Sensory Materials Library: Finally, a Materials Library that makes *Sense*

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Textile Designers rely on touch and their tacit knowledge and experience to navigate a constantly evolving world of material which they discover primarily through physical experiences such as expos and material collections. Digital material platforms would increase the accessibility of materials. However, the current material library landscape lacks the necessary sensory data. In addition, gathering this data is limited by the textile industry tools which are primarily focused on standardisation as opposed to design innovation. Faced with these challenges, this paper presents a research framework for an inclusive and holistic approach towards sensory properties within a materials library – the Sensory Materials Library (SML). Based on this framework, preliminary research into connecting the objective and subjective properties for a prototype library is presented, the aim being to support digital tools to help Designers discover, select and learn about materials. As an example of such a tool, we have developed the AiLoupe, an AI-enabled mobile application that uses image-based material classification to present sensory properties for properties to Designers. We present our initial iterative development process for AiLoupe and potential applications that fit within a greater research paradigm that aims to connect material research from raw materials, distributed manufacturing, branding, retail, product use, end-of-life and circular processes.

Keywords: Artificial Intelligence and Textiles, Sensory Properties, Digital Material Libraries, Material Selection, Inclusive materials research

Section 1. Introduction

The world of materials is constantly evolving, with new ones being developed, promoted, and discarded as trends change. However, it is infeasible for Designers to physically experience each material due to their sheer volume. Physical expos and material collections are not easily accessible to everyone. Digital material platforms, still in infancy, often lack the necessary sensory data. Material suppliers see them as a reluctant solution, as it remains challenging to accurately portray materials digitally and requires significant effort and cost to digitise them. Textile Designers in particular, rely on touch, tacit knowledge, and printed information to evaluate textiles, often through their relationships with suppliers and expos.

In response to these challenges, we are conducting research to develop digital technology to enable designers to have an intimate and reflective understanding of materials, as the choice of the right material is crucial for optimal product performance. The research seeks to expand these connections by using Artificial Intelligence (AI) to establish relationships between material properties – both objective and subjective data. AI excels at establishing connections between data and converting unstructured data such as images into structured information.

Over the past 10 years, the Material Science Research Centre has developed a research program that spans material research from the raw material, distributed manufacturing, design, branding, retail, product use, end of life and circular processes. This is captured in the Intelligence Design System for Innovation (IDSI), Figure 1.

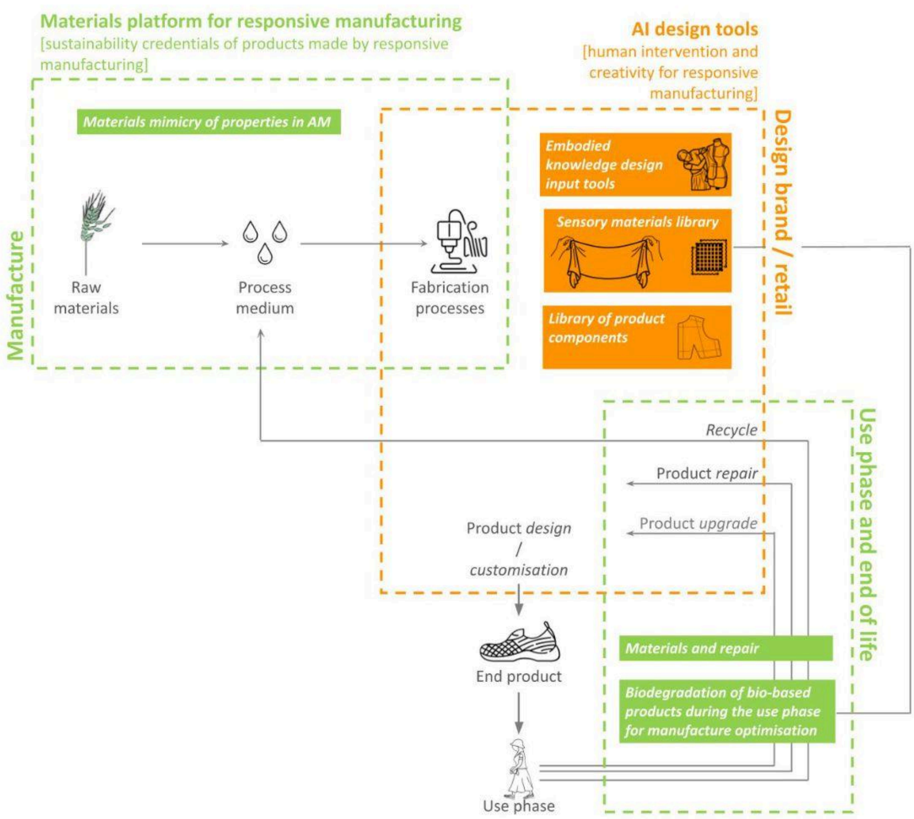

Fig 1. The Intelligent Design System for Innovation (IDSI) – a system-level approach towards material and

product design.

IDSI is split into three overlapping ecosystems – a Manufacturing perspective where Materials are developed through responsive manufacturing platforms, a Design brand and retail perspective with interoperable tools and libraries, and a Use phase perspective which embodies a circular economy spirit to encourage custodianship of materials rather than mass consumption. One core value for the IDSI is connections throughout the three ecosystems. Within the Design, Brand and Retail space, an overlapping part of that research involves building Human-centred AI design tools and libraries – in particular the *Sensory Materials Library* (*SML*), which is the focus of our research efforts.

Our research into addressing the challenges mentioned in Section 2 is towards building a *framework* for an inclusive and holistic approach towards sensory properties within a materials library which is presented in Section 3. Utilising this framework, in Section 4, we demonstrate our research through an AI-enhanced prototype *tool* which aims to help Designers discover, select and learn about materials. Finally, we conclude with potential applications and the next steps for our research in Section 5.

Section 2. Motivations / Challenges (with Background Review)

Challenge 1: Designer's tacit knowledge

Our project addresses three main challenges facing designers working with textile materials.
The first challenge is that Designers struggle to pass on their tacit and embodied knowledge of materials, which they have gathered over years of working and designing with them (Dormer 1994:15). There are no formal tools to enable a shared understanding, and therefore Designers often rely on curating mood boards and using references as a mode of communication. This does convey the nuances of their concepts visually, however, they often need further explanation for all to understand. The challenge of articulating and passing on their tacit knowledge has resulted in a general lack of understanding of materials for others without this data. The feel and behaviour of a material is vital information for a Designer when sourcing and selecting textile materials, hence why it is such a physical experience (Petreca, 2016). From studies and interviews with Designers, we have concluded they are reluctant to source new materials online as they cannot get accurate sensory data digitally. Likewise, Designers need to physically prototype to truly understand how the material behaves in a certain design or application. Despite this need to translate sensory information of materials which could attempt to capture Designer's tacit knowledge, this subjective data is often not well understood, and therefore excluded.

Without deep knowledge and experience working with a variety of materials, Designers might not be equipped to make the most appropriate or educated material choice, which could affect the performance, longevity or overall aesthetic of the product. Knowing the most appropriate material for a certain function or context also reduces countless samples and prototypes in different materials, therefore contributes to tackling waste issues in the Design process. Not only would translating the Textile and Fashion Designer's knowledge help other Designers when sourcing materials, it would also educate the consumer on a deeper level of the materials their clothes and products are made from, in turn increasing their appreciation and value for them. Gate keeping this knowledge will only result in furthering the detached relationship many have with materials around them.

Challenge 2: Textile Industry standard of digitalising material data

The textile industry has a long research history of developing methods of measuring the 'textile hand' – or the experience of textile which is available through the body, particularly the hand. The industry has developed these techniques over the last 100 years (Figure 2), in order to have more replicable methods for qualitative assurance purposes or to help replicate the feeling of popular materials. These techniques focused on industrial requirements in the textile industry (De Boos 2005), integrating human subjective assessments (Ciesielska-Wróbel and Van Langenhove 2012) and are standardised as technical protocols (AATCC 1990, 2019).

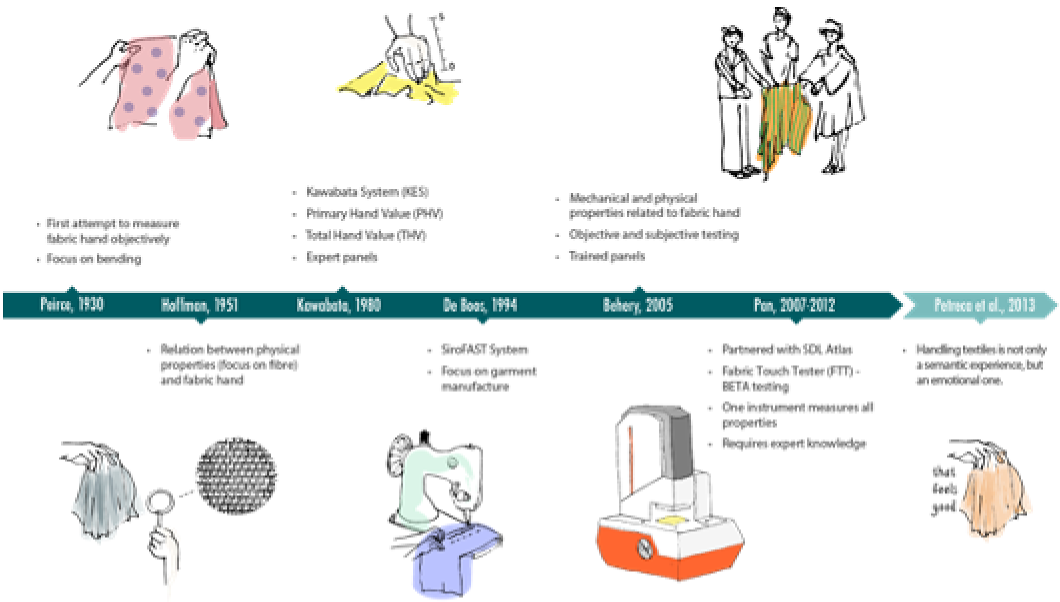

Figure 2 – The evolution of methods for measuring the 'textile hand' (adapted from Figure 3 in Chapter 2 of Petreca (2016)).

For example, the *Fabric Touch Tester* (FTT) is the most developed equipment to characterise 2-D soft materials to date. It combines multiple physical tests to measure compressions, flexibility, rigidity, heat conductivity and surface roughness which are mapped to three textile hand properties: *softness*, *smoothness* and *warmth* (SDLAtlas 2017), based on an internally ran hand-panel of textile assessments of a range of standard textiles.

The physical-subjective mapping as done by the FTT's software is a typical industrial practice, isolating a semantic experience and describing a textile via single scale (e.g. *soft*) or bipolar scales (e.g. *rough-smooth*). The textile industry has not focused on the feeling and wearing experience of materials, which is very important to designers (Petreca 2016). As well as broadening *how* one evaluates and describes a textiles material, *who* is doing the describing has broadened beyond traditional subjective assessment via expert panels to include non-experts (Atkinson et al 2016).

In addition, digitalising of material data via instruments such as the FTT is specific to quality assurance and standardisation – but not towards design innovation. Kuijpers et al. (2020) conducted a thorough review of the state-of-the-art textile testing equipment with a specific focus on properties that would be useful in virtual simulation of fabrics, a need unaddressed by the industrial textile industry. This points towards a greater desire to integrate material data into the design process, especially when a Designer can utilise instruments to gather their own data.

Finally, one large limitation to industrial 'textile hand' practises is that subjective testing is time consuming and costly, since it involves coordinating human participants. Fatigue and loss of focus sets in as the number of materials increase, and even methods that consider multiple sessions with subsets of fabrics can test at most 10-13 fabrics in a study (Musa et al 2019). Such small groups of materials, which is typical for published research, is very limiting considering the large data needs for contemporary AI methods. In addition, due these limitations, the industry tends to focus on studying materials for very specific narrow applications or ranges of material variations. Thus, due to sunk costs in addition to extreme competition, the industry is shy about sharing their own closed source material research data for public validation, verification and to allow others to build on top of their work.

Challenge 3: Current State of the Material Library Landscape

The third challenge lies within portraying material data in libraries, this is particularly difficult for virtual platforms. The result of challenges around the industry digitisation techniques has an impact on how Designers discover, source and select materials.

Examining features within four contemporary material libraries, Material District, Future Fabric Virtual Expo, Material ConneXion and The Material Library, we have reviewed the data they include comparatively, to the best of our knowledge (Table 1). Sensory categories in this chart are based on what the traditional textile literature calls them. We see sensory properties, as those that convey the experience of the textile - visual, through motion, sound, and smell. Sensory properties may be a mixture of the objective (i.e. have a video of a textile) and subjective (i.e. have someone describe the sound a textile makes). Making this distinction is based on the previous literature conducted within the MSRC (Adkinson 2014; Bruna 2016). Separating the review into these categories also demonstrates the clear lack of certain criteria. Objective data is easily gathered and standardised, displaying factual and measured data, and as a result, is well represented in all four. Sensory data, however, is more challenging to translate due to its reliance on physical experience, and therefore difficult online. Likewise with Subjective data, personal and emotional aspects that affect this data makes it challenging to test, capture or articulate.

	Name	Material District	Future Fabric	Material ConneXion	The Material Library
Objective properties:	Composition	X	X	X	X
	Textile construction	X	X	X	
	Weight/Density	X	X		
	Raw material info	X	X	X	X
	Resistances	X			X
	Other Technical Properties	X		X	X
Sensory properties:	Texture				
	Temperature	X			
	Hand Feel (Through description or imagery)	X	X		
	Video				
	Acoustics	X			
	Odour	X			
Subjective properties:	Verbal descriptors				
	Opinions				
	Raitings				
	Feedback				
	Written description	X	X	X	X
	Tags	X			X
	Number of materials	2,925	2,843	10,00+	361
	URL	Materials Archive - M	Future Fabrics Vi	w.materialconnexion.com	Materials Library - Institute of

Table 1 - Material Libraries Review

The table demonstrates the lack of dimension around sensory and subjective data of materials in the reviewed libraries, despite this data helping portray 'Fabric Hand' and suggesting tactile sensations of materials to Designers (De Boos, 2005)[1]. There is a history of industry researching subjective tests and data, however the complexities around capturing and portraying both sensory and subjective properties remain. As a result the human experience of materials are not recorded or shared in these libraries. Equipping Designers with subjective data through relating sensory properties to the objective properties gives them greater understanding of the material's performance and allows them to make more educated and appropriate material choices when selecting materials in the Design process. Some libraries do attempt this through photographs of materials being handled or draped which provides cues of the properties, feel and movement; however, this translation relies on the Designer's tacit knowledge to make educated assumptions around materials (O'Mahony, Marie, and Barker, Tom. 2012).

The inclusion of sensory and subjective data in a more standardised way would provide a more physical, sensory experience of interacting with materials, especially essential when sourcing online. A few attempt this through categories and tags, which help gauge an idea of the hand feel, while including other sensory data around sound and smell. Some do list properties beyond what's traditional, however, having single text labels is still limiting for Designers to understand how the material feels and provide richer representation. Some libraries' scope of materials is broad, ranging from Textile to building materials and hence the labels would be more universal, and thus generic.

While the four provide digital platforms, they all rely on a physical presence, presenting their collections through visitable libraries or at Expos and showcases. The semantic experience of materials, combined with the emotional and subjective feedback when interacting with materials makes it a very challenging thing to capture correctly and cohesively (Bruna, 2016). Perhaps this is why there is a lack of attempt to translate the materials data in a physical setting, as they rely on Designer's tacit knowledge when interacting with the materials in person. As virtual libraries appear

[1] De Boos, 'Concepts and Understanding of Fabric Hand'.

to come second to their physical counterparts, it is clear they need improvement when it comes to translating sensory data using digital tools.

One solution is through multimedia to capture more data of a material, such as video and sound. Translating the 'Fabric Hand' through video to suggest the weight, drape and softness. Another solution would be to provide subjective archives through personal designer's material libraries, where the Designer collects and organises their own libraries and archives, recording feedback. A third potential feature is to offer a comparative option, generating tables to compare a selection of materials' data next to each other. This could improve the sourcing experience online to mimic the Designer's physical experience of comparing materials in either hand or one after another. Translating data of new and novel biomaterials online can be challenging as they are unfamiliar or develop overtime (D'Olivo & Karana, 2021). Therefore, this feature could be particularly helpful when sourcing these unfamiliar materials, having a comparison or like for like feature could educate and promote these innovative and sustainable materials more.

Section 3 – Framework: Sensory Materials Library

To start to address the challenges mentioned in Section 2, we have been researching how humans experience textile materials, in particular, what sensory properties are useful to Designers. One core component is conceiving and building the *SML* at the Royal College of Art (RCA). The *SML* combines the features of conventional material libraries, sensory properties gathered throughout our research and AI technologies to combine and relate these properties with each other.

The *SML's* criteria is Textile materials, with a focus on promoting sustainable alternatives and novel and bio materials. Initially starting with a collection of 10 woven materials (Table 2), ranging from generic to novel blends, we are developing an approach to gather objective and subjective data. Lastly we are translating this data to Designers and co-creating with them to tailor the *SML* to their needs and desires.

Objective Data

We gathered objective data collating information from suppliers, while also using state-of-the-art industrial material testing equipment, such as SDL Atlas' Fabric Touch Tester (FTT) and Moisture Management Tester (MMT) in our Immersion Lab. The FTT measures mechanical properties of textile materials, such as stiffness, compression response, thermal conductivity, and surface friction.

id	name	medium	colour	composition	structure	sub-structure	construction	gsm
1	Crepe chiffon Silk	Animal	White	100% Silk	Woven	Plain	Crepe chiffon	14
2	Silky Natural Denim Blend	Plant/Animal	Un-dyed	55% BCI Cotton 35% TENCEL™ Fibres 10% Silk filaments	Woven	Twill	Denim	262
3	Ultra-lightweight Luxury Bark Crepe	Plant	Ivory	100% TENCEL™ Lyocell Filament	Woven	Plain	Textured Crepe	63
4	Silky Natural Denim Blend	Animal	Ivory	100% Silk	Woven	Twill	Tropical	80
5	Rare Chunky Cord	Plant	Warm Cream	67% TENCEL™ Lyocell Fibres 33% TENCEL™ LUXE Lyocell Filament	Woven	Other	Cord	307
6	Premium Peach Satin: TENCEL™ Luxe	Plant	Ivory	70% TENCEL™ Luxe Lyocell filaments 30% TENCEL Lyocell fibres	Woven	Twill	S Twist	141
7	Coated Juniper Linen	Plant	White	100% Linen	Woven	Plain		148
8	Wool Serge Natural (Dying)	Animal	Natural cream	100% Wool	Woven	Plain	Serge Felt	508
9	Soft Canvas Linen and TENCEL™ Lyocell Blend	Plant	Off White	52% Linen 48% TENCEL™ Lyocell	Woven	Twill	Broken Z with Slub	225
10	Polyester Organza	Synthetic	White sparkle	100% Polyester	Woven	Plain	Organza	14

Table 2. Initial 10 materials for the RCA Prototype the SML

Subjective Data

To gather the subjective data, we conducted a series of subjective material assessments with designers and non-designers. They assessed the 10 textiles shown in Table 2 above, on the basis of six bi-polar scales, shown in Fig X below. We have experimented with a variety of assessment formats, from individual interviews, in group workshops to digital tools. The Violin Plots shown in Figure 4 and 5 are translated from 15 individual interviewees' assessment boards. It is clear there are variations with materials with common properties, such as material 7, a 100% Linen plain weave. However, the plots are never at either extreme of the scale, perhaps to its generality. On the other hand, materials with more exaggerated properties, such as material 8, a heavy Serge Felted Wool, have a clear pattern, clustering around -5 to -2 for all. It is also clear that some scales in the assessment are more objective, such as Heavy-Light and Thick-Thin as participants approached these in similar ways, feeling the weight of the fabric, or pinching to measure the fabric. More subjective scales had a larger range of ratings no matter the material, such as Stiff-Flexible or Warm-Cool, as participants would approach these in a variety of ways, with different movements or concepts around the scales. The final scale, Least Favourite-Favourite, is clearly the most subjective, varying for all 15 participants as expected based on personal taste. Despite the scores varying across the whole scale in almost all the Violin Plots, there were often clear correlations with this scale and certain other traits. For instance, Figure 3 shows one Participant's board, where material 8, 5 and 2 score the closest to Favourite, but also the closest for Heavy, Stiff, Warm and Thick. This demonstrates how personal taste can be linked to curtain traits. Therefore, biases might influence material sourcing and selection if the properties are not well understood. However, even with the variation in the subjective assessments, including the personal aspect of opinion and experience is still valuable to capture and for Designers to be guided from.

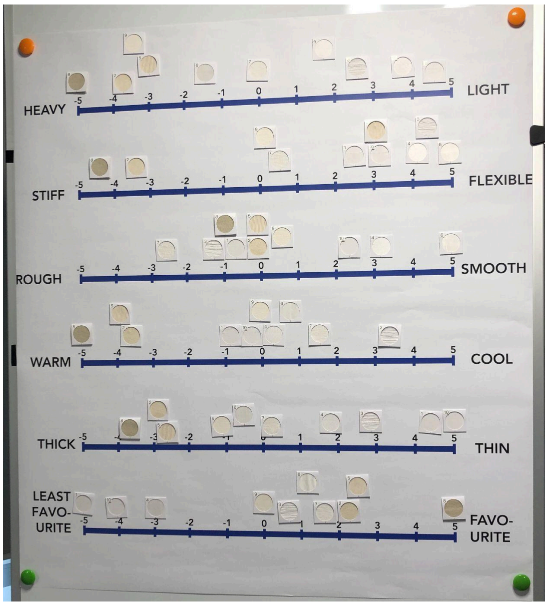

Figure 3 - Participants' assessment of 10 textile materials on the bipolar scale board.

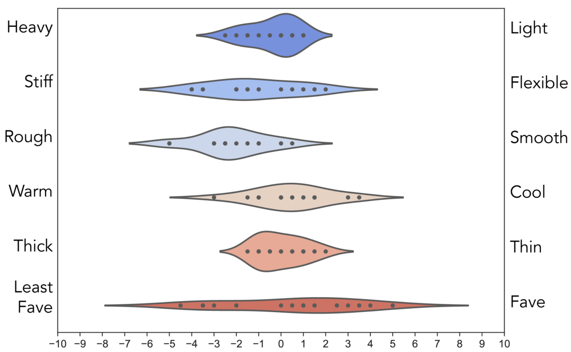

Figure 4 - Violin Plot of participants' assessment of material 7.

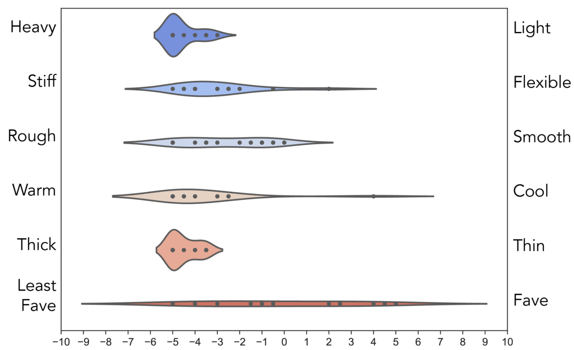

Figure 5 - Violin Plot of participants' assessment of material 8.

Designers' Needs and Desires

From our preliminary interviews with Designers, both individual freelancers and from larger companies, most curated their own material libraries, which were manual, personal and bespoke. However, there was a common resistance to digitalise their libraries, sceptical that the sensory data could be captured as well as in a physical library. Perhaps their hesitancy could be diminished by the *SML*, through translating the subjective results into an accessible digital library which could provide a more effective tool for material identification and selection.

Section 4 – Tool: Example of AI-Based Design Tool: AiLoupe

As a proof of concept, we are developing a prototype AI-based design tool. *AiLoupe* takes its inspiration from traditional textile analysis and its use of a hand magnifying lens - a loupe - to identify the structure, material composition, and other properties of a fabric. *AiLoupe* utilises AI-based image recognition techniques to identify materials and presents objective and subjective properties from the *SML* (described previously in Section 3) via a Material Data Card (Figure 6). Additional material properties such as aftercare, sustainability and supply chain transparency are presented connecting to overlapping ecosystems from IDSI as discussed in Section 3.

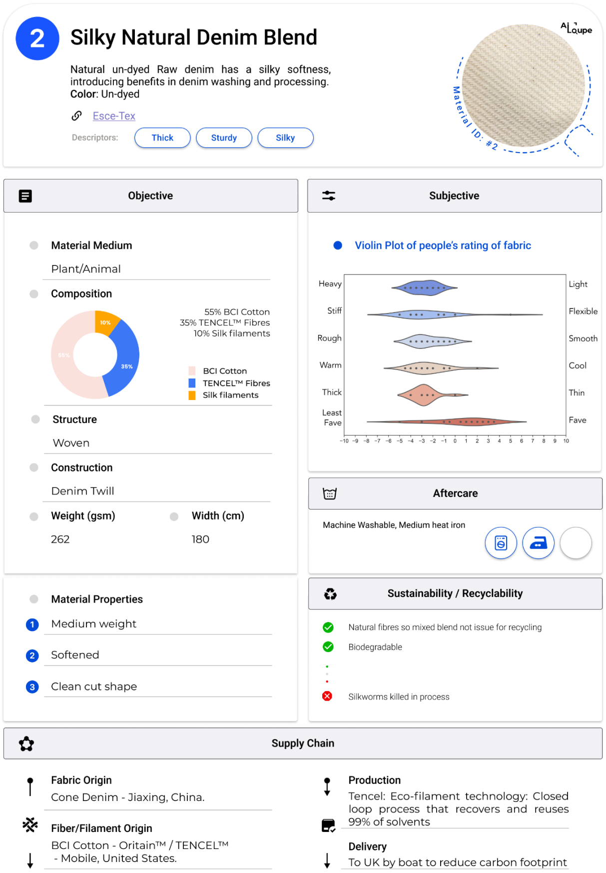

Figure 6. Material Data Card from AiLoupe

Figure 7. AiLoupe presented in exhibition - Fashion X AI, February 2023.

Because the aim was to learn how Designers might use *AiLoupe*, we prioritised getting a prototype out early to test it in exhibition and expo environments (Figure 7). *AiLoupe* was introduced with the emphasis that its material identification capabilities were imperfect due to the large amount of data and training an AI requires. We invited exhibition-goers to try *AiLoupe* out to identify a material, and to indicate whether the identification was correct and if not, correct the identification (Figure 8). We emphasised to exhibition-goers that AI systems require interaction and iteration in order to improve their underlying models of the world, and that their participation contributes toward improving *AiLoupe's* performance.

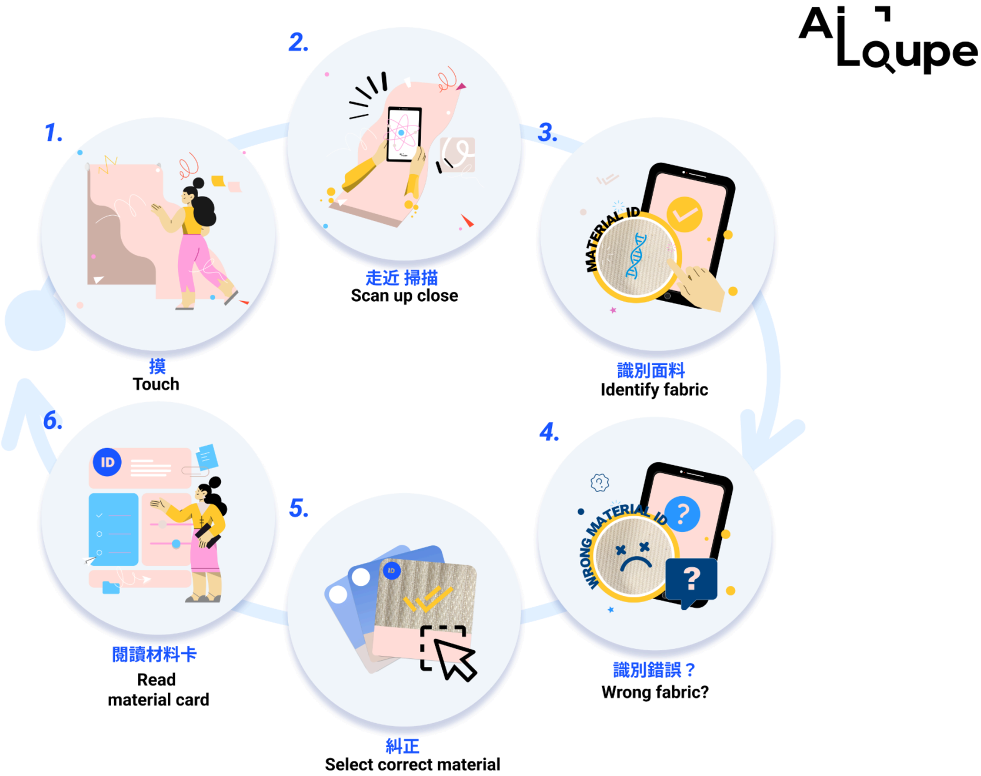

Figure 8. Instructions presented to the AiLoupe user, which instructs them to correct wrong identifications of materials.

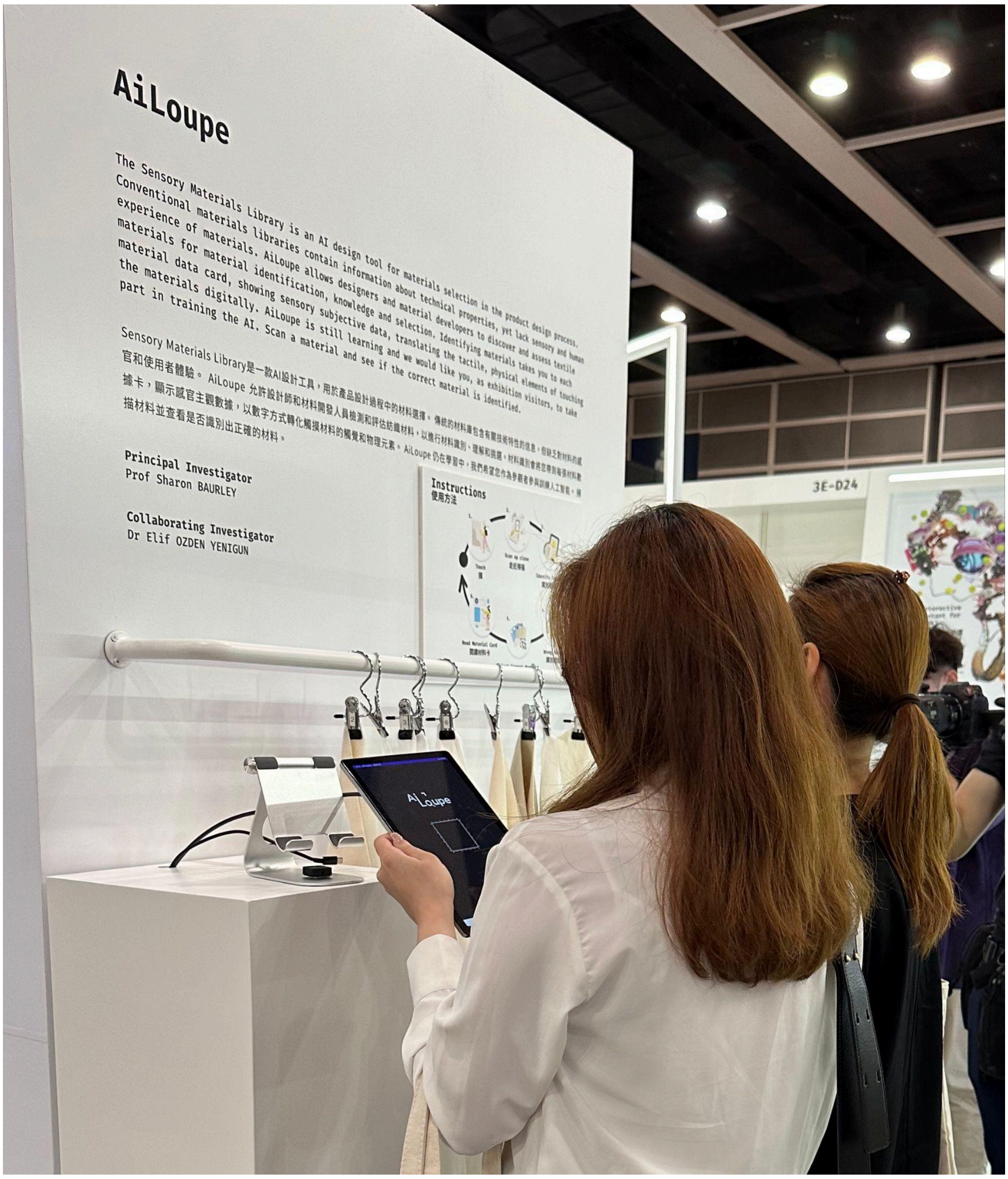

Figure 9. People using AiLoupe at InStyle 2023, Hong Kong.

Early trials with our initial *AiLoupe* prototype (Figure 9) provided us valuable insights by analysing the variety and framing of images from the exhibition as shown in Figure 10. The top row (a-d) are images of the fabric isolated, and we would rate them in decreasing clarity. The full frame image (a) classical ideal input image in that it is flat and has no distracting artefacts or background areas. However, the edges (b), folds (c), and drape (d) of a fabric might provide valuable additional visual information to an AI. The bottom row shows challenging images where multiple fabrics increase ambiguity for identification (e and f), very homogenous, flat colour or transparency produced out of focus images (g). Some exhibition goers were immediately drawn to see how *AiLoupe* would classify items that they had with them (h). We took this as positive feedback where *AiLoupe* spurred a curiosity to inquire about the material world around them.

(a) *Full frame* (b) *Not-so-full frame* (c) *Folds and edges* (d) *Drapey and Isolated*

(e) *Not Isolated* (f) *Cluttered* (g) *Blown Out* (h) *Not a Fabric*

Figure 10. “In-the-wild” images taken by exhibition-goers from the FashionXAI 2023 Exhibition

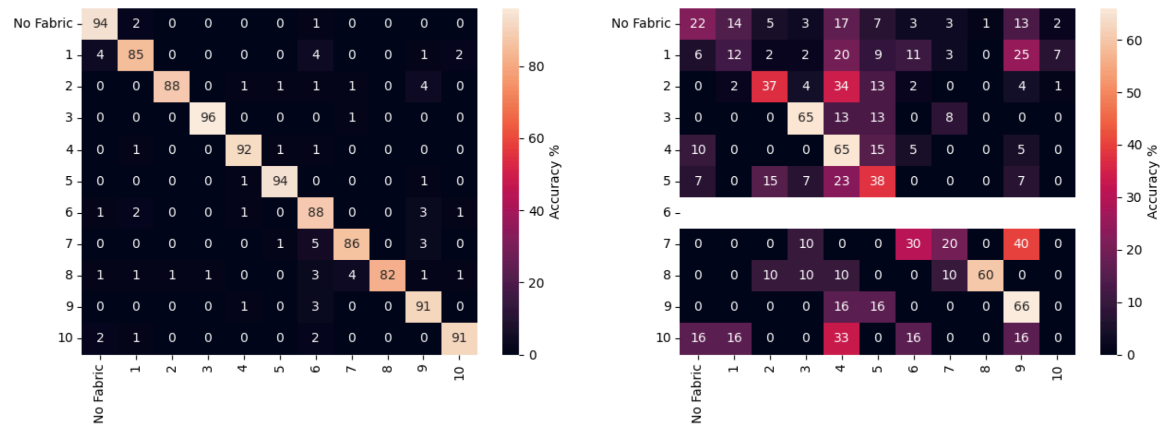

Figure 11. Confusion matrices showing the performance for prototype image-based material classifier with the results for the test data set (left) and the exhibition ‘in-the-wild’ images (right) (Note material 6 is missing because nobody chose to classify that materials in the exhibition).

Our initial development of a prototype image-based material classifier proved challenging, with a majority of classifications requiring corrections. Figure 11 shows the performance of the material classifier in the form of a confusion matrix. For a given material row in the matrix, the columns show the distribution of classifications by the classifier (shown as a percentage, each row adds up to 100%). The diagonal in the matrix shows the accuracy of the classifier, so with the validation portion of the training data (the left confusion matrix), the classifier performs with an 88-96% accuracy.

While with the exhibition images (the right confusion matrix), the classifier's best accuracy was 66% (material 9) and 0% (material 10).
We chose a challenging set of fabrics which were neutral coloured, in order to to focus on material identification from a textile analysis and structure perspective, and to avoid the AI system relying on distinctive colours and patterns for identification. In fact, classifying the texture of a particular instance of a fabric is an open research challenge (Trémeau et al. 2020), where the state-of-the-art classifiers perform best at material categorisation level (e.g. "wool" versus "linen"). These are preliminary results and we will be focusing on improving the image-based material classifier through growing the *SML* dataset with a wider variety of materials textures. In addition, we are learning how Designers implicitly take photos of materials with *AiLoupe*. We plan on evaluating how adding constraints to control scale, lighting, distance and camera angle could improve the performance of image-based material classification.

Section 5 - Conclusion, Application and Future Work

In this paper we presented research into utilising digital AI-based tools to improve the interaction of Designers and textiles through the *SML*. This work resides within a larger Intelligent Design System for Innovation that aims to transform a fashion and textile industry through circular economy practises and digital AI-based tools such as *AiLoupe*, which we develop through an iterative design-exhibit-evaluate process.

We see the *SML* and tools like the *AiLoupe* benefiting the Textile Intersection research community. First, interactions with textiles are only enhanced by considering the whole human experience with textile materials considering all of the senses. Next, a richer repository of material data, such as the *SML,* benefits designers for interactive and performative textile systems to better select and utilise materials for their systems designs. As a dynamic library, the *SML* allows the recording of a long history of materials, as opposed to short snapshots of materials studies common in research literature. Finally, the image-based texture identification and material property prediction research that is embedded in *AiLoupe*, provides core components for interactive systems which may use textiles as potential interfacing components.

In addition, we see our research has potential as two applications. First, as a Personal Material Library, which Designers can use as they go to material shops and expos, to record and retain a material's data and feel. Trying to recall the material properties is very challenging from a photo or scribbled note, especially when sourcing materials for a project or trying to convey and translate the experience of the discovered materials to their design team. Second, as a Consumer Application, it can provide a deeper understanding of the materials that they interact as a consumer. This relates to adjacent research at our Materials Science Research Centre – in particular with the UKRI Interdisciplinary Textiles Circularity Centre, where one of the research strands involves the *Consumer Experience* of textiles[2]. Having a consumer facing material identification and information tool as a mobile application is valuable by deepening the connection consumers have with the textile materials they shop and wear.

[2] https://textilescircularity.rca.ac.uk/our-research/consumer-experience/]

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