FROM BIO-BASED TO FOSSIL-BASED TO BIO-BASED

EXPLORING THE POTENTIAL OF HEMP AS A MATERIAL FOR NEXT-GEN FUR

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Abstract

Fur as a status-affirming adornment has been historically significant in fashion. There are three main categories of fur and fur-like materials: animal-based, synthetic, and next-generation (next-gen) fur. Animal-based fur is controversial and associated with ethical and environmental concerns, including animal welfare and the use of toxic chemicals. Synthetic fur is typically made from fossil-fuel-derived polymers like acrylic, which successfully mimic the properties of animal hairs in fur, such as aesthetics and touch. These non-renewable, fossil carbon-based fur replacements do not biodegrade, contributing to the plastics crisis in landfills and through fibre shedding. Next-gen furs made from bio-based, regeneratively sourced materials could mitigate this problem because the shed fibres would biodegrade naturally. This paper reports on preliminary findings from an ongoing study investigating the potential benefits of using hemp fibre as the hair in next-gen fur. Extensive material experiments demonstrate that hemp fibre can be used to produce a visually pleasing, appealing-to-touch, fur-like surface. Further research will investigate the base materials of next-gen furs, as well as the scalability of these new materials.

Keywords: *Next-gen Textiles; Material Design; Regenerative Systems; Hemp Fibre; Circular Economy.*

INTRODUCTION

This paper reports on preliminary findings from an ongoing study investigating the potential of hemp as a material for the next generation of fur-like materials, here referred to as next-gen fur. In this study, hemp fibre is used for the hair part of the fur alternative. While other animal-based materials usually utilise either the skin or fibre, fur is composed of both (Rawling et al., 2024). Thus, base materials for next-gen furs are also being investigated within the project but are outside the scope of this paper.

Before the Industrial Revolution, all raw materials used to produce garments could be considered natural or biologically based (Burgess & White, 2019). Presently, even biologically generated fibres are usually embedded with substances that significantly affect their degradation processes (Athey & Erdle, 2022). As fibre shed occurs, these fibres find their way into ecosystems and end up negatively affecting the environment (De Falco et al., 2020).

In principle, animal-based fur is a natural material (Popescu & Hoecker, 2007) that is part of nature's carbon cycle, which refers to the natural activity of carbon exchange involving the atmosphere, oceans, and land (Ghiat & Al-Ansari, 2021). Complex ecosystems on Earth depend on the relative stability of the carbon cycle (Malhi et al, 2020) and in addition to carbon in circulation through biological and other processes, a large amount of fossil carbon is stored in the ground as gas, oil and coal. When fossil carbon is extracted

and used in large quantities, the carbon cycle is gradually destabilised. Thus, part of the efforts to stabilise the carbon cycle must include keeping as much fossil carbon in the ground as possible and creating materials from biological regenerative sources.
However, even though fur is a natural material, prior to being applied to fashion products its production and finishing typically involve toxic substances that affect its natural biodegradation (Bijleveld et al., 2011). Still, animal welfare tends to be the main point of discussion. Consequently, commonly used alternatives are synthetic, which addresses the animal rights aspect but neglects anthropogenic emissions and microplastic pollution (Gladman et al., 2024). To mitigate the challenges that both animal-based fur and synthetic fur alternatives present, a transition to animal- and petrochemical-free materials is expected, justifying the growing interest in next-gen alternatives (Gladman et al., 2024). Due to the extremely limited number of next-gen fur innovators (Rawling et al., 2024) and even more limited scholarly research on next-gen fur alternatives, this research aims to address this gap in the literature by discussing the potential benefits of using hemp to mimic the hair part of a next-gen fur alternative to mitigate problems, such as fibre shedding-related pollution.

CONTEXT

This research investigates the potential of hemp in replacing the hair part of fur in next-gen fur, as part of a broader transition from an extractive, either animal- or petrochemical-based system to a bio-based regenerative system. This paper reviews current research in the field to establish the gaps in knowledge and avenues for further investigation to mitigate the impact related to animal-based and synthetic fur materials, such as the ones related to fibre shedding.
This research asks: What impacts of animal-based fur and synthetic fur alternatives could be addressed by a next-gen material in which the hair part is replaced by hemp fibre?
In response to the research question, the challenges of using animal-based fur and synthetic fur alternatives for applications in the fashion industry are presented in conjunction with a discussion of the properties expected from next-gen fur alternatives in a fashion context. The potential of hemp fibre as the hair component in next-gen fur materials is then discussed, drawing from both literature and empirical work.

ANIMAL-BASED FUR

The use of fur as a status-affirming adornment has been historically present in fashion (Faiers, 2020, p. 112). Even the first fur clothes can be considered hunting trophies, demonstrating that clothes were already a symbol of rank distinction (Faiers, 2020 p. 82) usually associated with power, be it the one originated from the animal kingdom or the social status brought by wearing fur clothes (Faiers, 2020, p. 56). Just the act of wearing fur may already be perceived as a promotion since it often instigates curiosity concerning how the wearer sourced the material (Taylor, 2024). It also incites proximity, simulating transferring the animal's characteristics to the wearer (Faiers, 2020, p. 52); it is a material that evokes almost primitive memories (Kwasny, 2019; Fairs, 2021) often associated with 'the wildness and ferocity of the animal kingdom' in opposition to 'the furrier's art' (Faiers, 2020, p. 86). However, fur is a controversial material (Gladman et al., 2024) due to a series of environmental and ethical concerns, including animal welfare, eutrophication and carbon emissions from fur farming (Bijleveld et al., 2011).
A major challenge with fur farming is that it is considered inefficient, especially because most farmed fur animals (e.g. mink, fox, raccoon dog) are carnivores, so other animals are needed for feed. For instance, producing one kilogram of mink fur (equivalent to eleven mink) demands over five hundred kilograms of feed (Bijleveld et al., 2011). Turning skinned fur into fashion products also requires processing, treatments and finishing, which consume electricity, transportation fuel, and toxic chemicals (Bijleveld et al., 2011). At the end of life, most animal-based fur products end up in landfills (Gladman et al., 2024). A 2011 study conducted by CE Delft found European mink to have the highest impact among all materials except for water depletion, while the presence of hazardous chemicals exceeded European regulations (Bijleveld et al., 2011). However, the lack of thorough and up-to-date life cycle assessments for animal fur and other alternatives prevents a precise comparison between materials (Bijleveld, 2013). Furthermore, fur farming can be a public health risk (Warwick et al., 2023). A study conducted by Lindh et al. (2023) on fur farms inthe South and Central Ostrobothnia regions of Finland,

verified an outbreak of highly pathogenic avian influenza (HPAI) A(H5N1) infections amongst foxes, American minks and raccoon dogs. Although no human infections were detected, the study highlights the risk of a serious problem. During the COVID-19 global pandemic, SARS-CoV-2 infection was detected in farmed minks (Oreshkova et al., 2020), which led to over fifteen million mink being killed in Denmark (Larsen et al., 2021).
Historically, the controversy over fur as a fashion material has led to several bans and specific legislation. These bans can be classified into either governmental or organisational that promote full or partial bans on fur sales or on fur production (Fur for Animals, n.d.). The first fur farming ban happened in the UK in 2000, followed by Belgium, Italy and France; the EU is the second largest producer of fur behind China (Fur for Animals, n.d.). In addition, California, which accounted for almost one-quarter of all fur sales in the United States, has banned the sale of fur starting in 2023 (California Legislative Information, 2019). Concerning organisational bans, the first major fashion brand to ban fur was Calvin Klein in 1994 (Spindler, 1994), while the first magazine to ban fur was InStyle in 2018 (PETA, 2018). Copenhagen Fashion Week banned fur in 2022, followed by London Fashion Week in 2024 (Bramley, 2024). Overall, at present, over one thousand design and retail brands have pledged to not use or sell animal fur, including Kering (Lange, 2023). The ways in which luxury conglomerates like LVMH and Kering approach fur vary significantly (Smith, 2024). While LVMH is known for pressuring its own maisons to avoid banning animal-based fur, Kering announced in 2021 that the material has 'no place in luxury' and encourages replacements, especially next-gen (Smith, 2024). So, even though bans often lead to more desire and imitation (Faiers, 2020 p. 66), they also serve as a trigger for innovation (Material Innovation Initiative, 2024).

ARTIFICIAL FUR

At present, there are three main categories of fur and fur-like materials: animal-based fur, synthetic fur alternatives, and next-gen fur (Gladman et al., 2024). In synthetic fur alternatives, synthetic fibres, usually polyester, acrylic, or modacrylic, are used to mimic the hair in animal fur (Gladman et al., 2024). Their fossil carbon or petrochemical origin, which also enables the material's successful properties, tends to be forgotten when garments are worn (Stanes & Gibson, 2017). Still, at the expected pace, the global market size of synthetic fur is estimated to grow at a Compound Annual Growth Rate (CAGR) of almost 18.92% from 2024 to 2028, representing a significant growth of USD 184.2 million (Technavio, 2024), which also means a growing production of toxic pollutants associated with the material, including PCBs, dioxins, nitrous oxide, hydrogen cyanide, as well as flame retardants and antimicrobial agents (Gladman et al., 2024). Moreover, considering that fur is composed of both skin and fibre (Rawling et al., 2024), the environmental impact of synthetic fur's backing also becomes an important part of the material's creation (Bijleveld, 2013).
As demonstrated by Stanes & Gibson (2017), the two key elements of fashion consumption, aesthetics and touch, can be extensively explored by using synthetics. Nevertheless, even though some current synthetic fur alternatives may be considered more sustainable than animal-based fur when comparing carbon footprints and, obviously, animal welfare (Bijleveld, 2013), these cause extensive environmental damage, including microplastic pollution (Gladman et al., 2024). Microplastics can be defined as primary or secondary, depending on the production source. Primary refers to the microplastics purposefully created in a size smaller than 5 mm within (European Chemical Agency, n.d.), whereas secondary refers to the microplastics generated through the fragmentation of larger plastics (Boucher & Friot, 2017). It is important to distinguish between microfibres and microplastics because the first concerns only the fibre diameter, while the second sets a maximum length of 5 mm and also covers the material's origin (Zhang et al., 2021). Fibre shedding from textiles naturally occurs during material/garment production (Cai et al., 2020), use (De Falco et al., 2020) -including maintenance, such as washing and drying (Mahbub & Shams, 2022) - and at the end of life (Zhang et al., 2021). In the case of microfibres, Athey & Erdle (2022) point out that anthropogenic microfibers can be defined as natural, semisynthetic or synthetic based on feedstock and production. However, although often underestimated, the shedding of natural and semisynthetic fibres is also significant because these fibres usually contain chemical additives and finishes that cause environmental pollution and should not be ignored. Additionally, a study conducted by De Falco et al.

that fibre release into the air is as significant as fibre release into water.

Microplastic pollution harms ecosystems, such as coral reefs and soil-based ecosystems and organisms that depend directly on topsoil (Huang et al., 2021; Roy et al, 2023). Globally, it is estimated that the amount of textile-related microplastics entering the oceans ranges between 200 and 500 tonnes per year (European Environmental Agency, 2022), and even though synthetic fur garments tend to be washed less frequently (Ecopel, n.d.), the plasticity of synthetic materials can elicit in the wearer the perception that the material might promote sweat and retain body smells, which can lead to repeat washings (Stanes & Gibson, 2017). Thus, since microplastic pollution is a problem that cannot be ignored, and textile design-related interventions to better manage fibre sheds are necessary, understanding the main sources of microplastic release is critical to designing strategies to mitigate the problem (Cai et al., 2020). To enable a transition that could possibly reduce fibrous microplastics shed, measures should include developing bio-based and biodegradable alternatives (Zhang et al., 2021). Mazzitelli et al. (2024) reinforce the significance of considering the fibre's nature when selecting textiles, while a study conducted by Cai et al. (2020) points out the significance of the production process when addressing microplastic fibre release; as an example, considering the samples analysed in the research, laser-cut samples shed almost twenty times fewer microplastic fibres than scissor-cut ones.

NEXT-GEN FURS AND HEMP

New technologies enable the creation of textile materials that can cause less environmental damage (Lee et al., 2021) while also avoiding some ethical issues. Next-gen furs aim to solve some of these issues by maintaining high performance while prioritising animal- and petrochemical-free alternatives (Gladman et al., 2024). In addition, next-gen fur offerings should aim to improve performance features and be cost-competitive. For instance, Gladman et al. (2024) comprehensively discuss the potential advantages of developing next-gen fur and the existing market gap that such materials could address. Critical attributes expected from next-gen fur options include the ability to accept non-toxic dyes, the ability to be created with multiple patterns and textures, as well as the material's 'lustre and softness' comparable to the currently available options (both animal-based or synthetic). Simultaneously, fibre shedding and release must be mitigated while using biobased inputs to create a material that is either recyclable, biodegradable or responsibly disposed of at end-of-life. Recommendations for next-gen fur also include reduced maintenance, pleasant or absent odour, flame retardancy, hypoallergenic properties (due to proximity to the skin), thermal resistance, and satisfactory appearance. In addition, since both animal-based and synthetic furs tend to elicit a desire to touch them, that should be transferred to next-gen alternatives (Gladman et al., 2024).

The first known alternative to animal-based fur dates back to a 1365 BCE woollen-cloth hat - made of a dense collection of extremely fine (10 - 20 mm long) knotted cords - found in Denmark that belonged to a Bronze Age warrior, referred to as the Muldbjerg man (Faiers, 2020, p. 151). Decades later, Tutankhamun's tomb, which featured supplies provisions for his journey to the afterlife, also included two 'leopard skins': one real skin and one fake (Faiers, 2020 p. 200). These alternatives to fur are believed to have been considered expensive materials considering the skill and time involved in their production. Rather than imitating fur, they celebrate fur's ability to be translated into a new skilled expression (Faiers, 2020, p. 151). Thus, from that perspective, fur alternatives do not necessarily need to be direct replacements and can have their own value. In more recent examples, for the Autumn/Winter '24 season runways, fur was one of the biggest trends (Tag Walk, 2024), including fur-like alternatives, such as Diesel's denim insets used to produce carefully crafted furry garments and accessories (Gordon, 2024), and Gabriela Hearst's fur-looking woven cashmere coats (Taylor, 2024). Even though these alternative materials do not yet present the same range of properties as animal-based fur, they are valuable for the market as exemplars.

To date, the lead author has conducted over one hundred material experiments as part of an ongoing research project, to identify opportunities for using hemp fibre to mimic animal hair in next-gen fur materials. In figure 1, a comparison between long hemp fibre (natural and bleached) and sheepskin (applied to a Fendi handbag (Fendi, n.d.)) is made to demonstrate opportunities for the material. The experiments demonstrate that hemp fibre can be a viable alternative to animal hair in some next-gen furs. It can create a visually

Fig. 01

pleasing surface that is also appealing to touch. Where hemp fibre shows particular promise as a material for next-gen fur is in mitigating the impact of fibre shedding. It is clear from the research and material experiments to date that in comparison to animal-based and synthetic fur materials, in a next-gen fur with the hair composed of hemp fibre, the impact from fibre shedding - which occurs with all materials - is greatly reduced. This is due to hemp fibre being readily biodegradable (Gedik & Avinc, 2020), therefore not contributing towards microplastic pollution during use (Zhang et al., 2021), and promoting less environmental damage if landfilled at the end of life (Liu et al., 2023). Although textile production will always have some environmental impacts, the fashion industry can implement various practices to reduce it. Hemp can demonstrably be a valuable addition to this strategy (Muthu & Dhondt, 2021). Industrial hemp (Cannabis sativa L.) is an annually grown multipurpose plant. Evidence of hemp being used as a textile dates back to around 6000 years ago in Asia. However, the peak production and use of hemp occurred in the last three centuries (Ranalli & Venturi, 2004), until the early 1900s, when many countries banned marijuana due to its psychoactive effects and, based on misinformation, included hemp in the ban (Rawson, 2018). Recently, the interest in hemp has been growing again. The global industrial hemp market, estimated at USD 5.49 billion in 2023, is expected to grow at a CAGR of 17.5% from 2024 to 2030, potentially reaching USD 16.82 billion (Grand View Research, 2024). In a 2005 study conducted by Cherrett et al. (2005)

comparing twelve scenarios involving hemp, organic hemp, cotton, organic cotton, and polyester based on energy requirements, carbon dioxide emissions, ecological footprint, and water usage, the results revealed that organic and traditionally produced hemp had the lowest footprint. Hemp is a fully biodegradable, low-input, fast-growing, and high-yield crop (Gedik & Avinc, 2020) that requires minimal pesticides, herbicides, or fertilisers (Muthu & Dhondt, 2021), and its extensive root system significantly reduces the need for irrigation (Zatta et al., 2012). Moreover, hemp fabrics are non-allergenic (Kostic et al., 2008), offer good UV protection (Kocić et al., 2019), and have excellent thermal conductivity, which facilitates heat transfer between the human body and the textile, helping to keep the wearer warm in cold temperatures and cool in warm temperatures (Stanković et al., 2019). In a recent report on reducing the impact of textile-based goods purchased by the city of New York, prepared by the Local Law 112 Task Force (Gabriel et al., 2024), the benefits of using hemp fibre include biodegradability, renewability, strength, natural mildew and pest resistance, hypoallergenic nature, potential reduction of soil erosion and its value as in crop rotation. Hemp is rated as low in environmental risk, while animal fur is rated high. The risks associated with hemp fibre include restricted availability related to drug stigma, the potential use of pesticides (even if not required), and the impact of chemical retting, which can be mitigated. Risks with fur include animal welfare and slaughter, carbon dioxide emissions, intensive water and land use, eutrophication, forced labour/worker exploitation, and toxic chemical exposure. The report also covers synthetic fibres such as acrylic, and it associates them with several environmental risks, including microfiber pollution and limited end-of-life solutions.

The production and consumption of fur have been historically linked to innovation (Faiers, 2020 p. 225) and when comparing the production volume of traditional animal-based materials, it becomes clear that targeting materials that share a smaller part of the market can promote more positive consequences. Still, consumer acceptance is an important consideration for all next-gen fur materials. A study by Seidu et al. (2024) on sustainable material innovations within circular fashion revealed that price is a key factor consumers consider when purchasing bio-based materials. As animal-based fur is part of the luxury market segment, a next-gen fur could offer price parity with currently available alternatives (Gladman et al., 2024). For instance, concerning the potential for consumer adoption of next-gen alternatives in the United States, Szejda (2023) conducted a study with over a thousand participants. Among the 54% who indicated an intention to purchase either traditional fur or a fur alternative within the next five years, 62% expressed a preference for next-gen alternatives. However, despite this positive indication, there often exists an intention-behaviour gap among consumers (Rausch & Kopplin, 2021), primarily because adopting next-gen alternatives frequently entails sacrifices, such as higher costs or reduced durability (Griskevicius et al., 2010).

Further research opportunities include the fixing of hemp fibre to a base that mimics an animal's skin. Future research will also investigate the possibilities for scaling hemp as a material for next-gen further. It is still unclear whether existing supply chain technologies would support the production of such materials. For instance, the technologies used to manufacture synthetic furs could not be used to reproduce the materials created as part of this research; so, future research will investigate the scalability of these materials.

CONCLUSION

This paper has explored the potential of hemp fibre as a source for the hair component in next-gen fur materials, as part of larger transitions from fossil-based towards bio-based fashion and textile systems. Fibre shedding from textiles naturally occurs during material/garment production (Cai et al., 2020), use (De Falco et al., 2020) - including maintenance, such as washing and drying (Mahbub & Shams, 2022) - and at the end of life (Zhang et al., 2021). Fibres shed from animal-based fur, which is a controversial material for several reasons (Gladman et al., 2024), could be, in theory, considered biodegradable and natural; however, the additives and finishings added to the material often affect its natural origins and how degradation occurs (Athey & Erdle, 2022). Synthetic alternatives, which solve some of the challenges related to animal-based fur, such as animal welfare and cost, are also significantly harmful to the environment and are petrochemical-based (Gladman et al., 2024). Consequently, it makes sense to consider these factors when designing a next-gen fur textile, which should be an animal- and petrochemical-free alternative. Based on hemp's natural properties, including biodegradability, renewability, strength, natural mildew and pest resistance, hypoallergenic nature, potential reduction of soil erosion and benefits when used as intercrop (Gabriel et al., 2024), hemp fibre could be a promising option to serve as the fibre part of fur in next-gen fur design. In this case, the fibres shed from the material could significantly promote less environmental impact and become part of nature's carbon cycle (Liu et al., 2023). However, it is essential to understand that the majority of research papers available investigating anthropogenic pollution caused by fibre sheds do not account for natural fibres, so the extent to which that could affect the environment is still inconclusive and could be currently underestimated (Athey & Erdle, 2022). Still, hemp demonstrates promise, as it is a low-impact fibre to grow in regenerative agriculture; it can also be coloured easily with bio-based dyes, and it biodegrades readily when the fibre is shed as well as at the end of life.

This paper has reported on preliminary findings from an ongoing study investigating the potential of using hemp as an alternative for the fibre part of fur in next-gen fur design, which could have several benefits, such as reduced impact promoted by fibre shed. Future research will further investigate the base materials for such next-gen furs, as well as the possibilities for scaling up the manufacturing of these materials.

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CAPTIONS

[Fig. 01]On top, two experiments demonstrating the potential of using hemp fibre to mimic animal hair in next-gen fur compared to a sheepskin Fendi bag (bottom).

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