock performed best.
2. PLA gave the most triboelectric effect of all the tested materials, especially when paired with wool.
3. The machine-learning algorithm must be prepared, since it does not work with non-continuous variables yet.



CHALLENGES

The research team experienced challenges in the training of the algorithm, for example the implementation of non-continuous variables. Another big challenge was the development of the tapping device used to standardize the measurement. Particularly, finding components which allowed the continuous tapping with the same force and frequency so that all the measurements were the same. Protecting the analyzer from the electrical noise of all the devices connected in the building also posed a challenge.

OPPORTUNITIES

With successful training, the algorithm should be able to predict the most optimal production parameters of a knitted textile. This would provide the textile industry with a new method to forecast tribo effect on a textile surface.

There is potential in investigating how the tribo effect can be integrated into clothing. To find the most optimal method, an analysis of the interaction between clothing and body would be relevant. In such an analysis, there should be a special focus on movements that cause friction between either body and material or material against material. The analysis could then form the basis for the development of styles.

NOVELTY

Machine-learning, e.g. Bayesian optimization, is revolutionizing material science by speeding up the discovery and improvement of new materials. This advanced method uses existing data to smartly guide experiments, reducing time and costs. By efficiently exploring different material properties, it helps scientists quickly find the best solutions, supporting faster and more cost-effective innovations.

SUSTAINABILITY

In terms of sustainability, being able to generate transferable energy via the tribo effect could minimize the use of other energy sources. PLA as a pure material is bio-based and biodegradable. Furthermore, PLA parts could be separated from the rest of the garment, melted and re-spun as manmade fibers.

However, PLA is degradable only at high temperatures, which is why a significant amount of energy would have to be used for the degradation. Therefore, an energy balance would have to be prepared before it can be concluded that the PLA tribo effect in clothing can contribute positively to green transition.

SUMMARY

Even though the charge produced through the experiment was limited, the research team still sees a very high potential regarding this project, especially for using the machine learning to help the optimization. Furthermore, by identifying the friction areas and designing the garments ad hoc, this tribo electric effect could be even further enhanced.

The multidisciplinary team also noted that working with people from a different educational background was intriguing and that the project would have been un-realizable without the knowledge and the competences of each other.

REFERENCES

1. Iannacchero, M., Kramer Pedersen, L. (2024). AI-yarn: Sustainable textiles, nanomaterials, and machine learning (Research stand). IMPACT Forum: Sustainability through innovative bio-based materials. FinnCERES Flagship and Aalto Bioinnovation Center. Helsinki, Finland. Featured at [https://www.linkedin.com/feed/update/urn:li:activity:7197088364754300928/] and [https://www.finnceres.fi/post/april-25-impact-forum-sustainability-through-innovative-bio-based-materials]
2. Iannacchero, M., Kramer Pedersen, L. (2024). Triboelectric PLA garment. Entangled – Reimagining textile functionalities / Designs for a Cooler Planet. Exhibition, Aalto University & Helsinki Design Week. [https://research.aalto.fi/en/publications/entangled-reimagining-textile-functionalities-designs-for-a-coole]. Featured at [https://www.linkedin.com/feed/update/urn:li:activity:7245775912682606592/].
3. Iannacchero, M., Kramer Pedersen, L. (2024). Machine learning and artificial intelligence meet bio-based materials. Fostering Bioinnovation / Designs for a Cooler Planet. Exhibition, Aalto University & Helsinki Design Week. [https://research.aalto.fi/en/publications/fostering-bioinnovation-designs-for-a-cooler-planet]. Featured at [https://www.linkedin.com/feed/update/urn:li:activity:7245775912682606592/] and [https://www.aalto.fi/en/events/fostering-bioinnovation]
4. Iannacchero, M., Kramer Pedersen, L. (2024). Machine learning and artificial intelligence meet bio-based materials. Fostering Bioinnovations / Dutch Design Week. Exhibition, Dutch Design Week. Featured at [https://www.linkedin.com/feed/update/urn:li:activity:7260277777017303040/] and [https://chemarts.aalto.fi/index.php/events/fostering-bioinnovation-at-dutch-design-week-2024/]

DESIGNING KINETIC TEXTILES USING HEAT-REACTIVE BIOPOLYAMIDE YARNS

This project aimed to suggest possible knitted textile designs using biopolyamide yarns that expand when subjected to infrared light or heat-stimulated structures. Through exploring the design potential of responsive kinetic textiles using these novel yarns, the research raised the following questions to inform their use in textile objects: "How does kinetic motion in textiles influence our emotional response?" And: "How can kinetic textiles be designed in meaningful ways for everyday life?"

All image credits: Delia Dumitrescu

GENERAL INFO

Involved partner: University of Borås
Name of researchers: Delia Dumitrescu, Erin Lewis, Linda Worbin

PROJECT OUTLINES

Broadly, the researchers aimed to explore the possible textile design expressions, reactions, and interactions that reactive biopolyamide yarns afford when integrated into textile structures. Knitted textile samples were stimulated by the exposure of heat or infrared light to actuate the yarn properties of lengthening when exposed to stimuli and contracting back to the original size when the stimuli is removed. This transforms the textile structure, creating varied visual and tactile expressions of kinetic movement.

PROJECT PURPOSE

It is beneficial to explore the possibilities of this newly developed sustainable shape memory yarn, which has unique kinetic characteristics, through experimentation that concerns not only the results but also how a designer might design with it. This applies to functionality, such as whether the yarns can be used with industrial machines like circular or flatbed knitting machines and jacquard looms, as well as hand-operated knitting and weaving machines. It also concerns speculation, such as how designers would like the yarns to perform in ideal conditions, and what possible design applications emerge. By working closely with material scientists, designers are in a prime position to give feedback on and discuss the possibilities and limitations of these biopolyamide yarns.

PROJECT METHODOLOGY

The project used experimental design research methodologies in the context of textile design. The qualities of the yarn were explored through heating and cooling on their own, to better understand the duration and degree of change when the yarn is uninhibited. The yarns were then sewn or pinned to existing knitted textiles to understand better the force that the yarn could exhibit on the textile.

FINDINGS

Through experimental work, novel design expressions were developed to highlight the reversible shape-changing capabilities of the biopolyamide yarns when integrated into knitted and woven textile structures. The exploration centered on two focus areas: knitted origami-inspired shapes with kinetic movement and surface-changing textural expressions.

The knitted origami shapes demonstrated dynamic, kinetic transformations, highlighting how the yarns could fold and unfold in response to stimuli, thereby creating fluid shape-changing forms. In addition, the surface-changing expressions demonstrated the potential for subtle shifts in the textile's texture, thereby introducing dynamic tactile feedback.

Central to these experiments was the aesthetic quality of the movement. Unlike the rigid, fast, and noisy movements associated with mechanical and electronic motors, the yarns produced gentle, soft, and fluid movements, mimicking natural and organic processes through the slow and gradual release of tension. These movements bring a poetic dimension to the expression, which suggests slowness and subtlety as key design qualities.

CHALLENGES

From a design perspective, a significant challenge involved heating the yarns to their change-threshold temperature without exerting additional forces on the textile, such as through blown air. Furthermore, the yarns' change-threshold temperature, which begins around 50°C and reaches maximum movement around 100°C, was perceived as higher than ideal for scenarios involving human-textile interaction. The relatively large gauge of the yarns, coupled with their coiled form, presented another limitation, as they could not be processed in industrial machines and needed to be manually inserted into the knitted structures after the textiles were created. Another challenge related to the directionality of forces within the textiles, particularly in relation to gravity. Designing with gravity introduced considerations around stored kinetic energy, such as in pleats, while the stretchability of the textile itself could also be manipulated to achieve specific effects.

OPPORTUNITIES

Further developments could enhance the design potential of these kinetic infrared and heat-reactive yarns. Having the yarns activated at a lower change-threshold temperature would allow for more intuitive interactions, such as activation through touch or ambient environmental changes, making them more suitable for human-textile interactions. Refining the yarns for compatibility with industrial knitting and weaving machines would expand their use and scalability in textile production. Additionally, continued exploration into ways to integrate these yarns into textile designs could open to more behaviours and aesthetic possibilities, thereby enhancing their versatility.

NOVELTY

The proposed applications include uses for both the body and interior spaces. For the body, the textile could respond to body heat by softening and flattening its textured surface. In this relaxed state, the textile structure becomes looser, creating small openings that facilitate airflow and help cool the wearer by moving heat away from the body. For interior spaces, folded and pleated textiles could function as a dynamic

sun-shading system. When exposed to strong infrared radiation from the sun, the condensed pleats would relax and expand, unfolding the structure to shield the interior from the sun's rays. As the sun sets and the infrared from the sun decreases, the folds would contract, condensing the shading system to allow for evening airflow and ambient light.

SUSTAINABILITY

From a material perspective, biopolyamide is a sustainable option when compared to conventional petroleum-based fibers that are more often used in active textiles and shape memory polymers (Baniasadi et al., 2023). Further, when integrated into textile products, biopolyamide yarns have the potential to open up to possibilities of multimodal textile designs that encourage not only kinetic behaviours of opening/closing, lifting/lowering, and condensing/expanding but also interactions of colour and pattern, changing textures, and shapes. This provides an array of design expressions that can hold one's interest over time, and which also can respond to environmental and bodily cues. These may generate emotional connections over time, leading to an increased likelihood that the owner keeps and maintains the textile product for longer periods than conventional products (Chapman, 2005).

SUMMARY

This project explored the design potential of infrared and heat-responsive bio-based nylon yarns in knitted textiles, focusing on kinetic shape-shifting and textural changes. Using experimental methodologies, the study integrates these smart yarns into textiles, reflecting on their ability to create dynamic, reversible changes when actuated through infrared or heat, and cooled. Designers collaborated with material scientists to explore the yarns' compatibility with knitting machines and their kinetic expressions, such as reactive origami-like pleats and surface textures. Challenges included the need for high activation temperatures and limited industrial machine compatibility. The findings suggest these yarns could enable sustainable, emotionally resonant textiles if improved for broader functionality and daily human-textile interaction.

REFERENCES

1. Chapman, J. (2005). Emotionally durable design: objects, experiences and empathy. London: Taylor and Francis Group.
2. Simonsen, J., Svabo, C., Strandvad, S.M., Samson, K. and Hertzum, M. eds., 2021. Situated design methods. Mit Press.
3. Romdenh-Romluc, K. (2010). Routledge Philosophy GuideBook to Merleau-Ponty and Phenomenology of Perception (1st ed.). Routledge. https://doi.org/10.4324/9780203482896
4. Baniasadi, H., Madani, Z., Mohan, M., Vaara, M., Lipponen, S., Vapaavuori, J., & Seppälä, J.V. (2023) 'Heat-Induced Actuator Fibers: Starch-Containing Biopolyamide Composites for Functional Textiles', *ACS Applied Materials & Interfaces*, 15(41), pp. 48584–48600. Available at: https://doi.org/10.1021/acsami.3c08774.

FROM INVASIVE PLANT TO TEXTILE FIBER: GARDEN LUPINE AS A SUSTAINABLE ALTERNATIVE IN YARN PRODUCTION

Textile waste and its environmental impacts have surged due to fast fashion and unsustainable fiber production. European strategies are pushing for sustainable textile solutions, emphasizing natural fiber utilization. This project explored garden lupine as a biodegradable bast fiber alternative, focusing on sustainable chemical extraction methods to produce lupine yarns. Discovering effective chemicals for lupine fiber degumming may offer a promising path to environmentally friendly textile production.

GENERAL INFO

Involved partner: Aalto University
Researchers: Maija Vaara, Mithila Mohan, Laura Koskelo, Jaana Vapaavuori

TECHNICAL TERMS

Bast fibers: A type of natural plant fiber sourced from the stems of certain plants. These fibers are part of the plant's structure that provides support, allowing them to stand upright. Common examples of bast fibers include flax, jute, and hemp.
Chemical degumming: A process where chemicals are used to remove substances that hold fibers together within a plant. This process helps in separating the fibers cleanly so they can be used for making yarn or fabric.
Retting: A technique used to extract fibers from plants. Traditionally, it involved soaking plant stems in water to break down or loosen the binding materials, so fibers can be separated. Chemical retting uses substances to aid this process more efficiently.
Binding agents: Materials naturally present in plants that hold fibers together. During fiber extraction, these agents need to be removed to separate the fibers for textile use.
Alkaline substances: Chemicals with a pH greater than 7. Examples include baking soda and sodium hydroxide. They are often used in processes like degumming to help break down natural materials and separate fibers.
ASC treatment: The use of a specific chemical solution containing acidified sodium chlorite to treat fibers. This method helps purify fibers by breaking down unwanted substances while bleaching them for textile production.

PROJECT OUTLINES

The project centered on evaluating garden lupine as a viable source of bast fibers for textile production. Researchers from Aalto University explored the chemical degumming of lupine fibers through various alkaline treatments. They assessed the efficacy of five chemicals across different retting processes to optimize fiber extraction. By analyzing fiber samples through visual examination, microscopy, and spectrometry, the project aimed to identify the most effective methods for achieving clean, strong, and spinnable fibers, comparing results to established baking soda treatments.

PROJECT PURPOSE

The primary purpose of the project was to address the environmental challenges posed by the textile industry, which relies heavily on non-biodegradable synthetic fibers. Garden lupine, being an invasive species in Scandinavia, presented a sustainable raw material alternative. By optimizing lupine fiber extraction, the project sought to contribute to the EU's circular economy goals, reducing waste and promoting biodegradable textile production. Exploring lupine fibers also aimed to leverage the plant's abundant presence and potentially mitigate its ecological impact.

METHODOLOGY

The methodology involved experimenting with various chemical treatments to remove binding agents from garden lupine bast fibers. Researchers selected alkaline substances like baking soda, sodium hydroxide, and others for their environmental friendliness. The process included retting lupine peels, analyzing fibers using optical and scanning electron microscopes, and visually inspecting the results. Successful methods were scaled up to produce larger fiber batches, which were spun into yarn by hand. The effectiveness of treatments was assessed through fiber texture, color, and structural integrity.

FINDINGS

The study discovered that two-step alkaline treatment using sodium hydroxide and sodium silicate yielded the purest fibers suitable for spinning, as compared to baking soda treatment. While ASC treatment offered pure fibers, it resulted in breaking the fibers too short for yarn production. The researchers noted that the alkaline treatment avoided manual processes and delivered cleaner fibers ready for spinning, although it left fibers rougher and less slippery than soda-treated fibers. Moreover, environmental benefits were observed from reduced chemical usage and energy demand.

CHALLENGES

Despite promising results, challenges emerged regarding the strength and durability of lupine fibers. The fibers were fragile and required spinning while wet, making industrial application difficult. Additionally, the chemical pretreatment process needed optimization, especially concerning chemical concentrations and combinations to enhance fiber quality. Further hindrance arose from the environmental effects of certain chemicals, such as sodium chlorite, which posed toxicity risks and made achieving complete sustainability challenging.

OPPORTUNITIES

Future explorations could focus on optimizing chemical concentrations to improve fiber integrity and sustainability. Testing the chosen extraction methods with other wild plant fibers could also help identify additional sustainable fiber sources.

NOVELTY

The project deviated from traditional bast fiber extraction methods by employing modern chemical treatments with lupine fibers, an underexplored raw material. The process reduced manual labor while offering new insights into fiber usability and treatment efficacy.

SUSTAINABILITY

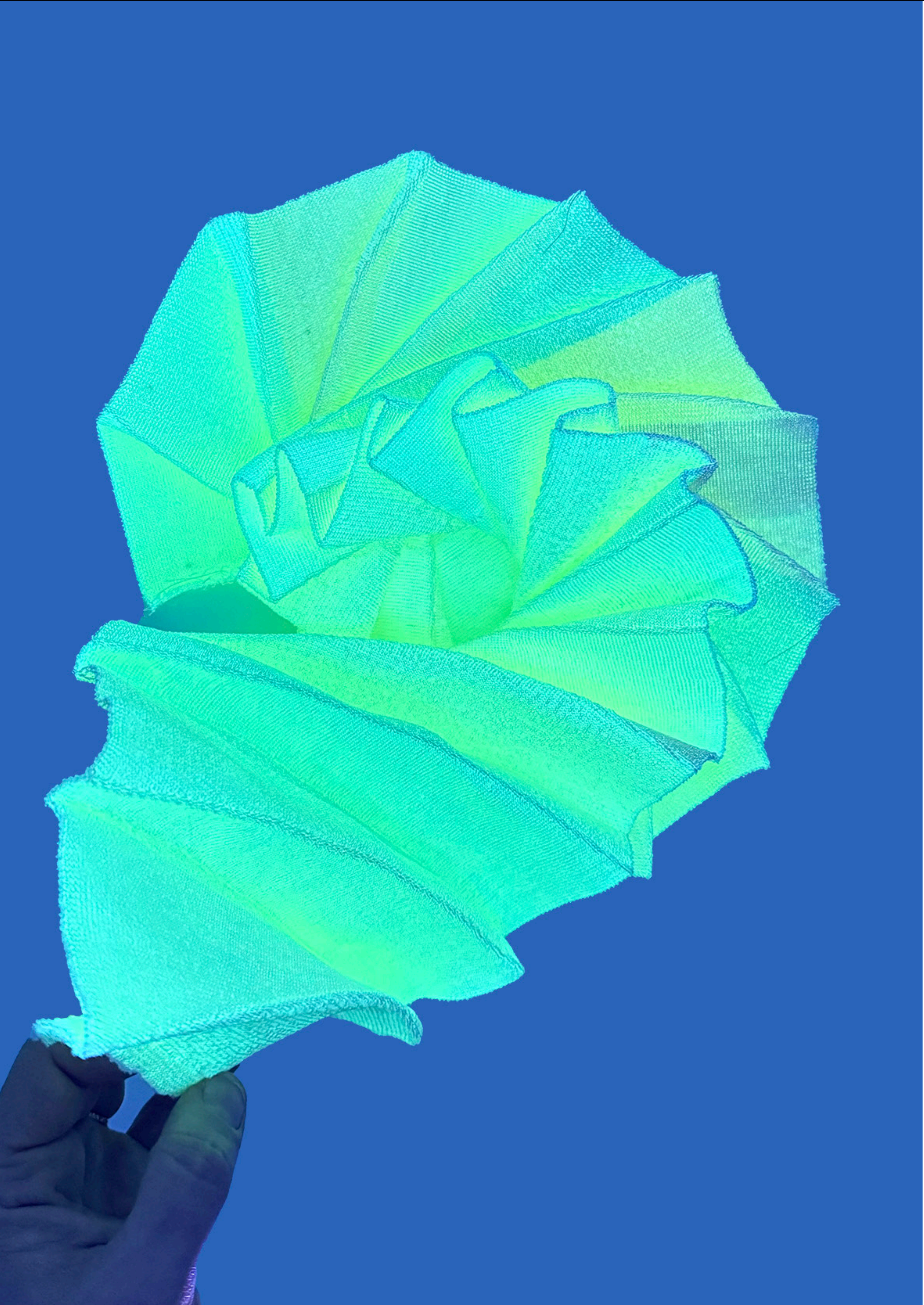
The project promoted garden lupine, which grows abundantly and doesn't compete with food production. It supported EU circular economy goals by using biodegradable fibers, reducing synthetic fiber reliance, and minimizing energy and chemical consumption.
Certain chemicals used in the extraction process posed environmental risks, complicating complete sustainability.

SUMMARY

The project succeeded in finding an effective chemical treatment for extracting bast fibers from garden lupine. Two-step alkaline treatment emerged as the most promising method for sustainable yarn production, offering environmental benefits. However, challenges remain regarding fiber strength and industrial applicability, and future research is needed to optimize chemical usage and explore other sustainable fibers.

REFERENCES

1. Koskelo, L. (2023). Garden lupin (Lupinus polyphillus) as a textile fiber - chemical treatments for cellulose extraction. [Master's Thesis, Aalto University]. Aalto University. https://urn.fi/URN:NBN:fi:aalto-202312187338.
2. Mohan, M., Vaara, M., Koskelo, L., & Vapaavuori, J. (2023). Textile Intersections exhibition. Exhibition, Loughborough University. [https://research.aalto.fi/en/publications/textile-intersections-exhibition-2].
3. Mohan, M., Vaara, M., Koskelo, L., & Vapaavuori, J. (2023). The Lupine project. Unlikely materials: Experimenting with underutilised bio-based materials / Designs for a Cooler Planet. Exhibition, Aalto University & Helsinki Design Week. [https://research.aalto.fi/en/publications/unlikely-materials-experimenting-with-underutilised-bio-based-mat-2]. Featured at [https://www.aalto.fi/en/events/unlikely-materials] and [https://www.linkedin.com/feed/update/urn:li:activity:7096822808827039746/].



SOLAR ENERGIES AS AGENTS FOR CHANGE IN SMART TEXTILE DESIGN

This research project explored solar energies beyond their traditional role as a mere power source, examining their capacity as agential materials (Barad, 2007; Bennett, 2020) within smart textile design. It emphasized the active participation of solar energies—encompassing visible light, ultraviolet (UV) wavelengths, and infrared wavelengths—in shaping both the material properties and interactive behaviours of textiles. These energies are framed as co-constituents in the dynamic interaction between natural and designed environments, influenced by a "more-than-human design" theoretical framework (Barzdzell et al. 2021; Giaccardi et al. 2025; Wakkary 2021).

All image credit: Delia Dumitrescu and Erin Lewis

GENERAL INFO

Involved partner: University of Borås
Researchers: Delia Dumitrescu, Hanna Landin, Erin Lewis, Kristian Rödby, Linda Worbin

TECHNICAL TERMS

Satin: A woven textile structure with floating yarns that create a smooth surface with minimal visible interlacing.
Double-weave: A woven textile structure formed by interlacing two separate layers of fabric simultaneously on the loom, which can be interconnected or kept distinct.
Inverse-plating: A two-color knitting technique where the placement of two different yarns alternates on the textile's surface, producing a pattern. On the reverse side, the colors are inverted, with each yarn taking the opposite position from the front side.
Single jersey: Single jersey is a weft-knit textile made using one set of needles, producing a textile that has a smooth, "V"-shaped knit on the front and a more textured, looped appearance on the back.
Double jersey: Double jersey is a dense, durable and reversible knit fabric produced with two needle beds on a double-bed circular knitting machine.
Whole garment knitting: The technique of seamless knitting on an industrial knitting machine.
Thermoplastic yarn: A synthetic yarn that shrinks around 50% and gives stiffening qualities to the material.

PROJECT OUTLINES

The interaction between textile designs and solar energies was explored through experimental textile design methods. Designers assessed the impact of sunlight intensity, UV levels, exposure duration, and textile properties on the resultant behaviours. In this process, it was considered how these factors contributed to the inherent unpredictability and variability of textile responses, and thus, highlighted the textiles' role as active participants in a continuous feedback loop with their environment.

PROJECT PURPOSE

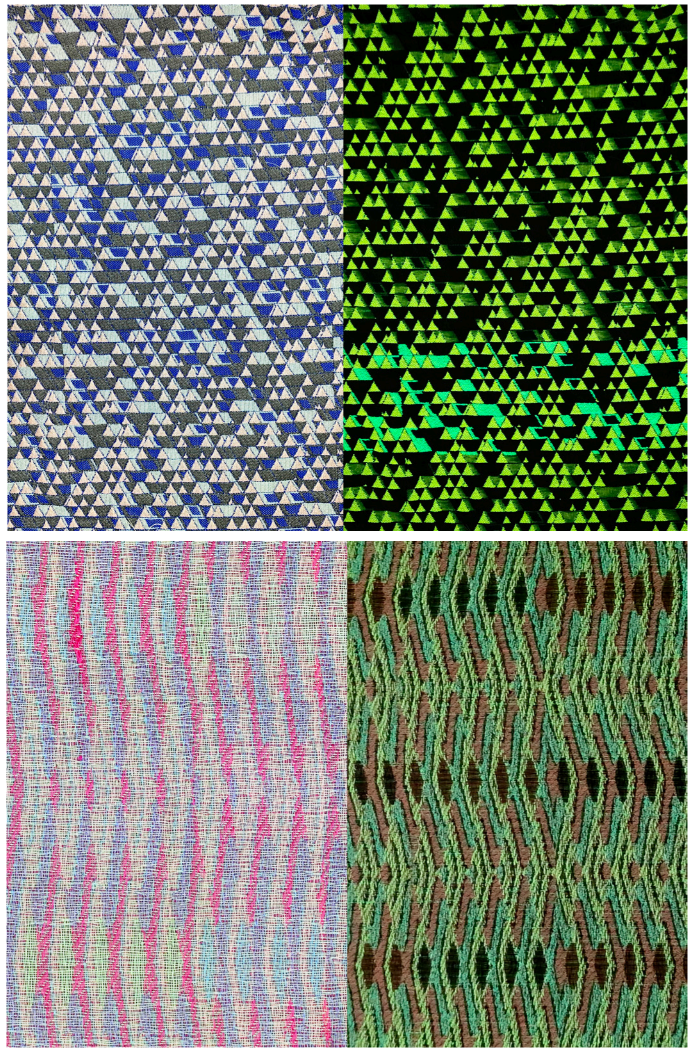
The purpose of this exploration was to challenge conventional views of passive material roles by proposing solar energy as an active participant in textile design. This involved recognizing the constituents of solar energy—from illumination and colour to visible light, UV and infrared energies—as integral to the textile's interactive and responsive characteristics. This perspective seeks to reshape our understanding of textiles as not only reactive but also proactive entities in their interactions with the environment.

PROJECT METHODOLOGY

Solar-reactive woven textiles:
In this example, the integration of phosphorescent and UV-reactive yarns was investigated within various satin structures in double-woven jacquard textiles. These satin structures are weft-faced, positioning the weft materials (as horizontal threads) on the textile's surface. As part of a double-weave structure, an additional layer resides beneath the surface, and the openness of the satin structures permits visibility of this lower layer, facilitating a blending of colours.

In this configuration, the phosphorescent yarns emit light from behind the UV-reactive yarns, occasionally reversing this effect in different sections. Various colours of phosphorescent yarns—white, pink, and green—were used, resulting in different illumination effects. Initially, the UV-reactive yarns appear in solid colours (green, blue), and upon exposure to UV light, they transition to dark purple. This material interaction demonstrates concurrent temporalities – both immediate and extended – due to the different charging and discharging cycles of the responsive yarns. As a result, the textile's expression is in constant flux, evolving throughout the day and also changing its temporalities of expressions over many months, spanning the yearly solar energy cycle.

Solar-reactive knitted origami textile:
A graphical pattern from origami was translated to a digital knitting program. Some areas of the textile were knitted with single jersey, and others with double



jersey in order to create density changes to guide the folding of the origami form. The faces of the panels were knitted in double jersey to give stability to the overall form. The inverse plating technique was conducted with UV-reactive yarn on the front face of the textile, followed by glow yarns on the second layer, and thermoplastic yarns in the interior layer. Due to the three-dimensional shape of the origami form, the UV light had different degrees of incidence, allowing for gradient colour intensities. Manipulation of the origami further influenced the appearance or disappearance of the colour on the surface.

Solar-reactive mittens:
A pair of mittens were knitted using a whole garment knitting technique with inverse plating for graphical patterning on the front and back of the mitten. The mittens are light green when not activated by UV radiation, white when semi-activated and light purple in full activation. They communicate the level of UV exposure by following the person's actions outdoors throughout the day, including their movements and gestures (for example, placing hands in pockets).

FINDINGS

When exposed to varying intensities and temporal patterns of solar energy, textiles exhibit qualitative changes that are both subtle and significant. These changes include variations in colour, luminosity, and responsive behaviours that adapt to environmental conditions. The design and material composition of the textiles allow these imperceptible energies to become perceptible, opening for textiles to act as interfaces for alternative perceptive materials for natural phenomena.

Solar energies affect textiles across multiple temporal scales, from the daily fluctuations of sunlight to seasonal changes affecting responsiveness. These temporal dynamics introduce a layered complexity into the material behaviour of textiles, thus requiring design strategies that accommodate both ephemeral and persistent changes. Designers are encouraged to embrace these dynamics, allowing for an expression of concurrent temporalities within textile designs.

CHALLENGES

A key challenge the team experienced when designing solar-reactive textiles was the inherent unpredictability of environmental exposure. Variations in UV intensity, light angle and cloud coverage, combined with the nuances of user interaction introduce behaviours that are highly context-dependent. This variability disrupts traditional design approaches which are often based on predictability and control, and instead, designers are required to embrace open-endedness as a new condition of their practice. Further, the temporal behaviours in these solar textile designs unfold across multiple timescales—immediate, diurnal, and seasonal—which complicates the idea of a final or stable outcome. Rather than creating static artefacts, designers are challenged by working with textiles that continue to evolve in form and appearance over time.

Compounding these complexities are the expressive limitations of existing phosphorescent and UV-reactive yarns. While technically functional, they can evoke narrow aesthetic associations, which in turn constrains their potential for broader material articulation, object expression, and use-case explorations. These challenges point to a need for more nuanced materials and for design strategies that can navigate the tension between material agency, aesthetic expression, and temporal uncertainty.

OPPORTUNITIES
Embracing the uncertainty and unpredictability inherent in designing with solar energies allows for the expansion of material, interactive, and responsive possibilities in smart textile design. This approach not only opens up to new aesthetic expressions but also deepens the material entanglements of textiles with the natural rhythms of the environment. When designing with phosphorescent and UV-reactive materials, we imagine a future where material developments could provide more nuanced material expressions that move away from their conventional aesthetics and temporal changes. The research team believes it is the job of designers to open this area for exploration and possibilities.

SUSTAINABILITY
By adopting a more-than-human design perspective, designers can shift the focus away from human-centered utility and consumption, opening to coexistence with other species, systems, and ecologies. This approach allows designers to work within our planetary boundaries by acknowledging the material realities of a finite planet. Further, it emphasizes the agency of materials by recognizing and accepting their capacities and limitations rather than attempting to control them. In doing so, more-than-human design supports adaptability, care, and sustainable temporalities over rapid degradation and obsolescence. Orienting textile design processes in this way opens toward more ethical and ecologically entangled forms of making.

SUMMARY
Designing with solar energies means accepting uncertainty as a design condition, and to engage with unpredictable rhythms of solar energy exposures throughout days, months and years, which is further governed by location, altitude, time of day, cloud coverage, reflections, and more. It opens to an aesthetic that is rooted not in control but in adaptability. Therefore, solar textiles can be seen not as fixed outcomes, rather ongoing negotiations between light, matter, time, and place.

REFERENCES

1. Barad, K., 2007. Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning. Duke University Press.
2. Bennett, J., 2020. Vibrant matter: A political ecology of things. Duke University Press.
3. Bardzell, J., Bardzell, S. and Light, A., 2021, May. Wanting to live here: Design after anthropocentric functionalism. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (pp. 1-24).
4. Giaccardi, E., Redström, J., Nicenboim, I. (2024). The making(s) of more-than-human design: introduction to the special issue on more-than-human design and HCI. Human–Computer Interaction, 40(1–4), 1–16. https://doi.org/10.1080/07370024.2024.2353357
5. Wakkary, R. (2021). Things we could design: For more than human-centered worlds. MIT Press. Cambridge, MA.

EXPLORING THE INFLUENCE OF NATURAL PHENOMENA ON TEXTILE EXPRESSIONS OVER TIME

This research project explored how natural phenomena influence textile expressions over time and aimed to develop alternative approaches to textile design and use. It investigated how textile lifespans can be adapted to their intended use, opening up to diverse rhythms of change that align with sustainable practices. Through this lens, the project reimagined how fiber properties and structural design can interact with environmental elements to shape textiles that evolve over time. The project consisted of a core long-term experiment documenting the transformations of textile samples exposed to organic matter, followed by an analysis of changes in colour and expression. The outcome is a material library that exemplifies these principles and contributes to a novel framework for co-designing responsive, temporal textile systems with nature.

GENERAL INFO

Involved partner: University of Borås
Researchers: Riikka Talman, Delia Dumitrescu

PROJECT OUTLINES

Grounded in the critique that material durability should align with its intended use, this project aimed at developing alternative design approaches for adaptable textile lifespans. The main objective was to explore how inherent fiber properties and structural design can interact with natural phenomena, creating materials that evolve aesthetically over time. Employing an experimental, practice-led methodology, the project utilized near-field design and material prototyping. The research challenges conventional notions of textiles by foregrounding material agency and gradual, sustainable transformation while speculating on new scenarios for textile design and use.

PROJECT PURPOSE

The research aimed to explore alternative scenarios of making and use, such as adapting textile properties to potential contexts of use. Fletcher (2014) and Goldsworthy (2017) propose that the lifespan of materials for garments, including aspects such as durability and recyclability, should be matched with the intended lifespan of the garments, creating garments with lifespans ranging from short to long based on intended use for a range of speeds and tempos. Similar principles could be adapted to designing changeable properties in textiles, by embedding slower and faster timespans of change into textiles through the use of fibers with different properties and different textile structures.

METHODOLOGY

Using experimental research methods, the research illustrates how textile methodology and materiality can be tackled to support sustainability from a bottom-up perspective. Material prototyping was used 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. The experiment extends the material expressive dimension by first exploring the intrinsic value of the raw material agency and the appropriateness of craftmanship; and second, by speculating on the use dimension by exploring the value of aesthetic discovery embedded in the material design through co-creation and natural phenomena.
The effects of long-term exposure to natural conditions on colour changes were explored by placing plain wool/cotton and paper/cotton textile samples, as well as patterned Jacquard-woven samples made from wool, paper, polyester, and cotton, in closed jars with various types of food waste for several years. At the time of writing, the experiment had been ongoing for eight years. Four jars contained plain wool/cotton and paper/cotton samples at the bottom, with vegetable peels, lingonberries, a banana, and an orange placed on top. Two jars had patterned, Jacquard-woven samples made of wool, paper, polyester, and cotton yarn at the bottom, with vegetable peels and coffee grounds placed on top.

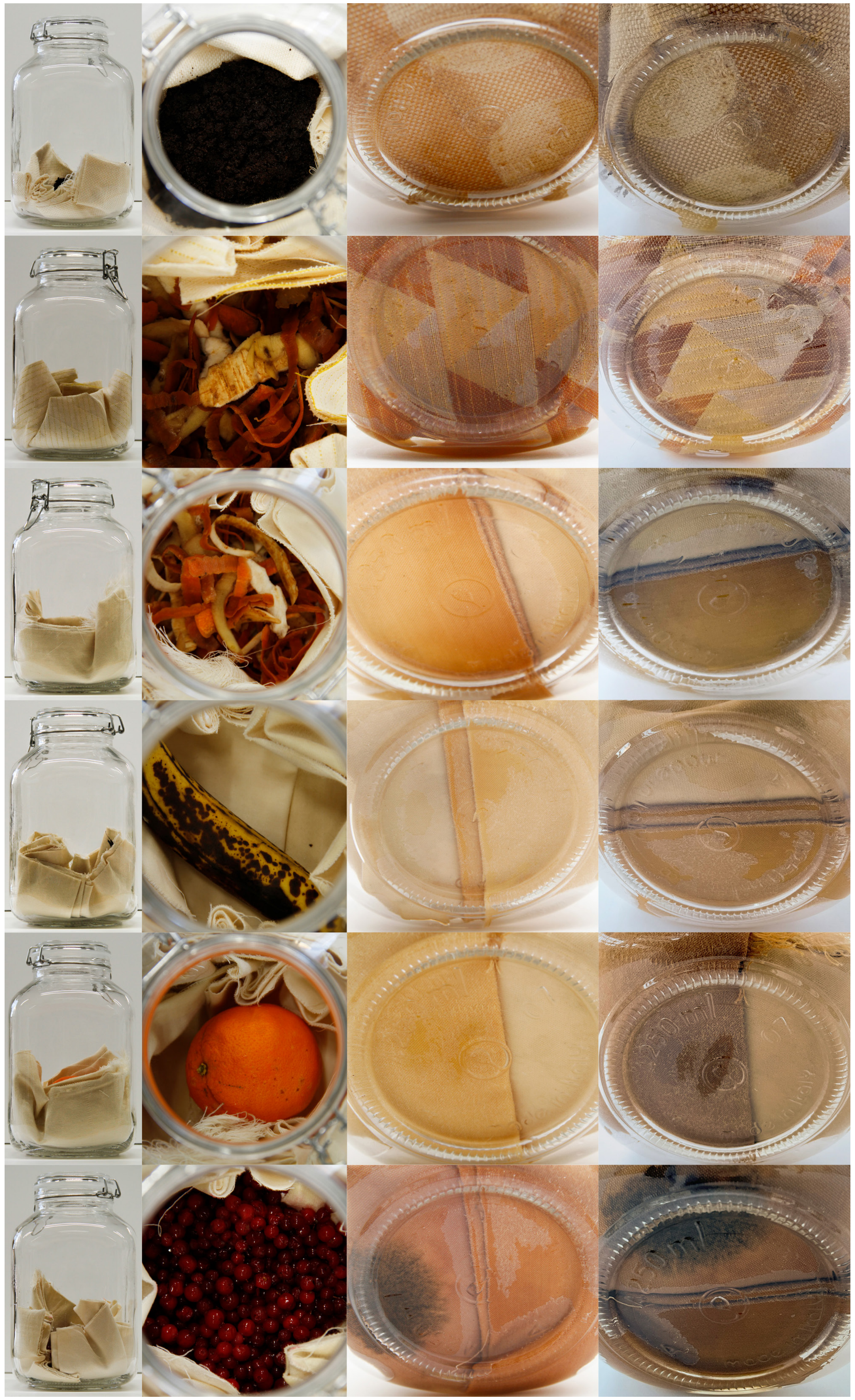
FINDINGS

The samples were photographed after three years and again after seven years without removing them from the jars. After three years, the food waste dyed the fabrics in shades ranging from red (lingonberries) to orange (vegetable peels) and brown (coffee grounds). The samples with banana and orange displayed the least colour change. After seven years, the colours of all textile samples had faded to shades of brown. Wool yarn in all jars exhibited the most colour change.

A textile can simultaneously embody multiple timespans overlapping or following one another. These changes could be considered part of what Harper (2018, p.92) describes as "the time of being," which encourages discovery and aesthetic curiosity in the user. In contrast, slower, more gradual timespans—where the textile's expression and colours evolve in collaboration with nature—may be more closely aligned with "the time of becoming" (ibid.). This process highlights the value of slowness and transformation through gradual change, a process that may involve the user depending on how they choose to expose their textiles to different elements.

CHALLENGES

The research points to several challenges in developing textiles that respond to natural phenomena over time. First is the balancing of aesthetic qualities with functional lifespans, meaning for example that the embedded changes do not compromise the usability or durability of the textiles. In addition, the integration of bio-based materials to enhance transformation possibilities requires further exploration, particularly in understanding how these materials interact with diverse environmental conditions. Finally, scaling these experimental approaches to align with broader design and production systems poses a challenge, particularly in maintaining sustainability at larger scales.



OPPORTUNITIES

The sample library provided by this research extends the research on sustainable, innovative textile systems by exploring the role of material expressiveness and temporality in textiles. 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, such as wool and cotton, indicate that some textiles are more appropriate for use in clothing.

NOVELTY

Recent research demonstrates that transformation and responsiveness in textile materials can be achieved using bio-based matter to trigger changes through the agency of the natural environment (Worbin, 2013; Keune, 2017; Talman, 2018). Users can be co-designers to enhance 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 designed for a prolonged lifespan.

SUSTAINABILITY

From the design perspective, the properties and lifespans of materials become key factors for sustainability. In addition to choosing less environmentally damaging materials, the lifespan of the materials will influence the lifespan and the use of the textile, suggesting different timespans can be designed into textiles based on how different materials are combined in a textile structure. The methodological framework aimed to expand on the principles of Papadopoulou et al. (2017) and Scott (2018) from the perspective of textile design, by suggesting that the inherent properties of materials and yarns, together with how they are placed in a textile structure, can be used to embed potential for changes over various timespans in textiles.

SUMMARY

The material library of experiments presented in this project suggests that the inherent properties of fibers and yarns, in combination with knitted and woven structures, can be used to embed expressions of timespans in textiles. In addition, the experiments show that elements from nature can be integrated in the process of change in various ways, suggesting alternative methods of co-designing material systems with natural phenomena as a catalysts for change. This suggests an alternative approach to smart textiles, using natural phenomena to create responsive properties in textiles instead of added electronics. Inviting nature to be a part of the design of responsive textile material systems could open alternative, more sustainable scenarios of textile making and use.

REFERENCES

1. Fletcher, K. (2014). Sustainable fashion and textiles: Design journeys (2nd ed.). Routledge.
2. Goldsworthy, K. (2017). Design for Cyclability: Prototypes for a circular economy. In L. Skjold (Ed.), Fashion research methods (pp. 120–136). Bloomsbury Academic.
3. Harper, K. H. (2018). Aesthetic sustainability: product design and sustainable usage. Abingdon: Routledge
4. Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A. (2017). Material Driven Design (MDD): A method to design for material experiences. International Journal of Design, 11(2), 7–17.
5. Keune, S. (2017). Changing matters: The performative practice of textile design. [Doctoral dissertation, Aalto University].
6. Papadopoulou, D., Zampelis, N., & Schmelzer, I. (2017). Designing with time as material. In Proceedings of the 2017 Research Through Design Conference (pp. xxx–xxx).
7. Scott, J. (2018). Textile design as a vehicle for material innovation and societal transformation. The Design Journal, 21(4), 489–510.
8. Talman, R. (2018). Textile thinking for change: Exploring methods of designing temporality in textiles. [Doctoral thesis, University of Borås].
9. Worbin, L. (2013). Designing dynamic textile patterns. [Doctoral dissertation, University of Borås].

DYEING WITH FOOD WASTE

In the Anthropocene epoque, there is an urgent need to change the paradigm of fashion. Fashion, the system, and the related industries provide one of the most damaging environmental footprints and are responsible for an extensive use of resources, including textiles, to make fashion. Political initiatives point to changes forcing the fashion industry to enter a green transition, though within our existing growth paradigm. To fundamentally change the system of fashion, we need to transcend our current paradigm and create a new alternative to ensure profound changes. But creating a new and alternative paradigm of fashion is, however, fraught with complexity due to the very nature of fashion. The current concept of fashion and specifically the interconnected business models consist of, and is thriving on newness, planned obsolescence, and fast replacements.

With dyeing and printing textiles as a focus area, the three projects, *Dyeing with food waste, Mordant and direct printing in layers,* and *Changing aesthetics* jointly explore different perspectives on how to contribute to the change of the current paradigm of fashion. The *Dyeing with food waste* project constitutes the origin and forms the foundation for the two others.

All image credits: VIA Team

GENERAL INFO

Involved partner: VIA University College Denmark
Researchers: Inger Marie Ladekarl, Malene Harsaae, Anne Louise Bang
Date of project: 2021 - 2023

TECHNICAL TERMS

Colorfastness: The ability of dyed fabric to resist fading or discoloration when exposed to various factors such as washing, light (especially sunlight), rubbing, and perspiration.
Mordant: A solution used to help fix the dye to the fiber, resulting in more colourfast results. It also affects the colour outcomes of the dye.
Tannin: Tannins are used in conjunction with mordants and are a key component when dyeing cellulose fibers. By pre-treating the textile with tannins before applying the mordant, both the tannins and the mordant become bound to the fiber, resulting in better dye fixation.
Protein-based fibers: Fibers derived from animal sources, e.g. wool, silk and cashmere
Cellulose-based fibers: Fibers derived from plant sources, e.g. cotton, linen, hemp and bamboo.

PROJECT OUTLINES

This project explored the potential of utilizing food waste as a dye source within the commercial textile industry. The research was conducted in three explorative sub projects, where each project iteratively informed the purpose and investigative direction of the subsequent one as questions and hypotheses emerged.

This first project, *Dying with food waste*, focused on testing and evaluating the compatibility of food waste dyeing with current industrial standards. The second project, *Mordant and direct printing in layers*, explored printing in layers and the third project, *Changing aesthetics*, shifted the focus towards a future scenario, exploring alternative options and approaches, with an emphasis on a change in aesthetics.

PROJECT PURPOSE

With the increasing focus on sustainability, particularly within the fashion design sector, there is a growing demand for alternative and more responsible textile production methods. Limited documentation exists regarding the colourfastness of textiles dyed with natural dyes. This knowledge gap impacts students, industry partners, and educators in their endeavours to apply and advocate for the use of natural dyes.

To address this, the aim of research team was to generate data on the colourfastness of naturally dyed textiles. This information will serve as a valuable resource for students, industry professionals and researchers in their investigations, projects and design considerations.

METHODOLOGY

The project involved a collaboration with the canteen at VIA University College, which provided food waste for the research, supplemented by independently collected food waste. The research covered experimentation with different types of food waste, including yellow and red onion skin, avocado skin and seeds, pomegranate, celery tops, walnut shells and passionfruit shell.

The initial phase of the research involved a thorough review of existing literature on natural dye recipes and techniques, including "BOTANICAL INKS Plant-to-Print Dyes, Techniques and Projects" (Behan 2018) and "The Art and Science of Natural Dyes, Principles, Experiments and Results" (Boutrup & Ellis 2019).

The primary objective was to apply traditional knowledge of natural dyes and compare the results with contemporary industrial standards, exploring alternative dyeing methods to the synthetic dyes

prevalent in the industry today.

To enhance the practicality of the process for industrial application, all tannin, mordant and dyeing processes were reduced to one hour, compared to up to 12 hours typically recommended by traditional recipes. The shorter processing time was designed to make the process more suitable for industrial use, as the traditional lengthy processes are considered impractical for large-scale production in the textile industry.

FINDINGS

Overall, the test results were considered good based on Danish and international standards, particularly for wool and silk. Dyeing with food waste on protein fibers like wool and silk thus shows promise for immediate textile applications. The testing however revealed inadequate colourfastness to washing and UV-light on cotton, failing to meet current industrial standards. To achieve commercial viability with cotton, improving colourfastness to washing on cellulose-based fabrics is crucial.

CHALLENGES

If dyeing with food waste is to become more widespread in the industry, there must be a willingness to accept that naturally dyed textiles may not achieve the same colourfastness as synthetic dyed textiles, and that products will evolve with use, aging gracefully over time. In essence, the team realised that a perception of changing aesthetics is required and this was further explored in case 20, *Changing aesthetics.*

OPPORTUNITIES

The findings point towards three promising directions for further research:

1. Can the current commercial colour standards be challenged? This involves re-evaluating aesthetic perceptions, moving beyond notions of colour perfection or imperfection.
2. Further testing of various tannins and mordants to improve colourfastness on cellulose-based fabrics. As Boutrup and Ellis (2019, p. 51) note, "The quality, quantity, and application of the mordant will affect the final colour of the dye. The mordant is essential for the light- and washfastness of a mordant dye."
3. Testing if different bio-coating alternatives could significantly improve the colourfastness of cotton to washing and UV-light.

NOVELTY

The project's results, a significant variation in colourfastness on different textile materials, point towards the importance of exploring alternative dyeing methods as well as understanding and challenging aesthetic norms. The team's use of food waste for dyeing shows the possibilities and value of already existing reseources that would otherwise go to waste.

SUSTAINABILITY

The project offers a promising approach to reducing the environmental impact of the textile dyeing industry, which currently is a major contributor to environmental pollution, as both the production of synthetic dyes and the dyeing process is highly dependent on harmful chemicals. Some companies, including Archroma and United Textile Group, have begun exploring natural dyeing of textiles, though utilizing organic waste and residues from various industries.

Using food waste for dyeing helps to reduce waste and extend the lifecycle of local resources by giving a new purpose to materials that would otherwise be discarded. This aligns with a growing trend towards a circular economy, where waste is transformed into valuable resources, reducing the need for extracting new raw materials and the reliance on finite resources.

SUMMARY

As dyeing of fabrics plays a major role in creating the fashion and textiles industries' current environmental impact, the *Dyeing with Food Waste* project constituted a significant contribution to exploring how this impact can be reduced to foster a green transition. The project identified challenges in meeting industrial standards and consumer expectations when using natural dyes, especially for cellulose based textiles, and revealed opportunities for disrupting and changing these standards and consumer expectations.

REFERENCES

1. Archroma (2025). Earth colors by Archroma. www.archroma.com/innovations/earth-colors-by-archroma (seen January 2025)
2. Behan, B. (2018). BOTANICAL INKS Plant-to-Print Dyes, Techniques and Projects. Quadrille Publishing Ltd.
3. Boutrup, J., & Ellis, C. (2019). The Art and Science of Natural Dyes: Principles, Experiments and Results. Schiffer Publishing Ltd.
4. United Textile Group: Elemental coloring (2025). Plantefarvet tøj til hele familien. www.elementalcoloring.com (seen January 2025)

MORDANT AND DIRECT PRINTING IN LAYERS

Based on the idea of printing in layers to transform aesthetics over time, this project explored how the initially designed aesthetics in clothing design can potentially evolve in the hands of the user, thereby contributing to prolong a product's lifespan and challenging the traditional linear fashion model. By utilizing natural dyes from food waste and experimenting with layered dyes and prints using mordant and direct printing techniques the research team explored and demonstrated the possibilities of a dynamic alternative to conventional textile dying and printing, with samples showing how printed cotton fabrics can evolve and transform over time, all through user interaction.

This opens up a new world of possibilities for how we engage with our clothes. It is possible to beautifully transform fabrics, even garments, through multiple layers of re-printing and re-dyeing, and most importantly, this can be done by everyone at home. The next step is to make it accessible – to move towards a future where our clothes are designed to evolve and last, reducing waste and our environmental footprint.

All image credits: VIA Team

GENERAL INFO

Involved partner: VIA University College Denmark
Researchers: Inger Marie Ladekarl, Amalie Ege
Date of project: 2023

TECHNICAL TERMS

Colour fastness: A quality of being fixed and a measure of the resistance of a material or dye to fading caused by exposure to light, rubbing, washing or age.
Direct printing: An analog printing technique. Screen printing or simply applying the dyestuff with a brush or other utensils.
Mordant: A solution used to help fix dye to fiber/fabric, resulting in more colorfast results. The mordant also affects the color outcomes of the dye.
Mordant printing: Mordant is applied directly to selected areas desired for pattern formation. The application of the mordant can be done with a brush (applied in liquid form like watercolor) or screen (thickened with guar gum). The fabric is subsequently dyed – this is where the colors emerge. Mordant printing works best on cotton.
Overdye: The process of dyeing fiber that has already been dyed, adding another layer of dye color. This may alter the overall shade of the fiber/fabric and can be used to change the color of a garment, to refresh faded colors, or to create interesting and unexpected color effects.
Overprint: A technique where you print one color on top of another color that has already been printed or dyed on the fabric. Inks are layered on top of each other to create multiple effects.

PROJECT OUTLINES

The focus of the *Mordant and direct printing in layers* project was to test various layering of direct printing and mordant printing techniques and to expand on earlier technical investigations within the *Dyeing with food waste* project. The textile dyeing and printing involved natural dyes, binders and auxiliaries, all of which are utilized during both the production and use phase of a textile product's life cycle.

PROJECT PURPOSE

The previous research project revealed that natural dyes achieved overall good fastness according to international standards. However, challenges emerged concerning lightfastness on cellulose based fabrics, inspiring further experimentation, specifically on cotton. Rather than solely aiming to replicate the lightfastness of synthetic dyes on this specific fiber, the project took an alternative approach. It questioned the conventional pursuit of established standards and instead explored novel design opportunities.

Therefore, the research team set out to investigate alternative dyeing and printing methods to facilitate a more interactive and sustainable approach to fashion. This exploration also involved challenging the existing aesthetic norms prevalent among designers, manufacturers, and consumers alike.

This project demonstrated how designers can incorporate opportunities for change and co-creation into their designs, empowering users to influence how their products age as they can re-dye and re-print them, thus extending their value and lifespan. The following project, *Changing aesthetics*, then explored further and in depth the challenges and opportunities of the change in aesthetics needed to facilitate a shift towards the industry wide adaptation of natural textile dyes.

METHODOLOGY

The research team's starting point was to explore two printing techniques: Mordant printing, a traditional technique, particularly suited for cotton textile printing, involving the application of mordants in a desired pattern followed by dyeing the fabric, and, direct printing done with printscreen, paintbrush or other printing utensil, adding color extract directly to the fabric. Both printing techniques utilised food waste as the dye material. Existing recipes were adapted, focusing on consumer involvement in textile aesthetics over time.

Initial experiments moved from even, solid colored "perfect" stripes to "imperfect" stripes with irregular coloring. This explored shifting aesthetic mindsets, where imperfection can be accepted as perfect, potentially countering product devaluation. Further exploration involved "imperfect" patterns of multi-layered stripes and dots.

The objective was to find ways to prepare prints for re-dyeing by the user, enabling new and personalized expressions. Textile samples were produced, showcasing how printed fabrics can evolve through user interaction and how designs can transform over time. These samples included a single-dyed reference piece, four pieces dyed twice with different colors, and finally, two pieces where additional mordant was applied with a brush and over-dyeing was explored.

FINDINGS

The experiments showed satisfactory results, demonstrating the feasibility of printing and over-dyeing multiple times to achieve a significant transformation of the aesthetic expression of the fabric. Furthermore, the methods used for the re-printing and re-dyeing are achievable in a home setting using common household items and food waste.

CHALLENGES

It is uncertain to what extent consumers and producers will accept and implement this approach to color, prints, product variation, and appreciation. If they are not willing to embrace it, the potential sustainability benefits related to longer lifespan and reduced consumption may not be realized. The *Changing aesthetics* project addressed this further.

OPPORTUNITIES

These results suggest three promising directions for further research:

1. Assemble accessible user guides: Technical know-how must be translated into user-friendly formats, such as DIY tutorials and kits, to empower users to transform garments at home, fostering a new appreciation for product longevity and encouraging co-creation.
2. Perform user studies: A test group of consumers should experiment with the printing methods firsthand, re-dyeing and re-printing garments/fabrics using the tutorials and kits provided.

3. Perform comparable tests: Can the findings from natural dyeing be transferred to existing textiles dyed with commercial dyes? This would leverage existing textile resources and infrastructure.

SUSTAINABILITY

The project aligns with the extended EU Eco-design directive, which includes textile products, and which emphasizes designing textiles to last longer, be repairable and recyclable. Natural dyes from food waste reduce the environmental impact in production and facilitate recycling in closed-loop systems. The option for consumers to redye a textile product themselves can lengthen product lifespan and potentially curb the urge for new purchases – thus contributing to making "fast fashion go out of style".

SUMMARY

Building on previous work with food waste dyes, this project explored layered dyeing and printing techniques using natural tannins and mordants. Aiming for a more sustainable and interactive approach to fashion, it investigated methods for users to re-dye and reprint textiles at home. Enabling these actions aims to encourage a shift in behavior towards longer product lifespans and reduced consumption.

The project demonstrated the feasibility of this approach, achieving significant aesthetic transformations. To promote wider adoption and challenge fast fashion, future research should focus on user-friendly guides, consumer testing, and comparable experiments with conventionally dyed fabrics.

REFERENCES

1. Boutrup, J., & Ellis, C. (2019). The Art and Science of Natural Dyes: Principles, Experiments and Results. Schiffer Publishing Ltd.
2. European Union (2024). REGULATION (EU) 2024/1781 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC. Official Journal of the European Union, 2024/1781 (Seen May 2025)

CHANGING AESTHETICS

This project emerged as an outcome of the dialogues with the materials of the situation (Schön, 1983) that emerged in the previous projects, *Dyeing with food waste* and *Mordant and direct printing in layers*. Contrary to those, the *Changing aesthetics* project did not involve practical material explorations, as the aim was to address and discuss the concept of changing aesthetics.

Traditionally, changing aesthetics are an inherent part of the intangible mechanisms of the fashion world. Fashion does not change and replace itself unless aesthetic preferences change. Fast fashion contributes to intensifying the speed of preference changes through business models focused on rapidly changing trends and novelty value. Therefore, changing aesthetics contribute to creating some of the same practices that establish fashion as an "ontologically designed unsustainability" (Fry, 2007). In this project, the research team adopted a speculative approach and discussed and reflected on perceptions and ontologies related to clothing to explore the potential of changing aesthetics as a contribution, and not a hurdle, to "ontologically designed sustainability" (Fry, 2007) and thereby as a contribution to the green transition.

All image credits: VIA Team

GENERAL INFO

Involved partner: VIA University College Denmark
Researchers: Inger Marie Ladekarl, Malene Harsaae, Anne Louise Bang
Date of project: September 2023

PROJECT OUTLINES
The project aimed to investigate whether a product's aesthetic evolution could enhance its value and to what extent the design decisions could promote this development and thus contribute to prolonged product value. *The Mordant and direct printing in layers* project provided technical knowledge that has the potential of guiding design decisions to alter garment appearance by developing print techniques as enablers. However, the research moved beyond the mere technicalities of altering garment appearance, so the main focus of the *Changing aesthetics* project became to explore how we can challenge and potentially change our deeply ingrained perceptions of beauty and value in what we wear and thus suggest a paradigm shift where the narrative a garment accumulates throughout its lifespan, marked by personal experiences and individual touches, is recognized as holding significant value, potentially surpassing that of its original, untouched state.

PROJECT PURPOSE
A genuine green transition in fashion and textile industry requires systemic change, impacting production, design, consumption and use. This necessitates a fundamental rethinking of how we value clothing and textiles and taps into a discussion around when a product possesses value and when that value diminishes, as well as how we contribute to sustaining or generating renewed value.

Overproduction and overconsumption are rampant in the fashion industry, fueled by constantly shifting aesthetics that encourage discarding perfectly functional items for the latest trends. The current fashion system is characterized by indifferent products with planned obsolescence, devalued almost before they reach the user.

The project directly challenged this cycle by introducing a new type of product, challenging the current perception of changing aesthetics as equal to fast and frequent, and promoting a new paradigm of changing aesthetics that foster slowness and long-term product attachment. This shift, where consumers actively participate in their garments' evolution, could be a first move away from disposable fashion and toward more sustainable practices within a circular economy, where products are cherished and utilized for longer.

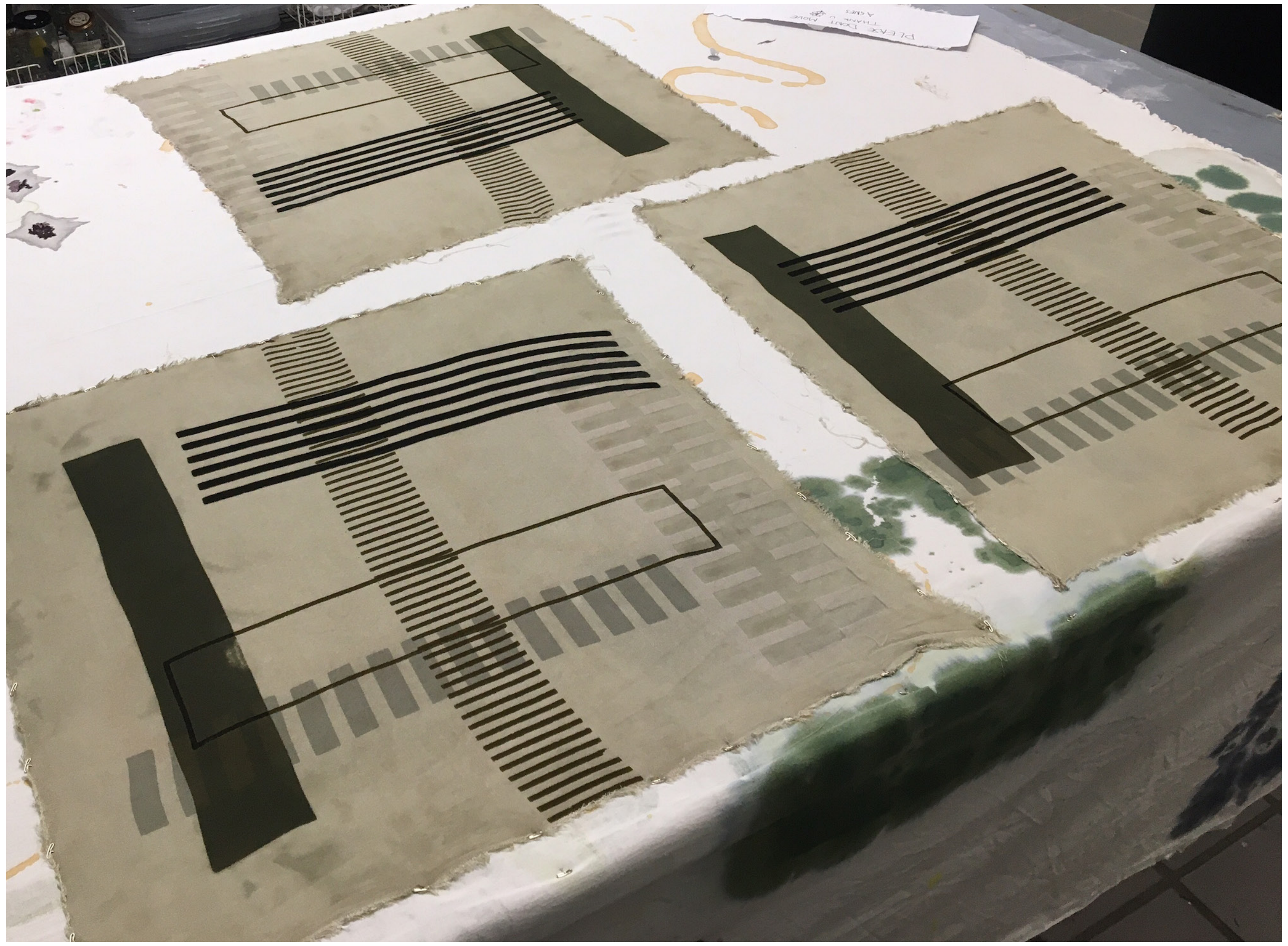
METHODOLOGY
The project's starting point was a speculative discussion on "changing aesthetics" to establish a conceptual framework. This thought-provoking dialogue challenged conventional expectations around products, manufacturers, designers and consumers, as well as product value, uniformity, and the role of trends. The dialogue fostered a preliminary framework for a speculative future scenario, where unique, uneven and

"imperfect" products are the new normal and products improve their value after the point of sale, through use and through pre-designed user interventions.

Building upon this speculative scenario, the project translated technical possibilities into practical applications. Drawing from the *Mordant and direct printing in layers* project, which demonstrated achieving desired color changes on textiles, meticulous documentation was compiled. This detailed how the finishing process could be replicated at home, simplifying complex procedures into accessible, step-by-step instructions for individuals without any technical know-how or specialized training.

While the finalization of these user instructions is still in process, their development represents the project's effort to bridge the gap between technical feasibility and consumer accessibility, empowering users to engage with changing aesthetics directly.

FINDINGS
The technical feasibility of creating aesthetic changes in textiles using the developed methods and natural dyes had been successfully demonstrated in the previous cases. It must be emphasized however, that the *Changing aesthetics* project has not succeeded



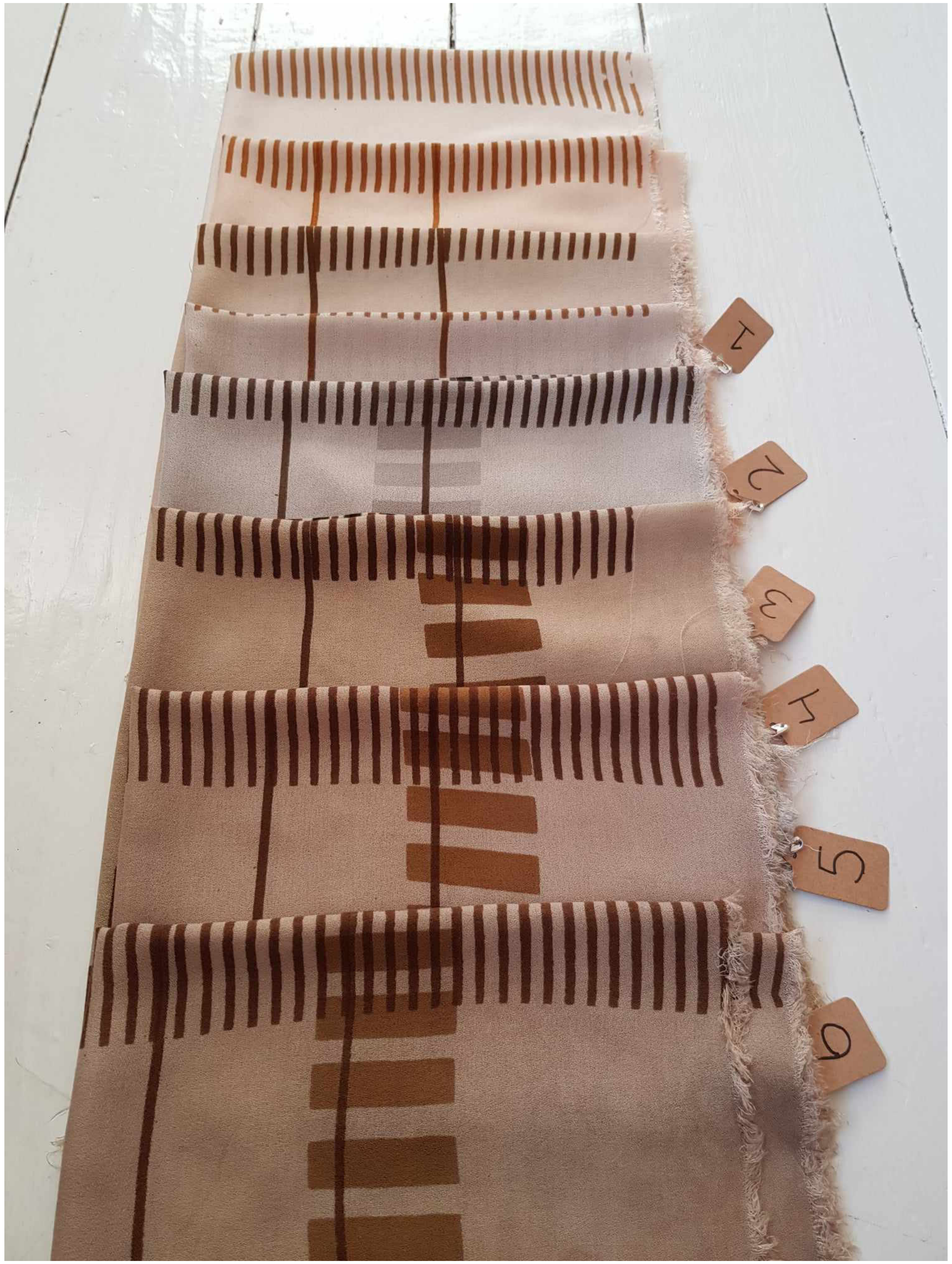
in transferring the technically achievable beyond the speculative scenario. The process of convincing users as well as the industry to embrace this and act accordingly, ultimately reaching a new fashion paradigm is still a long and challenging journey.

The central point of this case is that it emphasizes the importance of maintaining both curiosity and a critical approach in the investigative and experimental processes. Without this approach, the researchers would not have entered the dialogue with the materials and the conversations with materials of the situation (Schön, 1983). The questioning of the relevance and resonance of current textile dyeing and printing industry certifications and requirements that arose from the *Dyeing with food waste* project provided the foundation for the retake on changing aesthetics to emerge. This perspective was also highlighted during the scenario workshop, held at VIA University College in May 2022 (see case 3, *Scenario building as a dialogue tool*).

CHALLENGES
The greatest challenge in transforming consumer behavior is to change the mindsets around fashion. This endeavor requires a fundamental paradigm shift, demanding effective engagement to inspire adoption of this new perspective. Beyond this, clearly defining "changing aesthetics" to differentiate it from regular fashion cycles proves crucial for its potential acceptance and implementation within the wider fashion ecosystem.

A significant aspect of this challenge lies in the discrepancy between the intentions of fostering a green transition and the still increasing numbers in production and consumption of clothing and textile products (EU, 2025). This discrepancy is an outcome of the lack of action from industry as well as from consumers. While many consumers apparently desire more sustainable options, unwillingness to pay more or exert extra effort often hinders action. At the same time, cases where companies have been accused and some convicted of greenwashing have a major impact on consumers' confidence – or lack of – that products marketed as "responsible" or "sustainable" are actually better for the environment (Abelvik-Lawson, 2023). This highlights the speculative nature of the project's ambition to alter established consumption patterns, raising the question of its real-world impact.

Given these challenges, it was considered how this project as a single initiative could influence broader



behavioral change. It is of course speculative in nature, which may limit its intended impact, but increased publication and dissemination of findings are seen as vital steps in initiating public conversations and potentially influencing consumer attitudes.

Ultimately, the challenge lies in weaving together compelling, though speculative, concepts and tangible shifts in consumer expectations, beliefs, and actions within the fashion landscape.

OPPORTUNITIES

Future research should prioritize deeper user engagement. This involves testing the practical guides and assessing user willingness to adopt the concept and modify their consumption habits. Further exploration is still needed to understand user aesthetic preferences. Testing various print styles will reveal what consumers desire, shifting the focus from technical feasibility to user-driven design.

Investigating strategies to shift mindsets around fashion and facilitating a broader paradigm shift is crucial. This could involve focus groups and observations to understand user behavior and identify effective engagement methods.

Finally, a clear and concise definition of "changing aesthetics" is essential for wider understanding and acceptance.

NOVELTY

The *Changing aesthetics* project challenged existing industry standards, questioning their suitability for more sustainable dyeing methods. This opened a discussion between a paradigm shift and current norms. Are industry requirements workable if such a compromise exist?

Additionally, it highlighted a potential in aligning industry and consumer understanding of beauty and value. Through storytelling around responsible dyeing and printing, unique products can be developed, simultaneously shifting perceptions of acceptability and attractiveness. This offers opportunities to engage industry alongside consumer expectations of what is "right".

The project extends beyond materials and techniques such as food-waste dyeing and mordant printing, impacting our fundamental understanding of product aesthetics and value.

SUSTAINABILITY

Sustainability is central to the core concept of the *Changing aesthetics* project. The project contributes to the green transition by challenging existing norms and standards within the fashion industry as it explores novel perspectives on product value and lifespan. It empowers consumers to participate in sustainable practices by modifying their own products and it holds the potential to reduce overproduction and overconsumption

SUMMARY

The *Changing aesthetics* project is complex and compelling and challenges fundamental understandings of fashion and sustainability. It demonstrated the potential for rethinking product aesthetics and longevity, yet revealed hurdles in shifting consumer behavior and mindsets. Nevertheless, it initiated crucial discussions contributing to a greener fashion paradigm.

It is a complex project because it delves into deeply ingrained understandings of value, beauty, and desirability in products. Ultimately, it underscores the need for professionals to challenge norms and develop methodologies that reshape fashion's perception, use, and production.

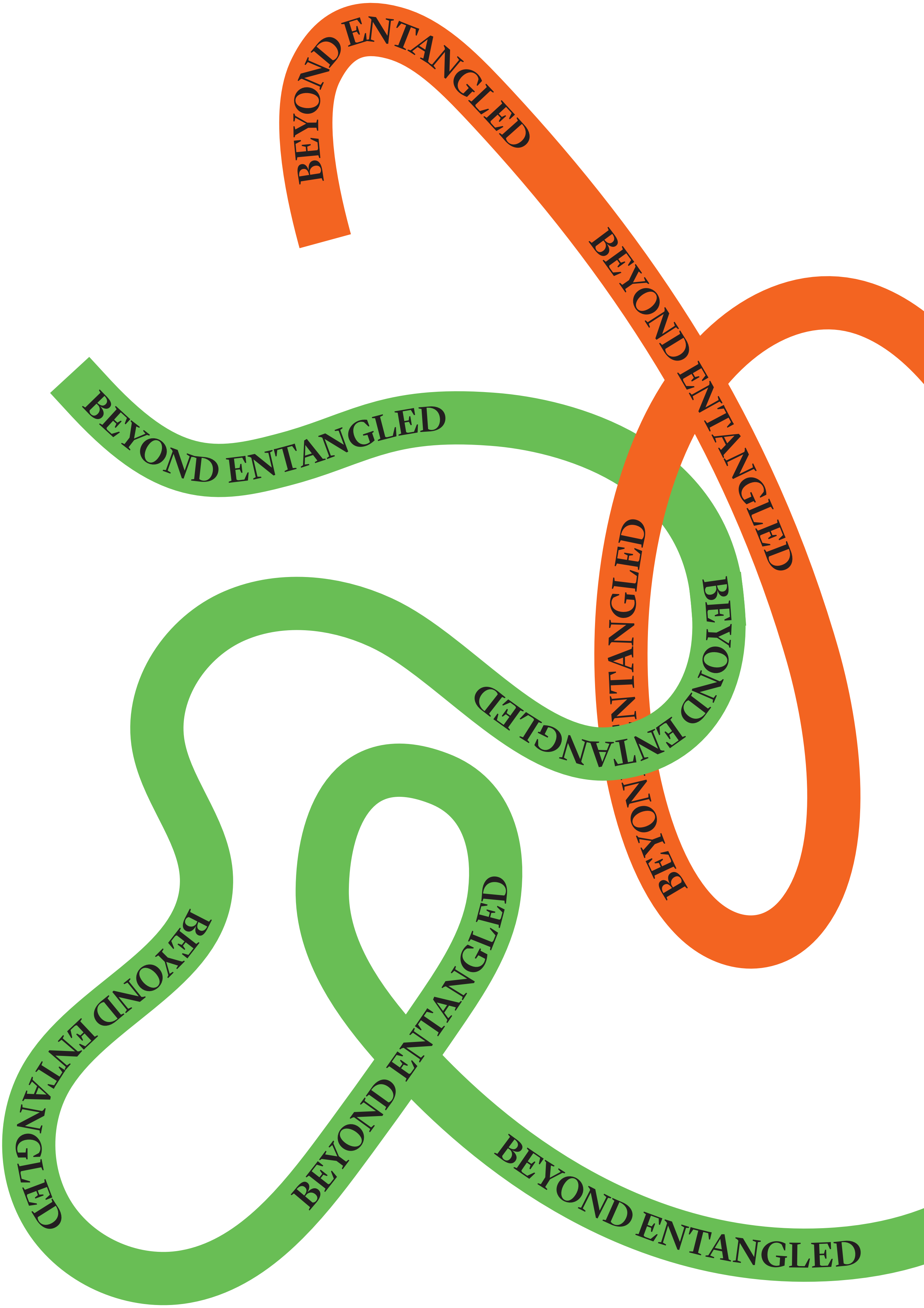
REFERENCES

1. Abelvik-Lawson, H. (2023) https://www.greenpeace.org.uk/news/fashion-greenwash-report-companies-hiding-true-environmental-costs-fast-fashion/ [Accessed May 7, 2025)
2. Dunne, A. & Raby, F. (2013). Speculative everything; design, fiction, and social dreaming. MIT Press
3. EU (2025) Consumption of clothing, footwear, other textiles in the EU reaches new record high | European Environment Agency's home page
4. Fry, T. (2007). Redirective Practice: An Elaboration. Design Philosophy Papers, 5(1), 5-20. Available at: http://dx.doi.org/10.2752/144871307X13966292017072
5. Schön, D. (1983) The Reflective Practitioner - How Professionals Think in Action, Ashgate Publishing Group

Further reading:

Harsaae, M. P., Bang, A. L., Ladekarl, I. M., Pedersen, L.K., Nielsen, T. B., Ege, A. (2023). The Matter of Matters. In: Proceedings of the Textiles Intersection Conference, Loughborough University, London.

Ladekarl, I. M., Harsaae, M. P., Bang, A. L., Pedersen, L. K., Nielsen, T. B., Ege, Amalie (2023). From Craft to Industry. In: Form Academic, Vol 16, No 4.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