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Biofibre explorer: An augmented reality (AR) tool to promote circularity through material knowledge

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ABSTRACT

Augmented Reality (AR), which overlays digital information on the physical world, is frequently used in textile retail to improve shopping experiences by simulating product appearance and enabling virtual customisation. While these applications foster brand engagement and purchasing decisions, they largely promote consumption rather than encouraging circular behaviours. This study introduces the AR Biofibre Explorer, an innovative tool designed to reconnect consumers with materials and processes by demonstrating the wet spinning process for producing cellulose-based textiles. Through a mixed-methods evaluation, we reveal how the tool enhances understanding of material origins and their applications, promoting informed decisions and circular practices. Aligning with The wellbeing framework for consumer experiences in the circular economy of the textile industry [1], the tool incorporates dimensions such as learning, attachment, competence, and playfulness. This research establishes AR as a means to foster sustainability and circularity in fashion by bridging material knowledge gaps, enhancing consumer engagement, and enabling sustainable consumption choices.

1. Introduction: AR in fashion and textile retail

Augmented Reality (AR) technology has been increasingly utilised in retail due to advancements in the telecommunication industry, which have reduced device prices and enabled widespread AR access through smartphones [2]. The relatively low cost of AR implementation compared to other immersive technologies like Virtual Reality (VR) has further accelerated this adoption [5]. AR is traditionally defined as a real-time, direct, or indirect view of a physical, real-world environment enhanced by virtual, computer-generated information [4]. This enhancement is always mediated through an electronic device, providing an augmented experience to the user. While AR applications span various retail fields, including furniture [23] and electronics [28], this discussion focuses on the fashion and textile industries.

In the fashion and textile sector, the primary objectives of using AR have been to enhance the shopping experience for consumers, reduce uncertainties and product risk perceptions, assist consumers with their purchase decisions, increase store attractiveness, brand engagement, and intentions to visit and recommend the store [17]. AR is considered an effective technology for both in-store and online remote shopping experiences. It supports consumers' mental intangibility via realistic product presentations and interaction possibilities that can produce several different cognitive, affective, and behavioural outcomes. Previous research highlights the application of AR in branding and marketing, emphasising its role in engaging customers through emotional interactions and establishing brands as technologically innovative and creative [1]. AR applications, such as virtual try-ons and smart mirrors, have improved conversion rates and reduced return rates by allowing consumers to realistically visualise products, thereby increasing their confidence in purchasing them [5,35]. Additionally, AR improves after-sale customer services by providing complementary product-related information in context, which boosts customer satisfaction and loyalty [10]. In workflow management, AR is employed in warehouse planning and order picking, increasing logistics operations' efficiency and accuracy [24].

AR has shown the potential to extend the lifespan of materials by offering after-purchase information and helping consumers make better purchase decisions through product visualisation [30]. However, its

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primary goals are centred around boosting sales and driving consumption rather than intentionally supporting the principles of the Circular Economy (CE) [13]. The CE strives to minimise waste and optimise resource use, but AR applications in the fashion and textile industries have not fully integrated these principles.

An AR application that incorporates and promotes circular practices by design can be a valuable asset for brands strengthening their sustainability strategies. For fashion and textile consumers, this tool can help them better understand and value the materials and processes that make their clothes, emphasise the importance of circular practices, and how they can be part of a fashion and textile CE.

This paper will demonstrate the use of AR as a tool to connect fashion and textile consumers with the materials and techniques used to construct their clothes. With this purpose, first, a conceptual model that suggests the promotion of circularity through material knowledge will be proposed. Next, the methodology of development and analysis of the AR tool that follows this conceptual model will be explained, and the study will be analysed. The final section will present the discussion, limitations, and suggestions for future research.

This paper's contribution is threefold. First, it introduces the Biofibre Explorer, an AR tool designed to enhance consumer understanding of biobased textiles by visualising the wet spinning process. Unlike existing AR applications in fashion, which primarily focus on retail engagement and product visualisation, this tool reorients AR toward sustainability education, bridging the knowledge gap between consumers and circular material innovations. Second, it expands the application of The wellbeing framework for consumer experiences in the circular economy of the textile industry [26] by integrating AR with the specific wellbeing dimensions of Learning, Attachment, Competence, Playfulness, and Future-self. Third, the paper contributes empirical insights into the design and evaluation of AR for material storytelling, offering practical design guidelines based on user studies conducted in real-world settings. These insights can inform future developments in AR-driven consumer experiences for fashion, textiles and other material-intensive industries.

2. Conceptual model: promoting circularity through material knowledge

The transition to a circular textile economy requires a range of interconnected activities. Research from the [*Centre name removed for anonymity*] argues that a successful shift to circularity in the fashion and textile industries can benefit from strategies that align human wellbeing with material resource flow [26]. This alignment can be structured through The wellbeing framework for consumer experiences in the circular economy of the textile industry [26], which is a holistic model that integrates hedonic (short-term pleasure) and eudaimonic (long-term fulfilment) aspects of wellbeing within the circular textile economy. It comprises three overarching elements—Feeling Well, Doing Well, and Being Well—encompassing 16 interconnected dimensions. In this article, we focus on how the wellbeing factors of learning, attachment, competence, playfulness, and future-self were applied to create the AR Biofibre Explorer—a tool designed to enhance consumer interaction with and understanding of bio-based materials. These concepts, summarised in Table 1, are part of The wellbeing framework for consumer experiences in the circular economy of the textile industry [26]. For a more detailed account of the framework, see [26].

One way to support circular practices in fashion and textile retail is through experiences that reconnect consumers with the different stages of the life cycle of their clothing, including origin, production and performance. Consumers often lack knowledge about the materials used in their clothing, a gap that significantly limits informed material choices and negatively impacts purchasing decisions [14]. This limited awareness has negative implications for meaning-making and the creation of value. For instance, previous research found that when consumers become aware of the components and labour involved in producing a shirt, they are more likely to appreciate the garment and adopt better care practices [34]. This disconnection is further complicated by introducing new bio-based materials as an alternative to conventional textiles. Bio-based materials have the potential for a smaller carbon footprint and more sustainable fabrication methods [18]. However, many new circular bio-based materials are still in the research and development phase. Also, when these materials enter the market, they often come at a higher price point and may not match traditional textiles' performance. For consumers to consider these circular bio-based materials as viable alternatives, they need to understand the environmental significance and the extensive research and development invested in their creation [11]. By bridging this knowledge gap, consumers can better appreciate bio-based materials as sustainable options, making them more likely to prioritise these alternatives in their purchasing decisions now and in the future.

Table 1
Selected wellbeing concepts are to be articulated through the AR Biofibre Explorer, adapted from [26].

Concept	Description
Learning	Active engagement in acquiring skills and knowledge.
Attachment	Emotional bonds formed through connection and affection influenced by meeting expectations, utility, aesthetic appeal, effort, and positive experiences.
Competence	Skill and confidence in making informed choices about product use and acquisition, as well as their ability to engage in specific circular practices like renewal and repair.
Playfulness	The inclination toward fun, spontaneous, and creative activities, especially in social interactions with familiar individuals.
Future-self	Ability to envision future outcomes and take proactive steps to create desired changes.

For circular bio-based materials to gain broader acceptance and thus contribute more to reducing environmental impact, consumers must appreciate their value and understand how they contribute to a better textile economy. This calls for a shift in consumer perception—moving beyond cost and immediate performance comparisons to a more holistic recognition of the long-term benefits of a circular fashion and textile industry [19].

The AR Biofibre Explorer aims to reconcile consumer knowledge and sustainable material practices, making bio-based materials more understandable and desirable in the market and empowering consumers with the knowledge they need to make better material choices when purchasing a garment. This approach in consumer experience design contributes to a variety of strategies necessary for transitioning to a circular fashion and textile industry and promoting sustainable consumption [32]. Our approach is meaningful for consumers both materially and experientially, driving broader engagement and long-term (eudaimonic) satisfaction. To clarify how the wellbeing framework underpinned both the design and evaluation of the AR Biofibre Explorer, Table 2 maps the five wellbeing dimensions to specific AR design decisions, the evaluation constructs used, and the intended circular-economy outcomes.

3. Current ways to help consumers make meaning around new materials

One effective method for communicating material properties is through material narratives, which utilise storytelling techniques and play a critical role in fostering material acceptance [15,20]. Material narratives enable designers, companies, and consumers to understand the materials conceptually before physically interacting with them, especially in cases where material samples are not readily accessible.

Rognoli et al. [29] introduced the concept of materials biography to communicate and explore the lifecycle, origins, processes, temporality, and identity of new materials. This approach enhances the understanding of bio-based and bio-fabricated materials, enabling designers, manufacturers, and consumers to appreciate their unique qualities and

Table 2
Conceptual model linking wellbeing dimensions to AR design and evaluation.

Wellbeing Dimension	How it Informed AR Design	What Was Evaluated	Intended Circular-Economy Outcome
Learning	Step-by-step simulation of wet-spinning; layered explanations	Perceived learning; clarity of information; comprehension of the process	Increased **material process literacy**
Competence	"Do-to-advance" interactions; clear feedback indicating progress	Confidence in understanding; perceived ability to use knowledge	**Empowerment to make informed sustainable choices**
Playfulness	Interactive gestures (hold, drag, tap); vibration feedback during actions	Enjoyment, curiosity, and engagement	**Positive emotional connection** to emerging circular materials
Attachment	Physical samples co-present with AR overlay; emphasis on material journey	Meaning-making, personal relevance, interest	**Value perception & care mindset** toward biomaterials
Future-Self	Final garment visualisation contextualising the material	Optimism toward biomaterials; future purchasing intentions	**Future-oriented sustainable consumption behaviour**

sustainability potential. Additionally, there appears to be a link between knowledge of how garments are made and the value attributed to the material or finished product [34].

In a case study on how biobased material development companies communicate their innovations, D'Olivo and Karana [8] introduced the concept of material framing as a strategy to accelerate the adoption of new bio-based materials. They identified three key categories companies use to frame their products: material origins, fabrication processes, and material outcomes.

While these approaches enhance the understanding and appreciation of bio-based materials, they would benefit from a clearer connection with human wellbeing. The wellbeing framework for consumer experiences in the circular economy of the textile industry [26] advocates that meaningful engagement should not only inform consumers about circular practices but also support emotional connection, personal fulfilment, and a sense of participation in positive change. Without this dimension, material-focused interventions risk remaining informational rather than transformative.

Guided by this perspective, we sought to extend existing storytelling strategies through the wellbeing lens, ensuring that material learning is coupled with experiential value and emotional resonance. This aim led to the development of the AR Biofibre Explorer. The following section details the design process behind the tool and how it integrates these wellbeing-oriented principles.

4. Methodology

The research methodology followed a structured, multi-phase approach to develop and evaluate an AR tool to enhance consumer understanding of bio-based textiles. We hypothesise that improving people's knowledge of bio-based materials' origins, uses, and qualities contributes to purchasing decisions more aligned with human and planetary wellbeing. First, a literature review on the use of AR within fashion and textiles, alongside consumer behaviour insights from the [*Anonymised research platform*], informed the design of the initial prototype. The [*Anonymised research platform*] is an innovative "living lab" and speculative retail environment designed to explore sustainable fashion consumption. It offers alternative circular consumer experiences—such as interactive stations for material exploration, co-design, and garment repair—explicitly crafted to enhance human wellbeing while promoting circular textile practices, linking personal and collective wellness with sustainable material use throughout a garment's lifecycle.

An initial study (Study One) evaluated the prototype, identifying key characteristics that guided the tool's refinement. Following this, a co-design process was conducted with design researchers, materials scientists, a digital design studio, and a retail designer to ensure alignment with research goals, scientific rigour, production feasibility, and retail integration. Next, a pilot study was conducted to test the situational deployment of the AR tool within a simulated retail space. Insights from this stage informed adjustments to the setting of the experience, arriving at its final configuration. A final study (evaluation study) assessed the tool's effectiveness.

The choice of methods, presented in Table 3, corresponded to the stage of the tool development and the information required at that stage. In Study One, the team had a good understanding of the need (including storytelling and experience design in the delivery of information about the materials), but still needed a better definition of the appropriate format to do so. Hence, the study design was intended to support the further specification of the tool. In the Pilot and Evaluation Studies, the tool had already been developed; thus, the study design accommodated some qualitative feedback to allow for further tool refinement, but there was greater focus on the user experience and understanding that emerged from the interaction with the tool.

Participants with different levels of expertise were engaged according to the stage of the tool development, as detailed in Table 2. We started with experts, in Study One, to take advantage of their specialist and complete feedback in support of the specification and consolidation of the tool concept, and only later opened it to the general public, who are the main intended users for the tool, and therefore was important to gather their feedback during the development and also in the evaluation.

The data was analysed through the lens of existing literature and The wellbeing framework for consumer experiences in the circular economy of the textile industry [26]. The research concludes with the development of a set of design specifications intended to assist designers and researchers in exploring the integration of AR in the context of circular fashion and material storytelling.(Fig. 1 and 2)

4.1. Design 1: prototype AR

The [*Centre Name Anonymised for review*] is an interdisciplinary research initiative comprising three research strands: [*Research Strand names Anonymised for review*], each addressing different aspects of the CE in fashion and textiles. [*Centre Name Anonymised for review*]showcased their research in a public-facing event titled the [*Anonymised research platform*], held at [*Place Anonymised for review*].

Within the [*Anonymised research platform*], the [*strand name anonymised for review*] strand presented their research on textiles made from bacterial cellulose through an installation titled the *Material Showcase* (Fig. 3). This installation displayed physical samples and prototypes produced via various advanced textile manufacturing processes.

Although the Material Showcase effectively communicated the visual aspects of the bacterial cellulose textiles, its ability to convey the complexity and inherent qualities of the material was limited. To fill this gap, a card-based tool - the Materials Library - was available, and visitors could check technical information in the form of illustrations, images, and text about advanced circular bio-based materials, including those exhibited in the Material Showcase. Although the Materials Library and the Material Showcase were technically integrated, our goal was to better integrate them through storytelling for future [Anonymised research platform] iterations. It became clear that translating these resources into an accessible version for consumers was necessary to integrate materials circularity innovations with the design of consumer experiences.

This insight led to the hypothesis that integrating a digital layer—displaying information from the Materials Library directly onto the samples exhibited in the Material Showcase—would enhance

Table 3
Detailing of the study methodology.

Phase	Aim of Study	Participants (N, expertise)	Recruitment/Setting	Method	Key Design Decisions	Key Outcomes
Study One	Specify the tool format	15 Experts	Convenience sampling. In situ at sustainable textiles fair.	Mixed methods survey	Step-wise process; and playful "hold-to-act"; enlarge text/zoom	Processed design specs (step-wise, interactivity, readability, plain-language)
Co-design	Translate specs into final app	Design researchers, materials scientists, agency	Research team. Lab and Studio	Iterative design reviews; lab observation; content simplification	Five scenes; minimal haptics; 4 markers; process →application linkage	AR lab metaphor; validated content and wording.
Pilot	Check if the whole experience is effective and coherent	13 Non-experts consumers	Convenience sampling. Advertisement on social media and with the team's network, and recruitment *in situ*. Living lab.	Mixed methods survey and 3 open questions	Co-locate samples + AR elements	Confirmed engagement; need physical -digital colocation
Evaluation	Evaluate the interaction and its perceived effect on the user (knowledge, wellbeing)	39 Non-expert consumers	Convenience sampling. Advertisement on social media and with the team's network, and recruitment *in situ*. Living lab.	Mixed methods. Survey (likert measures (wellbeing), Bayesian Wilcoxon, open questions)	Final UI/content; colocated samples.	Decisive evidence for engagement & process understanding; areas to improve.

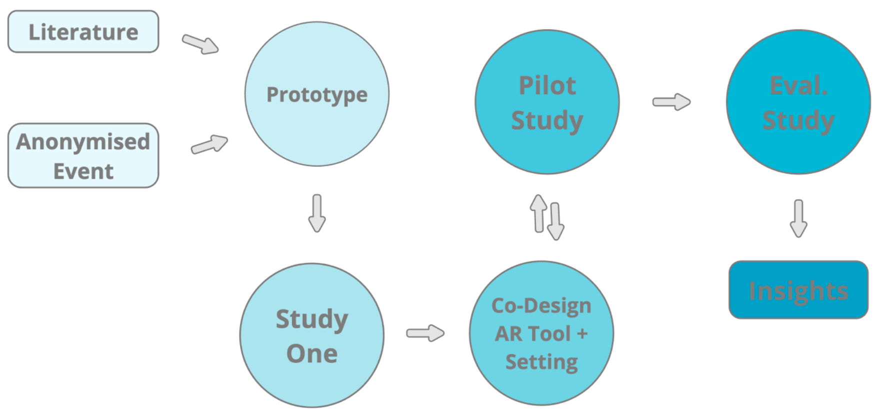

Fig. 1. Diagram illustrating the methods employed in this study.

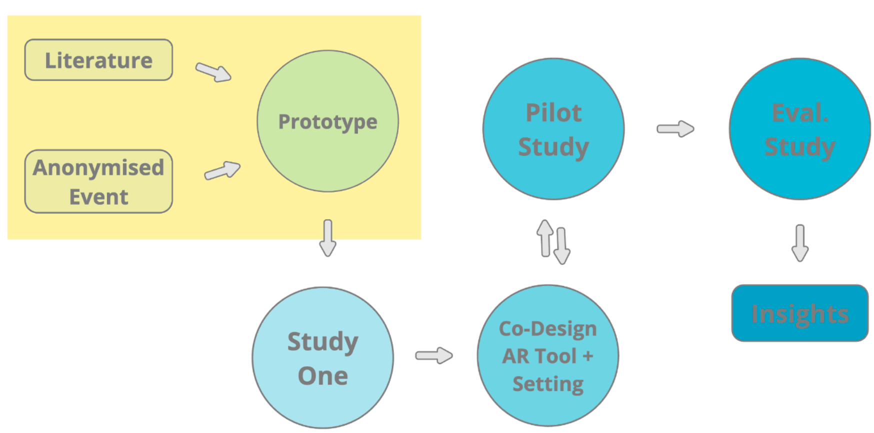

Fig. 2. Diagram illustrating the methods employed in this study, highlighting its initial phase.

consumer understanding by adding context, fostering participation, and introducing playfulness to the static display. Drawing on the storytelling concepts of material narratives and material framing, we proposed that augmented reality (AR) could more effectively communicate materials' origins, fabrication processes, and applications. We developed an initial AR application prototype and conducted a preliminary study using a survey to capture participants' perceptions of the AR's effectiveness in increasing their understanding of the bio-based textile and its circular production process. In this first iteration, we have chosen to display two types of information. In one sample, the digital layer will show the Materials Library card related to that sample (Fig. 4- left). In another sample, the digital layer will display a shirt made from that material (Fig. 4- right).

Fig. 3. Material Showcase of the new biobased textile developed at [*Centre Name Anonymised for review*].

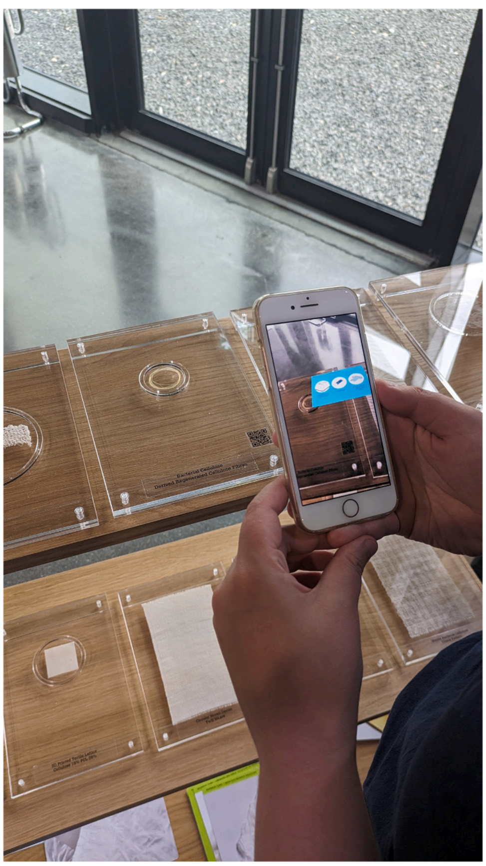

Fig. 4. Materials Sample being assessed through the AR application.

4.2. Study one: generating initial design specifications

The study adopted a comparative approach to evaluate participants' experiences of the Materials Showcase in two conditions: without implementing the AR layer (Fig. 3) and with the AR layer integrated into the material samples' visualisation (Fig. 4). The AR Layer consisted of a representation in 3D of a shirt made from the material presented and another with information about the fabrication process similar to the one available in the Materials Library (Fig. 4). During the experimental procedure, participants could interact with the material samples in both conditions successively. Following these interactions, participants were requested to complete a survey to capture their qualitative feedback, enabling the systematic evaluation and comparison of their perceptions and understanding of the materials in the presence and absence of the AR intervention.(Fig. 5 and 6)

The study was conducted at the [*Anonymised sustainable textiles fair]*, the largest dedicated showcase for sourcing certified, sustainable material solutions. It was approved by the local ethical committee, counted 15 participants who were visitors to the fair and recruited *in situ*.

The survey combines items authored for this study with constructs well-established in HCI/AR research: a **global experience** prompt (Q1) aligned with user-engagement measures (e.g., the User Engagement Scale's overall judgements of "endurability/overall impression") [22, 21], **perceived diagnosticity** items capturing how well AR helps users judge appearance/feel and suitability (Q2–Q3), a construct originating in information-systems/retail research and frequently applied in AR product presentation [6,31], and **interest/learning** prompts (Q4) that mirror common self-report treatments of perceived learning/motivation in interactive experiences. Finally, the **open-ended effectiveness/ineffectiveness and improvement** questions (Q5–Q6) follow best practice in heuristic/Usability-In-the-Large evaluations of AR, prompting comments on realism/legibility, spatial stability and interaction clarity [9]. Together, the six questions (Q1–Q6) map onto these literatures while remaining tailored to biomaterial understanding in the AR context.

The post-experience survey comprised six items (Table 3). Q1 captured global experience using a four-option scale (Excellent/Good/ Average/Poor). Q2–Q4 assessed perceived diagnosticity (appearance/ feel), feasibility/decision comfort, and interest in learning through fixed categorical responses, aligning with established constructs in HCI/AR evaluation (Jiang & Benbasat, 2007; [22,31]). Q5–Q6 were open-ended prompts eliciting effective/ineffective aspects and suggested improvements, following heuristic XR evaluation practice [9].(Table 4)

Participants offered a range of evaluations on the AR experience, with ratings spanning from "poor" (3 participants) to "good" (7 participants) and "excellent" (3 participants). For nine participants, AR provided an engaging way to explore biomaterials, particularly enhancing their understanding of these materials' appearance and potential texture when used in garments. Six respondents noted that AR reinforced their interest and curiosity in biomaterials, and for ten participants, it

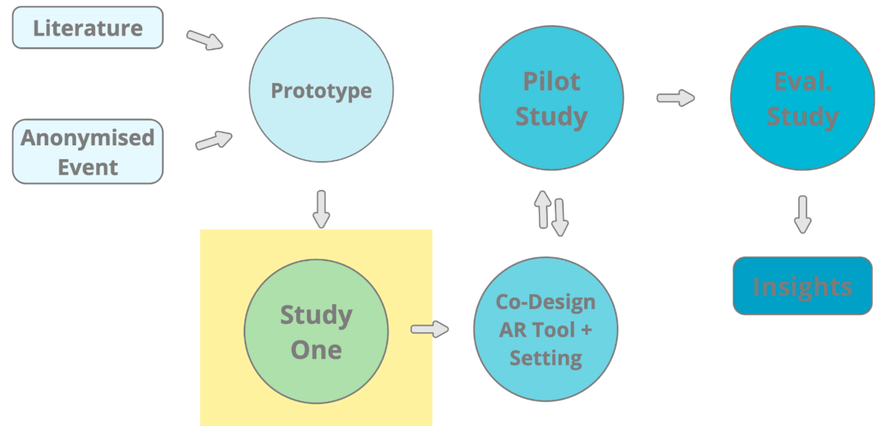

Fig. 5. Diagram illustrating the methods employed in this study, highlighting the first study.

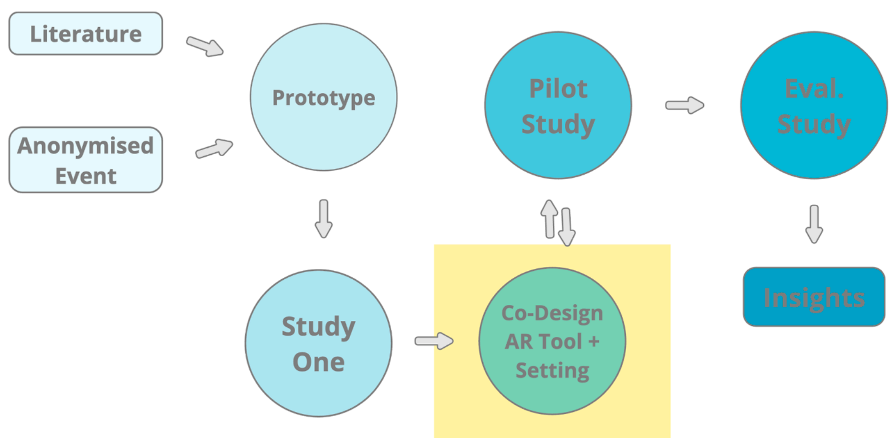

Fig. 6. Diagram illustrating the methods employed in this study, highlighting the co-design process.

Table 4
Questionnaire items, response formats, rationale, and supporting sources.

Theme	Question (verbatim)	Response options	Rationale	Source
Global Experience	(Q1) How would you describe your overall experience viewing the biomaterial samples coupled with augmented reality?	Multiple choice: Excellent / Good / Average / Poor.	Overall impression/endurability check to contextualise other responses.	[22, 21]
Perceived Diagnosticity (appearance/feel)	(Q2) Did augmented reality change your understanding of how biomaterials would look and feel when applied to a product?	Multiple choice: Yes, it provided a better understanding of their appearance and texture. / Yes, it completely transformed my perception of their appearance and texture. / No, it did not change my understanding significantly.	Captures how well AR helps users judge visual/tactile qualities (diagnosticity).	[6,31]
Decision comfort / Feasibility judgment	(Q3) Did the augmented reality presentation influence your perception of the biomaterials' feasibility for real-world applications?	Multiple choice: Yes, it made me more confident in their feasibility for real-world applications. / No, it did not significantly affect my perception of their feasibility. / It slightly diminished my perception of their feasibility for real-world applications.	Assesses downstream decision comfort/confidence about real-world use.	[6,31]
Interest / Perceived Learning	(Q4) Did the augmented reality experience make you more interested in learning about the characteristics of biomaterials?	Multiple choice: Yes, it sparked my curiosity and made me want to learn more. / No, it did not increase my interest in learning about biomaterials. / I was already interested in biomaterials, so the augmented reality experience reinforced my curiosity.	Captures motivation/curiosity and perceived learning triggered by the AR experience.	[22,9]
Open feedback: effective/ ineffective	(Q5) Were any specific aspects of the augmented reality presentation that stood out to you as particularly effective or ineffective? (Please, provide details)	Open-ended (free text).	Elicits qualitative evidence for design decisions; aligns with heuristic/XR evaluation practices.	[9]
Open feedback: Improvements	(Q6) What improvements or changes would you suggest to enhance the effectiveness of using augmented reality to communicate about new materials in the future?	Open-ended (free text).	Gathers actionable design implications for iteration.	[9]

increased their confidence in the feasibility of biomaterials for real-world applications. However, five participants indicated that the AR layer did not significantly alter their initial perceptions, suggesting that the impact of AR on understanding bio-based materials may vary depending on prior interest and expectations.

Participants found AR helpful in visualising garment fit and drape, which led them to imagine potential applications they had not previously considered, as expressed by Participant Three: "The garment showed the fabric is strong enough to form a jacket, rather than fragile." It was suggested that a more dynamic approach—such as animations of the garment being worn or a virtual hand manipulating the fabric—could enhance the user experience by showcasing the fabric's physical properties in a lifelike manner, as expressed by Participant Five: "It would be better if each step could appear on the screen one after the other … I find 3D simulations of garments always a bit stiff, so maybe a video of the material being handled could be nice."

Feedback included the need for more detailed information about the materials, with participants recommending additional zoom functionality, larger and more detailed images, and even videos to illustrate material properties better. For example, Participant Two stated that "A zoom for the samples or pop-up graphic – it's too small", and Participant Four expressed that "the quality needs to be greatly enhanced: image quality, try-on applications, easier to see/read/zoom in." Also, the AR experience could further benefit from showing the step-by-step processes in biomaterial fabrication through sequential pop-up visuals and more contextual information about what is being displayed, allowing for a more intuitive understanding, as expressed by Participant Thirteen: "1. This example (cards) - pop-up interactivity to show steps in a more dynamic way - playfulness missing. 2. if you show the shirt vertically, you are engaged directly. Should be able to zoom + carry with you (should not disappear so easily)."

Based on the data collected, the following initial design specifications were established:

- Present fabrication processes and complex information in a step-by-step, interactive format to support incremental learning and user engagement.
- Integrate more interactive elements, such as animations, gamification, or a virtual manipulation feature, to enrich engagement and convey the materials' qualities more realistically.
- Ensure larger text, clearer graphics, and zoom functionality to enhance readability and enable close examination of material details.
- Provide accessible explanations that contextualise the material properties within practical applications, using simple, user-friendly language to ensure inclusivity.

4.3. Collaborative design process: consumer experience + materials circularity + [Design agency name anonymised for review]

The design specifications suggest demonstrating fabrication processes and complex information through a step-by-step, interactive format to support incremental learning and engagement. Enhanced interactivity, including animations, gamification, and virtual manipulation, will help convey material qualities more realistically. Improved readability will be ensured through larger text and clear graphics. Additionally, accessible explanations using simple, user-friendly language will contextualise material properties within practical applications, promoting inclusivity. Based on these design specifications from the initial study, we collaborated with a design agency and materials scientists from [*Centre's name anonymised for review]* to develop the final AR application, which should integrate the material samples with AR simulations of their fabrication and potential uses.

To better understand the steps involved in Wet spinning, one of the researchers visited the laboratory setting (Fig. 7), where the process took place to identify critical steps in the fibre production process. This stage provided foundational knowledge that informed the design of a virtual simulation for the wet spinning method. Wet spinning is a fibre manufacturing process in which a polymer solution is extruded through a syringe into a coagulation bath (which selectively removes the cellulose solvent), solidifying the fibre as it emerges [16]. This laboratory observation and documentation phase grounded the AR simulation in scientifically accurate practices. Together with the researchers from the [Anonymised for review], the key steps of fibre fabrication were identified.

4.3.1. Scene 1: introduction

The design agency and the researchers decided to illustrate the wet spinning process by creating an augmented reality (AR) laboratory experience. This virtual laboratory showcases the devices used in the process (see Fig. 8). The experience includes four AR markers, each serving as a trigger for a specific step in the process (see Fig. 9). The first AR marker activates a virtual beaker; users must press and hold a button to fill it with solvent (see Fig. 10).

This interaction was designed to be playful and engaging, as the user controls the pace of the filling action, adding a dynamic element to the experience. A vibration accompanies this action to enhance sensory involvement, engaging the sense of touch and reinforcing interactivity beyond the visual aspect. This feature aligns with the initial design specifications aimed at using interactive elements to boost engagement. In discussions with the design agency, it was decided that due to the limitations of AR, the haptic feedback would be restricted to a uniform

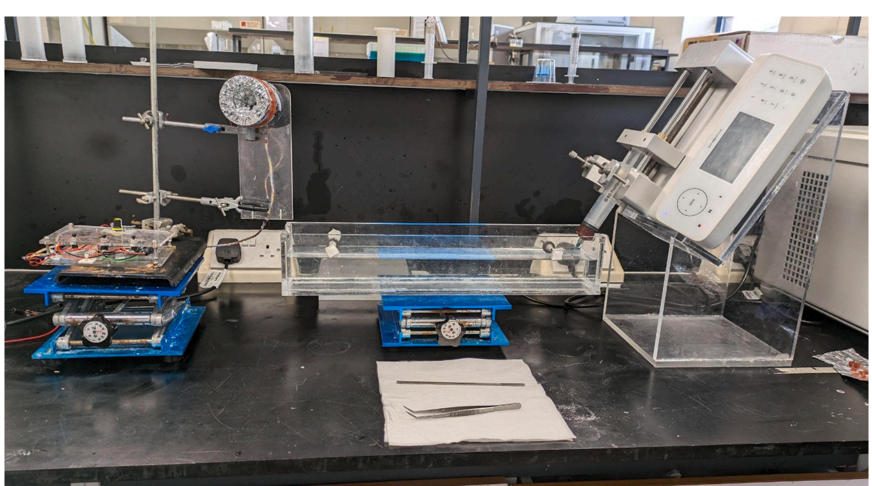

Fig. 7. Wet spinning device developed in the [*Anonymised University Name for review*].

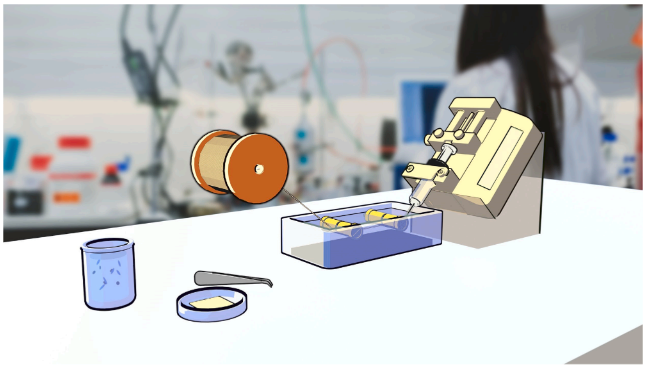

Fig. 8. The digital elements representing the devices responsible for the wet spinning process. A specific AR marker triggers each step of the process.

vibration.

4.3.2. Scene 2: discovering bacterial cellulose

In this scene, the user interacts with a virtual representation of bacterial cellulose, the foundational material for the [*Centre's name Anonymised for review*] biobased textile [16]. Through the AR interface, the user lifts the virtual cellulose sample and drops it into the beaker, which visually sinks into the liquid, simulating a chemical reaction. Once the beaker fills, an informational pop-up window offers further insights into bacterial cellulose (Fig. 11).

4.3.3. Scene 3: preparing the syringe

In this scene, a virtual syringe appears beside the beaker (Fig. 12). The user's task is to draw the reacted liquid into the syringe. As the user presses and holds a button, the syringe gradually fills. This interactive step simulates the preparation of the material for the next phase in fibre production. Again, a textual explanation of the process. The text was initially written by the materials scientists and simplified through an iterative process to simplify it and remove jargon as determined by the design specification.(Fig. 13)

4.3.4. Scene 4: manual task simulation

This scene focuses on engaging users with simulated physical tasks. By pressing and holding a button, the user controls a pair of virtual tweezers that grab the material from the syringe and navigate it through a series of virtual gears and other mechanical components, finally attaching it to the spinner within the simulated device. The user then presses and holds a button again to witness the filament passing through the virtual gears. Again, a pop-up with more information about that part of the process appears at the end of the task.

4.3.5. Scene 5: witnessing the creatio

In the final scene, users are presented with a view of the wet spinning process. With the syringe securely positioned, the AR interface initiates the simulation of the wet spinning device. As the yarn is spun and winds onto a sample spool, the user sees the gradual formation of the material. As a concluding step, the yarn forms a virtual shirt to contextualise the material properties within practical applications according to the design specification.

4.4. Pilot study

Once the AR tool was finalised, we held a pilot study at [*Place's name anonymised for review*] to evaluate participants experiences with the Biofibre Explorer. The study (see Table 5) was designed to capture demographic characteristics, prior familiarity with bio-based materials, and baseline knowledge of circular economy concepts, alongside purchase preferences and shopping orientation [33], which influence adoption in retail [3]. Measures of general wellbeing were included to establish a baseline of the satisfaction and eudaimonic fulfilment, allowing for comparison with affective and cognitive responses elicited during the AR experience. Following exposure to the tool, participants reported on the wellbeing concepts of enjoyment & Pleasure, playfulness, Body & Sensory, Engagement and, Optimism towards biomaterials [26]. Three open question were included to gather qualitative reflection on memorability, effectiveness, and potential improvements of the AR presentation [27]. This mixed-method approach provided a comprehensive assessment of how the analysed tool impacts consumer understanding and perception of biobased textile materials.

4.4.1. Results

Among the participants, 62 % (eight individuals) identified as female. The most represented age group was 25–34 years old. Participants reported limited prior knowledge of biobased textiles, with an average self-rated experience score of 34.45 on a scale from 0 to 100. When asked to define CE in the context of textiles, participants demonstrated a general awareness of principles such as zero-waste, supply chain transparency, and the concepts of reducing, reusing, and recycling. However, their responses revealed a lack of depth and clarity, often oversimplifying the broader systemic implications of CE practices.

When considering the factors influencing purchasing decisions, quality and durability were the most valued qualities, with the majority marking these as "Very important," shown by ratings peaking at 6. Similarly, comfort and fit received high importance, reflecting consumer emphasis on functionality and wearability. Price, while important to many, showed more variability, with significant ratings spread across "Fairly important" and "Important." In contrast, attributes like brand and fashion/trend were less critical. Overall, practical and functional aspects outweighed aesthetic and brand-related factors in consumer decision-making. However, responses to shopping as a leisure activity showed more variation. A broader spread of responses is evident for the statement, "Shopping is a way I like to spend my leisure time." While only a minority (1 participant) strongly agreed, a slightly higher proportion (5 participants) somewhat agreed.

Participants' responses also revealed insights into their wellbeing. Most participants expressed a general sense of life satisfaction, with four somewhat agreeing and three strongly agreeing with the statement "I am

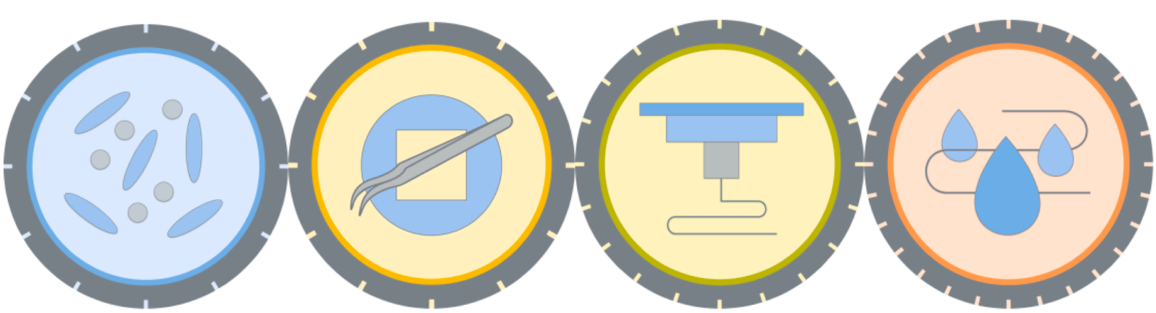

Fig. 9. AR markers.

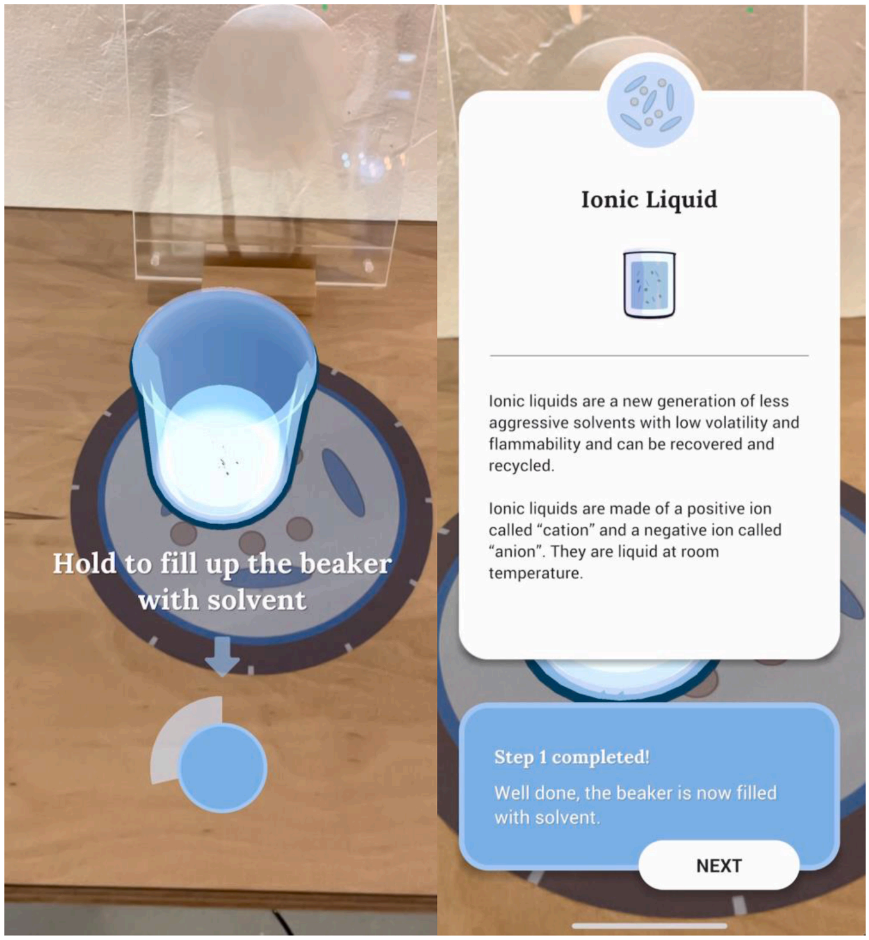

Fig. 10. Screenshot of the first step, followed by a textual explanation.

satisfied with my life." Responses to the statement "I have been finding pleasure in my life" were even more positive, with seven somewhat agreeing and three strongly agreeing. However, feelings of happiness were mixed; only one strongly agreed they were mostly happy, while six somewhat agreed, and three were neutral. Regarding negative emotions, six participants were neutral, and three slightly agreed they felt overwhelmed.

After participants engaged with the AR experience, the findings revealed high levels of enjoyment and engagement. Most participants strongly agreed that the activity was fun, with positive responses to the statement, "I had fun doing this activity." Similarly, participants found the experience engaging, as reflected in their agreement with the statement, "I found this experience engaging." The multi-sensory nature of the activity, which combined visual and tactile stimulation, contributed significantly to participants' immersion, with many agreeing that these features enhanced their understanding and interest. Participants found movement important to the experience, with half of the participants strongly agreeing that moving the body was important for the experience.

The AR experience also positively influenced participants' knowledge and perceptions of biomaterials. Responses to the statement "I completely understood the wet spinning process" were mixed, suggesting that some participants struggled with comprehension. However, participants strongly agreed that the clarity of animations and texts effectively communicated the process. Participants found the information helpful, with many agreeing that it provided practical value applicable to their daily lives. Additionally, the statement "Knowing more about the manufacturing process might influence me to select better products" received the highest level of agreement, highlighting the potential of educational tools to shape consumer decision-making. Participants also noted that the experience improved their perception of biomaterials, particularly their feasibility for real-world applications, and positively changed their attitudes toward CE practices.

Several participants offered suggestions for improving future AR experiences. These included enhancing accessibility by providing clearer instructions on interacting with AR elements and incorporating sound effects to complement visuals. Participants also expressed interest in more detailed content, such as explaining scalability requirements and comparing bio-based materials and traditional textile manufacturing processes to provide reference points for considering the advantages and/or disadvantages of each. Additionally, they suggested incorporating gamified or motion-capture features to enhance interactivity and offer try-on capabilities to make the experience more immersive. Overall, most participants viewed the AR presentation as successful, striking an effective balance between text and visuals while engaging beginners and those with prior knowledge.

The main insight of this pilot study was that **augmented reality (AR) is an effective tool for engaging individuals with bio-based materials by combining interactivity, multi-sensory experiences, and straightforward educational content to enhance understanding and positively influence perceptions of sustainability and CE practices.** The findings demonstrate that the 'Biofibre Explorer' can bridge knowledge gaps, make abstract processes tangible, and encourage participants to consider biomaterials' practical applications. However, to make the experience more coherent and time-efficient, it was decided that the material samples of each phase of the bacterial cellulose fabrication should be displayed in the same space as the AR elements (Fig. 14). This alteration was implemented in the second

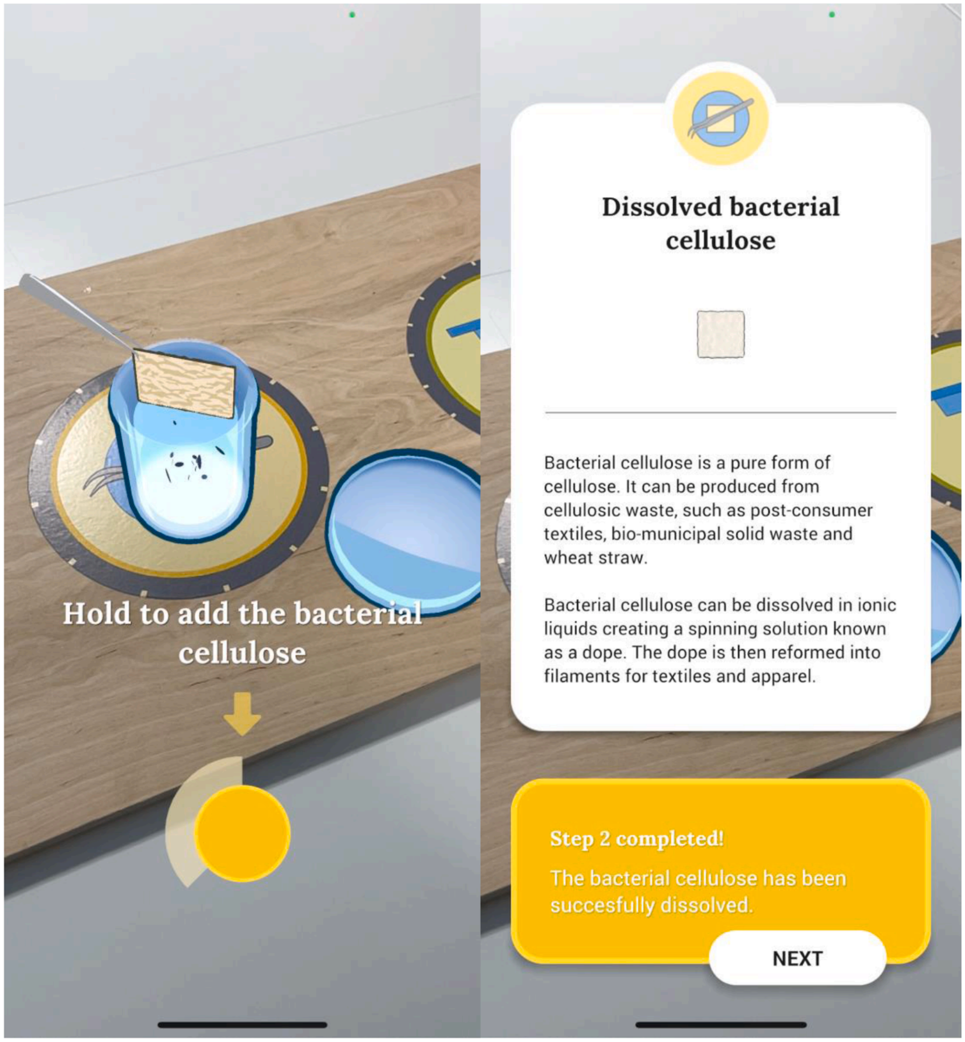

Fig. 11. Screenshot of the step where the bacterial cellulose dissolves in the ionic liquid, creating the material for the next fabrication step (left). Pop-up explaining the process in more detail (right).

version of the study, which is explained next.(Fig. 15)

4.5. Evaluation study

The evaluation study encompassed 39 participants, with the majority identified as female (62 %) and aged between 25 and 34. The Local Ethics Committee approved the study. The objectives and methodology were consistent with those of the pilot study. The only difference from the pilot study was the placement of the material samples on the table next to the markers (see Fig. 16).(Fig. 17)

Before the study, participants reported limited familiarity with bio-based textiles, reflected in an average self-rated knowledge score of 34.45 on a scale from 0 to 100. Despite this, initial responses to questions about the CE indicated a basic understanding of principles such as zero-waste and reuse-recycle strategies, albeit with limited depth regarding systemic implications as represented in the word cloud Fig. 18.

4.5.1. Sustainability is not yet top-of-mind

The participants highlighted several priorities in their clothing purchase decisions. Quality, durability, comfort, and fit were consistently rated as highly important, while sustainability received moderate importance. Fashion trends and brands are less critical overall, receiving higher responses in the 'slightly important' and 'Moderately important' categories. Variability in responses related to price indicated diverse priorities among participants. 50 % of participants reported shopping for clothing monthly, reflecting significant consumer engagement in the fashion sector.

For the data collected after the participants were exposed to the experience, Bayesian Wilcoxon Signed-Rank tests were used to compare participants' ratings against the neutral value of 4 ("Neither agree nor disagree"). To quantify central tendency and dispersion for our ordinal Likert data, we employed the interpolated median and the median absolute deviation (MAD). On this scale, a score of 4 corresponds to "neither agree nor disagree", 5 to "somewhat agree", 6 to "agree", and 7 to "strongly agree". Bayesian methods were preferred to control for Type I errors and to differentiate between insufficient data and genuine null effects [7]. Bayes Factors (BF_{10})—which compare the evidence for the alternative relative to the null hypothesis—were interpreted as follows: values between 0.333 and 3 were considered insensitive, $BF_{10} > 3$ provided moderate evidence, $BF_{10} > 10$ strong evidence, $BF_{10} > 30$ very strong evidence, and $BF_{10} > 100$ decisive evidence [12].

4.5.2. Emotional responses to the experience

As shown in Fig. 19, participants "somewhat agreed" they felt excited (median = 5.34, MAD = 1.48, $BF_{10} = 981.47$) and joyful (median = 5.23, MAD = 1.48, $BF_{10} > 999$), and "agreed" they felt enthusiastic (median = 5.82, MAD = 1.48, $BF_{10} > 999$), entertained (median = 5.75,

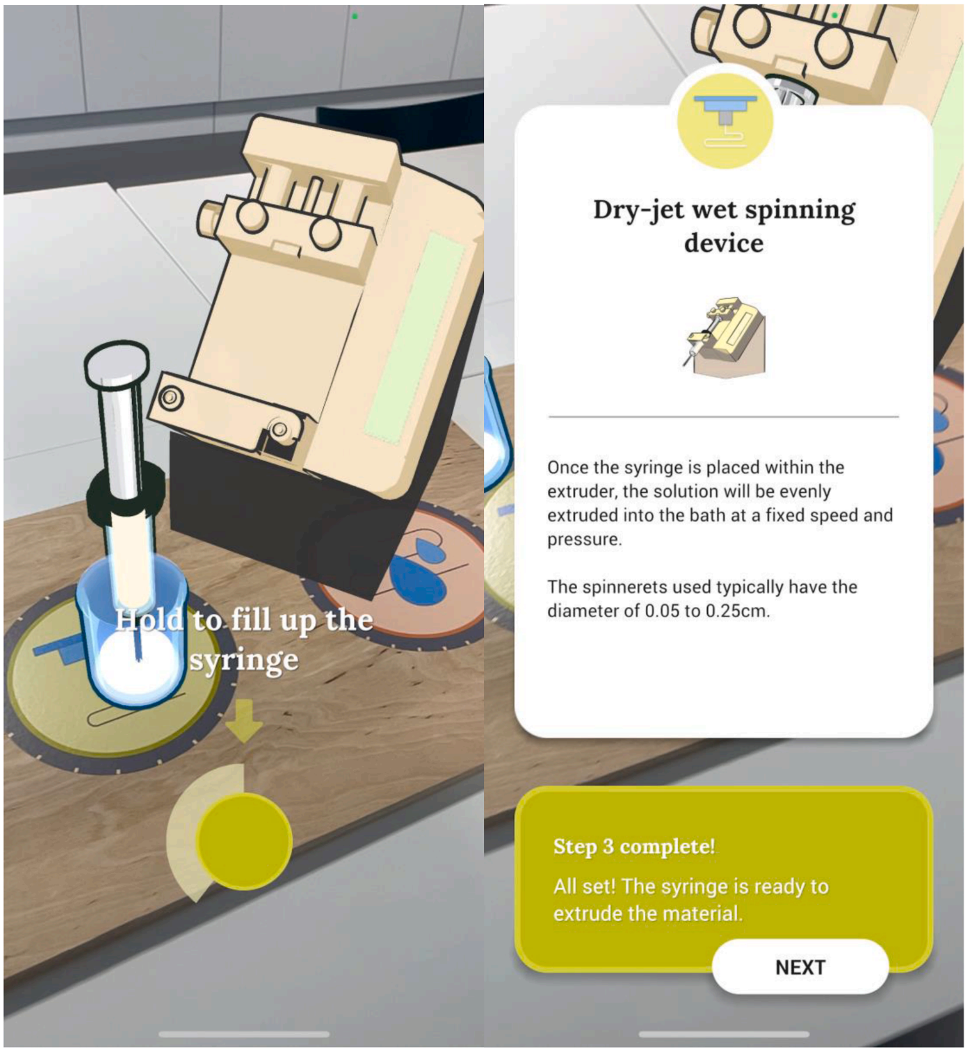

Fig. 12. Screenshot of the stage where the solution is placed inside the syringe and within the extruded.

MAD = 1.48, $BF_{10} > 999$) and happy (median = 5.71, MAD = 1.48, $BF_{10} > 999$). Consumers "strongly agreed" that the experience was interesting (median = 6.65, MAD = 0, $BF_{10} > 999$) and that they felt inspired (median = 6.45, MAD = 1.48, $BF_{10} > 999$), with decisive evidence for a marked deviation from neutrality.

4.5.2.1. Bodily & sensory engagement benefits enjoyment and comprehension. Fig. 20 displays the engagement ratings. Participants rated the experience as highly engaging, with fun (median = 5.80, MAD = 0, $BF_{10} > 999$), engagement (median = 5.92, MAD = 0, $BF_{10} > 999$) and visual-tactile immersion (median = 6.04, MAD = 1.48, $BF_{10} > 999$) all supported by decisive evidence. Although bodily engagement was rated slightly lower (median = 5.31, MAD = 1.48, $BF_{10} = 85.40$), it still significantly diverged from the neutral midpoint.

4.5.2.2. Supporting better product choices. As illustrated in Fig. 21, all knowledge-related ratings were significantly above the midpoint. Understanding of the wet spinning process (median = 5.11, MAD = 0, $BF_{10} = 338.82$) was significantly above the neutral value. Ratings for clarity of text (median = 5.55, MAD = 1.48, $BF_{10} > 999$), clarity of animations (median = 6.09, MAD = 1.48, $BF_{10} > 999$) and comprehension of the overall process (median = 6.20, MAD = 1.48, $BF_{10} > 999$) all provided decisive evidence. Although the rating for helpfulness (median = 4.96, MAD = 1.48, $BF_{10} = 37.43$) was significant, the evidence was comparatively weaker. Overall, these findings suggest that the experience effectively conveyed key knowledge components, with some scope for improvement regarding the perceived helpfulness of the information.

5. Discussion

Unlike prior "material narratives/biographies/framing" that emphasises what materials are (origins, processes, outcomes) through static or text-first lenses [32,15,20,29], Biofibre Explorer contributes: a wellbeing-aligned, process-diagnostic AR experience that makes fabrication legible through playful, bodily interaction. We show that the same AR mechanisms known to reduce retail uncertainty [31] can be re-purposed from driving conversion to building circular literacy, improving understanding of wet spinning, optimism, and future-self orientations toward sustainable choices. Further, we treat multimodal engagement as design lever for material comprehension, not an embellishment. This reframes AR from product visualisation to knowledge-building instrumentation for the circular economy.

5.1. Complementing and expanding storytelling techniques

Our findings confirm that our approach to using AR guided by The wellbeing framework for consumer experiences in the circular economy of the textile industry [26] complements and extends existing material storytelling techniques discussed in the literature. Prior work on materials narratives [15,20], materials biography [29], and materials

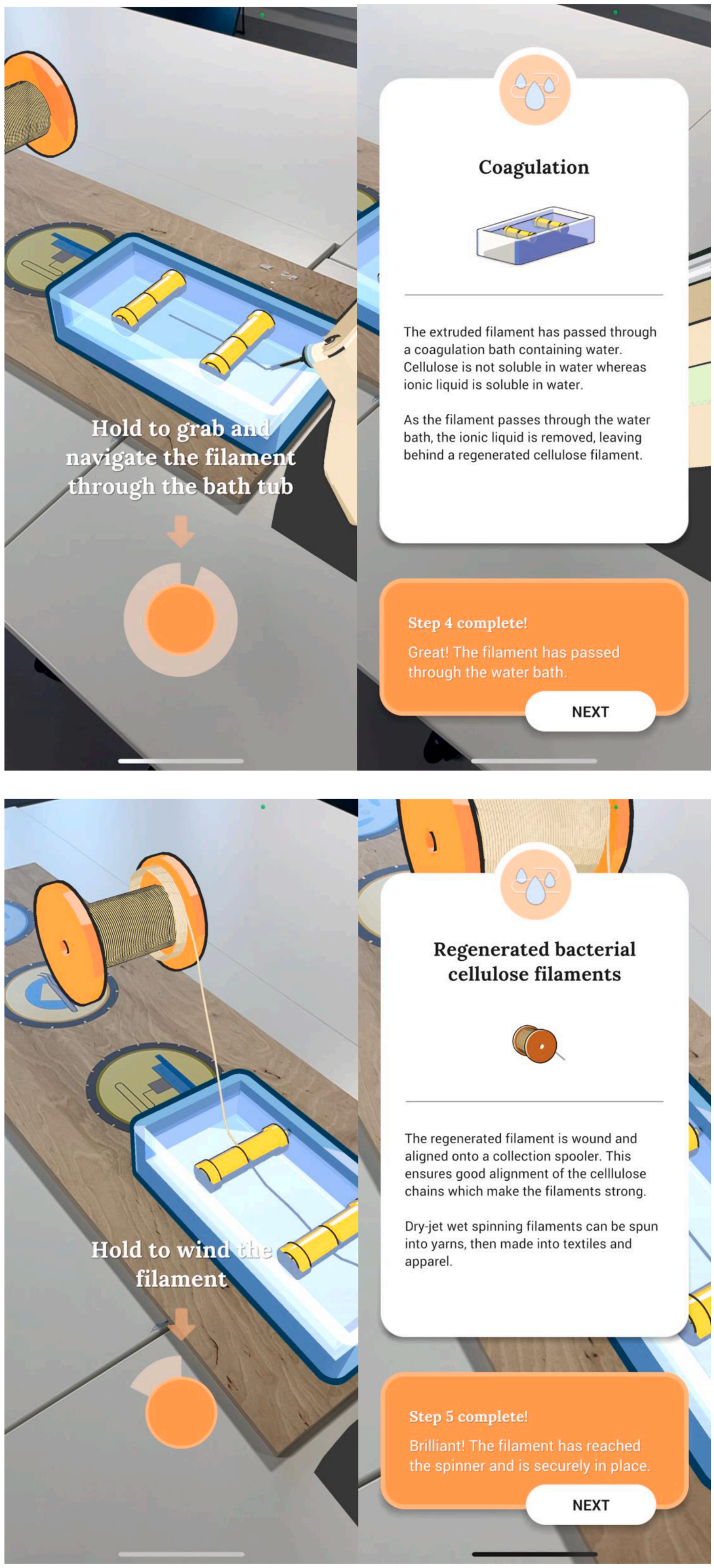

Fig. 13. Screenshot of the process of coagulation and spinning the material.

Table 5
Questionnaire items, response formats, rationale, and supporting sources.

Theme	Question (verbatim)	Response Options	Rationale	Source
Demographics	Q1. What gender do you identify as? Q2. How old are you?	Gender: Female, Male, Other, Prefer not to say Age: open numeric	Provides demographic baseline to examine variation in AR/XR adoption and perception across different groups.	
Background	Q3. Rate your experience with bio-based materials (0–100 %) Q4. A circular economy in the context of textiles is ____ (open).	Scale 0–100; Open text	Captures prior familiarity with sustainable materials and baseline literacy in circular economy concepts before AR exposure.	Authored question
Purchase Preferences	Q5. How often do you buy clothes? Q6. Thinking about when you buy clothes, what qualities are you looking for? (Durability, Colour, Fashion, Brand, Multipurpose, Price, Sustainability, etc.) Q7. To what extent do you agree: (1) Shopping is a way I like to spend my leisure time. (2) Shopping is one of my favourite activities. (3) Shopping is fun. (4) I look for fun/enjoyment in shopping.)	Q5: frequency scale (never → daily) Q6: rating of qualities Q7: Likert 1–7	Identifies consumption frequency, functional vs hedonic preferences, and shopping orientation, which influence AR adoption in retail.	[3]
General Wellbeing	Q8. Wellbeing statements: (1) I am satisfied with my life. (2) I have been finding pleasure in my life. (3) I am mostly happy. (4) I feel overwhelmed by negative emotions. (5) My health allows me to enjoy life.) Q9. Daily activities: (1) I feel best when doing something worth effort. (2) I can't understand why some work so hard [R]. (3) It is important that I feel fulfilled by activities.)	Likert scale 0–4 (Strongly Disagree → Strongly Agree)	Provides a baseline for subjective and eudaimonic wellbeing, enabling comparison of AR effects on positive affect and fulfilment.	[26]
AR Experience – Qualitative	Q10. Can you please describe what you have just experienced?	Audio recording (open)	Captures first-person descriptions of immersion and material perception through AR.	Authored Question
AR Enjoyment & Pleasure	Q11. Right now I feel…excited, enthusiastic, joyful, entertained, happy, interested, inspired.	Likert scale 1–7	Measures hedonic affect in AR biomaterial exploration	[26]
AR Playfulness, Bodily & Sensory, Engagement	Q12. I had fun; I found the experience engaging; Visual/tactile stimulation contributed to immersion; Moving my body was important.	Likert scale 1–7	Measures embodied engagement in AR biomat4erial exploration	[26]
AR Learning & Competence	Q13. I understood the wet spinning process; Texts were clear; Animations were clear; Information is helpful; Knowledge may influence me to choose biomaterials in future.	Likert scale 1–7	Assesses clarity of AR educational content and its potential to influence consumer choices.	[26]
AR Optimism	Q14. (1) This experience positively changed my perception of biomaterials. (2) It positively influenced my perception of feasibility for real-world applications.	Likert scale 1–7	Evaluates how AR experiences shift consumer optimism and perception of material feasibility.	[26]
AR Reflection – Open	Q15. What is the most memorable part of the experience? Q16. Were there aspects of the AR presentation particularly effective or ineffective? Q17. What improvements would you suggest for using AR to	Open text	Captures user reflections on strengths, weaknesses, and opportunities for improving AR material communication.	[9]

(continued on next page)

Table 5 (*continued*)

Theme	Question (verbatim)	Response Options	Rationale	Source
	communicate about new materials?			

framing [8] demonstrates that origins, processes, and outcomes shape the reception of new bio-based textiles. By intentionally incorporating the wellbeing dimensions of Enjoyment & Pleasure, Learning, Playfulness, Bodily & Sensory and Future self, the Biofibre Explorer enhances the storytelling framework to create a more holistic and impactful experience. This alignment with wellbeing dimensions extends the potential of AR and other creative technologies to inform and emotionally

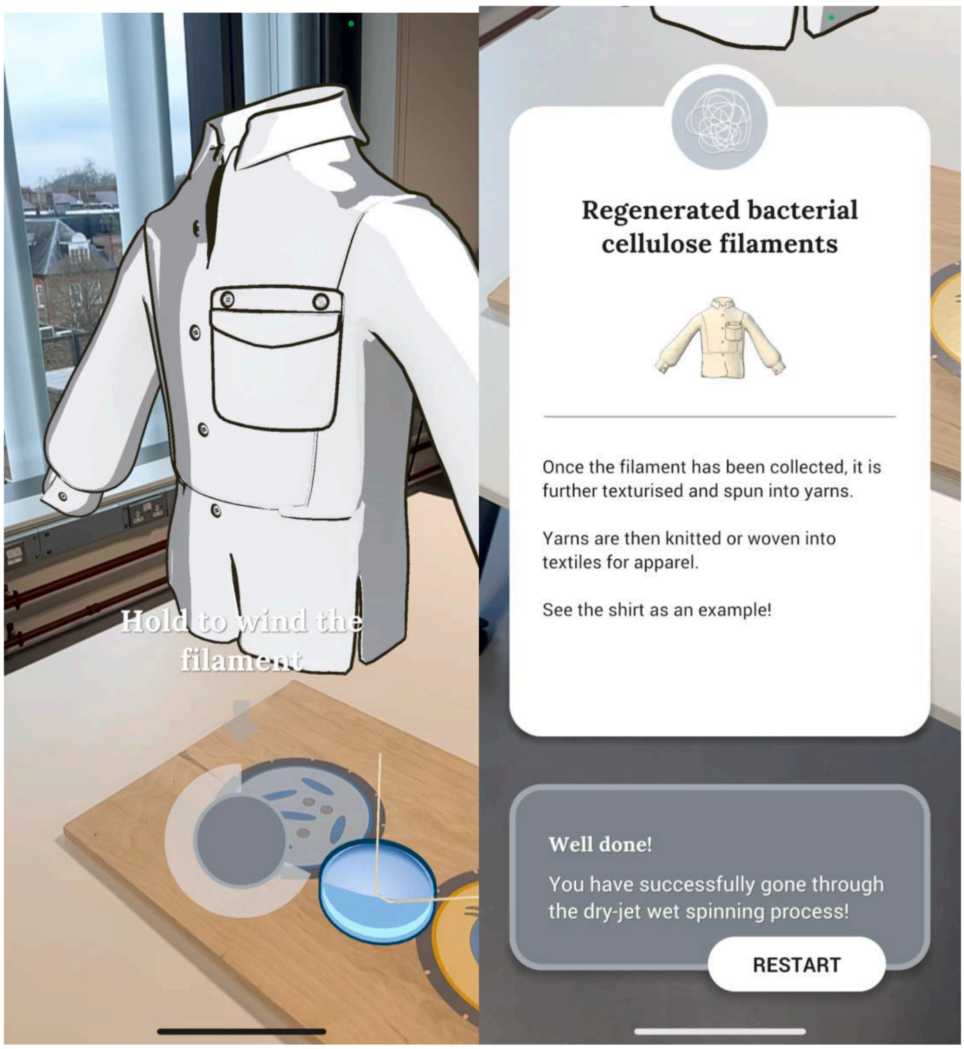

Fig. 14. Screenshot of the final step of the experience, displaying a virtual shirt.

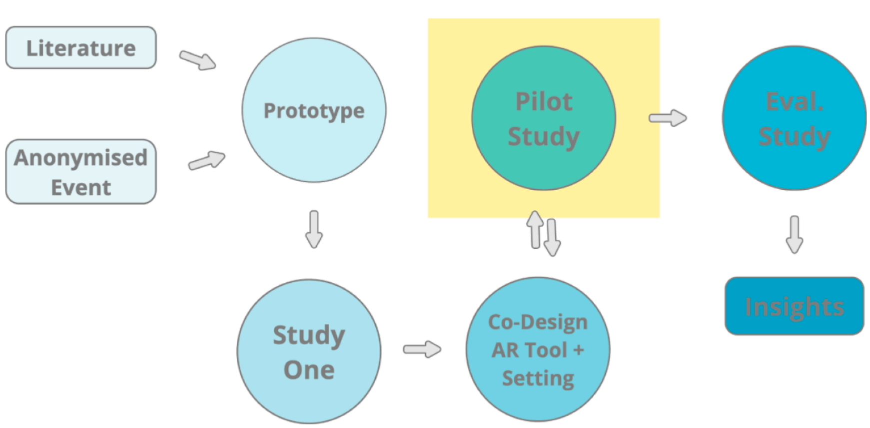

Fig. 15. Diagram illustrating the methods employed in this study, highlighting the pilot study.

Fig. 16. Final set-up of the experiment.

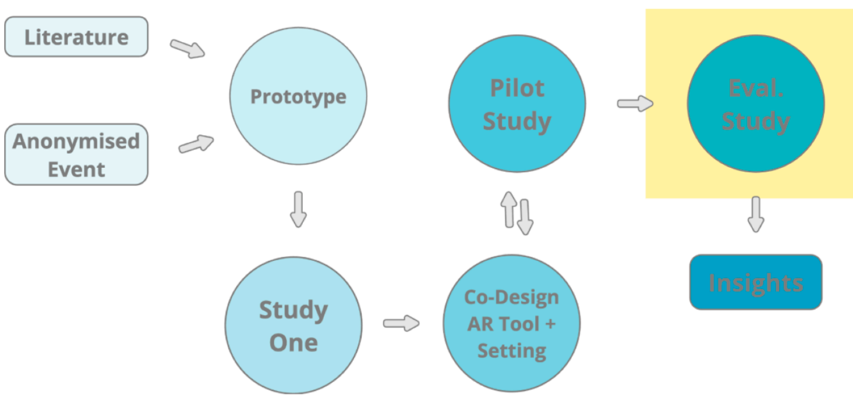

Fig. 17. Diagram illustrating the methods employed in this study, highlighting the evaluation study.

and physically engage consumers, fostering deeper understanding and connection with bio-based materials.

5.2. The importance of form beyond content

While the content elements, origin, processes and outcomes, remain consistent with established practices [15,20,29,8], our study highlights that the form in which these elements are presented significantly affects their assimilation. Retail AR research has long leveraged perceived diagnosticity to reduce product uncertainty and improve purchase confidence [5,30,6,31]. Our results transpose this mechanism from retail-focused appearance/fit diagnosticity to process diagnosticity by prioritising the emotional and embodied aspects of material knowledge through immersive and multi-sensory design. This shift enables users to connect with the material on both intellectual and emotional levels. A prior study indicated that consumers value engaging with new bio-based materials through a multisensory experience [25,13]. However, such engagement is frequently constrained by the limited availability of materials and the high costs associated with their production until these innovations are sufficiently scaled. Therefore, creating a more immersive and multi-sensory narrative around these materials emphasises the significant role of form in translating technical information into experiences that are meaningful, relatable, and memorable for consumers. Thus, the affective and cognitive gains that previously supported sales [30,33,27] can be enhanced and redirected toward sustainability knowledge.

5.3. Promoting wellbeing and multimodal engagement

The application effectively promotes dimensions of wellbeing such as learning, competence, engagement, enjoyment, playfulness, and future selves. Results from our study demonstrated high levels of engagement and enjoyment among participants, particularly due to the immersive and interactive features of the AR tool. These outcomes mirror earlier findings that AR shopping experiences are engaging, entertaining, and enjoyable [33,3,27], and align with the User Engagement Scale (UES) literature [22,21]. Here, however, enjoyment and playfulness were directly linked to understanding material processes, suggesting that the motivational pathways usually supporting purchase behaviour can also scaffold learning outcomes.

Notably, 69.2 % of respondents agreed on the importance of combining visual and tactile stimulation, emphasising the value of multimodal engagement. This resonates with earlier AR evaluation studies emphasising realism and interaction clarity [9], but it also expands the scope by positioning multisensory and bodily engagement as first-class design variables when the goal is material literacy. Current AR reviews highlight a persistent vision-centric bias [2,5,28,17]; our findings suggest that engaging multiple senses provides richer immersion and deeper understanding, particularly for sustainability communication.

5.4. Alignment between physical space and the digital experience

The comparison between the fragmented experience in Pilot Study and the integrated experience in the Evaluation Study reveals critical

Fig. 18. Word Cloud composed by the most used words to describe what a CE of textiles is.

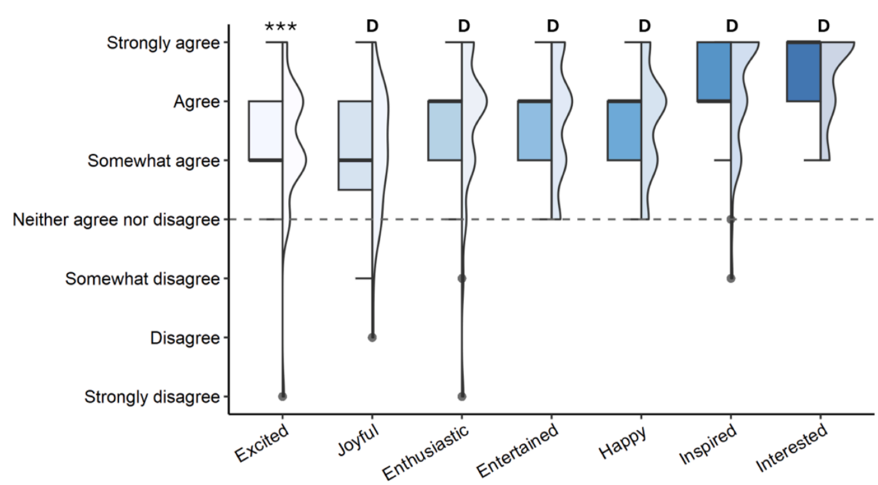

Fig. 19. Participants' emotional responses on a 7-point Likert. Bayesian Wilcoxon Signed-Rank tests revealed decisive evidence that ratings deviated from "Neither agree nor disagree", suggesting, for instance, that participants Strongly Agreed the experience was inspiring. Note: *** = BF10 >100, *D* = BF10 >999.

insights into the importance of unified narratives and physical contexts. In the Pilot Study, participants encountered material samples separately from the AR experience, which fragmented their understanding. Conversely, integrating physical samples with the AR tool created a cohesive experience that facilitated cognitive connections between the process and its outcomes, addressing known AR challenges with realism, spatial stability, and interaction clarity [9]. Despite this improvement, participants frequently requested direct tactile interaction with the samples, indicating that while the smartphone application's vibrations were perceived as engaging and playful, they could not substitute for the richness of actual touch.

5.5. *Redefining AR for multisensory perception*

This research calls for a redefinition of AR to incorporate the full spectrum of human perception. Reviews of AR in retail confirm that most applications remain vision-led [2,5,28,17], overlooking the contributions of other senses. By contrast, our findings demonstrate that tactile and bodily cues are critical to immersion and comprehension. Future AR applications designed for sustainability and circularity should

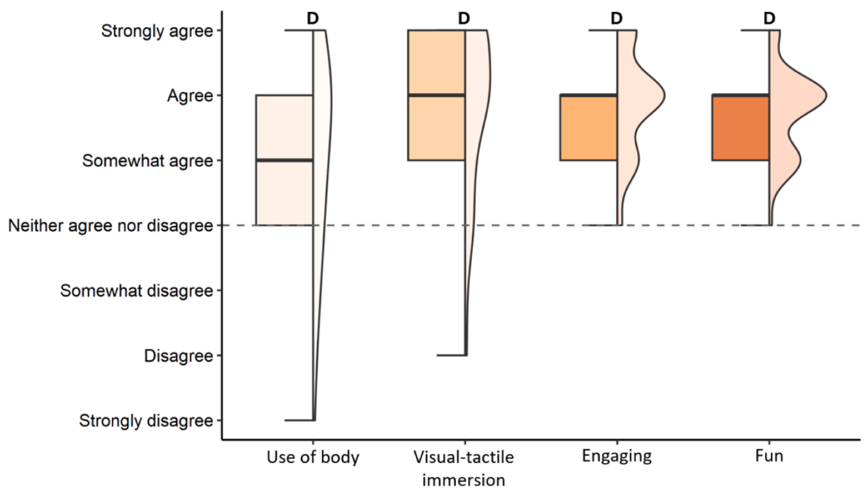

Fig. 20. Participants' engagement responses on a 7-point Likert. Responses suggested that participants agreed the experience was fun and engaging and that the visual and tactile aspects added to the immersion. However, they only somewhat agreed they needed to use their body for the experience. Note: *** = BF10>100, *D* = BF10>999.

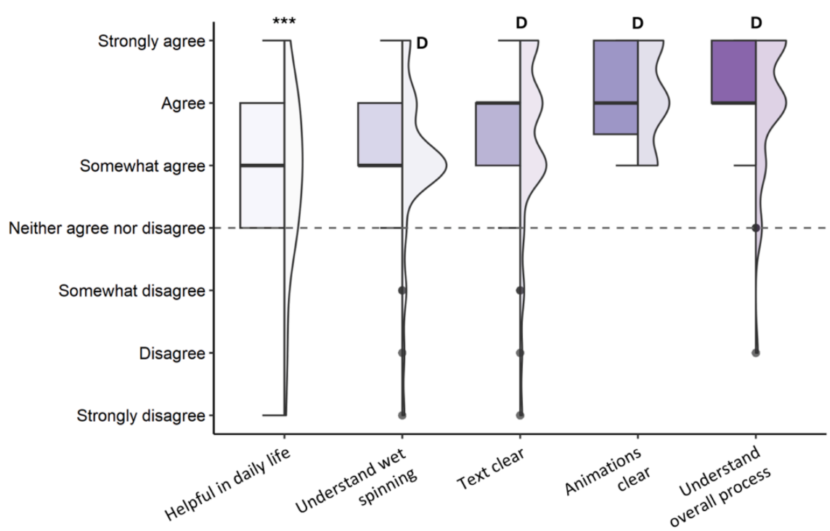

Fig. 21. Participants' knowledge responses on a 7-point Likert. Responses suggested that participants agreed the experience increased their understanding of the overall process and that both the text and animations were clear. They also somewhat agreed that they felt they understood the wet spinning process and the information would be helpful in their daily life. Note: *** = BF10>100, *D* = BF10 >999.

prioritise multimodal engagement.

5.6. Engaging diverse stakeholders

The Biofibre Explorer demonstrates significant potential as a tool for engaging diverse stakeholders, including consumers, manufacturers, materials scientists, and brands. By linking the AR experience to current biotextile science [16] and industry primers on bio-material innovation [18], the tool combines scientific accuracy with accessible explanation. This strategy responds to calls for transparent communication to de-risk novel materials [13,11], and provides a shared reference point across consumer, industry and research contexts.

5.7. Reorienting AR toward circular literacy

Most prior AR-in-retail studies highlight effects on conversion, brand engagement, and uncertainty reduction [5,17,35,33,3,27]. Our results demonstrate that these same mechanisms can be reoriented toward circular literacy. By enhancing perceptions of feasibility and fostering future-self orientations, AR can complement industry-level innovation [11] with consumer-level behaviour change [32]. This repositioning aligns with work on positive tipping points [19], where small, cumulative shifts in consumer knowledge may accelerate transitions to more sustainable norms.

5.7.1. Design recommendations (derived from insights)

1. **Stage the process.** Use stepwise, "hold-to-act" scenes to externalise process causality (supports Learning/Competence, improves process diagnosticy).
2. **Couple physical and digital.** Co-locate real samples with AR overlays to maintain narrative unity; vibrations alone do not substitute for touch.

3. **Write for lay readers, then layer up.** Provide plain-language pop-ups with optional "learn more" depth to serve mixed audiences without cognitive overload.
4. **Make play purposeful.** Use playful controls to motivate focused attention on manufacturing steps (Playfulness in service of Learning, not a side-quest)
5. **Close with future use.** End scenes by situating outputs in plausible applications to scaffold future-self reasoning (linking present learning to later choices).

6. Limitations and future research

Despite the success of the Biofibre Explorer in enhancing material communication, several areas require further refinement. One key challenge identified was the complexity of the textual content. While the descriptions were scientifically accurate, some participants found them overly technical, which hindered engagement. Our collaboration with materials scientists revealed that while precise terminology is essential, adjusting language to suit different audiences could improve accessibility and user experience. Future iterations could draw more explicitly on material framing strategies [8] to explore adaptive content delivery, tailoring complexity based on user expertise or offering multiple levels of explanation.

Another limitation concerns the long-term impact of the experience. While the benefits of immediate engagement and comprehension were evident, longitudinal studies are needed to assess whether process knowledge persists and whether it influences behaviour. Such work could parallel prior findings that AR influences purchase behaviour [30,6,31,33], but shift the focus toward sustained literacy and circular behaviours. Examining whether short-term enjoyment and engagement [22,21,3,27] translate into future-self motivations [32] would provide critical evidence on the durability of AR's contribution to circularity.

A further limitation relates to sensory engagement. Current touch interactions in the AR experience were restricted to smartphone vibrations. While the device's vibrations provided an engaging and playful element, they were insufficient in replicating the tactile qualities of bio-based textiles. Emerging haptic technologies, such as high-fidelity actuators or smart materials capable of simulating different textures, could enhance user immersion.

The use of smart glasses presents another promising direction for future work. Transitioning toward wearable AR could support more natural, hands-free interactions with materials, allowing participants to connect cognitive and bodily knowledge more effectively. This shift may also mitigate barriers to adoption identified in CE innovation research, where consumers often struggle to grasp the feasibility and scalability of bio-based textiles [18,11].

Finally, expanding the scope of the Biofibre Explorer to incorporate other creative technologies, such as Virtual Reality, and materials could enhance its versatility and impact. Exploring alternative digital technologies, interactive storytelling strategies, or multisensory integration—including sound and even scent—could further enrich the user experience and contribute to broader consumer engagement with bio-based materials.

7. Conclusion

This study demonstrates how AR can be extended beyond its conventional retail applications to support circularity in the fashion and textile industries. The Biofibre Explorer was designed to bridge the material knowledge gap by engaging consumers in the wet spinning process of bio-based textiles, fostering informed decision-making and sustainable consumption behaviours. By aligning the tool with The wellbeing framework for consumer experiences in the circular economy of the textile industry [26], we illustrate how AR can enhance understanding while also promoting dimensions such as Enjoyment & Pleasure, Playfulness, Bodily & Sensory, Learning, and Future-self. Through mixed-methods evaluation, our findings demonstrate the effectiveness of multisensory and interactive approaches in fostering material engagement and cognitive retention. This research contributes to the growing discourse on AR's potential in sustainability communication, emphasising the importance of multimodal interaction in material storytelling. Future work should explore advanced haptic feedback, wearable AR solutions, and expanded creative technology applications to further enhance material education and deepen consumer connection with bio-based materials. By redefining AR as a tool for knowledge-building rather than just product visualisation, this study advances the role of digital tools in fostering more circular and sustainable consumer behaviour.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly to check for grammar and usual sentence constructions. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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CRediT authorship contribution statement

Ricardo O'Nascimento: Writing – original draft, Methodology, Investigation, Conceptualization. **Bruna Petreca:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Roberta Morrow:** Writing – review & editing. **Christopher Dawes:** Writing – review & editing, Formal analysis. **Miriam Ribul:** Writing – review & editing. **Sameer Rahatekar:** Writing – review & editing. **Sharon Baurley:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The raw data was deposit in our repository. The link is included in the cover letter.

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