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Biodesign for a Sustainable Future: Overcoming Barriers to Biomaterial Adoption in Fashion

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ABSTRACT

The fashion industry is notoriously resource-intensive and environmentally damaging. Biodesign, with its focus on leveraging biological processes and living organisms, offers a transformative solution. This research explores the potential of bio design to drive sustainable practices within fashion, using SCOBY as a case study.

Through a multifaceted approach, the project investigates the systemic barriers hindering the widespread adoption of bio-based materials. This includes a comprehensive review of existing SCOBY research alongside hands-on experimentation to understand the challenges faced by designers. Key areas of focus include manufacturer resistance to adaptation, securing partnerships and funding, and fostering transparency across siloed research efforts. Employing a systems thinking framework, the research delves into core challenges within the biomaterial production and integration process. This includes supply chain optimization and logistics efficiency. Actionable insights will be generated to facilitate a seamless integration of biomaterials into the fashion industry, promoting a regenerative and sustainable future.

The project culminates in the development of a tangible product concept inspired by SCOBY, alongside a sustainable and viable business model emphasizing circularity and collaborative partnerships.

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Introduction and Motivation

The fashion industry faces a critical crossroads. Defined by "extractive capitalism", its reliance on unsustainable materials and processes has contributed significantly to environmental degradation [1]. As Chase Kahmann, Co-Founder and CEO of ESG Brands, aptly states, "It's rooted in optimism. It's about solving the problems created by extractive capitalism where a path of least resistance was prioritized and resulting materials and processes gained significant momentum" [1]. This begs the question: what defines "next-generation innovation" in the context of materials used for fashion and other industries?

The current focus on sustainability, while crucial, may not be enough. Existing research emphasizes the need to optimize current systems and mitigate their hazardous impact. However, a more transformative approach is needed. As the Future vvorld article proposes, "looking to create a new solution, instead of making the current systems more efficient and less hazardous, it would mean more to make and design something ground up which is completely novel and regenerative" [1]. This aligns with the emerging concept of bio design, "a growing field that combines biology and design to create sustainable and often self-repairing products" [2]. Biodesign utilizes organic materials, draws inspiration from nature, and even explores the relationship between living organisms and product creation.

The potential market value of bio design and biomaterials represents not just a passing trend, but a transformative opportunity for the future of both fashion and broader industries. The Biomaterials Market size was valued at approximately $11 billion in 2017 and projected to reach $94 billion by 2026 [3]. This rapid growth reflects the increasing demand for sustainable, innovative materials and highlights the immense opportunity for businesses to lead the charge in this emerging field. While our primary focus is environmental sustainability, illustrating the financial viability of bio design can incentivize investment and participation, encouraging more companies to enter this space. Much like how Tesla became a pioneer in the electric vehicle market, companies that prioritize bio design today will not only drive environmental progress but also secure a competitive advantage in an increasingly eco-conscious marketplace. By demonstrating the market potential, we hope to inspire a shift toward regenerative, sustainable practices that benefit both the planet and the bottom line. Through increased investment and innovation, the growth of this sector could help catalyze a broader shift in industries reliant on unsustainable materials, paving the way for a future where the financial success of sustainable practices goes hand in hand with their environmental impact.

Our data collection processes involved conducting ten in-depth qualitative interviews, complemented by a thorough literature review and physical research, to uncover key insights into both the opportunities and challenges within this rapidly developing field.

Participants were selected from four distinct groups biomaterial innovators, academic experts, fashion industry professionals, and target consumers which provided a multifaceted view of the state of biomaterials and their potential for large-scale adoption. Biomaterial innovators offered insight into the scientific and technological aspects of material development, while academic experts contributed theoretical frameworks and trends shaping the future of biomaterials. Fashion industry professionals, on the other hand, provided a practical perspective on the challenges of scaling and implementing these innovations in the marketplace. Finally, input from target consumers allowed us to gauge market demand and consumer perceptions, which are crucial for understanding the potential for large-scale adoption. Together, these data sources provided a multifaceted view of biomaterials, highlighting both the promising opportunities and the significant barriers to widespread integration into the fashion industry. As a PhD bio design researcher at Central Saint Martins, UAL, noted, "Biobased prototypes are often designed in a lab space scenario, and so the scalability is quite difficult most of the time" (Lucrezia Alessandroni, personal communication, November 5, 2024). This statement underscores the challenges faced by small bio design innovators, including the need for significant investment to scale their innovations, leading us to our proposed solution.

Our research has revealed that the development loop is broken companies are not ready to invest in bio design unless they see something that specifically aligns with their business interests, while material innovators are unable to develop these tailored solutions without the necessary funding. This creates a cyclical problem where neither party is able to move forward without the other. Although significant progress has been made in technological research, there remains a notable lack of focus on the business models required to scale bio-based innovations. Research on circular business models and their role in overcoming financial and operational barriers, as highlighted by, is particularly limited [3]. Addressing this research gap is critical to advancing the successful commercialization of bio-based materials. This paper aims to contribute to this understanding, exploring strategies to integrate sustainable biomaterials into the fashion market effectively.

To address this challenge, we propose the establishment of a consultancy focused on uniting material innovators with investors and businesses. This consultancy would serve as an intermediary, connecting innovators with companies that are ready to invest in sustainable biodesign solutions. By providing the necessary strategic, financial, and operational support, the consultancy would help facilitate the development of market-ready solutions, ensuring both parties can advance together. Through targeted partnerships and a revenue-sharing model, this consultancy would unlock the potential for both innovation and investment in the biodesign space, accelerating the transition toward a more sustainable fashion industry.

Review of Related Work

Material Driven Design Methodology

To understand how material innovators work and reveal the challenges they face, we adopted the Material Driven Design (MDD) methodology. Unlike traditional product first approaches, which often hinder innovation by forcing materials to fit predefined visions, MDD begins with material exploration, leveraging inherent qualities to inspire sustainable and innovative outcomes [4].

Positioning ourselves as material designers, we used MDD to immerse ourselves in the biomaterial innovation process, identifying systemic barriers in biodesign for fashion. As described in New Sustainable Fashion

Design Scenarios: A Designer Journey in Textile Experimentation with Plants, MDD is a "journey" that evolves through four stages:

1. Understanding Materials: Exploration and characterization through tinkering.
2. Creating Materials Experience Vision: Envisioning materials' potential for performance and user experience.
3. Manifesting Materials Experience Patterns: Connecting material attributes to user needs.
4. Designing Material/Product Concepts: Developing tangible designs.

In our case, we used MDD as a framework not just to explore biomaterials but to adopt the mindset of material designers, allowing us to engage deeply with the challenges of bio-design in fashion. Although our research did not focus extensively on physical outcomes from material tinkering, this approach served as a vital lens through which we could understand the headspace of biomaterial innovators. By treating the MDD process as a case study, we illuminated key pain points and challenges in bio-design, such as scalability, lifecycle limitations, and user perception of biomaterials. This firsthand immersion allowed us to bridge our interview and secondary research findings with practical insights, enhancing our understanding of systemic barriers in adopting bio design practices.

Valley of Death: Barriers and Solutions

As previously discussed, the bio-based materials market has demonstrated remarkable growth. This growth reflects a broader shift toward sustainability and an increasing demand for alternatives to fossil-based materials, creating a prime opportunity to invest in bio-based technologies. However, achieving a step-change in sustainability requires the fashion industry to secure $20–$30 billion annually by 2030 to develop and commercialize disruptive solutions and business models that align with evolving consumer preferences and regulatory pressures [5].

A major obstacle for innovators is the "Valley of Death," a critical gap between research breakthroughs and the successful commercialization of new technologies. This challenge is especially acute in the bioeconomy, where the transition from prototype to market-ready solutions is hindered by financial constraints, uncertainty regarding market acceptance, and scalability issues [3]. Within this framework, two distinct gaps emerge: the technology gap, where early-stage funding is needed to develop prototypes and viable business models, and the commercialization gap, which requires substantial growth capital to scale proven technologies [5]. These challenges are exacerbated by the absence of financing mechanisms such as project finance, corporate R&D, and growth capital tools commonly utilized in sectors like energy and chemicals but notably lacking in fashion [5].

Further complicating matters, investors often overlook opportunities in this space due to weak demand signals from brands, nascent regulations, insufficient awareness of growth-stage investment criteria, and a lack of precedent within the industry [5]. Six critical barriers to financing innovation have been identified: misaligned incentives, limited awareness of opportunities, the absence of structured innovation processes, a lack of technical expertise, misconceptions about pricing and externalities, and poorly structured exclusivity agreements [5]. These barriers perpetuate the impact-return paradigm, a misconception that sustainable solutions inherently deliver lower financial returns.

Additionally, bio-based materials face stiff competition from commoditized options like cotton and polyester. However, rising raw material costs, coupled with increasing regulatory and environmental pressures, underscore the necessity of scaling renewable alternatives for long-term viability. Analysts must account for future material prices, carbon costs, and externalities to accurately assess business cases [5].

The interplay of market-pull and technology-push strategies further shapes the adoption of bio-based materials. In the market-pull approach, consumer demand drives innovation, whereas technology-push strategies rely on speculative development of products to meet unrecognized needs [3]. While the former offers clearer pathways to market, the latter often struggles due to high upfront costs and risks associated with unproven technologies.

To bridge these gaps, systemic solutions are necessary. The report outlines key recommendations, including the creation of targeted consortiums and structured innovation processes, stronger advocacy from brands, greater engagement from supply chain partners, practical implementation plans from innovators, mobilization of diverse investment types, and public sector involvement to catalyze private investment [5]. However, despite being proposed in 2020, these solutions have yet to be fully implemented, reflecting the slow pace of change within the industry. Scaling renewable materials, even at non-competitive initial prices, is imperative, as rising costs and regulatory pressures will force brands to adapt [5].

Technology Approach

Bio-based materials represent an innovative technology, comprising living organisms, such as yeasts or bacteria, programmed to perform specific functions within a carrier material [6]. These organisms possess unique metabolic capabilities, enabling the synthesis of diverse chemicals, including metal oxides, biopolymers, inorganic salts, and potent medicinal compounds. This allows for the creation of technical and medical materials with properties unattainable in non-living materials. Bio-based materials, in particular, offer sustainable and functional solutions, demonstrating malleability and addressing environmental challenges through recyclable and biodegradable alternatives facilitated by micro- and nanofabrication [7].

Bio-based materials, sourced renewably and bio-fabricated, offer the fashion industry a sustainable alternative, with "Materials Biography" enhancing transparency and traceability [8]. This supports a circular economy and eco-friendly production via [9]. The term “SCOBY” (Symbiotic Culture of Bacteria and Yeast), coined by Len Porzio, designates a microbial community crucial in fermentation processes [10]. SCOBYs, consumable at all stages, offer potential probiotic benefits and yield microbial cellulose, a byproduct with a finer, purer, and more intricate structure than plant cellulose, exhibiting superior oxygen barrier properties and potential for large-scale 2D sheet production.

We conducted an experiment to produce bacterial cellulose (BC) from SCOBY using a simple recipe of sugar, black tea, kombucha starter, and water. While the ingredients were few, optimizing ratios and environmental conditions like temperature (approximately 80°F), absence of direct sunlight, and pH (4-7) were critical for optimal yield. A 15-16-day process, including two weeks for growth and several days for moisture removal, yielded a usable sheet. The production of BC for fashion, though seemingly straightforward, involves complex biological, chemical, and engineering factors. BC, synthesized by microbial communities like Gluconacetobacter xylinus (SCOBY), offers a sustainable alternative to traditional materials. BC cultivation requires a controlled environment with a suitable growth medium (carbon, nitrogen, and minerals) to optimize yield and quality [11].

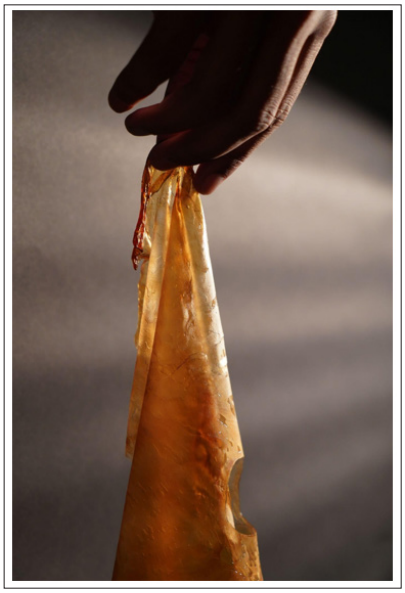
Harvesting the BC pellicle involves gentle removal and purification through washing with water, dilute acid or alkali solutions, or dehumidification, as in our experiment, to remove impurities [12]. Shaping and modification processes, such as casting, molding, electrospinning, chemical modification (acetylation, carboxymethylation), blending with fibers (cotton, silk), and surface treatments (coatings), are essential for fashion applications, enhancing hydrophobicity, dye-ability, strength, and other properties [13].

Scaling BC production presents challenges in maintaining consistent quality, optimizing efficiency, and minimizing costs. Automation, process control, waste minimization, and life cycle assessments are crucial for industrial-scale viability. This necessitates collaboration between material, manufacturing, and product designers.

Beyond its sustainability and circular nature, bacterial cellulose (BC) presents diverse advantages for the fashion industry. Its high absorbency allows for vibrant natural dyeing, utilizing sources like carrot juice, lemon juice, beetroot, coffee, and flower pigments. The simple four-ingredient recipe streamlines manufacturing, while BC's adaptability to surface textures during drying allows for varied finishes. The material's natural origin and unique production process provide compelling marketing opportunities for brands targeting conscious consumers.

Innovations in BC application within fashion are evident in examples such as the experimental jacket from Bio couture, demonstrating its potential for garment construction, as well as its use in accessories like card holders and packaging [14]. Furthermore, researchers and designers are exploring BC for creating footwear components, such as shoe uppers, and for developing seamless molded garments, showcasing its versatility beyond traditional textiles [13].

The production of BC for fashion is a complex system of interconnected components, from microbial cultivation to integration into the supply chain. A systems thinking approach is essential to understand these interdependencies and optimize the process for sustainability and efficiency. By considering broader impacts and feedback loops, we can create a resilient and sustainable BC production system that minimizes environmental impact and meets the evolving needs of the fashion industry. Continued research promises further advancements in BC-based textiles, opening new avenues for sustainable and innovative fashion.



Results of Bacterial Cellulose experimentation

Discussion

Our research revealed several key benefits of regenerative design, which is essential for the growth and scalability of biomaterials in fashion. Regenerative design takes a holistic approach that considers the entire ecosystem, emphasizing the need to work in harmony with nature. This perspective highlights the potential for biomaterials to reduce environmental impact and enhance the sustainability of the fashion industry. By using living organisms, such as bacteria and fungi, regenerative design eliminates harmful chemicals and significantly reduces water and energy consumption. Additionally, bio design supports the use of local ecologies for material creation, promoting decentralized, sustainable production systems and reducing reliance on global supply chains, thus minimizing carbon footprints. Despite rapid advancements in bio design, our research identified a significant divide between the potential of these materials and their market adoption, presenting a major challenge to their integration into the fashion industry.

Four core challenges emerged as barriers to scaling up and adopting biomaterials in fashion. First, the gap between small-scale, experimental processes, where biomaterials are often developed, and large-scale manufacturing hinders the ability to scale these solutions. Second, fragmentation in research, development, and production processes slows progress, with misaligned standards leading to inefficiencies. Third, smaller design studios face challenges in securing funding and resources to invest in advanced technologies for large-scale production. Without financial support, biomaterial innovators struggle to move from prototype to viable solutions. Finally, larger fashion studios face barriers to adopting biobased materials due to misaligned workforce priorities, profit-driven models, and concerns over reputational risks. Despite bio design's promise, many larger studios hesitate to embrace new technologies due to perceived risks and slow operational change.

We propose a consultancy designed to support innovators in navigating the "Valley of Death," overcoming technological and commercial challenges that prevent the transition from concept to market-ready solutions. The consultancy would serve as a key intermediary, securing funding, establishing strategic partnerships, and translating complex scientific advancements into compelling narratives for investors and stakeholders. By partnering selectively with innovators based on their potential for success, the consultancy would offer services in exchange for a share of future revenue once products reach profitability, aligning incentives to promote scalability and long-term impact.

Conclusions & Recommendations

The future of fashion depends on its transition toward sustainability, with biomaterials playing a crucial role. However, to achieve widespread adoption by 2030, material innovators must overcome significant structural and financial barriers. While scientific progress has been made, activating systemic collaboration among key stakeholders innovators, investors, supply chain partners, brands, and public institutions remains essential.

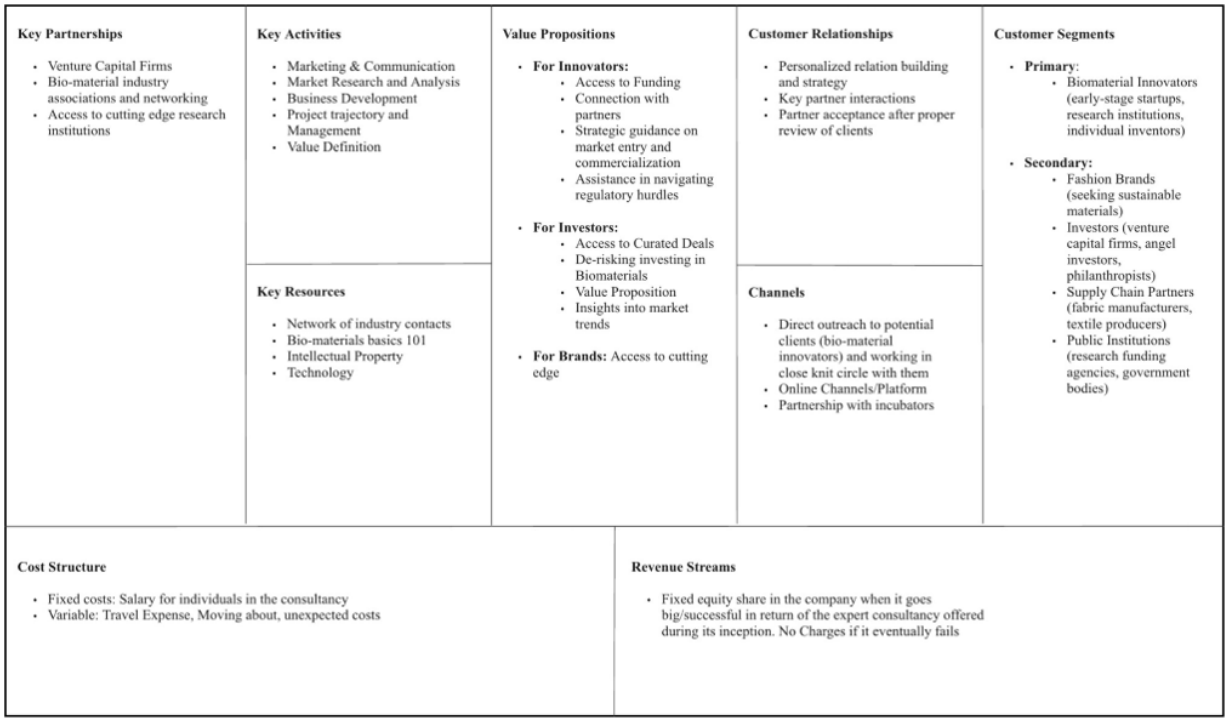
The consultancy would function as both a strategic advisor and connector, guiding biomaterial startups through the critical early stages of commercialization. We would provide tailored consulting services to refine business models, strengthen go-to-market strategies, and prepare compelling investment pitches. Additionally, the consultancy would leverage our extensive network to introduce startups to venture capitalists, angel investors, corporate partners, and philanthropic organizations. We would also assist in navigating public and private grant opportunities, securing non-dilutive funding to support R&D and early-stage growth. By addressing financial and strategic challenges, the consultancy would de-risk biomaterial investments, positioning partners for successful market entry and long-term viability. Through this hands-on intermediary role, the consultancy would accelerate biomaterial adoption, ensuring innovators have the resources, funding, and strategic guidance to scale.

A core offering would be educating stakeholders about biomaterial science and its market potential. Many investors perceive biomaterial innovations as high-risk due to a lack of technical knowledge. The consultancy would bridge this gap by translating biomaterial science into actionable opportunities, unlocking much-needed funding.

Simultaneously, it would serve as a systems integrator, connecting fragmented sectors financial institutions, material innovators, brands, and public-sector organizations fostering cross-sector collaboration and aligning goals to scale biomaterials globally.

To ensure long-term sustainability, the consultancy's revenue model, illustrated below, would combine upfront service fees with performance-based returns. Rather than taking equity stakes, the consultancy would adopt a revenue-sharing model, where a portion of future profits or licensing agreements is allocated once startups become commercially viable. This structure aligns incentives, ensuring the consultancy remains invested in the long-term growth of biomaterial companies while enabling them to scale without immediate financial burden. By positioning ourselves as a strategic accelerator with a vested interest in the success of biomaterials, we create a self-sustaining business model that supports ongoing innovation while generating returns in proportion to the impact we help create.

Business Model Canvas



The biomaterials revolution requires more than scientific innovation it demands activation. The solutions are already available; what's needed is a way to connect innovators with the financial and institutional support to bring these solutions to life. The consultancy would facilitate collaboration, raise awareness, and catalyze the action necessary to accelerate biomaterial adoption. By building relationships, advocating for opportunities, and equipping innovators with the tools to succeed, this initiative would empower the fashion industry to embrace biomaterials as a cornerstone of its future.

The time to act is now. By launching this consultancy, we can drive the transition to a regenerative, sustainable fashion industry, making biomaterials central to a better, more sustainable future [15-25].

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